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WHEN THE "GOLDEN HOUR" IS DEAD: PREPARING INDIGENOUS GUERRILLA MEDICAL NETWORKS FOR UNCONVENTIONAL CONFLICTS

by

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The capability to treat and recuperate casualties to return to combat is a vital component of a force's defense strategy. The current luxury of large specialized medical teams and expedient patient evacuations will no longer be available in future unconventional (UW) and guerrilla warfare (GW) conflicts. It is the goal of this research to determine how to prepare a resistance medical network for unconventional conflict. First, historical guerrilla medicine cases are used to show the irrelevance of the current NATO roles of care. A more applicable framework to GW/UW based on treatment goals is proposed. Then, tangible requirements were determined through systems dynamics analysis and modeling. The developed model provides casualty statistics based on these tangible requirements for planners to optimize their medical network. Social network analysis was utilized to determine non-tangible considerations for each stage of care. Finally, these analyses were synthesized into a decision support algorithm to determine the best possible level of care for a given conflict's medical system. These analyses supported conclusions from historical cases that battlefield mortality is based on the movement of patients and of supplies in denied environments. Ultimately, improving medical interoperability, enhancing the movement of people and supplies, and preparing medical personnel for clandestine operations are required to decrease mortality in denied environments.

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ABSTRACT

The capability to treat and recuperate casualties to return to combat is a vital component of a force's defense strategy. The current luxury of large specialized medical teams and expedient patient evacuations will no longer be available in future unconventional (UW) and guerrilla warfare (GW) conflicts. It is the goal of this research to determine how to prepare a resistance medical network for unconventional conflict. First, historical guerrilla medicine cases are used to show the irrelevance of the current NATO roles of care. A more applicable framework to GW/UW based on treatment goals is proposed. Then, tangible requirements were determined through systems dynamics analysis and modeling. The developed model provides casualty statistics based on these tangible requirements for planners to optimize their medical network. Social network analysis was utilized to determine non-tangible considerations for each stage of care. Finally, these analyses were synthesized into a decision support algorithm to determine the best possible level of care for a given conflict's medical system. These analyses supported conclusions from historical cases that battlefield mortality is based on the movement of patients and of supplies in denied environments. Ultimately, improving medical interoperability, enhancing the movement of people and supplies, and preparing medical personnel for clandestine operations are required to decrease mortality in denied environments.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACS	American College of Surgeons
AFSOC	Air Force Special Operations Command
AOR	area of responsibility
ARSC	austere resuscitative and surgical care
ACS/COT	American College of Surgeons' Committee on Trauma
AST	austere surgical team
CASEVAC	casualty evacuation [platform]
CFR	case fatality rate
CIDG	Civilian Irregular Defense Group
CNS	central nervous system
CONUS	continental United States
CT	computed tomography
DCR	damage control resuscitation
DCS	damage control surgery
DIMO	Defense Institute for Medical Operations
DOD	Department of Defense
DOW	died of wounds
EU	European Union
GW	guerrilla warfare
ICU	intensive care unit
IED	improvised explosive device
JTS	Joint Trauma System
KIA	killed in action
LM	light maneuver
MACV-SOG	Military Assistance Command, Vietnam—Studies and Observations Group
MEDEVAC	medical evacuation [platform]
MTF	military treatment facility
NATO	North Atlantic Treaty Organization
NCTH	non-compressible truncal hemorrhage

NDAA	National Defense Authorization Act
NSHQ	NATO Special Operations Headquarters
OCONUS	outside of the continental United States
OPORD	operation order
OR	operating room
PFC	Prolonged Field Care
PJ	pararescueman
R2B	Role 2 Basic
R2E	Role 2 Enhanced
R2F	Role 2 Forward
RAND	Research and Development [Corporation]
RTD	return to duty
SEAL	[Navy] Sea, Air, and Land [Teams]
SNA	social network analysis
SOCEUR	Special Operations Command—Europe
SOCOM	Special Operations Command
SOF	special operations forces
SOMA	Special Operations Medical Association
SOST	Special Operations Surgical Team
TCCC	Tactical Combat Casualty Care
UN	United Nations
USASOC	United States Army Special Operations Command
USMC	United States Marine Corps
UW	unconventional warfare
WIA	wounded in action
WWII	World War II

EXECUTIVE SUMMARY

The capability to provide treatment of battlefield injuries and recover casualties for current and/or future combat is critical to a force's warfare strategy. Additionally, an organization lacking this capability increases the risk of death for those sustaining life-threatening injuries, potentially dampening their combatants' motivation to fight. Over the last two decades, the United States has grown accustomed to a robust and efficient casualty care system that, in guerrilla warfare (GW) and unconventional warfare (UW), would be unrealistic and unsustainable.

The formation of a GW/UW medical system has no doctrinal principles as a foundation. It is from this point that this research was conducted, looking at the following strategic problem: The U.S. has no known GW/UW medical network framework to use for establishing a medical system in such warfighting environments.

Designing a strategy for optimizing a medical network in GW/UW battlespaces starts with doctrine. Therefore, this research evaluated the applicability of the levels of care defined by U.S. and NATO medical doctrine to the GW/UW operational environment. The current structure of care echelons was described for U.S. and NATO doctrine, and through review of military medicine literature and historical recounts from Yugoslavian partisan hospitals, it became evident that the denied environment of UW makes the application of current echelons of care for all potential conflicts unrealistic. To address this problem, a new framework for medical care was created that focused on treatment goals, rather than capability. The Casualty Treatment Stages that make up this framework are proposed as the foundation for designing a GW/UW medical system.

A systemic approach was used to further characterize the proposed GW/UW Casualty Treatment Stages. The development of a GW/UW medical system is a robust, complex problem involving multiple interacting external, influencing systems, and the GW/UW Medical System of Interest itself. Some of these influencing systems may be complex and difficult to identify even after the onset of conflict. Some systems, however, are "known" and applicable to all medical systems developed with the proposed Casualty

Treatment Stage framework. These “known” systems were used to create causal loop diagrams that identified the most significant tangible limitations: trained personnel; hospital capacity; blood supply; and evacuation resources. The lack of these limited resources may cause the system to fail, but their presence does not guarantee success. Non-tangible limitations also play a significant role in the development of a GW/UW medical system.

Social network analysis and network structures can help illustrate the concepts of UW and identify the non-tangible limitations of a GW/UW medical system. For these conflicts, an occupying force network has increased density in their strong-holds, mandating that insurgent forces project forward into the occupied area to carry out harassing attacks. The increased density of the occupying force network, however, leads to an increased risk of compromise, requirement for clandestine operations, and reliance on the underground and auxiliary forces. These operational implications influence the employment of medical assets and their ability to render expedient, appropriate medical care. Decreased freedom of movement caused by increased opposition force density mandates medical teams to be more mobile, to decrease their footprint, to set up supply caches, and to rely on the clandestine movement of patients and supplies by the underground and auxiliary supporting networks.

A system dynamics model was created to provide planners with a decision support tool. It was designed based on the tangible limitations identified by the systemic analysis and takes into account some non-tangible limitations that still have an impact on the GW/UW Medical System that is being simulated by the model. Although limited in function in its current state, the model reflects the cause-and-effect relationships depicted in the causal loop diagrams. Patients were noted to have a delay in care and subsequent worsening in conditions primarily when awaiting evacuation. Evacuation, therefore, plays a large role in optimizing care and will rely on the ability to provide prolonged field care. Blood supply and medical supplies are also limiting factors in the ability of teams to treat patients and eventually caused attrition of the friendly force. Medical planners in the future will need to ensure that an auxiliary system supports the movement of blood, supplies, and most importantly, patients through the medical system to have the greatest mitigating impact on casualty statistics.

Planners who are trying to develop a medical system for a GW/UW conflict must have realistic expectations regarding the level of care possible for that system. The research synthesized the analyses conducted and developed an algorithm planning tool to determine to what treatment stage a medical system can realistically be developed for a given conflict. This tool identifies the best possible level of care that can be achieved for a given scenario based on two variables that cannot easily be modified: the existing capability of the indigenous forces, and whether there is a “safe zone” in the operating environment. The decision algorithm helps guide these decisions to avoid wasting precious resources on unrealistic goals. Regardless of the determined best possible level of care, this does not guarantee success in achieving that level. The other limitations discussed in this research, such as medical supplies, blood, evacuation, and risk of compromise, still hinder the ability to treat patients, independent of the medical skills of personnel.

Ultimately, the successful development and execution of a GW/UW medical system requires intervention into policies. Significant differences in medical standards, protocols, legal, and ethical guidance between nations hinders the ability to train indigenous personnel prior to the onset of conflict. This will be the hardest obstacle to overcome. A solution may be to use the NSHQ Comprehensive Defence strategy as justification for early training in non-standard medical practices. U.S. medical teams expected to support special operations need to receive training in UW and clandestine skills to improve survivability. Finally, the integration of medical officers competent in operations, mission analysis, and planning can optimize the use of medical assets to ensure battlefield deaths are minimized and strategic objectives are achieved.

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I. INTRODUCTION TO THE STRATEGIC PROBLEM AND STUDY DESIGN

The capability to provide treatment of battlefield injuries and recover casualties for current and/or future combat is critical to a force's warfare strategy. Additionally, an organization lacking this capability increases the risk of death for those sustaining life-threatening injuries, potentially dampening their combatants' motivation to fight.

The U.S. health system has been integral in progressing combat casualty care. In the 1970s, R. Adams Cowley propagated the idea that trauma patient mortality triples for every 30 minutes from injury, eventually leading to the "the golden hour" concept.[1] Military medicine advocated that the casualty system must be able to meet the golden hour to avoid preventable deaths in our warfighters. In 2009, Secretary of Defense Robert Gates required all missions in the Middle East to have an evacuation capability in order to provide this "golden hour" standard to all U.S. troops.[2] However, as we begin to face future conflict environments with reduced freedom of movement, our current combat casualty standards become impracticable.

In November 2017, COL (Ret.) Dr. Warner "Rocky" Farr bluntly outlined the challenges for medical care in denied territory in *The Death of the Golden Hour and the Return of the Future Guerrilla Hospital*.[3] Unconventional conflicts in these environments will likely involve special operations forces (SOF) working with guerrilla or resistance forces, utilizing auxiliary and underground support networks. Until recently, it had been assumed U.S. medical assets would be adequate for such conflicts. In a 2018 multinational unconventional warfare exercise hosted by Special Operations Command—Europe (SOCEUR) in the Baltic region of Eastern Europe, the medical leadership observed that a

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[1] E. Brooke Lerner and Ronald M. Moscati, "The Golden Hour: Scientific Fact or Medical 'Urban Legend'?," *Academic Emergency Medicine* 8, no. 7 (2001): 758–60, https://doi.org/10.1111/j.1553-2712.2001.tb00201.x.

[2] Russ S. Kotwal et al., "The Effect of a Golden Hour Policy on the Morbidity and Mortality of Combat Casualties," *JAMA Surgery* 151, no. 1 (January 2016): 15–24, https://doi.org/10.1001/jamasurg.2015.3104.

[3] Warner D. Farr, *The Death of the Golden Hour and the Return of the Future Guerrilla Hospital* (Tampa, FL: Joint Special Operations University Press, 2017).

medical system based only on U.S. military doctrine was unrealistic and unsustainable.[4] In the absence of a robust U.S. casualty system, both U.S. and resistance force casualties will have two choices: be treated by local medical personnel or risk dying from potentially treatable combat trauma. To avoid incapacitation from attrition, a resistance medical network will be indispensable for these conflicts.[5]

The establishment of a guerrilla combat casualty care system is no small task. Guerilla forces are classically limited on resources and are rarely of a demographic with extensive medical experience. In addition, the practice of austere resuscitation and surgery requires additional training for even the most qualified U.S. medical professionals. And finally, training and coordination of the full spectrum of necessary medical assets requires more than a few short certification courses. Consequently, mission commanders may be reluctant to entrust care of U.S. forces to a guerrilla medical system, and the potential time horizon for establishment of an indigenous medical system is disillusioning to stakeholders and strategic planners.

Although valid concerns, these potential objections are based on the assumption that the end-goal for every guerrilla or unconventional conflict is to establish a complete full-spectrum medical system, no matter the available resources or initial operating standards. In reality, a resistance medical network will be tailored to the complex circumstances of the resistance. This will cause variation in the level of trauma care provided within the network while decreasing the casualty death rate of the resistance without medical support. Therefore, it is the goal of this research to determine how SOF can prepare a resistance medical network to optimize casualty care for future unconventional conflict.

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[4] Jake Hickman, Jay Baker, and Elizabeth Erickson, "Survivability: Medical Support to Resistance," *Special Warfare Magazine*, December 2019, 17–21.

[5] Hickman, Baker, and Erickson, 18.

A. STRATEGIC PROBLEM DESCRIPTION

The current U.S. doctrinal medical system is a well-organized process with multiple levels of care, linked together by advanced medical evacuation assets.[6] Each level of care, or "role," has minimum operating standards, and theater medical assets are assigned roles based on their capabilities.[7] Higher roles are expected to have the minimum capability of that role in addition to all the capabilities of lower roles.[8] As casualties progress through the system, they transition to medical assets with more sophisticated capabilities, increasing the likelihood of recovery.

The problem is that the medical system outlined by current U.S. doctrine is too robust and unrealistic for a guerrilla warfare or unconventional warfare (GW/UW) scenario, emphasizing the lack of generalization across the spectrum of military conflict. As a result, the formation of a GW/UW medical system has no doctrinal principles as a foundation. It is from this point that this research was conducted, looking at the following strategic problem:

The U.S. has no known GW/UW medical network framework to use for establishing a medical system in such environments.

Below, the associated strategic questions for our strategic problem are listed.

1. For GW/UW, how should levels of medical care be defined?
2. What is the systemic nature of a GW/UW medical network?
3. What are the most influential limitations, tangible and non-tangible, for the establishment of each level of care?

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[6] Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," in *Emergency War Surgery*, Fourth edition (Falls Church, VA: United States Army Medical Department, 2013), 17–28, https://permanent.fdlp.gov/websites/www.cs.amedd.army.mil/borden/Portlet.aspx-ID=cb88853d-5b33-4b3f-968c-2cd95f7b7809.htm.

[7] North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, Edition C, AJP-4.10 (Belgium: North Atlantic Treaty Organization, 2019), 2.13.

[8] Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 19; North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, sec. 2.42.

4. Based on these findings, what is the "best case scenario" for a casualty care system in a given unconventional environment?

B. LITERATURE REVIEW

Over the last two decades, the United States has grown accustomed to a robust and efficient casualty care system. In his extensive report, Dr. Farr asserts that the luxury of large specialized medical teams and expedient patient evacuations to which we have become familiar will no longer be available in future GW and UW conflicts.[9]

Information regarding casualty care in previous GW/UW conflicts is primarily buried within personal recounts of leaders or physicians. In World War I, German General Paul von Lettow-Vorbeck led native African troops against the British and recognized the resource and manpower burden of evacuating and treating casualties in order to recover his fighters for the war effort.[10] Sympathizers without formal medical training were given credit for housing casualties recovering from their injuries. The lack of literature on casualty care during this period impaired preparations for the second world war.[11]

The Yugoslavian partisans in World War II (WWII) had one of the more well described resistance medical support systems, despite the country having limited existing medical capabilities. Dr. Lindsay Rogers was a British Royal Army physician who spent years with the partisans providing austere, forward guerrilla medical care.[12] Dr. Rogers describes the clandestine nature of casualty care in such environments, the essential ability to relocate and conceal supplies and patients, and the reliance on the underground and auxiliary networks for logistical and medical support. Personal accounts and medical journal articles from the partisan war describe "on the job" battlefield medicine training to local nationals both with and without previous medical experience, expanding treatment

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[9] Farr, The Death of the Golden Hour and the Return of the Future Guerrilla Hospital, 8.

[10] Farr, 11–13.

[11] Farr, 13.

[12] Lindsay Rogers, Guerilla Surgeon: The Adventures of a New Zealand Doctor in Yugoslavia (United Kingdom: Doubleday, 1957).

capacity for the wounded.[13] Allied forces provided several surgical teams, including some inserted by parachute to forward locations.[14] One Yugoslavian surgeon emphasized the unique nature of war surgery and the need for trained surgeons to undergo specific training for austere, clandestine surgery.[15]

In some conflicts of GW/UW, the denied operational environment, the lack of U.S. medical assets trained in clandestine tactics, and the evolution of indigenous medical systems made treatment of U.S. soldiers by partner forces acceptable to commanders. In a review of the literature by Dr. Farr, he quoted an operational order from a commander in the Korean War which stated "wounded can be evacuated by air to the 121st Hospital at Yongdongp'o where they will receive the same medical treatment as U.S. wounded…Local medical support is believed to be adequate for our current needs. You will continue to exploit the services of Korean doctors."[16] There is no literature from the medical community on how this assessment was made of the Korean medical capabilities or network established to support U.S. operations. In Vietnam, Special Forces within the Military Assistance Command, Vietnam—Studies and Observations Group (MACV-SOG) had developed a "Civilian Irregular Defense Group" (CIDG) clinical and hospital system. This system was manned by young, untrained physicians and Special Forces medics for their guerrilla partners and, on occasion, American casualties.[17] The MACV-SOG mission was a dangerous one behind enemy lines, unsuitable for most medical units to be located in close proximity to the points of injury. While several books regarding the operations have been written, there have been none accounting for CIDG medicine. However, there is documentation of large Viet Cong guerrilla hospitals in underground tunnels and

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[13] Rogers; Izidor Papo, "The Organization of Surgical Care in the Partisan War in Yugoslavia and Aspects Relevant to Training of Surgeons for Modern Warfare," *Journal of Trauma and Acute Care Surgery* 28, no. 1 (January 1988): S170-4.

[14] Warner D. Farr, "Guerrilla Warfare Medicine: A Review of the Literature and the Problem," *Journal of Special Operations Medicine* 6, no. 1 (January 2006): 18–29.

[15] Papo, "The Organization of Surgical Care in the Partisan War in Yugoslavia and Aspects Relevant to Training of Surgeons for Modern Warfare," S171.

[16] Farr, "Guerrilla Warfare Medicine: A Review of the Literature and the Problem," 27.

[17] Farr, 27; Farr, The Death of the Golden Hour and the Return of the Future Guerrilla Hospital, 47.

labyrinths.[18] One Special Forces physician describes extensive medical training for Viet Cong physicians to perform battlefield surgery.[19] The author described enemy surgical capabilities comparable to that of Western medicine at the time combined with Eastern and alternative medicine practices.

During the Soviet-Afghan War, mujahideen warfighters operated in a country without existing medical support and without coalition military medical augmentation. Injured mujahideen fighters were evacuated by mule across the Pakistan border to hospitals. Analysis of over 1300 patients treated in a Pakistani hospital from 1985–1987 demonstrated a markedly low ratio of critical wounds/extremity wounds compared to other wars, suggesting that those with critical injuries died due to prolonged evacuation to surgical care.[20] Few cases of medical teams supporting the mujahideen have been documented. One case was a three-person civilian Norwegian surgical team on bicycles attempted to improve the mujahideen's access to surgical care.[21] Another such instance involved Médecins Sans Frontières operating out of Peshawar into the Pashtune Valley to support the famous mujahideen commander, Ahmad Massoud.[22] In contrast, the medically sophisticated Soviets progressed their medical care in counter-guerrilla operations. Medical publications reported a reduction in battlefield deaths from expedient surgical care, efficient evacuation of wounded, and the establishment of special surgical teams in proximity to forward operations.[23]

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[18] Farr, "Guerrilla Warfare Medicine: A Review of the Literature and the Problem," 27.

[19] Arthur Mason Ahearn, "Viet Cong Medicine," *Military Medicine* 131, no. 3 (March 1966): 219–21.

[20] Mohit K. Bhatnagar and Gordon S. Smith, "Trauma in the Afghan Guerrilla War: Effects of Lack of Access to Care," *Surgery* 105, no. 6 (June 1, 1989): 699–705, https://doi.org/10.5555/uri:pii:0039606089903279.

[21] Farr, "Guerrilla Warfare Medicine: A Review of the Literature and the Problem," 28.

[22] Gordon McCormick, personal communication, January 7, 2021.

[23] Lester W Grau and William A Jorgensen, "Handling the Wounded in a Counter-Guerrilla War: The Soviet/Russian Experience in Afghanistan and Chechnya," U.S. *Army Medical Department Journal*, January 1998, 2–10.

1. Battlefield Statistics

Battlefield medicine efficacy for decreasing battlefield fatalities is determined by analyzing combat casualty data. Multiple factors play a role in the numbers of killed in action (KIA) and died of wounds (DOW), including weapons employed, ballistic characteristics, protective equipment, and medical care.[24] KIA is defined as the casualty population who die prior to reaching a military hospital, while DOW are those who died after reaching a medical facility. KIA rates over the last century have ranged from 20–25% while DOW rates dropped significantly in the latter half of WWII to around 5% with improvement of evacuation and medical techniques.[25] Critics of battlefield medicine advancements may allude to the increased DOW rate of the recent conflicts in Iraq/Afghanistan compared to WWII and Vietnam. However, when calculating the case fatality rate (CFR), or the fatality rate of all battlefield wounded and KIA, the rates declined from 19.1% in WWII to 9.4% in Iraq/Afghanistan.[26] Decreased KIA rates with increased DOW imply better evacuation as more serious casualties are reaching treatment facilities, and a CFR decrease supports an improvement in battlefield medicine research and practice improvements.[27] These studies look at all casualties and do not differentiate between SOF and conventional forces, which may have different statistics given the more restrictive operational environments.

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[24] Howard R Champion et al., "A Profile of Combat Injury," *The Journal of Trauma: Injury, Infection, and Critical Care* 54, no. 5 (2003): S13–19; John B. Holcomb et al., "Understanding Combat Casualty Care Statistics," *The Journal of Trauma: Injury, Infection, and Critical Care* 60, no. 2 (February 2006): 397–401, https://doi.org/10.1097/01.ta.0000203581.75241.f1; Ronald F. Bellamy, Peter A. Maningas, and Joshua S. Vayer, "Epidemiology of Trauma: Military Experience," *Annals of Emergency Medicine* 15, no. 12 (December 1, 1986): 1384–88, https://doi.org/10.1016/S0196-0644(86)80920-9; Basil A. Pruitt, "Combat Casualty Care and Surgical Progress," *Annals of Surgery* 243, no. 6 (June 2006): 715–29, https://doi.org/10.1097/01.sla.0000220038.66466.b5.

[25] Holcomb et al., "Understanding Combat Casualty Care Statistics," 398; Champion et al., "A Profile of Combat Injury," S16.

[26] Holcomb et al., "Understanding Combat Casualty Care Statistics," 399–400.

[27] Holcomb et al., 400–401; Joseph F. Kelly et al., "Injury Severity and Causes of Death From Operation Iraqi Freedom and Operation Enduring Freedom: 2003–2004 Versus 2006," *The Journal of Trauma: Injury, Infection, and Critical Care* 64, no. Supplement (February 2008): S21–27, https://doi.org/10.1097/TA.0b013e318160b9fb.

Further analysis of the causes of battlefield fatalities have changed our focus of medical research and technologies. Casualties in which the cause of death may have been thwarted if they had received timelier and/or advanced medical care are called "preventable deaths."[28] A 2007 study looking specifically at SOF combat fatalities between 2001–2004 labeled 12 (15%) of 82 fatalities as potentially preventable deaths had the situation afforded extensive care or expedient transport.[29] Studies such as these have emphasized the need for protocolized point of injury care, advanced capabilities for medics in the field, and reduction in the time to surgical care.[30] In 2004, the Assistant Secretary of Defense for Health Affairs directed data collection and research to improve trauma care for combatants and case fatality rates, leading to the evolution of the Joint Trauma System.[31] Tactical Combat Casualty Care (TCCC) was developed in the 1990s to establish prehospital care guidelines and protocols for combat medics, and eventually all combatants, using evidence-based medicine.[32] Multiple studies emerged over the next two decades showing improvement in preventable deaths, including the lowest rate of preventable deaths recorded in modern conflicts by the 75th Ranger Regiment.[33] With the development of one hour evacuation rings, SOF medic training placed more emphasis on TCCC, but in theaters with delayed evacuations up to 96 hours, medics identified the lack of sufficient training

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[28] Brian J. Eastridge et al., "Death on the Battlefield (2001–2011): Implications for the Future of Combat Casualty Care," *Journal of Trauma and Acute Care Surgery* 73 (December 2012): S431–37, https://doi.org/10.1097/TA.0b013e3182755dcc; Kelly et al., "Injury Severity and Causes of Death From Operation Iraqi Freedom and Operation Enduring Freedom," S22; Champion et al., "A Profile of Combat Injury," S15; Christopher G Blood et al., "An Assessment of the Potential for Reducing Future Combat Deaths through Medical Technologies and Training," *The Journal of Trauma* 53, no. 6 (2002): 1160–5.

[29] John B. Holcomb et al., "Causes of Death in U.S. Special Operations Forces in the Global War on Terrorism," *Annals of Surgery* 245, no. 6 (June 2007): 986–91, https://doi.org/10.1097/01.sla.0000259433.03754.98.

[30] Eastridge et al., "Death on the Battlefield (2001–2011)," S434-435; Blood et al., "An Assessment of the Potential for Reducing Future Combat Deaths through Medical Technologies and Training," 1165.

[31] "History," Joint Trauma System, accessed February 4, 2021, https://jts.amedd.army.mil/index.cfm/about/origins.

[32] Frank K. Butler, "Two Decades of Saving Lives on the Battlefield: Tactical Combat Casualty Care Turns 20," *Military Medicine* 182, no. 3–4 (March 1, 2017): e1563–68, https://doi.org/10.7205/MILMED-D-16-00214.

[33] Butler, e1567; Russ S. Kotwal et al., "Eliminating Preventable Death on the Battlefield," *The Archives of Surgery* 146, no. 12 (December 2011): 1350–58.

to address critical casualties.[34] The Special Operations Command (SOCOM) and the Special Operations Medical Association (SOMA) formed the Prolonged Field Care (PFC) Working Group to identify capabilities necessary to manage casualties in the field for extended periods of time.[35]

One of the subcategories of preventable deaths is non-compressible truncal hemorrhage (NCTH), which is life-threatening bleeding in areas only accessible by surgeons. In the study looking at causes of death from 2001–2011, 88% of the preventable deaths were from hemorrhage, and two-thirds of those were from NCTH.[36] Based on the definition of NCTH, this subset of preventable deaths supports the argument for decreased transport times to surgical care.[37] The SOF and UW operational environment, as previously discussed, make evacuation of patients difficult, paving the way for formalization of austere resuscitative and surgical care (ARSC). ARSC has recently been defined by the Joint Trauma System as "advanced medical capability delivered by small teams with limited resources, often beyond traditional timelines of care, and bridges gaps in roles of care in order to enable forward military operations and mitigate risk to the force."[38] Several surgical teams across the services, both conventional and SOF, have been formed to provide forward damage control surgery and resuscitation to address NCTH in areas of prolonged evacuation. While initial data from these teams have confirmed decreased time

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[34] Kotwal et al., "The Effect of a Golden Hour Policy on the Morbidity and Mortality of Combat Casualties," 22–23; Christopher J Mohr and Sean Keenan, "Prolonged Field Care Working Group Position Paper: Operational Context for Prolonged Field Care," *Journal of Special Operations Medicine* 15, no. 3 (2015): 78–80.

[35] Mohr and Keenan, "Prolonged Field Care Working Group Position Paper," 78–80; Justin A Ball and Sean Keenan, "Prolonged Field Care Working Group Position Paper: Prolonged Field Care Capabilities," *Journal of Special Operations Medicine* 15, no. 3 (2015): 76–77.

[36] Eastridge et al., "Death on the Battlefield (2001–2011)," S434; Jay B Baker et al., "Austere Resuscitative and Surgical Care in Support of Forward Military Operations—Joint Trauma System Position Paper," *Military Medicine* 186, no. 1–2 (January 1, 2021): 12–17, https://doi.org/10.1093/milmed/usaa358.

[37] Kyle N. Remick et al., "Defining the Optimal Time to the Operating Room May Salvage Early Trauma Deaths," *The Journal of Trauma and Acute Care Surgery* 76, no. 5 (May 2014): 1251–58, https://doi.org/10.1097/TA.0000000000000218; Kotwal et al., "The Effect of a Golden Hour Policy on the Morbidity and Mortality of Combat Casualties," 23; Lerner and Moscati, "The Golden Hour," 759.

[38] Baker et al., "Austere Resuscitative and Surgical Care in Support of Forward Military Operations—Joint Trauma System Position Paper," 14.

to advanced medical care, these light, mobile teams have capacity limitations which may not be sufficient for UW casualty estimations.[39]

2. Medicine in Unconventional Warfare and Partner Building

SOCEUR has been evaluating the application of current U.S. medical doctrine in support of resistance scenarios in Eastern Europe. After a 2018 multi-national UW exercises in Europe, SOCEUR determined that there would be increased reliance on field care by medics and that SOF surgical teams, based on current training and capabilities, have low probability of sustainment or survival.[40] As a result, SOCEUR turned to the Resistance Operating Concept to form a whole-of-society approach to medical support to resistance, recognizing the critical importance of coordination and training between U.S. military, partner military, and civilian medical personnel.[41]

Discussions on building partner capacity are usually focused on those of security force assistance and foreign internal defense, with little discussion of medical contributions other than medical support. A Research and Development Corporation (RAND) study conducted for the Air Force Special Operations Command (AFSOC) in 2009 thoroughly discussed the development of civilian medical systems in order to provide stability for partner nations through healthcare.[42] This study, however, fails to address the support to security forces, which was addressed by Dr. Ramey Wilson's thesis on strengthening partner security forces through their own medical network.[43] Admittingly, one of the challenges of building partner capacity in medicine compared to security is the required

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[39] S Satterly et al., "Special Operations Force Risk Reduction: Integration of Expeditionary Surgical and Resuscitation Teams," *Journal of Special Operations Medicine* 18, no. 2 (December 31, 2017): 49–52; Baker et al., "Austere Resuscitative and Surgical Care in Support of Forward Military Operations—Joint Trauma System Position Paper," 15.

[40] Hickman, Baker, and Erickson, "Survivability: Medical Support to Resistance," 18.

[41] Hickman, Baker, and Erickson, 18–20.

[42] David E. Thaler et al., *Building Partner Health Capacity with U.S. Military Forces: Enhancing AFSOC Health Engagement Missions*, TR1201 (Santa Monica, CA: RAND, 2012), https://www.rand.org/pubs/technical_reports/TR1201.html.

[43] Ramey L Wilson, "Building Partner Capacity and Strengthening Security through Medical Security Force Assistance" (master's thesis, Naval Postgraduate School, 2013).

duration of training depending on the current level of capability.[44] As a few authors have pointed out, however, by recognizing the potential need in future UW conflicts, development of medical networks can start prior to conflict.[45]

UW literature and manuals place emphasis on the necessity on building relationships with the guerrilla, underground, and auxiliary forces to succeed in future UW conflicts.[46] However, these assertions are in relation to operations, intelligence sharing, and logistical support within the coalition. Little, if any, attention is paid from the operational community to medical support other than recognition of the underground and auxiliary forces assisting in casualty care. In fact, little attention has been paid to the need in training our partner forces in medical support. The absence of care created when U.S. medical support left partner force operations has been documented to cause partner force fighters to defect to the enemy, stressing the value of creating an indigenous medical system.[47]

There has been discussion within the medical community in regard to providing medical support to resistance or guerrilla forces within denied environments. As these conversations have become more common, there have been articles which restate the challenges from past UW conflicts and suggest system structure designs for U.S. medical

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[44] Wilson, 90; Ramey L. Wilson, Lance Spielmann, and Kelly Dowdall-Garberson, "A Medical Interoperability Scale for Medical Security Force Assistance and Health Engagements," *Military Medicine* 182, no. 11 (November 2017): 1735–37, https://doi.org/10.7205/MILMED-D-17-00320; Sean D Mclaughlin and Ramey L Wilson, "A Tiered Framework for Organizing and Categorizing Medical Interoperability," *Military Medicine* 185, no. 3–4 (March 2, 2020): 330–33, https://doi.org/10.1093/milmed/usz420.

[45] Farr, *The Death of the Golden Hour and the Return of the Future Guerrilla Hospital*, 61–72; Hickman, Baker, and Erickson, "Survivability: Medical Support to Resistance," 21.

[46] J Darren Duke, Rex L Phillips, and Christopher J Conover, "Challenges in Coalition Unconventional Warfare," *Joint Force Quarterly* 75, no. 4 (2014): 129–34; Department of the Army, *Special Forces Unconventional Warfare*, TC 18–01 (Washington, DC: Department of the Army, 2019); Mark Grdovic, *A Leader's Handbook to Unconventional Warfare*, SWCS PUB 09–1 (Fort Bragg, NC: U.S. Army John F. Kennedy Special Warfare Center and School, 2009).

[47] Nick Paton Walsh, "Afghan Soldiers Desert as Taliban Push," CNN, last modified April 11, 2016, https://www.cnn.com/2016/04/11/middleeast/afghanistan-helmand-taliban-soldiers/index.html.

support.[48] Some of these recommendations focus primarily on patient evacuation and establishment of larger hospitals, which are not capable of rapid mobilization in the event of attack or compromise. There is little consideration for any existing indigenous medical system or interoperability. Current medical support requests are filled by a multitude of possible assets with a wide range of capabilities and limitations.[49] While Dr. Farr mentions the utility of and historical success of forward, mobile teams, discussion of the development, preparation, and employment of these teams for future UW conflict is lacking.[50]

For those resources which do discuss development and training of indigenous medical support, emphasis is primarily on training of medics and nurses. The Army Manual TC 18–09, Special Forces Medical Support to Resistance provides detailed instructions on the establishment of a resistance medical system, the set-up of hospitals, and the training of indigenous nurses and medics after initial contact.[51] However, there is no discussion as to the origin, acquisition, training, or development of the surgeons and physicians required for these hospitals. This manual also does not address the development of a system in phase 0 operations, prior to infiltration.

3. Foreign Medical Education

The medical literature has a plethora of data related to the development, evaluation, optimization, and training of civilian trauma systems in regions of the United States and foreign nations. It is recognized that the demand of trauma care, category of injuries, physician and population density, and patient movement are all factors that need to be

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[48] M. T. Colesar, "Study of Yugoslav Guerrilla Forces of WWII to Inform Modern U.S. Army Strategy During A Near-Peer Military Conflict" (Bethesda, MD: Uniformed Services University of the Health Sciences, May 30, 2019), https://apps.dtic.mil/sti/citations/AD1077565.

[49] Baker et al., "Austere Resuscitative and Surgical Care in Support of Forward Military Operations—Joint Trauma System Position Paper," Table 1; Farr, *The Death of the Golden Hour and the Return of the Future Guerrilla Hospital*, 54–57.

[50] Farr, *The Death of the Golden Hour and the Return of the Future Guerrilla Hospital*, 57; Hickman, Baker, and Erickson, "Survivability: Medical Support to Resistance," 18–20; Farr, "Guerrilla Warfare Medicine: A Review of the Literature and the Problem," 29.

[51] Department of the Army, *Special Forces Medical Support to Resistance*, TC 18–09 (Washington, DC: Department of the Army, 2019).

considered independently for each location.[52] These studies, however, do not fully consider military or combat medical care, which offers unique limitations on resources and patient evacuation. The American College of Surgeons' Committee on Trauma (ACS/COT) has published basic trauma criteria for assessment of American civilian trauma systems.[53] A research group from Albania evaluated these criteria in developing countries and determined their applicability to trauma care in low-income and middle-income countries.[54] These criteria are specific to civilian systems, do not offer a prioritization of items, and fail to provide a grading scale for each item. Gubás notes that United Nations (UN), North Atlantic Treaty Organization (NATO), and European Union (EU) supported military operations must take into consideration "whether local hospitals and clinics within the area of operations are able to meet the standard of care for the participating nations."[55] However, such standards of care are not well defined.

[52] Chris Atkin et al., "The Evolution of an Integrated State Trauma System in Victoria, Australia," *Injury* 36, no. 11 (November 1, 2005): 1277–87, https://doi.org/10.1016/j.injury.2005.05.011; Gloria J. Bazzoli, "Community-Based Trauma System Development: Key Barriers and Facilitating Factors," *Journal of Trauma and Acute Care Surgery* 47, no. 3 (September 1999): S22; Simon Bergman et al., "Assessing the Impact of the Trauma Team Training Program in Tanzania," *Journal of Trauma and Acute Care Surgery* 65, no. 4 (October 2008): 879–83, https://doi.org/10.1097/TA.0b013e318184a9fe; Tyler E. Callese et al., "Trauma System Development in Low- and Middle-Income Countries: A Review," *Journal of Surgical Research* 193, no. 1 (January 1, 2015): 300–307, https://doi.org/10.1016/j.jss.2014.09.040; Rifat Latifi et al., "Trauma System Evaluation in Developing Countries: Applicability of American College of Surgeons/Committee on Trauma (ACS/COT) Basic Criteria," *World Journal of Surgery* 38 (April 3, 2014), https://doi.org/10.1007/s00268-014-2538-7; Ari Leppäniemi, "Trauma Systems in Europe," *Current Opinion in Critical Care* 11, no. 6 (December 2005): 576–79, https://doi.org/10.1097/01.ccx.0000186918.00382.58; Ari Leppäniemi, "A Survey on Trauma Systems and Education in Europe," *European Journal of Trauma and Emergency Surgery* 34, no. 6 (December 1, 2008): 577–81, https://doi.org/10.1007/s00068-008-7157-2; Julia Pemberton, Madan Rambaran, and Brian H. Cameron, "Evaluating the Long-Term Impact of the Trauma Team Training Course in Guyana: An Explanatory Mixed-Methods Approach," *The American Journal of Surgery* 205, no. 2 (February 1, 2013): 119–24, https://doi.org/10.1016/j.amjsurg.2012.08.004.

[53] "Trauma Systems Components/Models," American College of Surgeons, accessed February 2, 2021, https://www.facs.org/quality-programs/trauma/tqp/systems-programs/tscp/components.

[54] Latifi et al., "Trauma System Evaluation in Developing Countries," 6.

[55] Frantisek Gubás, "Medical Support of Military Operations Led by Organizations of International Crisis Management," *Science & Military Journal* 10, no. 1 (2015): 25–29.

There are also articles discussing basic trauma skills training in foreign countries and maintenance of trauma surgical skills.[56] These studies do not address the training of foreign physicians in the uncommon practices in battlefield surgeries. The Defense Institute for Medical Operations (DIMO) is an Air Force-implemented security cooperation program that provides "foreign civilian and government agencies health education and training that builds strong, resilient, international partnerships."[57] It has several basic courses in trauma care, but it does not specifically address special operations, UW, or the unique medical challenges in these environments.[58]

The existing literature is extensive for the topics of GW, battlefield medicine, and civilian trauma system standards. Military doctrine is littered with topics of UW and guerrilla force development. There have been more recent publications acknowledging the need for abandoning current conflicts' casualty care standards and reverting to guerrilla medicine. Articles and manuals in response to this call for change, however, lack guidance in key areas and draw attention to the complex task at hand. More research is required to understand a resistance medical network framework, the requirements to achieve each level of care within that framework, and to what extent a network can be established for a given resistance force to optimize its casualty statistics.

C. METHODS

The establishment of a guerrilla medical support system is a complex problem involving several interacting processes and organizations. Additionally, each guerrilla and unconventional conflict has unique characteristics. Although we know some of the challenges and limitations from impromptu guerrilla medicine system, not all will be

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56 Bergman et al., "Assessing the Impact of the Trauma Team Training Program in Tanzania," 882–83; Pemberton, Rambaran, and Cameron, "Evaluating the Long-Term Impact of the Trauma Team Training Course in Guyana," 122–24; Colin F. Mackenzie et al., "Efficacy of Trauma Surgery Technical Skills Training Courses," *Journal of Surgical Education* 76, no. 3 (May 1, 2019): 832–43, https://doi.org/10.1016/j.jsurg.2018.10.004.

57 "The Defense Institute for Medical Operations (DIMO)," Air Force Research Laboratory, accessed February 3, 2021, https://www.afrl.af.mil/711HPW/USAFSAM/dimo/.

58 Donald Berwick, Autumn Downey, and Elizabeth Cornett, eds., A National Trauma Care System: Integrating Military and Civilian Trauma Systems to Achieve Zero Preventable Deaths After Injury (Washington, DC: National Academies Press, 2016).

applicable to every case. Education, existing medical training/practices, and extent of population support are important variables that are not equal across all guerrilla forces. Likewise, not all trauma care guidelines, standards, or advancements will be feasible for every resistance force or all areas of operation. Ultimately, the goal of battlefield medicine is to minimize the case fatality rate by decreasing preventable deaths. This research evaluated the applicability of current medical system doctrine, identified tangible and non-tangible challenges to UW medical support, and developed a model and decision algorithm to identify and scale the most attainable medical system for a given force. In order to achieve this, it used a variety of methods to fully analyze the problem set.

1. Defining a GW/UW Medical Network and Levels of Care

U.S. and NATO medical doctrine have established casualty care systems and roles of medical care. As discussed, the circumstances of guerrilla and unconventional conflicts are unique and not typically addressed in medical doctrine. Therefore, the applicability of doctrinal medical networks to the UW scenario is questionable. This analysis used historical recounts of guerrilla warfare and guerrilla medicine in comparison with current medical doctrine to refute the application of current medical doctrine to the GW/UW battlespace. A review of the literature on the development and efficacy of TCCC, PFC, Austere Surgical Teams (AST), and the Joint Trauma System (JTS) casualty evacuation system supports the strategic reassessment of battlefield echelons of care. A new medical system framework is proposed using stages focused on treatment goals, rather than asset capabilities. Previous conflict battlefield casualty statistics and data in published studies, government reports, and expert presentations were used as markers of efficacy for the proposed framework. These stages not only address the unique nature of GW/UW conflicts but can be universally applied to all combat medical systems.

2. Identifying Tangible Limitations for the GW/UW Medical Network

Battlefield casualty care occurs within a complex system of systems, characterized by a dynamic operational environment and a large number of interrelated parts that interact with probabilistic non-linearity. Because this complex system is goal-seeking and adaptive to changes in its environment, it can result in emergent, and often unpredictable, behavior.

Based on the proposed medical system framework, systemic analysis identified dominant feedback components within the system. Causal loop diagrams of the proposed system detected reinforcing and balancing feedback loops, subsequently isolating the system's most impactful cause-and-effect, independent and dependent variables. Guerilla medicine case studies, battlefield medicine research, austere medicine research, and medical doctrine were used to select key variables and their likely interactions within the system. These variables define the baseline requirements for each treatment stage of the system. The tangible variables identified in this analysis include personnel, supplies, or infrastructure and will set the criteria for the treatment stages to ultimately determine what level a guerrilla force medical system can realistically establish and sustain.

3. Identifying Non-tangible Limitations for the GW/UW Medical Network

UW is at least partially defined by the denied environment in which it operates. The dense network of the occupying force creates the hostile and unwelcoming conditions and atmosphere intended to thwart insurgent efforts. This section applies social network analysis concepts to explain the unique interpersonal and social attributes in dynamic unconventional conflicts, ultimately creating a non-permissive, denied environment. Social networks graphically depict theories of an insurgency by mapping examples of two opposing forces. The study used the Lithuanian Forest Brothers during the Soviet occupation as a historical case to validate these insurgency social network maps. The analysis of these theoretical social networks provided the operational implications in the unconventional warfare environment. Most importantly, those implications were related to medical care in these environments, providing non-tangible constraints for establishment of a GW/UW medical system.

4. GW/UW Medical Network System Dynamics Model

Based on the causal loop diagrams developed through system analysis, a systems dynamics model simulating the flow of casualties through the system was created. This model highlights for the user the influencing systems that most affect the fighting force attrition rate. This modeling required quantitative values for accuracy. Data was extracted from published medical research and GW/UW literature. Existing databases from the

Special Operations Surgical Teams (SOSTs) provided another significant source of data in creating the model. During their Operation INHERENT RESOLVE deployments from 2016–2020, SOSTs collected anonymized data on all patients for future research and austere medicine process improvement. Statistics such as blood product utilization, treatment time, injury pattern frequency, and mortality rates were used for portions of the model involving small, forward surgical teams. For data that could not be extracted from literature or that is unknown, the initial model used estimated values based on expert suggestions.

5. Synthesizing Findings into Planning Algorithms

The operating environment and circumstances for each conflict are unique, especially in UW. Although this study creates foundational concepts for medical support in such conflicts, it becomes apparent that the systemic nature of this problem dictates that designing a medical system cannot provide a "cookie cutter," one size fits all solution. Planners need to take all variables into consideration to determine the best possible medical network for a given conflict in a specific area of operations. This section put all the discussed theories and concepts together to offer a simple decision support tool planners can use to help determine the best possible level of medical support that can be achieved. The effect on mortality between these levels of support are provided using the designed systems dynamics model to facilitate mission commander's risk assessment.

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II. APPLICATION OF CURRENT U.S. AND NATO MEDICAL DOCTRINE TO UW MEDICAL SUPPORT

Designing a strategy for optimizing a medical network in GW/UW settings should start with doctrine. According to the Department of Defense (DOD) Dictionary, joint doctrine is a set of “fundamental principles that guide the employment of U.S. military forces in coordinated action toward a common objective and may include terms, tactics, techniques, and procedures.”[59] U.S. and NATO medical system doctrines exist and lay the foundation for establishing these networks; however, doctrine specific to GW/UW medicine has been absent for decades since the focus of conflicts has been on counterinsurgency.[60] In fact, the current definition of UW was in limbo until the SOCOM and Army Special Operations Commands (USASOC) adopted it in 2009.[61] In theory, the principles of existing medical doctrine should be made applicable to the full spectrum of military conflicts and tailored to the process of execution based on operational context. If this is not the case, either new doctrine specific to GW/UW should be developed or current doctrine should be adjusted.

This chapter evaluates the applicability of the levels of care defined by U.S. and NATO medical doctrine to the GW/UW operational environment. NATO medical doctrine was included because some of the U.S.’s major allies are NATO members and use this doctrine to establish nation state standards (as the U.S. did). The current structure of care echelons is described for U.S. and NATO doctrine, highlighting differences or points of confusion between the two and providing a visual summary of the findings. Next, I review the evolution of military medicine in response to more austere environments and the challenges that Yugoslavian partisan hospitals faced during World War II. Through this review, it is evident that the denied environment of UW makes current echelons of care

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[59] Office of the Secretary of Defense, *DOD Dictionary of Military and Associated Terms* (Washington, DC: Department of Defense, 2021), 114.

[60] Warner D. Farr, “American Guerrilla Warfare Medical Doctrine – The First Manuals: Lessons Learned,” *Journal of Special Operations Medicine* 6, no. 2 (Spring 2006): 23–33.f

[61] Mark Grdovic, “Developing a Common Understanding of Unconventional Warfare,” *Joint Force Quarterly* 57, no. 2 (2010): 136.

unrealistic for all potential conflicts. To address this problem, a new framework for medical care is proposed as the foundation for designing a GW/UW medical system.

A. CURRENT ECHELONS OF CARE

Combat casualty care is a progressive continuum across a large geographic area to address injuries sustained on the battlefield and decrease preventable deaths. This system is a well-organized process with multiple levels of care, linked together by advanced medical evacuation assets.[62] Each level of care, or "Role," has minimum operating standards, and theater medical assets are assigned roles based on its capabilities.[63] Higher roles are expected to have the minimum capability of that role in addition to all the capabilities of lower roles.[64] As casualties progress through the system, they transition to medical assets with more sophisticated capabilities, increasing the likelihood of recovery. Casualties do not require progressing sequentially through roles and may skip to a higher role if more efficient or operationally necessary, but they cannot retrograde to a lower level, or less capable role.[65]

Although the concept of the stepwise military medical roles may resemble the U.S. civilian trauma levels established by the American College of Surgeons (ACS), they are not synonymous.[66] There are five echelons of care in the military casualty system, denoted Roles 1–5 (some references only use Roles 1–4).[67] These are applicable only to medical entities within the combat casualty system, which includes some, but not all, in-garrison

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[62] Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 17.

[63] North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, sec. 2.41-2.42.

[64] Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 17; North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, sec. 2.42.

[65] Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 17.

[66] Brian J. Eastridge et al., "Trauma System Development in a Theater of War: Experiences From Operation Iraqi Freedom and Operation Enduring Freedom," *Journal of Trauma and Acute Care Surgery* 61, no. 6 (December 2006): 1366–73, https://doi.org/10.1097/01.ta.0000245894.78941.90.

[67] Mark Bagg, Dana Covey, and Elisha Powell, "Levels of Medical Care in the Global War on Terrorism," *Journal of the American Academy of Orthopaedic Surgeons* 14, no. 10 (October 2006): S7–9; Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 18–28.

military treatment facilities (MTFs).[68] The differing capabilities between all in-garrison MTFs are not translatable to the Role system, and only those facilities that meet the ACS trauma standards are designated with the appropriate trauma level accreditation.[69] Conversely, garrison treatment facilities may both have a Role and trauma level assigned to it; for example, San Antonio (or Brooke Army) Medical Center is considered a Role 5 casualty care facility and a level 1 trauma center.

The roles system allows medical planners to place medical assets appropriately within the theater based on medical evacuation availability and capabilities. Typically, medical evacuation units are co-located with Role 2 or Role 3 medical assets, and a medical evacuation ring is formed from their location to establish the area of operations typically covered by this facility.[70] Graphical depictions of the evacuation rings and location of each medical asset with their assigned role of care are created by the theater surgeon's office and distributed in the operation order (OPORD) Annex Q for coordination of casualty movement within the system.[71] Theoretically, the role designations establish a universal classification which effectively communicates each facility's capabilities to other medical assets in theater.

Unfortunately, the universal nature of the roles is only theoretical. Each role is defined by a minimum capability standard, allowing for assets with significant ranges of capabilities to be classified in the same role. Furthermore, each U.S. military branch of service has its own unique medical assets which are classified using this typology, but vary significantly in operational capabilities, operational environment, required resources, and required support.[72] In addition, NATO has its own Roles 1–4 that closely resemble, but

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68 Bagg, Covey, and Powell, "Levels of Medical Care in the Global War on Terrorism," S9.

69 "Trauma Center Levels Explained," American Trauma Society, accessed March 9, 2021, https://www.amtrauma.org/page/traumalevels.

70 Joint Chiefs of Staff, *Joint Health Services*, JP 4-02 (Washington, DC: Joint Chiefs of Staff, 2018), II-3–5. I was deployed as the team leader for a Special Operations Surgical Team in Syria in 2019. During this time, some evacuation assets were co-located at Role 2s. Although only listed in doctrine at Role 3s, in practice, they are not limited to the higher roles.

71 Joint Chiefs of Staff, G-7.

72 Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 18–28.

are not identical to, the U.S. system. The loose definitions of the NATO roles allow participating nations latitude in their assets' capabilities while attempting to provide a common classification for collaboration in the combined operational environment.[73] The differences between vague role definitions further broaden the scope of each echelon and lack precision in communicating to forces what an asset's capabilities are based on its assigned role.

The remainder of this section will define the different roles of care in terms of minimal capability requirements, mobility, and medical personnel present at that role. Descriptions will be provided for U.S. and NATO doctrine. Examples of medical assets from U.S. medical services will be used to demonstrate the variation in capabilities within an echelon of care. Finally, a table will be constructed to summarize and organize each role of care.

1. Role 1 Echelon of Care

Role 1's defining standard is "point of injury care" or care provided to the patient immediately after injury, usually without evacuation from the site.[74] The primary personnel rendering Role 1 care are typically non-medical first responders or battlefield medics integrated into the operational unit, such as special forces medics (18D), Army combat medics, Navy Sea, Air, and Land (SEAL) corpsmen, pararescuemen (PJ), and independent medical technicians.[75] TCCC has become the mainstay for this Role and has shown significant improvements in treatment of potentially survivable life-threatening injuries.[76] The battlefield is not conducive to staying in one place, and this level of care does not have the ability to hold patients. Patients are either returned to the fight or evacuated to the next level of care.[77] This basic standard for a Role 1 is ubiquitous across military branches.

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[73] North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, 2.13.

[74] Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 18.

[75] Office of the Army Surgeon General, 18.

[76] Kotwal et al., "Eliminating Preventable Death on the Battlefield," 1353–56; Butler, "Two Decades of Saving Lives on the Battlefield," E1567-1568.

[77] Joint Chiefs of Staff, *Joint Health Services*, II-1–2.

The United States Army, United States Marine Corps (USMC), and SOCOM have expanded Role 1 to include medical treatment areas away from the point of injury.[78] In these instances, battlefield casualties are evacuated from the point of injury to the aid stations.[79] These aid stations are staffed by a physician, physician's assistant, and/or medic/corpsman, provide initial treatment and stabilization, and either return patients to duty or evacuate them to the next level of care.[80] There is no holding or surgical capability at the aid station.

At one time, the Marine Corps Role 1 assets included a larger shock trauma platoon attached to the Marine Expeditionary Force.[81] The platoon provided slightly more advanced treatment with two emergency medicine physicians and a total of 25 medical personnel.[82] Like the aid station, the shock trauma platoon stabilizes and evacuates patients and lacks surgical capability. With the expanded resources, however, the platoon has the ability to hold patients for up to 48 hours.[83] Per the most recent U.S. doctrine, the shock trauma platoon is listed as a Role 2 asset but does not have surgical capabilities.[84]

NATO doctrine's definition of Role 1 is short and vague, leaving specifics up to the individual states to discern. Per AJP-4.10, a Role 1 asset "encompasses a set of primary health care capabilities which includes but is not limited to triage, pre-hospital emergency care and essential diagnostics…[it] may also include a limited patient holding and medical supply capability."[85] By this broad description, it is unclear whether a battlefield medic in the field is considered to be a Role 1 capability or if it requires an actual treatment facility. In line with the U.S. standards, however, there is no surgical capability and "limited" holding.

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[78] Joint Chiefs of Staff, II–2; Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 18.

[79] Bagg, Covey, and Powell, "Levels of Medical Care in the Global War on Terrorism," S8.

[80] Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 18.

[81] Office of the Army Surgeon General, 18.

[82] Office of the Army Surgeon General, 18.

[83] Office of the Army Surgeon General, 18.

[84] Joint Chiefs of Staff, *Joint Health Services*, II–4.

[85] North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, 2.13.

2. Role 2 Echelon of Care

The Role 2 echelon of care has become the most varied among the taxonomy, leading to the call for subcategories to further differentiate between medical unit capabilities.[86] Role 2 is the first echelon that can perform damage control surgery, or surgery addressing only immediate life-threats.[87] Some resources claim Role 2 assets have basic primary care capabilities, although as the forward, remote teams focus more on life-threatening surgical injuries, this is no longer a realistic expectation.[88] At a minimum, teams are staffed with physicians who are able to provide more advanced resuscitative care than a Role 1, but the number of medical personnel varies significantly from five to as many as 176.[89] Critical patients treated at a Role 2 require evacuation through the system for definitive care and recovery.[90]

Joint U.S. medical doctrine states that Role 2s may provide any of the following: resuscitation fluids, blood products, limited x-ray, limited laboratory, dental care, combat stress care, preventative medicine, and veterinary damage control resuscitation and surgical support.[91] The latitude afforded by the words "may" and "limited" created a range of Role 2 constructs whose capabilities were challenging to anticipate by that designation alone. For clarification, Role 2 was subdivided into Role 2 light maneuver (LM) and Role 2

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86 Joint Chiefs of Staff, *Joint Health Services*, II-2–3.

87 Baker et al., "Austere Resuscitative and Surgical Care in Support of Forward Military Operations—Joint Trauma System Position Paper"; Joint Chiefs of Staff, *Joint Health Services*, II–2.

88 Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 19–20; Baker et al., "Austere Resuscitative and Surgical Care in Support of Forward Military Operations—Joint Trauma System Position Paper," 15.

89 Baker et al., "Austere Resuscitative and Surgical Care in Support of Forward Military Operations—Joint Trauma System Position Paper," Table 1; Clinton K. Murray et al., "Spectrum of Care Provided at an Echelon II Medical Unit during Operation Iraqi Freedom," *Military Medicine* 170, no. 6 (June 1, 2005): 516–20, https://doi.org/10.7205/MILMED.170.6.516; Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 19–26.

90 North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, 2.13-14; Joint Chiefs of Staff, *Joint Health Services*, II-2–3; Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 19–23.

91 Joint Chiefs of Staff, *Joint Health Services*, II–2.

enhanced (E).[92] Role 2 LM range from highly mobile units to fixed facilities and only meet the advanced care requirement up to damage control surgery.[93] These assets usually do not have holding capacity and must evacuate their patients to the next level of care for primary surgery, or initial injury surgery addressing issues beyond hemorrhage control and continued contamination.[94] Role 2 E are the first assets in the casualty system with the ability to perform primary surgery and post-surgical care and, therefore, possess greater diagnostic and basic healthcare capabilities.[95]

NATO doctrine provides a wide description for Role 2s, but then further clarifies the capabilities with three subcategories, compared to the United States' two categories. A Role 2 asset is defined as an asset with more resuscitative capabilities than a Role 1 to provide life-, limb-, and function-saving care and stabilization.[96] Although it is not mentioned in the overall Role 2 definition, surgical care is listed as a minimal requirement for each NATO Role 2 subcategory: Role 2 forward (R2F), Role 2 basic (R2B), and Role 2 enhanced (R2E).[97] R2F, comparable to the smallest U.S. Role 2 LM, are highly mobile units projected forward to austere environments to provide damage control measures prior to immediate or expedited evacuation.[98] R2E are almost identical to the U.S. Role 2 E in that they provide primary surgery and have expanded diagnostic capabilities. R2B splits the difference between R2F and R2E, providing damage control surgery and resuscitation with a short-term critical care patient holding capability.[99]

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[92] Joint Chiefs of Staff, II–2.

[93] Joint Chiefs of Staff, II–2.

[94] Joint Chiefs of Staff, II–2; Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 19–20.

[95] Joint Chiefs of Staff, *Joint Health Services*, II–2.

[96] North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, 2.13.

[97] North Atlantic Treaty Organization, 2.13-14.

[98] North Atlantic Treaty Organization, 2.13-14.

[99] North Atlantic Treaty Organization, 2.14.

3. Role 3 Echelon of Care

Described as "Theater Hospitalization," Role 3 facilities offer the highest level of medical and surgical care in the combat area of operations.[100] These more well-established facilities have extensive surgery and surgical subspecialty capability, can provide extensive postsurgical monitoring and treatment, and possess the personnel and equipment required for this care.[101] The foundational reason for these Role 3 hospitals is to provide more stabilizing surgical and medical care for casualties who are too unstable for long-distance evacuation outside of theater.[102] This is also the first echelon, according to doctrine, to provide patient evacuation from supporting units; however, in my experience, medical evacuation units, such as DUSTOFF, have been located at forward locations with only Role 2 medical assets.[103]

As with Roles 1 and 2, the U.S. Services, excluding the USMC, have their own construct of Role 3 assets. Role 3 hospitals are typically modular in nature and are expanded over the course of weeks as a theater matures.[104] Depending on the operational needs, assets, and stage of conflict, sizes of Role 3 facilities can vary widely from 25–248 beds.[105] The Navy has mobile Role 3 hospital ships, the USNS *Mercy* and USNS *Comfort*, which each have 999 beds and 1,216 medical staff.[106] Despite the range in sizes, all U.S. Role 3s have surgical subspecialties, advanced diagnostic equipment, and the ability to hold more patients for longer periods of time.

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100 Bagg, Covey, and Powell, "Levels of Medical Care in the Global War on Terrorism," S9.

101 Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 23–24; Joint Chiefs of Staff, *Joint Health Services*, II–3.

102 Joint Chiefs of Staff, *Joint Health Services*, II–3.

103 Joint Chiefs of Staff, II–3; Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 23.

104 Bagg, Covey, and Powell, "Levels of Medical Care in the Global War on Terrorism," S9.

105 Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 24–28.

106 Office of the Army Surgeon General, 27–28.

U.S. Role 3 hospitals possess specialist and hospital care capabilities, while NATO Role 3s also require computed tomography (CT) and oxygen-production.[107] NATO doctrine implies that Role 3's extensive medical capabilities can potentially fully treat and recover patients, decreasing the need to evacuate patients out of country.[108]

4. Role 4 (and Role 5) Echelon(s) of Care

This level of care is deemed a "nation's responsibility" and occurs at large military or civilian-contracted hospitals outside the combat area of operations. U.S. doctrine most recently includes both OCONUS-based hospitals (Landstuhl Medical Center, Germany) and CONUS-based hospitals in Role 4.[109] Role 5, however, has been used to describe the CONUS-based hospitals because patients will transition from Landstuhl to a CONUS center for long-term treatment and rehabilitative care.[110] NATO doctrine only clarifies that Role 4 hospitals are permanent facilities that provide extensive specialty care and rehabilitative services that are impractical in theater.[111]

The lack of well-defined guidance can become challenging for battlefield decision-making. The currently prescribed standards of the echelons of care are vague, allowing assets with varying capabilities to fall within a given echelon and affording flexibility and decentralization for subordinate entities to construct their assets. On the tactical level, a patient may require a specific capability, such as an x-ray or computed tomography (CT), which may or may not be present at a given facility depending on which doctrine the Role designation follows. This was a larger issue for Role 2s prior to the subcategorization, but the subcategories are not equivalent across doctrines. The doctrinal standards for U.S. and NATO echelons of care are summarized in Table 1.

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[107] North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, 2–14.

[108] North Atlantic Treaty Organization, 2–14.

[109] Joint Chiefs of Staff, *Joint Health Services*, II–3; Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 28.

[110] Bagg, Covey, and Powell, "Levels of Medical Care in the Global War on Terrorism," S9.

[111] North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, 2–14.

B. APPLICABILITY OF DOCTRINAL ECHELONS OF CARE TO GW/UW

Unconventional warfare has been defined by the DOD as "Activities conducted to enable a resistance movement or insurgency to coerce, disrupt, or overthrow a government or occupying power by operating through or with an underground, auxiliary, and guerrilla force in a *denied* (emphasis added) area."[112] The "denied environment" component of this definition creates significant limitations to the implementation of medical care in UW regarding the ability to set up larger medical facilities without compromise and the freedom of movement for evacuation. For these reasons, the basic premises of the current echelons of care are unrealistic for applicability to all potential unconventional conflicts U.S. and NATO forces will encounter.

The military medical systems have evolved substantially in the last three decades during a period of conventional and counterinsurgency conflicts in which the U.S. and our allies have had overwhelming superiority. Air superiority and freedom of movement within the area of operations makes nearly every patient evacuation feasible within "the golden hour." The experiences and employment of medical assets in these environments shaped the development of the medical support doctrines throughout the Global War on Terror. Three-fourths of the echelons of care are within the area of operations, and half of those echelons offer relatively robust surgical and medical support. The final echelon assumes the ability to move patients long-distances out of theater, but for the guerrilla forces in UW, the "theater" is their country of origin. This makes an "out of theater" echelon moot for a guerrilla medical system.

The austere surgical and resuscitative care teams and PFC concepts are examples of military medicine advancements in support of special operations missions. Their emergence and non-conformity to the rigid doctrinal standards challenge the applicability of these echelon constructs, especially as conflicts adapt to unconventional forms and make trade-offs based on increased mobility requirements or restrictions. The more capabilities and/or capacity an asset has, the more resources it requires, and the larger and less mobile it becomes.[113]

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[112] Farr, The Death of the Golden Hour and the Return of the Future Guerrilla Hospital, 7.

[113] Baker et al., "Austere Resuscitative and Surgical Care in Support of Forward Military Operations—Joint Trauma System Position Paper," Table 1.

	Role 1	Role 2	Role 3	Role 4	Role 5
U.S. Doctrine	• Field care • Initial stabilization • Limited/no holding	• Advanced Resuscitation *Light Maneuver (LM)* • Damage Control Surgery *Enhanced (E)* • Primary Surgery • Holding capability • Some diagnostics	• In-Theater Surgical Specialty care • Expanded holding and critical care • Advanced diagnostics	• Extra-Theater Medical Centers • Prolonged treatment and Rehab • OCONUS Centers • (Debated) CONUS Centers	• CONUS Medical Center
NATO Doctrine	• Initial stabilization • Limited holding	• Advanced Resuscitation *Forward (F)* • Damage Control Surgery *Basic (B)* • Damage Control Surgery • Limited Holding • Some diagnostics *Enhanced (E)* • Primary Surgery • Range of holding capability • Some diagnostics	• In-Theater Surgical Specialty care • Expanded holding and critical care • CT • Oxygen-production	• Extra-Theater Medical Centers • Prolonged treatment and Rehab • "Usually" in patient's home country	NOT APPLICABLE

Table 1. Current U.S./NATO Medical Role Echelons of Care Summary.[114]

[114] Adapted from Office of the Army Surgeon General, "Chapter 2: Roles of Medical Care (United States)," 17–28; North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, sec. C; Eastridge et al., "Trauma System Development in a Theater of War," 1366–73; Bagg, Covey, and Powell, "Levels of Medical Care in the Global War on Terrorism," S7-9; Joint Chiefs of Staff, *Joint Health Services*, II3-5.

The creation of Role 2 subcategories indicates changing battlefield environments. Over the course of the global war on terror, special operations deployments with small units in remote locations became more frequent.[115] These missions required more medical units of smaller size capable of operating in and relocating to austere environments but still able to provide emergent surgical intervention within the 60-minute requirement.[116] These smaller, mobile units in remote locations did not offer patient holding, diagnostic capabilities, or primary surgery capabilities previously prescribed, leading to the creation of Role 2 Forward (NATO) and Role 2 Light Maneuver (U.S.).[117] The environment and operational requirements of these teams limit their resources and sustainability in a given location, mandating the limitation of surgical care to damage control only.[118]

The challenges of remote combat theaters, specifically in regard to availability of patient evacuation to higher roles of care, have also had an impact on the evolution of battlefield medic capabilities.[119] The concept of PFC was developed with the intent of providing SOCOM battlefield medics with advanced training to treat, hold, and monitor patients for periods "beyond doctrinal planning time-lines."[120] Although PFC exceeds the traditional idea of battlefield care by medics, the care is still rendered solely by a medic rather than a physician, lacks surgical capability, and is concerned with initial stabilization, not massive resuscitation.[121] Technically, the lack of surgical capability would define this

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115 Baker et al., "Austere Resuscitative and Surgical Care in Support of Forward Military Operations—Joint Trauma System Position Paper," 12.

116 Satterly et al., "Special Operations Force Risk Reduction: Integration of Expeditionary Surgical and Resuscitation Teams," 49.

117 North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, 2.13-14; Joint Chiefs of Staff, *Joint Health Services*, II-2–3.

118 Baker et al., "Austere Resuscitative and Surgical Care in Support of Forward Military Operations—Joint Trauma System Position Paper," 14.

119 Sean Keenan and Jamie C. Riesberg, "Prolonged Field Care: Beyond the 'Golden Hour,'" *Wilderness & Environmental Medicine*, Tactical Combat Casualty Care: Transitioning Battlefield Lessons Learned to Other Austere Environments, 28, no. 2, Supplement (June 1, 2017): S135–39, https://doi.org/10.1016/j.wem.2017.02.001.

120 Prolonged Field Care Working Group, "PFC Resources," Special Operations Medical Association, accessed March 10, 2021, http://www.specialoperationsmedicine.org/pages/pfcresources.aspx; Keenan and Riesberg, "Prolonged Field Care," S136.

121 Keenan and Riesberg, "Prolonged Field Care," S136-137.

level of care as Role 1, but SOCOM medics are trained to render PFC for up to 72 hours, which is outside the intended holding timeline for Role 1's.[122] PFC offers more advanced care than TCCC, addressing ongoing shock rather than only immediate life-threats.[123] It concedes a requirement to hold a patient, but its dependence on minimal equipment enables greater mobility than an aid station.[124] Just as light maneuver surgical teams created ambiguity in the Role 2 echelon, PFC is the next medical development from special operations to challenge the current construct of doctrine.

It is unrealistic to think a patient can progress through a system of care based on current doctrine in a battlespace that requires clandestine tactics to avoid detection. This is evident in historical cases of guerrilla medicine, Yugoslavian partisan medical support during WWII being the most organized and well-documented.[125] Hospitals along transportation lines and close to the point of injury reported improved mortality rates secondary to accessibility of care but had a serious, omnipresent problem of compromise by German forces.[126] To increase security, hospitals moved into more secluded areas away from high trafficked areas, but the casualties arriving at these sites were more often unable to be saved.[127] The Yugoslavian guerrilla hospitals were the first line of medical care for fighters, were primarily staffed with partisans trained on the job, and had varying levels of surgical care.[128] These hospitals also were too large to be completely mobile, making a speedy retrograde cumbersome.[129] Even after the birth of TCCC and light maneuver surgical teams, the SOCEUR UW exercise exposed the current U.S. medical support

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[122] Joint Chiefs of Staff, *Joint Health Services*, A-11.

[123] Keenan and Riesberg, "Prolonged Field Care," S137.

[124] Ball and Keenan, "Prolonged Field Care Working Group Position Paper," 76–77; Mohr and Keenan, "Prolonged Field Care Working Group Position Paper," 78.

[125] Farr, "Guerrilla Warfare Medicine: A Review of the Literature and the Problem," 20–22.

[126] Farr, 20; Rogers, *Guerilla Surgeon*, 182–84.

[127] Farr, "Guerrilla Warfare Medicine: A Review of the Literature and the Problem," 20.

[128] Rogers, *Guerilla Surgeon*, 98–101.

[129] Rogers, 152–61.

doctrine as grossly unrealistic.[130] In order to address the issue of UW medical care, the framework in which we structure a system needs to be changed.

C. NEW GW/UW LEVELS OF CARE, A PROPOSAL

The NATO Allied Joint Publication 4.10 describes the military health system as a "continuum of care" which spans from battlefield first aid to definitive treatment.[131] Rather than thinking in a linear evacuation process from one echelon of care to the next level, the continuum of care is based on the type of medical intervention necessitated by the patient's condition.[132] The explanations of the different types of care within the continuum have considerable overlap with the echelons of care. It is more prudent, especially in the dynamic, denied UW environment, to define a system based on the *care* provided to avoid preventable deaths rather than *capability*, or the tools used to provide that care.[133]

Advancements of battlefield medicine are based on data presented by medical literature evaluating the injury patterns and causes of death of battlefield casualties. Three statistical values are important for the analysis of battlefield casualty data. KIA is defined as battlefield deaths prior to being treated at an MTF.[134] DOW are deaths which occur after receiving care at an MTF.[135] CFR is the percentage of deaths, both KIA and DOW, of all injured warfighters and does not differentiate between location of death.[136] KIA and DOW can further be categorized into potentially survivable and non-survivable deaths.[137]

These statistics can help identify intervention points along the continuum of care as well as provide markers of effectiveness for a medical system. Data from the Vietnam War,

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130 Hickman, Baker, and Erickson, "Survivability: Medical Support to Resistance," 18.

131 North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, 3–16.

132 North Atlantic Treaty Organization, 3.16-20.

133 North Atlantic Treaty Organization, fig. 3–3.

134 Holcomb et al., "Understanding Combat Casualty Care Statistics," 398.

135 Holcomb et al., 398.

136 Holcomb et al., 398.

137 Champion et al., "A Profile of Combat Injury," S15-17.

which had both conventional and guerrilla components, will be used as an example. Figure 1 depicts the mechanism of death of Vietnam casualties.

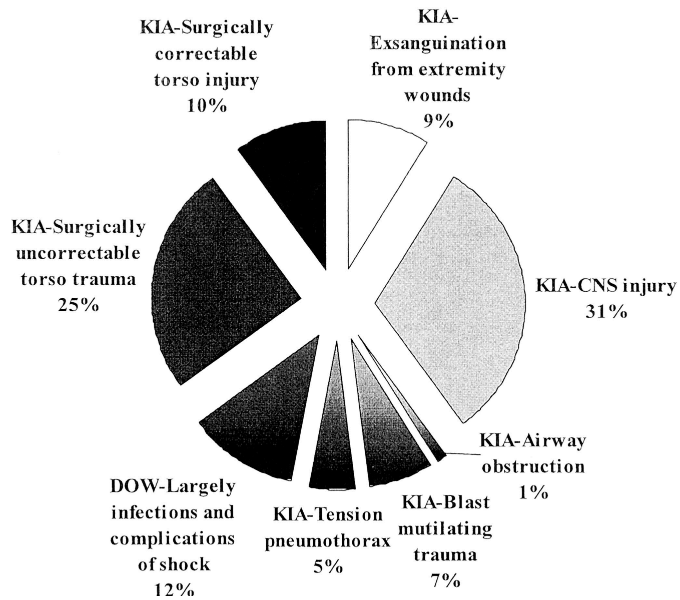

Figure 1. Breakdown of the Mechanism of Death in the Vietnam War.[138]

As discussed previously, KIA rates are based on pre-hospital deaths, comprising 88% of total deaths in Vietnam. The KIA rates "CNS Injury," "Blast mutilating trauma," and "Surgically uncorrectable torso trauma" are non-survivable injuries, comprising 63% of the deaths. The KIA rates labeled as "Airway obstruction," "Tension pneumothorax," and "Exsanguination from extremity wounds" account for 15% of deaths, are considered potentially survivable, and could have been prevented with basic TCCC practices.[139] Implementation of TCCC protocols within the 75th Ranger Regiment in Operation IRAQI FREEDOM/ENDURING FREEDOM decreased preventable deaths from the reported standard rate of 24% to 3% within the regiment.[140] The KIA rate "Surgically correctable torso injury" comprises another 10% of preventable deaths that require timely access to a

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138 Champion et al., fig. 4.

139 Eastridge et al., "Death on the Battlefield (2001–2011)," S435.

140 Kelly et al., "Injury Severity and Causes of Death From Operation Iraqi Freedom and Operation Enduring Freedom," S24; Kotwal et al., "Eliminating Preventable Death on the Battlefield," 1356.

surgeon for at least damage control surgery.[141] Assuming access to TCCC and damage control surgery, 25% of these deaths could have been prevented.

The last category, DOW, accounts for 12% of deaths, primarily due to infections and complications of shock, including multi-organ system failure. Infection and shock complications take a while to manifest and would be ultimately managed by primary surgery and/or critical care. These processes have decreased DOW rates to approximately 6–9% in recent conflicts, likely with the increased use of blood products and early antibiotic administration.[142] Damage control resuscitation can be employed prior to surgical care to treat shock by improving circulation and protecting against infection.[143] Blood product resuscitation is directed in TCCC, but wide-spread adoption is limited at this time due to training and logistics challenges. Because of the forward location in which PFC is employed, addressing infection and hemorrhagic shock is primarily preventative.[144] The patient ultimately requires critical, definitive care to treat these conditions.

By focusing on preventable death casualty statistics, three stages of care exist that address these causes of death and decrease battlefield mortality. A fourth stage provides definitive surgical care and long-term recovery care. These four stages of care make up the proposed framework for a GW/UW medical system outlined below.

- *Casualty Treatment Stage 1*—Battlefield care provided through self-aid/buddy care or battlefield medics and based on the foundational principles and procedures of TCCC. This stage intends to address acute, life-threatening injuries with the exception of noncompressible torso hemorrhage requiring surgical control.

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141 Baker et al., "Austere Resuscitative and Surgical Care in Support of Forward Military Operations—Joint Trauma System Position Paper," 14; Eastridge et al., "Death on the Battlefield (2001–2011)," S434.

142 Kelly et al., "Injury Severity and Causes of Death From Operation Iraqi Freedom and Operation Enduring Freedom," S23-25.

143 North Atlantic Treaty Organization, *Allied Joint Doctrine for Medical Support*, 3.18.

144 Keenan and Riesberg, "Prolonged Field Care," S136-137.

- *Casualty Treatment Stage 2*—Prolonged battlefield care provided by battlefield medics for extended periods of time and based on the foundational principles and procedures of PFC and damage control resuscitation. This stage intends to provide more advanced and prolonged management of serious casualties in a field or austere setting with limited resources.

- *Casualty Treatment Stage 3*—Damage control resuscitation and surgery provided by forward, mobile Austere Resuscitative and Surgical Care teams. This stage intends to address acute, life-threatening injuries, especially noncompressible torso hemorrhage.

- *Casualty Treatment Stage 4*—Definitive surgery, recovery, and rehabilitative care provided by medical personnel at sites suitable for long-term care. This stage intends to provide definitive surgery to address subacute issues, prevent and treat shock and infection, and recover patients to return to duty.

There are two main variables for this proposed framework: provider training level and holding capability. Stages 1 and 2 require only battlefield medics, while Stages 3 and 4 mandate physicians. The differentiating factor between Stage 1 and Stage 2 is that the latter has holding capability, although limited. Stage 4 also has a requirement for holding capability to meet its intent. Table 2 has been constructed to offer a visual representation of this framework.

		Holding Capability	
		None	**Present**
Required Skill	**Medic**	Treatment Stage 1 (TCCC)	Treatment Stage 2 (PFC)
	Physician	Treatment Stage 3 (Damage Control Resuscitation/Surgery)	Treatment Stage 4 (Definitive Care/Recovery)

Table 2. Proposed GW/UW Casualty Treatment Stages Organized by Required Skill Level and Holding Capability

Similar to the doctrinal roles, patients cannot move backward from stages because lower stages, by definition, cannot provide the same amount of care as the current stage. Barring operational requirements, downgrading a patient's care could cause harm and would be unethical.

Tactical units require clear understanding of medical assets to determine the appropriate disposition for a casualty. Some may argue that this proposed construct of care is just as, if not vaguer than, only describing the type of medical care provided. However, in the denied, hostile environment of UW, the more important objective of a medical system is to improve battlefield mortality statistics by addressing preventable deaths. The dangers of non-urgent evacuation for non-debilitating or non-lethal injuries can cause increased risk to force, which in turn, may increase casualty numbers. It is unlikely that a tactical unit will have to worry about where the nearest x-ray facility is located. First, cumbersome resources such as x-rays are not likely present in these conditions. Second, the resources which matter in addressing preventable deaths have more to do with the treatment skills and time to treatment than with extensive technology. To minimize movement in theater, evacuation should only be performed if a patient is combat ineffective, and to what asset they are evacuated is determined by whether they have an immediate, treatable life-threatening condition. So long as an asset meets the expected objective for their assigned stage without increasing their vulnerability to compromise, variability regarding what tools they use to accomplish that objective is irrelevant.

D. CONCLUSION

In 1983, Secretary of the Army John O. Marsh stated, "doctrine is the cornerstone upon which a special operations capability can be erected…Our failure…to develop doctrine has prevented special operations…from gaining permanence and acceptability within the ranks of the military."[145] Over the history of military medicine, battlefield medical research has improved our knowledge of combat trauma care and played a part in establishing and refining existing medical doctrine. Special operations have played a significant part in advancing our trauma knowledge with the development of TCCC, PFC, and light maneuver surgical teams. The evolution of our medical assets and the requirement to adjust doctrinal concepts, such as the subcategorization of Role 2s, illustrate that the doctrine is becoming less relevant to the current operational environments. The applicability of current doctrine becomes even less practical when considering the GW/UW battlespace.

The establishment of a GW/UW medical system needs to be rooted in foundational principles which guide casualty treatment and improving retention of assets. The current framework for echelons of care assumes physician-level care, requires relatively established facilities, and focuses heavily on resources. The type of care provided overlaps significantly between these echelons, demonstrating that this is not the main criterion for echelon discrimination. The resource-based divisions cannot be used to establish a medical network in a resource-constrained environment such as GW/UW. Instead, the fundamental principles of levels of care should be defined based on the type of medical treatment as proposed in the GW/UW Casualty Treatment Stages. By linking levels of care to TCCC, PFC, damage control resuscitation, and damage control surgery, a system can more effectively reduce the number of potentially survivable combat deaths

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[145] Grdovic, "Developing a Common Understanding of Unconventional Warfare," 138.

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III. STRATEGIC SYSTEMIC ANALYSIS TO IDENTIFY TANGIBLE LIMITATIONS FOR A GW/UW MEDICAL SYSTEM

This chapter uses a systemic approach to further characterize the proposed GW/UW Casualty Treatment Stages. The analysis begins by defining and outlining the systemic nature of the problem set. Next, causal loop diagrams created for each Treatment Stage highlight the variables of primary focus based on the previously proposed stage definitions. These causal loop diagrams illustrate the cause-and-effect relationships of independent and dependent variables that result in tangible limitations on a GW/UW medical system.

A. GW/UW MEDICAL SYSTEM OF INTEREST

As a system of interest, the GW/UW medical system of systems is complex, goal-seeking, and adaptive. Its sub-systems anticipate and adapt to localized changes in an extremely dynamic environment, resulting in the emergent behavior of the overall system itself. Figure 2 is a graphic representation of the major external systems (and their influencing sub-systems and/or characteristics) that provide input to, and respond to output from, the GW/UW system of interest.

The [denied] Operating Environment creates obstacles for access to patient evacuation, treatment facilities, and potential support from the population. Current U.S. medical assets are not accustomed to this environment after three decades of superiority within the area of responsibility (AOR). The operating environment includes considerations for the region of the conflict, such as varying levels of existing civilian medical networks. Enemy capabilities, tactics, procedures, and weapons influence the effectiveness and lethality of weapon employment, creating different injury patterns and influencing likelihood of survival.[146]

[146] Kelly et al., "Injury Severity and Causes of Death From Operation Iraqi Freedom and Operation Enduring Freedom," S24; Champion et al., "A Profile of Combat Injury," S14-15.

Each circle represents a system. The GW/UW medical system is influenced by several systems seen in different colors, and these systems are influenced by other systems (smaller, connected circles). Therefore, the GW/UW medical system is a "system of systems."

Figure 2. External Systems that Influence a GW/UW Medical System of Interest

By definition, UW operates "through or with an underground, auxiliary, and guerrilla force," making the Partner Force the next external system in this diagram.[147] A GW/UW medical system of interest is meant to be primarily dependent on the partner force, rather than solely being provided by U.S. or coalition forces, with the intention of the

147 Farr, The Death of the Golden Hour and the Return of the Future Guerrilla Hospital, 7.

partner force to sustain medical treatment of their casualties for the duration of conflict. For this reason, the medical system is reliant on any existing medical capabilities of the force, the baseline education level of the resistance, and the robustness of the support network (auxiliary and underground).

The U.S. Military contributes the JTS, military medicine, and UW doctrine to the GW/UW medical system of interest. The JTS specializes in raising readiness and improving outcomes through combat casualty analysis and evidence-based battlefield medical standards.[148] The military medical corps have trained assets and subject matter experts in austere combat medicine. As previously noted, however, the JTS and military medical corps are most comfortable with conventional or counterinsurgency conflicts in which the U.S. has area superiority and freedom of movement. For that reason, UW doctrine must be incorporated into the process to adjust existing standards to this unfamiliar operational context.

The U.S. Government system, separate from the U.S. Military, also has specific input to the GW/UW medical system of interest. The U.S. adherence to the Geneva Conventions and NATO doctrine influences the application of known military medical practices to the GW/UW medical system of interest. Involvement of the Department of State and/or Embassy staff can augment the preparation and/or execution of a medical network. Finally, the U.S. Government has the means to provide funding for required training, logistical support, etc.

Lastly, in general, the practice of Medicine influences the GW/UW medical system of interest. Even though military medical research from the battlefield has greatly influenced the evolution of trauma care in the civilian sector, civilian trauma organizations set the "gold standard" of care for trauma, both in and out of hospitals.[149] The JTS has suggested alternative approaches for more challenging operational contexts, but the "gold standard" is the goal.[150] These standards set by civilian institutions also dictate the requirements for training and sustainment for most medical assets. Military medicine

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[148] Joint Trauma System, "History."

[149] "The Committee on Trauma," American College of Surgeons, accessed March 16, 2021, https://www.facs.org/Quality-Programs/Trauma.

[150] "Clinical Practice Guidelines (CPGs)," Joint Trauma System, accessed November 13, 2020, https://jts.amedd.army.mil/index.cfm/PI_CPGs/cpgs.

subscribes to these training standards, and military medical personnel are credentialed by civilian licensing boards and certification agencies. Medical innovations and technological advancements provide more effective medical care in comparison with that of historical guerrilla medicine.[151] However, the operational environment requires greater light and sound discipline, reduced access to electricity, and reduced electronic signatures from Wi-Fi or Bluetooth connections.[152] Telemedicine capabilities may be incredibly beneficial to remote medical teams but may compromise the guerrilla force's proximity to the enemy.

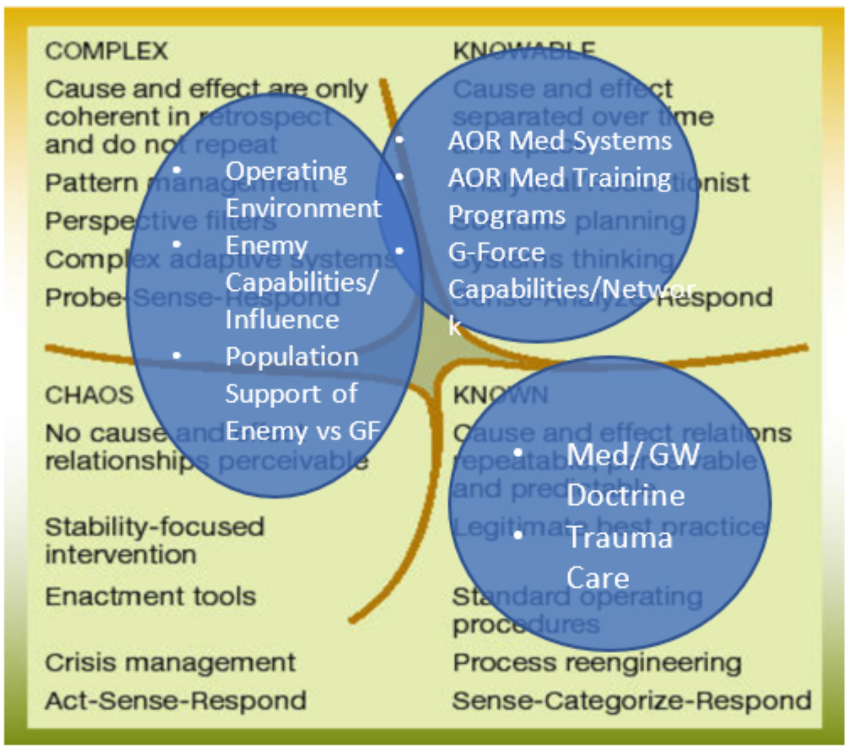

Figure 3. Cynefin Domains that Impact the GW/UW Medical System of Interest.[153]

151 Marc Northern et al., *Austere Resuscitative and Surgical Care (ARSC) Clinical Practice Guideline*, CPG ID: 76 (San Antonio, TX: Joint Trauma System, 2019), https://jts.amedd.army.mil/assets/docs/cpgs/Austere_Resuscitative_Surgical_Care_30_Oct_2019_ID76.pdf.

152 Northern et al., 6.

153 Adapted from CF Kurtz and DJ Snowden, "The New Dynamics of Strategy: Sense-Making in a Complex and Complicated World," *IBM Systems Journal* 42, no. 3 (2003): 468.

The Cynefin framework is used as a sense-making tool of systemic problem sets to help decision makers understand what approaches are necessary.[154] The problem of forming a GW/UW medical system has components in each of the Cynefin domain quadrants, depicted in Figure 3. The "complex" domain is dominated by systems in which cause-and-effect relationships are present and can be perceived, but because of non-linear feedback mechanisms, these causes and effects result in behavioral outcomes that cannot be predicted.[155] The variables that fall into this category are operational in nature and dependent on the conflict scenario. The operational environment, enemy, and population attitudes and support towards each side of the conflict are dynamic and react to various feedback mechanisms of the system. This creates a situation that is hard to predict and must be continually evaluated. In the initial stages of the conflict or during periods of significant instability, these aspects of the system may reside primarily in the chaos domain and require crisis management until a more homeostatic state can drive them to the complex domain.

The "knowable" domain has cause and effects separated by time and space that can be identified through systems thinking and analysis with the assistance of subject matter experts.[156] This is the primary domain into which the ongoing development of a GW/UW medical system of interest falls because it includes the medical systems within the operating environment, the medical training standards and programs in the region, and the baseline medical capabilities of the partner. By employing austere medicine and GW/UW subject matter experts, these variables can be analyzed to determine the best medical system construct for a given GW/UW scenario based on the framework. At that point, these variables may move into the "known domain."

The "known" domain consists of well-established processes with standard operating procedures and best practices not open to dispute.[157] Medical support doctrine,

[154] Kurtz and Snowden, 468.

[155] Kurtz and Snowden, 469.

[156] Kurtz and Snowden, 468.

[157] Kurtz and Snowden, 468.

GW/UW doctrine, and trauma care practice standards fall into this category. To identify universal tangible limitations on the proposed framework, these "known" standards will be applied to the stages. While other limitations may be identified unique to a specific area of operations, it is the goal of this research to establish a doctrinal framework to build upon.

B. GW/UW MEDICAL SYSTEM CAUSAL LOOP DIAGRAM

The causal loop diagrams presented in this section were created using Stella Architect © Version 2.1.2 (ISEE Systems).[158] They represent cause and effect relationships within a generic GW/UW medical system based on the previously proposed GW/UW Casualty Treatment Stages. The Treatment Stages are designed to address pre-hospital preventable deaths (surgical and non-surgical) and post-hospital preventable deaths to the maximum extent possible. The definitions and explanations of the proposed Treatment Stages can be found in Chapter I and Table 2.

Figure 4 illustrates the battlefield casualty and treatment cycle in relation to the proposed GW/UW system, with each Treatment Stage labeled. For each variable listed in the diagram, there is a corresponding relationship with another variable, denoted as positive (+) or negative (-). In a positive influencing relationship, as the independent variable increases or decreases, the dependent variable increases or decreases (coinciding with the independent variable) beyond what it otherwise would have been. In a negative influencing relationship, when the independent variable increases or decreases, the dependent variable decreases or increases (opposite of the independent variable) beyond what it otherwise would have been. Loops of variables within a causal loop diagram are labeled as "reinforcing" (R) or "balancing" (B). In reinforcing causal loops, the sum of positive and negative relationships amplify to create an exponential positive or negative trend. In balancing causal loops, the positive and negative relationships between variables counteract each other to create a "net zero" effect. The loop in Figure 4 is balancing, indicating that as treatment interventions increase, the number of recovered fighters

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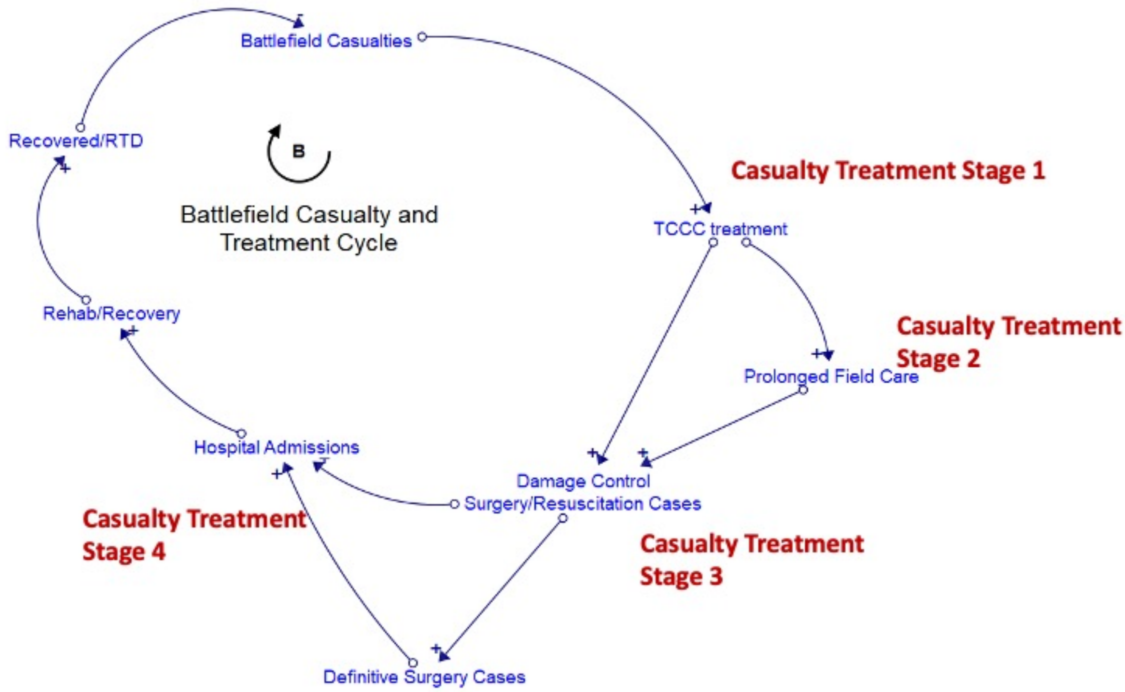
[158] ISEE Systems, Stella Architect, version 2.1.2 (Lebanon, NH: ISEE Systems, 2021), accessed November 1, 2021.

increases beyond what they otherwise would have been, and battlefield casualties decrease beyond what they otherwise would have been.



Each variable listed (blue) is related to another variable (blue arrow). These relationships can be positive (+) or negative (-). The conglomerate of relationships within a loop creates either a reinforcing (R) or balancing (B) loop, as the loop in this diagram. The treatment stages are noted in red.

Figure 4. Primary Patient Care Causal Loop in a GW/UW Medical System[159]

Although medical supplies and equipment are required for medical care to be performed, the acquisition and distribution of supplies is a system that impacts all aspects of the GW/UW conflict. Because the need for supplies does not unevenly affect Treatment Stages, it was not included in this analysis to identify unique limitations by stage. However, blood products are essential to the treatment of trauma casualties and have specific

159 Adapted from ISEE Systems, Stella Architect.

collection and storing procedures that vary based on region.[160] Given the vitality and uniqueness of this commodity and its uneven use across stages, it was included in the system.

Finally, this system was bounded by only those wounded and recovered, as the system is designed to decrease battlefield mortality. This is not to say that deaths will not occur, but for simplicity, the system excluded those killed in action and those who died of wounds. The system is also primarily intended to support the partner force so the resistance effort can be sustained. Although treatment of civilians and enemies may occur, these factors were not included in the system. Finally, even though the end goal is to have a system on which the supporting U.S. forces can rely for medical care in these denied environments, the evacuation of U.S. forces from the area of operations were not included.

Next, each Treatment Stage will be illustrated with causal loop diagrams to demonstrate how that stage is affected by endogenous and exogenous factors. After each stage is evaluated, the full system will be put together and the individual stages will be highlighted to show their relative influence on the system as a whole.

1. GW/UW Casualty Treatment Stage 1

Treatment Stage 1 (Figure 5) is focused on addressing non-surgical preventable pre-hospital deaths. The concepts and practice of TCCC was developed and fostered by SOCOM, was subsequently implemented across the DOD, and has shown great success in current conflicts.[161] Although evacuation is required from this stage, high quality training of medics and unit personnel are primarily necessary to implement Stage 1. Both the Unit TCCC Training Loop and Medic Training Cycle Loop are reinforcing. Therefore, the more TCCC treatment provided, the more training will be needed, increasing the amount of training and subsequently the use of TCCC.

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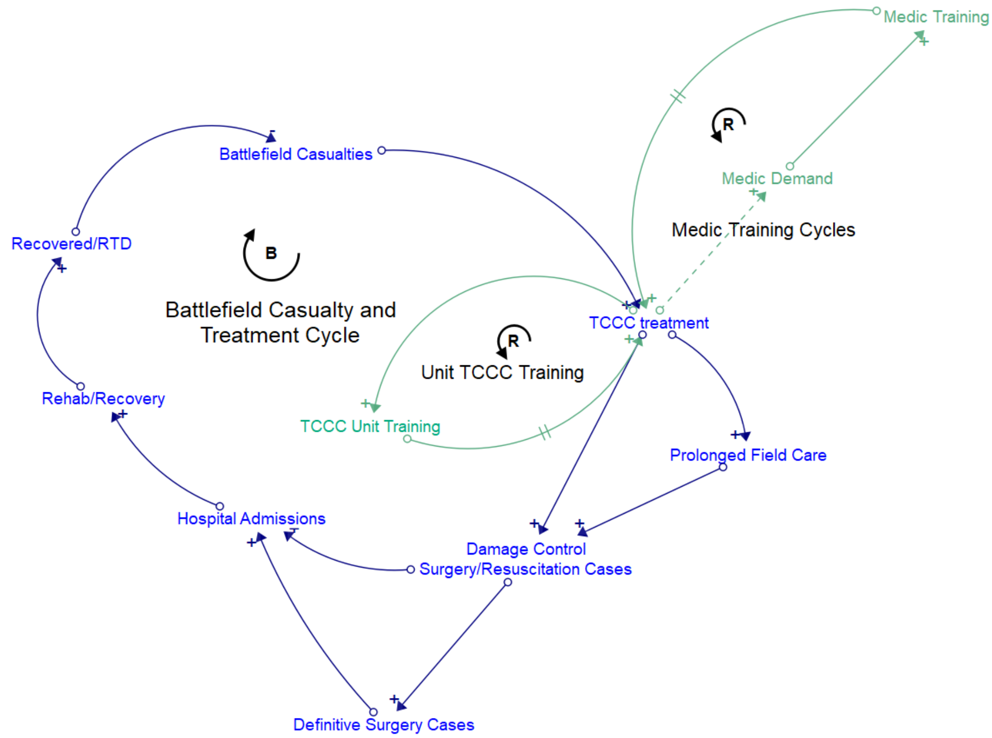
[160] Northern et al., Austere Resuscitative and Surgical Care (ARSC) Clinical Practice Guideline, 17–18.

[161] Kelly et al., “Injury Severity and Causes of Death From Operation Iraqi Freedom and Operation Enduring Freedom,” S25; Kotwal et al., “Eliminating Preventable Death on the Battlefield,” 1356.



The primary loop for patient care in the GW/UW medical system with the associated causal loops specific to Treatment Stage 1.

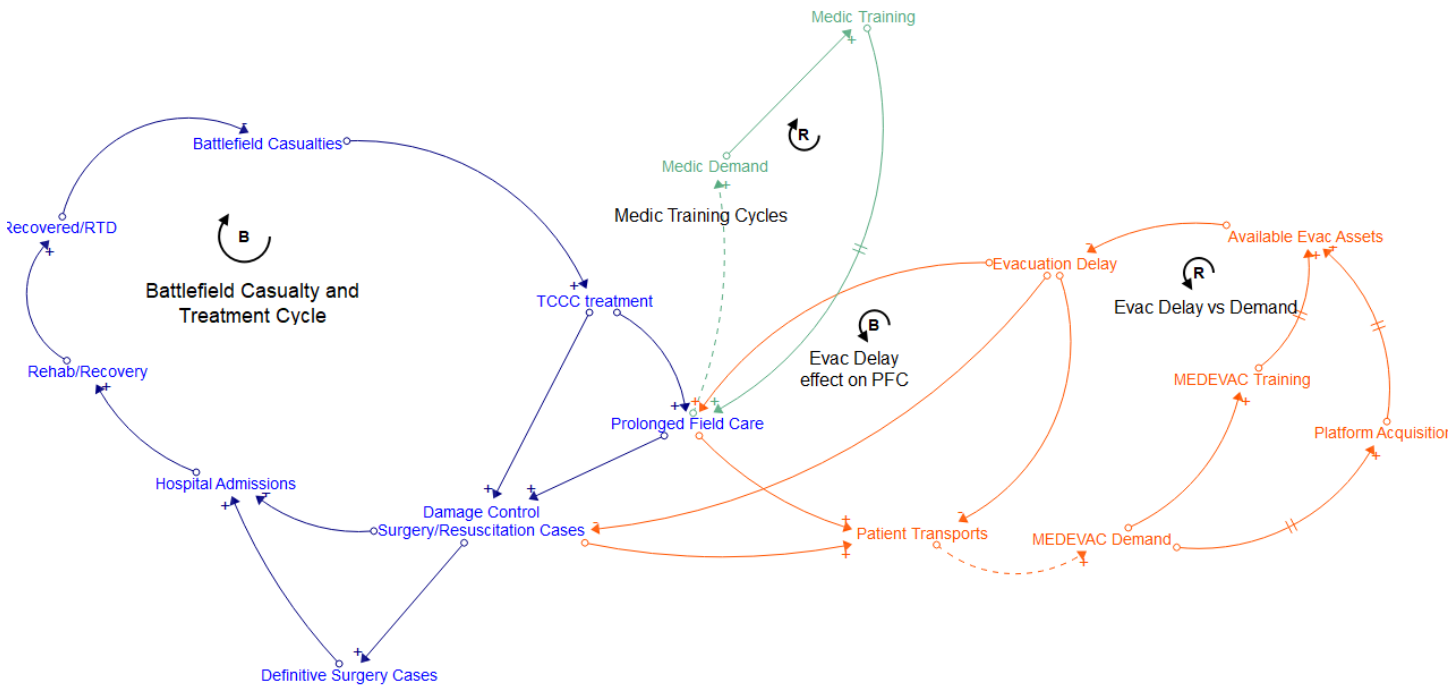
Figure 5. Treatment Stage 1 Causal Loop Diagram[162]

2. GW/UW Casualty Treatment Stage 2

Treatment Stage 2 (Figure 6) is focused on providing continued field care and damage control resuscitation on the battlefield by medics. The Medic Training Cycle, a reinforcing loop, was again included in this stage. Although swift evacuation is desired, the operational environment of GW/UW makes this more difficult and causes delays in evacuation, demanding the Treatment Stage 2 capability. As evacuation directly influences the need for PFC, the evacuation demand and medical evacuation (MEDEVAC) development was included in this causal loop diagram. There are two loops with different behaviors relating to evacuation. The first loop, "Evac Delay effect on PFC," is balancing. Therefore, as more PFC increases patient transports and MEDEVAC Demand, this increases their development, increasing Available Evac Assets, and eventually decreases

162 Adapted from ISEE Systems, Stella Architect.

Evacuation delay. Decreased evacuation delay decreases the need for PFC, which is more beneficial to the patients. The second loop in the evacuation system is the “Evac Delay vs Demand” with reinforcing behavior. An increase in Evacuation Delay creates a decrease in patient transports performed, a decrease in MEDEVAC Demand, and decreased Available Evac Assets. A decrease in Available Evac Assets increases the Evacuation Delay, and further decreases Patient Transports. This loop alone would only worsen the casualty statistics, but there are other parts of the complete system that affect the number of patient transports and MEDEVAC demand, shifting this from a vicious reinforcing loop into a virtuous reinforcing loop.



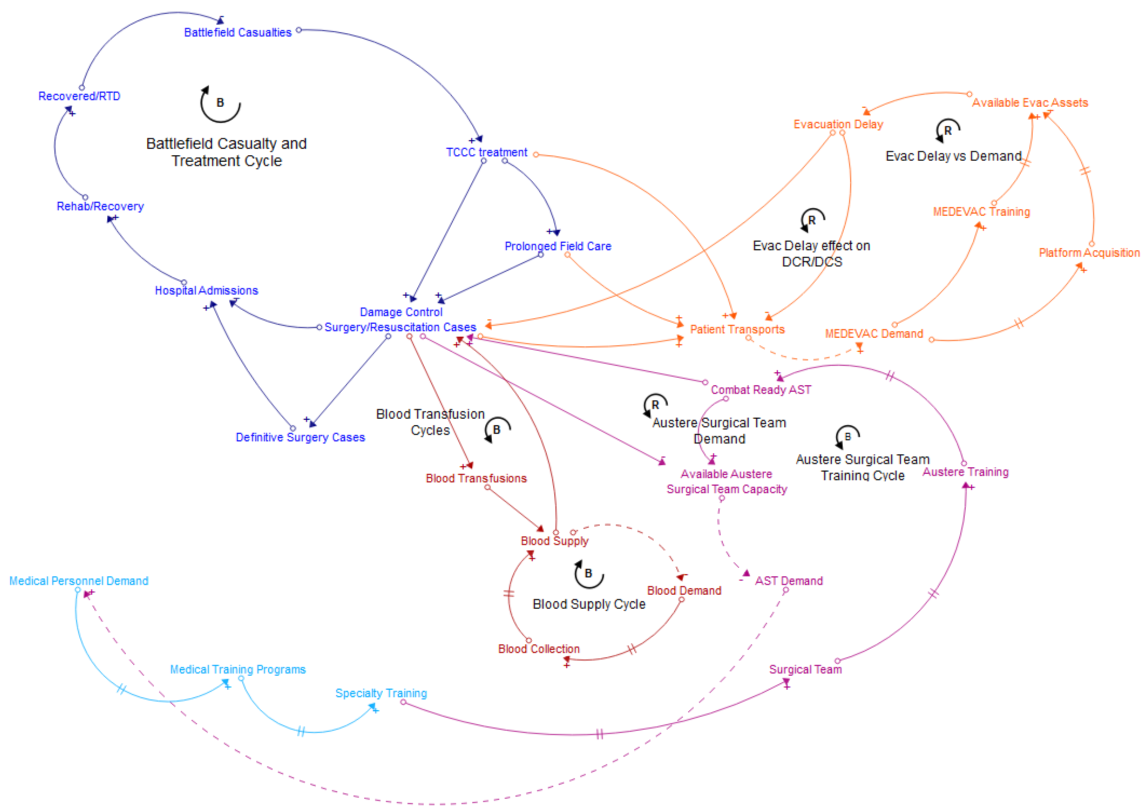
The primary loop for patient care in the GW/UW medical system with the associated causal loops specific to Treatment Stage 2.

Figure 6. Treatment Stage 2 Causal Loop Diagram[163]

163 Adapted from ISEE Systems, Stella Architect.

3. GW/UW Casualty Treatment Stage 3

Treatment Stage 3 (Figure 7) is focused on providing damage control resuscitation and damage control surgery (DCR/DCS) at forward locations by austere surgical teams (AST) to address surgical preventable deaths. The three related systems for this stage are evacuation, training/team formation, and blood supply.



The primary loop for patient care in the GW/UW medical system with the associated causal loops specific to Treatment Stage 3.

Figure 7. Treatment Stage 3 Causal Loop Diagram[164]

Due to their relative proximity to the battlefield, patients must be evacuated by some means to Treatment Stage 3, therefore, the evacuation system was included in this causal loop diagram. There are also two loops relating to evacuation for this stage, but the

164 Adapted from ISEE Systems, Stella Architect.

behaviors are both reinforcing. The "Evac Delay vs Demand" loop is the same as discussed before and will not be addressed again here, but the cases performed by this stage increase patient transports, lengthening evacuation delay. The other evacuation loop is "Evac Delay effect on DCR/DCS." Because evacuation to this stage from the battlefield is still required, any Evacuation Delay will decrease the chance of survival from wounds and decrease the number of Damage Control Surgery/Resuscitation Cases. The decrease in Damage Control Surgery/Resuscitation Cases then decreases the Patient Transport from this stage, decreasing MEDEVAC Demand and formation of Evac Assets, which worsen the delay.

The next system is the training and formation of the ASTs. Again, there are two loops within this system. The first loop is the "Austere Surgical Team Training Cycle," which is balancing. A decrease in Austere Surgical Team Capacity increases AST Demand. An increase in AST Demand increases Medical Personnel Demand, Medical Training Programs, and Specialty Training. An increase in trained medical personnel increases the number of Surgical Teams that can then attend Austere Training, forming Combat Ready ASTs. An increase in Combat Ready ASTs increases the Austere Surgical Team Capacity, which decreases AST Demand. The second loop is the "Austere Surgical Team Demand" loop, which is reinforcing. As Damage Control Surgery/Resuscitation Cases increase, the Austere Surgical Team Capacity decreases. The "Austere Surgical Team Training Cycle" Loop sends a signal for developing more combat ready ASTs. As the number of Combat Ready ASTs increase, more Damage Control Surgery/Resuscitation Cases can be performed, decreasing the Available Austere Surgical Team Capacity, and further increasing AST Demand.

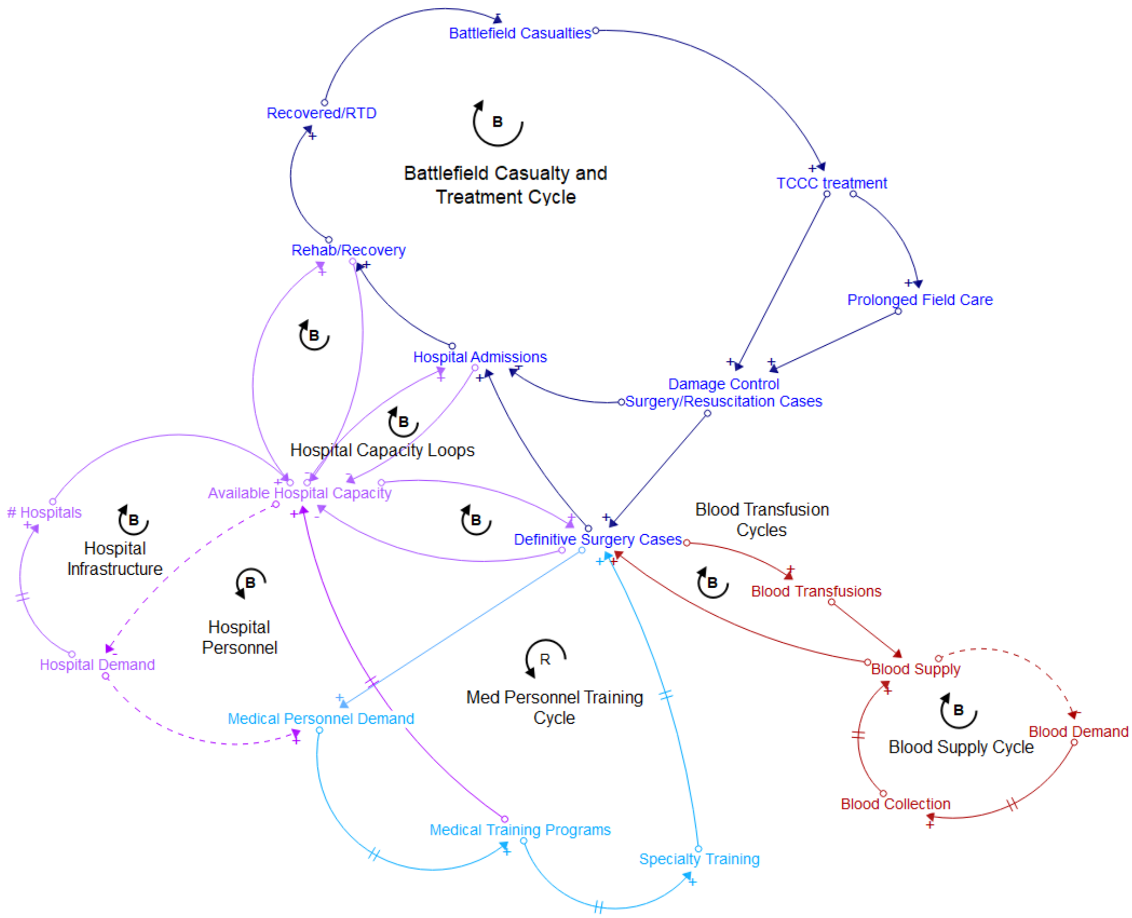
The final system that influences this stage is the blood product supply system. There are also two loops to this system, both of which are balancing. The first loop is the "Blood Transfusion Cycle" loop. Damage Control Surgery and Resuscitation are meant to 1) stop the bleeding and 2) replace lost blood. If one of these cannot be accomplished, the patient has a poor prognosis, and in resource constrained environments, further treatment may be abandoned. Therefore, as Damage Control Surgery/Resuscitation Cases increase, the number of Blood Transfusions increase. This decreases the Blood Supply that then decreases the number of cases performed. The second loop is the "Blood Supply Cycle" loop. As the Blood Supply increases, the Blood Demand decreases, decreasing Blood

Collection and the Blood Supply. As seen in the first loop, if the Blood Supply decreases, then cases decrease. Therefore, these two loops working together creates a reinforcing pattern. This illustrates how influential blood supply is for traumatic surgery cases and a battlefield medical system.

4. GW/UW Casualty Treatment Stage 4

Treatment Stage 4 (Figure 8) is focused on providing definitive surgical care and rehabilitation at more established facilities to address post-hospital preventable deaths. The three related systems for this stage are blood supply, medical personnel training, and hospital capacity. It should be noted that in the GW/UW environment, "hospital capacity" may not be consolidated into one location, but instead, spread out within the community or local population. Regardless, there is a patient capacity limit, whether in the form of guerrilla hospital beds or space within the community to care for patients. The blood supply loops are the same as that for Treatment Stage 3 and will not be addressed again in this section.

Medical personnel training is depicted in two different areas of this causal loop diagram. The first area is depicted in light blue and is in relation only to the performance of definitive surgery, or surgery to address the unaddressed and non-emergent injuries. This loop is a reinforcing loop. As Definitive Surgery Cases increased, the Medical Personnel Demand increases, specifically for those who require Specialty Training. As more people become trained in the required specialties to perform surgery, more Definitive Surgery Cases can be performed. The other area that medical personnel training is depicted is in relation to Available Hospital Capacity. When isolating the loop of medical training to Available Hospital Capacity, this is a balancing loop. A decrease in Available Hospital Capacity increases the Hospital Demand, and therefore the Medical Personnel Demand. As trained medical personnel are available through more Medical Training Programs, the Available Hospital Capacity increases, decreasing further demand.



The primary loop for patient care in the GW/UW medical system with the associated causal loops specific to Treatment Stage 4.

Figure 8. Treatment Stage 4 Causal Loop Diagram[165]

The final system involved in this stage is hospital capacity. Available Hospital Capacity forms three separate Balancing loops with the interventions included in this treatment stage (Definitive Surgery Cases, Hospital Admissions, and Rehab and Recovery). As these three interventions within the treatment cycle occur, Available Hospital Capacity decreases, decreasing the availability to perform these interventions. The interaction of Available Hospital Capacity with medical training has already been discussed. Available Hospital Capacity also forms a balancing loop with the formation of hospitals. Decreased Available Hospital Capacity increases Hospital Demand, increasing

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165 Adapted from ISEE Systems, Stella Architect.

the formation of hospitals (# Hospitals) and increasing Available Hospital Capacity. The hospital capacity system is formed by several balancing loops, but if these balancing loops are evaluated collectively, it's easily seen how the hospital capacity system has a reinforcing influence on the medical system.

5. Complete System of Systems Causal Loop Diagram

Figure 9 combines all the previous causal loop diagrams into one diagram for the GW/UW medical system construct. Figure 10 highlights the portions of the system relating to each Treatment Stage. This system analysis of the proposed treatment stages and how they interact with significant variables expands on the definitions to include tangible limitations by stage. The highlighted areas easily demonstrate how the number of influencers for a given stage increases at each level, indicating the required preparation and resources needed to establish these stages. Not all GW/UW cases will have the time, money, baseline capability, or resources to realistically achieve a complete system of systems, but an analysis using this framework should be accomplished for each case.

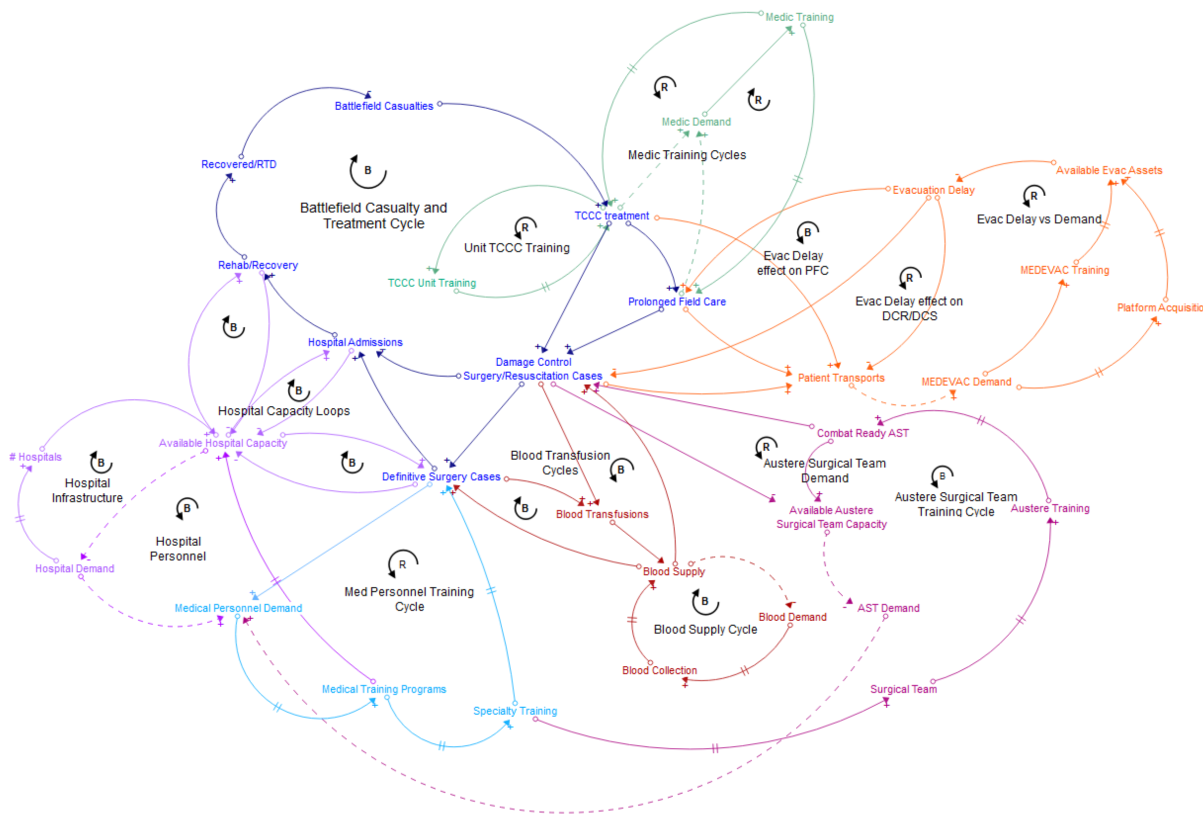
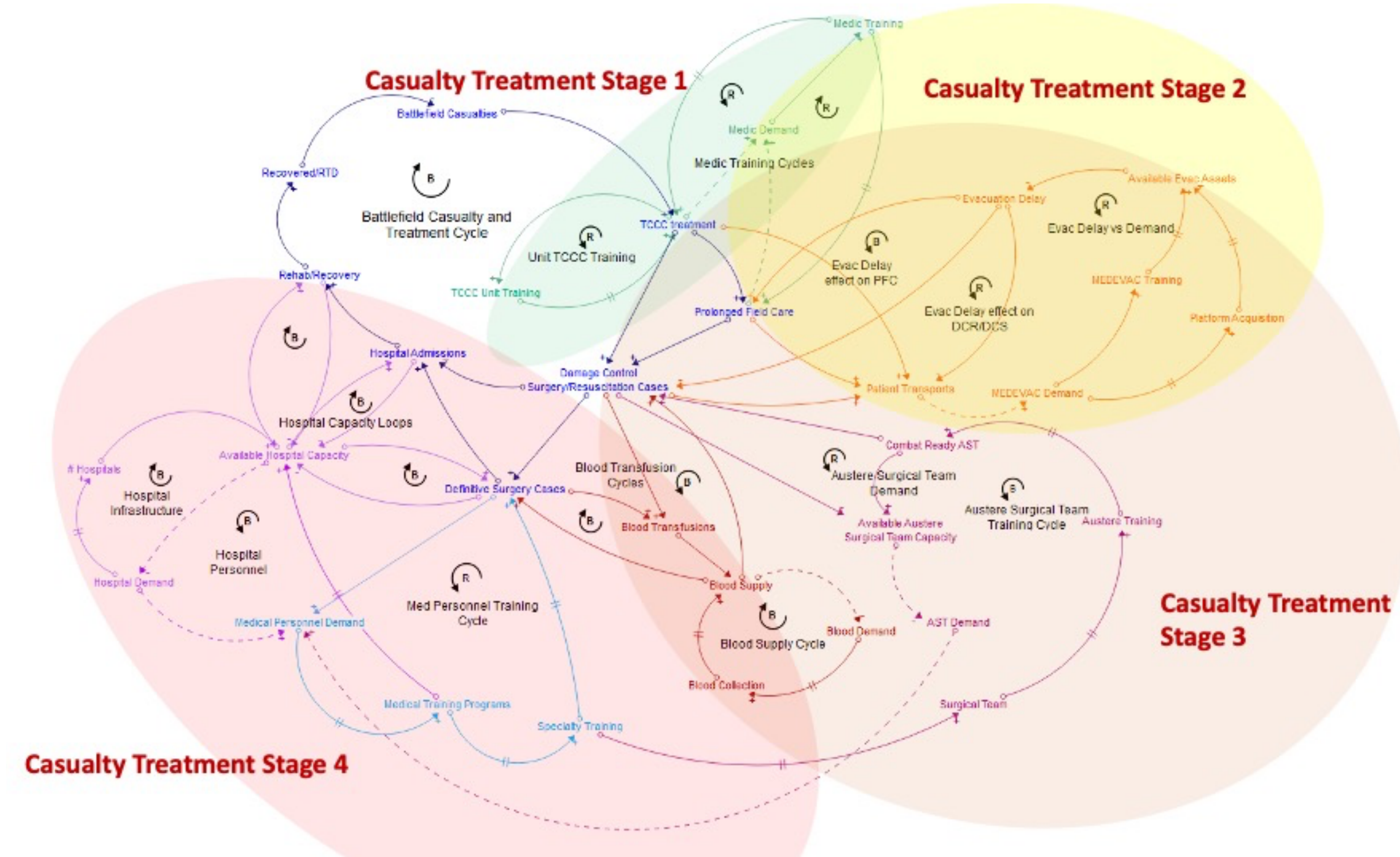


Figure 9. Comprehensive GW/UW Medical System of Systems Causal Loop Diagram[166]

166 Adapted from ISEE Systems, Stella Architect.



The complete causal loop diagram for the GW/UW medical system with the associated systems for each treatment stage highlighted.

Figure 10. Comprehensive GW/UW Medical System of Systems Causal Loop Diagram by Treatment Stage[167]

[167] Adapted from ISEE Systems, Stella Architect.

C. CONCLUSION

The development of a GW/UW medical system is a robust, complex problem involving multiple interacting external, influencing systems, and the GW/UW Medical System of Interest. Some of these influencing systems may be complex and difficult to identify even after the onset of conflict. Some influencing systems may be "knowable" but are dependent on the specific area of operations or operating environment of a given conflict. Some systems, however, are "known" and applicable to all medical systems developed with the proposed Casualty Treatment Stage framework. These "known" systems were used to identify the most significant tangible limitations, which are trained personnel, hospital capacity, blood supply, and evacuation resources. The lack of these limited resources may cause the system to fail, but their presence does not guarantee success. Non-tangible limitations also play a significant role in the medical system development.

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IV. SOCIAL NETWORK ANALYSIS TO IDENTIFY NON-TANGIBLE LIMITATIONS FOR A GW/UW MEDICAL SYSTEM

Social network analysis (SNA) has been used extensively to map terrorist cells or other illegal networks, commonly referred to as "dark networks.[168]" Much of the intent of dark network analysis has been focused on defeating such networks through diffusion of information, targeting, influence, etc.[169] The same concepts of SNA used for dark networks can be applied to understanding the dynamics of other adversaries, including near-peer or occupying forces. Research by Brooke and Ketchley identified through network analysis that the spread of Islamic movements occurred more efficiently along transportation lines.[170] The same analysis for the Germans in WWII could have helped the Yugoslavian partisans anticipate potential compromise of hospitals close to railways.

This chapter uses examples of a social network diagram to illustrate theoretical uses of SNA in identifying non-tangible limitations in GW/UW. Examples of social network maps, known as sociograms, were used to graphically depict opposition forces in a conflict. The proposed use of sociograms were then applied to the historical case of the Lithuanian Forest Brothers, demonstrating SNA's potential use for resistance movements. Using these graphical representations, analysis of the implications for a social network structure in a resistance or unconventional conflict were provided. Most importantly those implications were related to medical care in these environments, providing non-tangible constraints for establishment of a GW/UW medical system.

A. NETWORK MAPS IN CONFLICT

In conflicts such as UW in which the "adversary" is the current government or occupying power, SNA could be useful to understand important dynamics of the battlefield for an insurgency, including its underground and auxiliary network. The sociograms

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[168] Valdis E. Krebs, "Mapping Networks of Terrorist Cells," *Connections* 24, no. 3 (2002): 43–52.

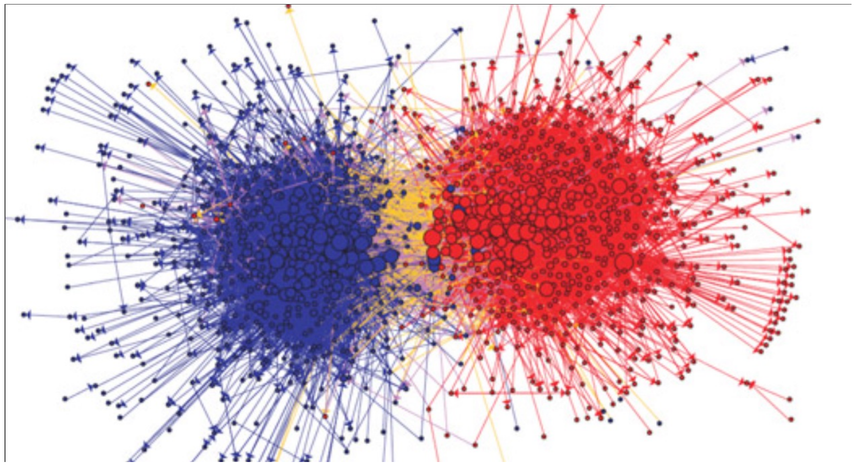
[169] Nancy Roberts and Sean F. Everton, "Strategies for Combating Dark Networks," *Journal of Social Structure* 12 (2011): 1–32.

[170] Steven Brooke and Neil Ketchley, "Social and Institutional Origins of Political Islam," *American Political Science Review* 112, no. 2 (May 2018): 376–94, https://doi.org/10.1017/S0003055417000636.

discussed in this chapter represent interpersonal relations (represented by lines or "ties") between members of a fighting force (represented by dots or "nodes"). Areas with more ties are considered "denser" and have a higher connectivity between nodes. This section used examples of network diagrams to illustrate the theoretical use and do not represent actual network data.

In the most basic concept of war, two opposing sides meet at a point of conflict. To maximize likelihood of success, each side would employ the principle of "mass" to overwhelm and overcome their opponent.[171] Figure 11 is an example of a network diagram illustrating this concept. The two sides (represented by blue and red nodes) will amass their forces at the point of conflict, creating increased density at that location. An overlapping of these highly dense networks will create an increased likelihood of interactions with the opponent, through geographic proximity (a phenomenon known as propinquity), increasing the likelihood for conflict. Moving to the periphery, networks become less dense, and overlap with these areas would have a lower likelihood for conflict. Overlapping a less dense portion of one network with a denser portion of the other would likely lead to an overwhelming defeat of the former, assuming all other variables are equal.

[171] Joint Chiefs of Staff, *Joint Operations*, JP 3-0 (Washington, DC: Joint Chiefs of Staff, 2017), A.2.



This example could represent a friendly force network (blue) and adversary network (red).

Figure 11. Social Network Analysis Diagram Example.[172]

Unconventional warfare, or conflict using guerrilla or insurgent tactics, does not follow this construct. Guerilla tactics are used when an objectively weaker force takes on an objectively stronger force, using other principles such as "surprise" to it advantage.[173] For a resistance, the occupying force has a stronghold in an area in which insurgent fighters project forward to execute acts of harassing violence.[174] Unconventional warfare is defined by this "denied environment" the occupying force dominates.[175] When the occupying force mounts an overwhelming response to insurgent attacks, the insurgent forces must retreat to their "base area" or risk annihilation. Figure 12 represents this type of dynamic in which the blue is the insurgent force and red is the occupying force. The insurgent force network with increased density represents their "base area" with forward projections of insurgents into the occupying force network's dense area. Figure 13 was created using the network maps in Figure 12 to illustrate battlefield zones for an insurgent force in relation to the network.

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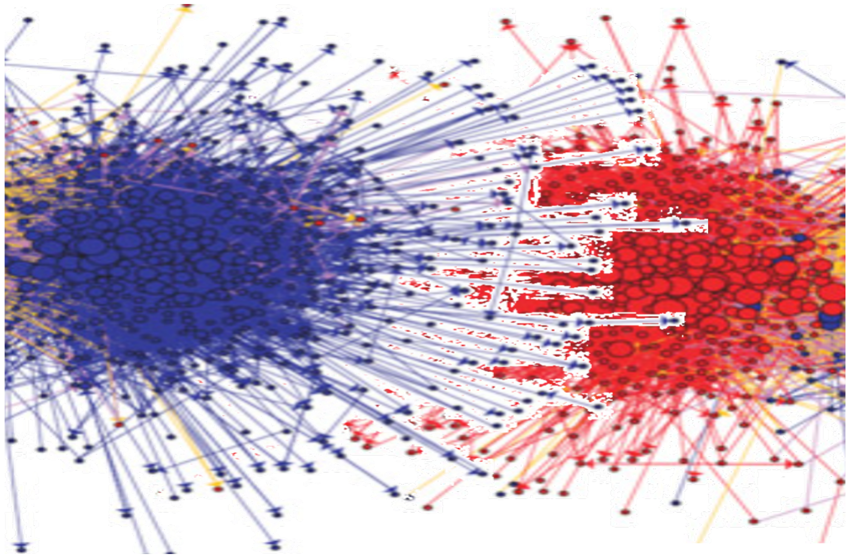
172 Source: "GLO 410: Systems Thinking - (Campion, Spring 2016): Chapter 3: Social Network Analysis," Saint Leo University Library, accessed June 15, 2021, https://slulibrary.saintleo.edu/c.php?g=449435&p=3067598.

173 Chalmers A. Johnson, *Revolutionary Change* (United States: Stanford University Press, 1982), chap. 7; Joint Chiefs of Staff, *Joint Operations*, A.3.

174 Johnson, *Revolutionary Change*, chap. 7.

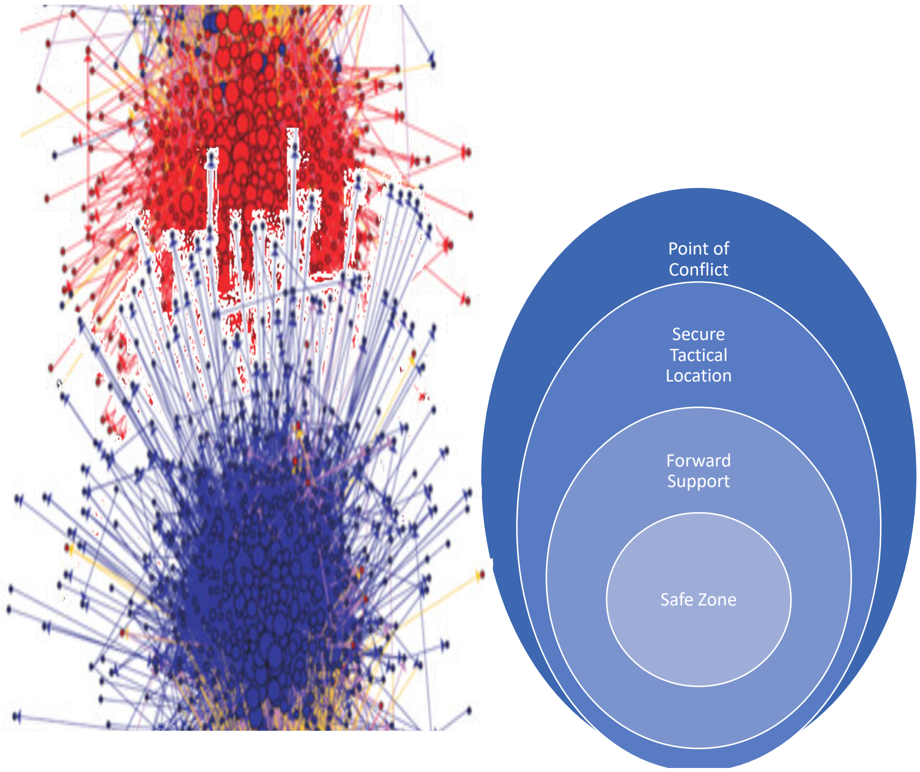
175 Grdovic, "Developing a Common Understanding of Unconventional Warfare," 136.



This example could represent a friendly force network (blue) and adversary network (red).

Figure 12. Social Network Diagram Illustrating an Unconventional or Insurgency Conflict.[176]

176 Adapted from Saint Leo University Library, "GLO 410: Systems Thinking - (Campion, Spring 2016): Chapter 3: Social Network Analysis."



Friendly force network (blue) and adversary network (red).

Figure 13. Social Network Diagram Depicting Battlefield Zones of Insurgent Force.[177]

The Lithuanian Forest Brothers were a partisan force against occupying German Nazi and Russian forces between 1945–1956.[178] They received their name because they primarily stayed in the central area of Lithuania with dense forests, waterways, lakes, and undesirable terrain.[179] Figure 14 represents the primary engagement area for the Forest

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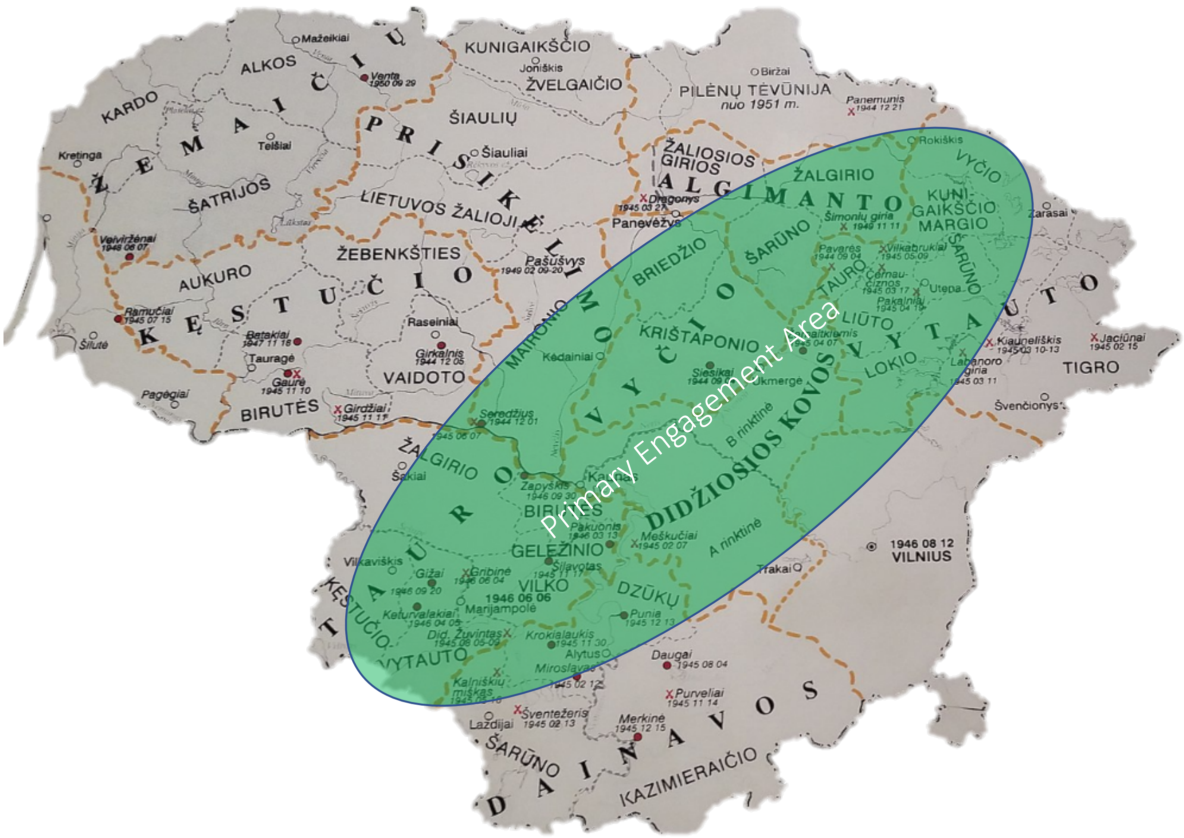
[177] Adapted from Saint Leo University Library, "GLO 410: Systems Thinking - (Campion, Spring 2016): Chapter 3: Social Network Analysis."

[178] Juozas Daumantas, *Fighters for Freedom: Lithuanian Partisans Versus the USSR*, 2nd ed. (Toronto, Ontario: The Lithuanian Canadian Committee for Human Rights, 1975), chaps. 10–11, http://partizanai.org/failai/html/fighters-for-freedom.htm; Wikipedia, s.v. "guerrilla war in the Baltic states," June 1, 2021, https://en.wikipedia.org/w/index.php?title=Guerrilla_war_in_the_Baltic_states&oldid=1026356929; Wikipedia, s.v. "Lithuanian partisans," June 7, 2021, https://en.wikipedia.org/w/index.php?title=Lithuanian_partisans&oldid=1027340993.

[179] Daumantas, *Fighters for Freedom: Lithuanian Partisans Versus the USSR*, chap. 11; Wikipedia, "Lithuanian partisans."

Brothers within Lithuania. Cities in the central part of this area were the main partisan communities, rather than the peripheral urban areas. Figure 15 uses a network diagram to illustrate the collection of Forest Brothers in central areas.



This area features dense forests and other undesirable terrain, giving the force their name.

Figure 14. Lithuanian Forest Brothers Primary Area of Operations.[180]

[180] Adapted from Museum of Occupations and Freedom Fights, “The Armed Resistance between 1944 and 1953: The Main Battles and Towns Attacked by the Partisans,” image in Wikipedia, s.v. “guerrilla War in the Baltic States,” accessed June 15, 2021, https://en.wikipedia.org/wiki/Guerrilla_war_in_the_Baltic_states#cite_ref-2.

The central cities were most densely occupied by partisans with the peripheral cities less dense due to proximity to borders in which opposing forces amassed.

Figure 15. Lithuanian Forest Brothers Primary Area of Operations Using a Network Map.[181]

The peripheral areas were closer to borders from which invading forces originated, increasing the presence and density of the opposition.[182] Figure 16 adds the opposition force network to represent its occupation of major border urban areas.

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[181] Adapted from Janet C. Long et al., "Leadership in Complex Networks: The Importance of Network Position and Strategic Action in a Translational Cancer Research Network," *Implementation Science* 8, no. 1 (October 11, 2013): 122, https://doi.org/10.1186/1748-5908-8-122; Museum of Occupations and Freedom Fights, "The Armed Resistance between 1944 and 1953: The Main Battles and Towns Attacked by the Partisans."

[182] Daumantas, *Fighters for Freedom: Lithuanian Partisans Versus the USSR*, chap. 18; Wikipedia, "guerrilla war in the Baltic states."

Network map illustrating respective densities of Forest Brothers (blue) and Occupying Forces (orange).

Figure 16. Network Map Illustrating Forest Brothers vs Occupying Forces.[183]

Points of major conflict or attacks of the Forest Brothers primarily occurred in these peripheral areas (Figure 17).[184] As previously discussed, insurgent forces using guerrilla tactics will forward project to the occupied areas to conduct operations until they become overwhelmed.[185] At that point, they retreat to base where they have a strong network of support. Figure 17's points of conflict peripheral to the primary central location of partisan

[183] Adapted from Long et al., "Leadership in Complex Networks"; Museum of Occupations and Freedom Fights, "The Armed Resistance between 1944 and 1953: The Main Battles and Towns Attacked by the Partisans."

[184] Daumantas, *Fighters for Freedom: Lithuanian Partisans Versus the USSR*, 253–78; Museum of Occupations and Freedom Fights, "The Armed Resistance between 1944 and 1953: The Main Battles and Towns Attacked by the Partisans."

[185] Johnson, Revolutionary Change, chap. 7; Daumantas, Fighters for Freedom: Lithuanian Partisans Versus the USSR, chap. 11.

cities supports the theories depicted in Figure 12 and 13. More conflict occurs when interactions between opposing forces are more likely, or when higher density networks are infiltrated. An insurgency projecting forces forward away from their base have less of a support network the further they project. This does not become a major issue until they project into an area of denser opposing forces, increasing the likelihood of “interactions” or conflict.

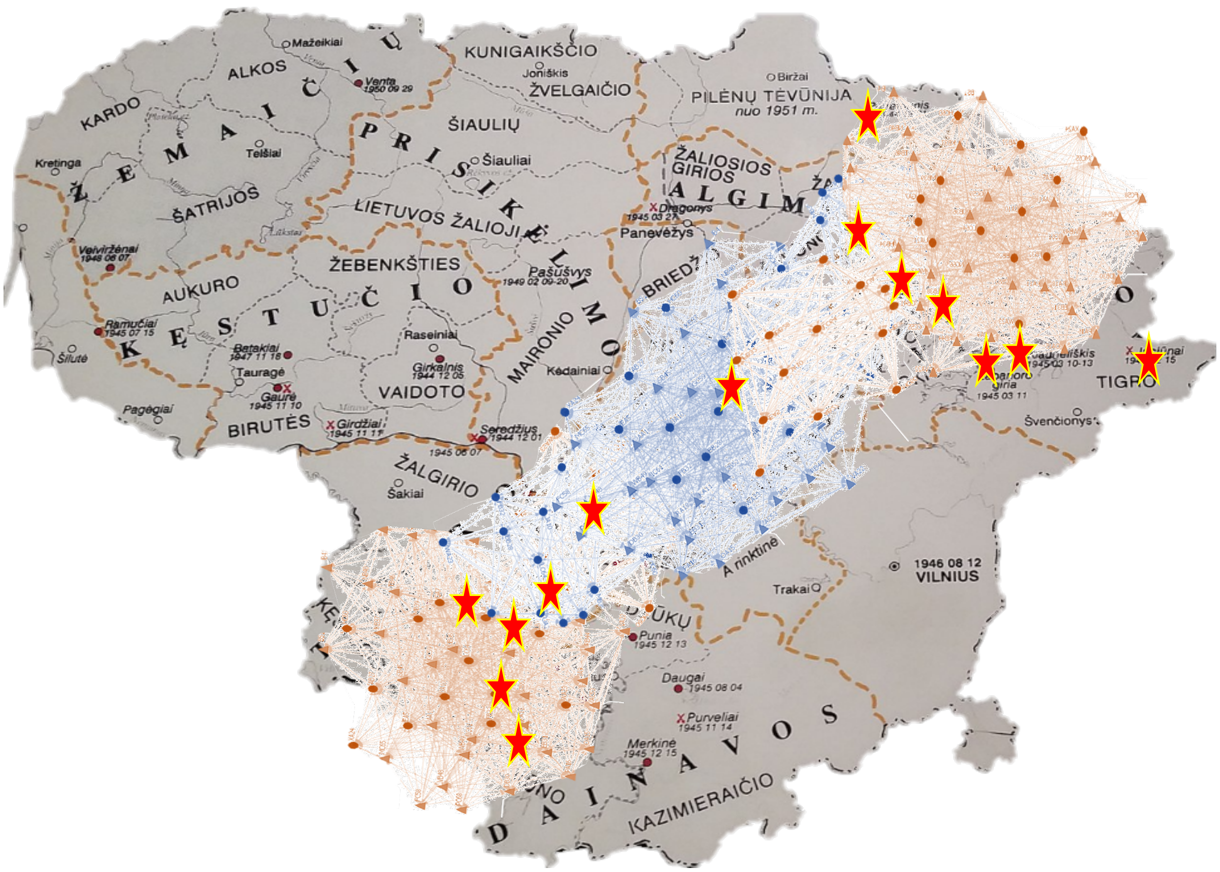

Figure 17. Major Insurgent Attacks/Missions in Relation to Conflict’s Network Map.[186]

186 Adapted from Long et al., “Leadership in Complex Networks”; Museum of Occupations and Freedom Fights, “The Armed Resistance between 1944 and 1953: The Main Battles and Towns Attacked by the Partisans.”

B. RESISTANCE FORCE NETWORK ZONES OF CONFLICT

The proposed GW/UW Casualty Treatment Stages are organized and designed in a way that implies location on the battlefield. To begin the discussion of a network's impact on operational considerations, it is important to establish this relationship based on Figure 13. Figure 18 shows the relationship of the Treatment Stages with the zones of conflict for an insurgent network.

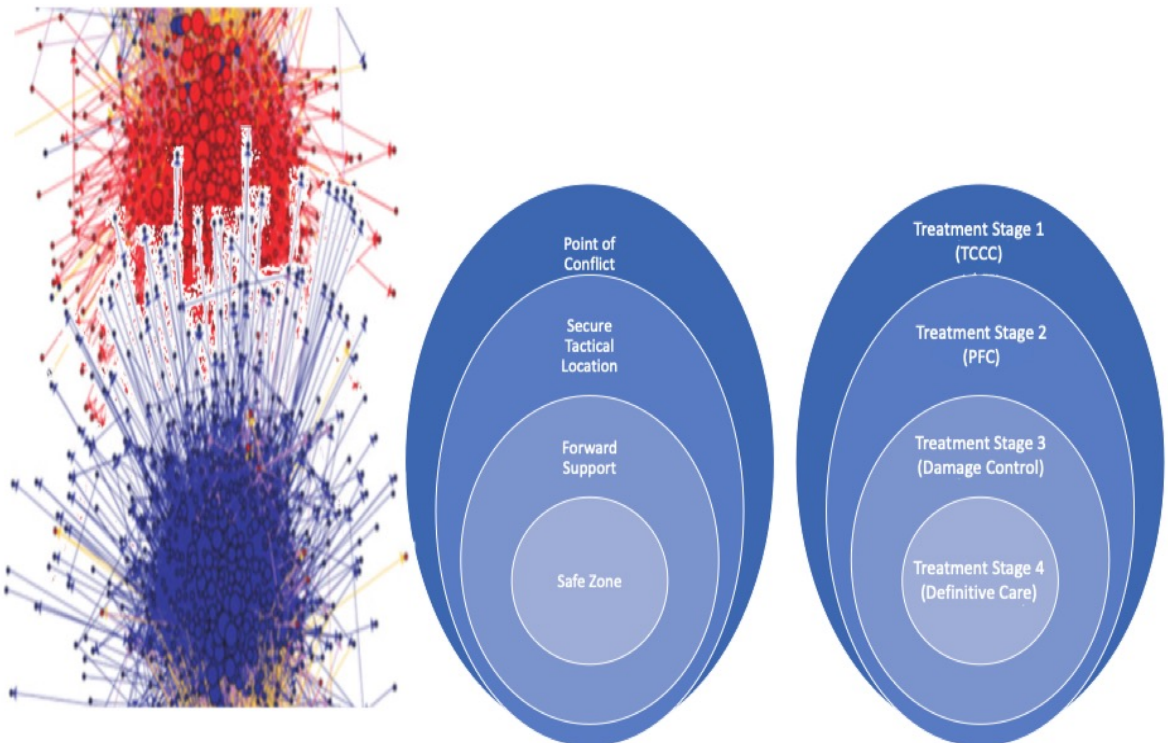

Figure 18. Relation of Treatment Stage Asset Location with Insurgent Network and Conflict Zones.[187]

Guerrilla or insurgent forces must be flexible and dynamic based on the response of the opposing force. This may require the forces to collapse to a safe area until ready for another attack. Figure 19 illustrates this collapsing of insurgent forces, its effect on battlefield zones, and the corresponding effect on medical assets. As the opposing force

187 Adapted from Saint Leo University Library, "GLO 410: Systems Thinking - (Campion, Spring 2016): Chapter 3: Social Network Analysis."

grows in its strength, it forces the insurgent force to collapse to a safe area, assess the damage from the conflict, and prepare for the next phase. With the collapsing of the network, the zones collapse with points of conflict becoming almost non-existent, and in parallel, the medical assets in different treatment stages move with their respective operation zones.

An important consideration is that the collapsing of a network does not have to be literal. Meaning, teams or members of the insurgent force that are in forward areas do not have to literally move to the "safe zone." The key element in using the social network map are the connections between nodes. The fact that a "friendly" node exists within a dense network of "enemy" nodes becomes an issue if the ties between respective nodes are picked up by the other. So, if a "friendly" node has a connection with another "friendly" node in an area of density for the "enemies," it will likely get compromised. Severing connections and isolating a node, even deep into enemy territory, can achieve the same effect as retrograding to the safe area in regard to reducing risk of compromise. Planners should not limit contingency plans to retrograding and need to consider assets going into isolation until the insurgency reorganizes.

In extreme circumstances in which the opposing force overruns the insurgent base area, the safe zone may completely disperse, leaving only forward support and/or secure tactical zones. The circumstances that this overwhelming occupation occurs, collapsing an insurgency in its entirety, is outside of the scope of this chapter, but they are important reminders of how dynamic the battlefield of an unconventional conflict can be.

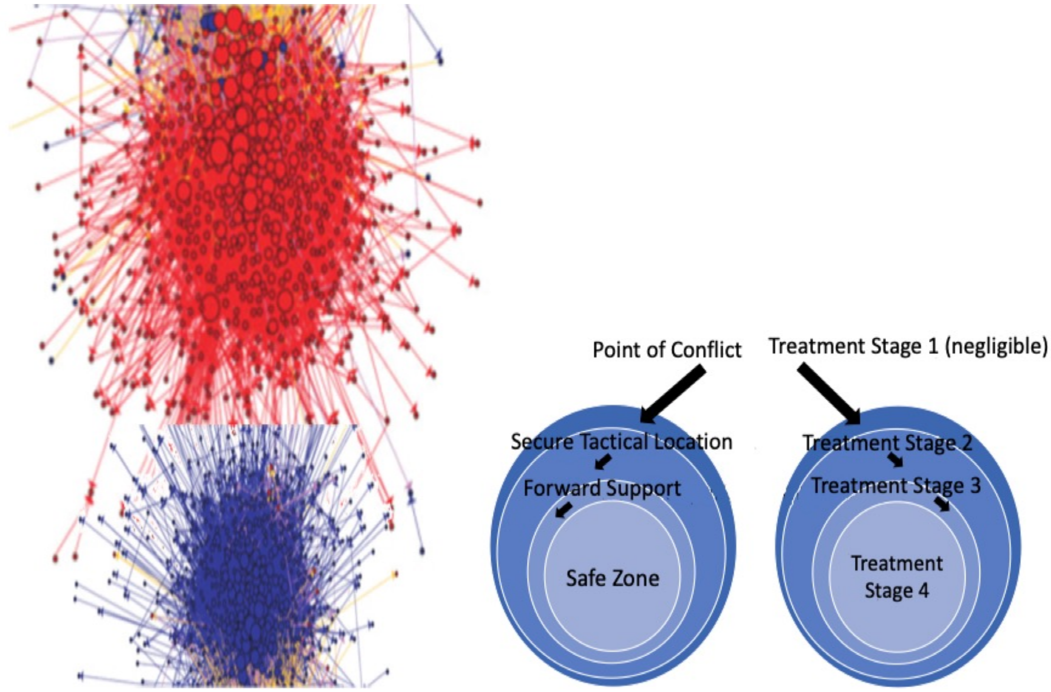

Figure 19. Insurgent Network Dynamic Nature's Effect on Conflict Zones and Medical Asset Location.[188]

C. IMPLICATIONS OF NETWORK DENSITY ON OPERATIONS

The zones of conflict based on insurgent (and adversary) network densities have an impact on operations, tactics, and procedures, contributing to the uniqueness of insurgencies, counterinsurgencies, and UW. This section will evaluate secondary effects of the network structures and principles discussed.

The denied environment in which resistance movements and GW take place limits movement in the area of operations due to enemy presence and their efforts to maintain superiority.[189] Opposite to a denied environment is a permissive environment where friendly forces have control.[190] In Figure 20, the first operational consideration for friendly, or resistance forces, is "permissiveness." The arrow grows larger (more

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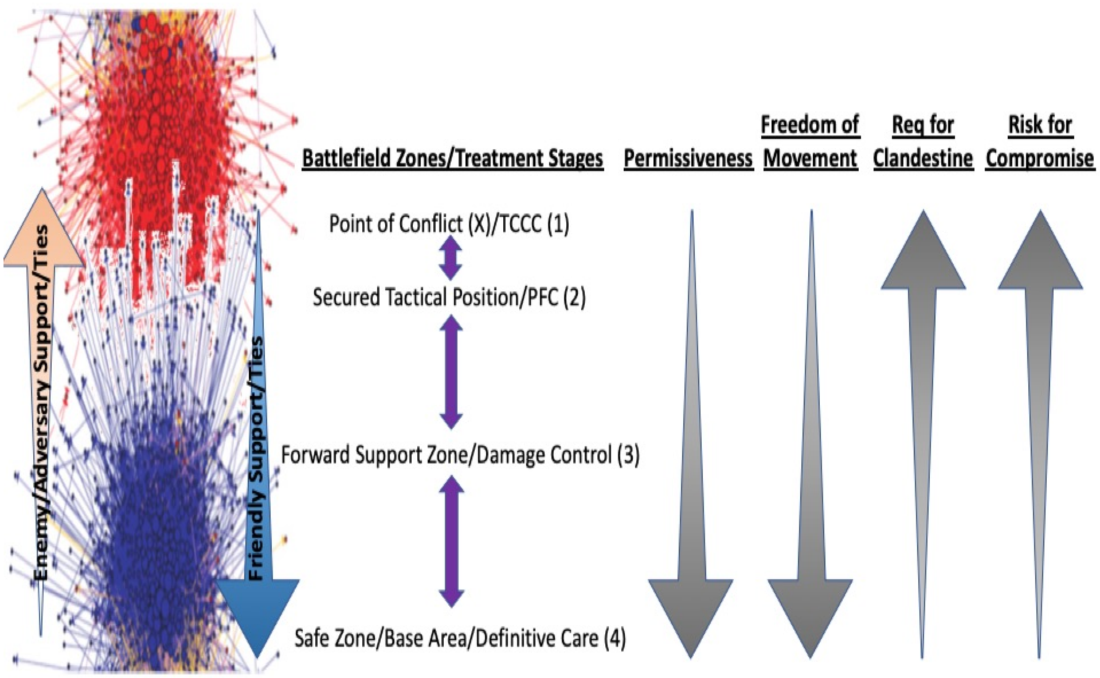
188 Adapted from Saint Leo University Library, "GLO 410: Systems Thinking - (Campion, Spring 2016): Chapter 3: Social Network Analysis."

189 Office of the Secretary of Defense, DOD Dictionary of Military and Associated Terms, 61.

190 Office of the Secretary of Defense, 166.

permissive) the further from the adversary and parallels the density of the resistance network.



These operational considerations justify the use of auxiliary and underground networks during unconventional conflicts.

Figure 20. Operational Considerations in Relation to Insurgent Network Map.[191]

"Freedom of Movement" refers to the ability of a force to move around an environment without being compromised or engaged upon by the opposing force. This is directly related to the permissive (or denied) nature of the operating environment. Another factor in freedom of movement is the likelihood of engagement in the event of identification by the enemy. This factor was not taken into consideration for this chapter, and it is assumed that the GW/UW environment is "high threat" with a high likelihood of enemy engagement. Freedom of movement improves the closer to the safe area for an

[191] Adapted from Saint Leo University Library, "GLO 410: Systems Thinking - (Campion, Spring 2016): Chapter 3: Social Network Analysis."

insurgent force, but it becomes more difficult as the friendly's network density decreases and the enemy's increases.

The last two considerations listed in Figure 20 are "Requirement for Clandestine." And "Risk for Compromise." These variables are also intertwined with permissiveness. A network with high density has maximal number of ties to other nodes. If a member of the opposite force was in a high-density area, there is a high likelihood that they would be identified and/or reported to authorities, compromising their position and mission. To avoid compromise, clandestine practices obscuring identity, affiliation, and purpose are required.

These movement restrictions and requirements to "blend in" with clandestine procedures underscore the need for strong relationships with underground and auxiliary.[192] The use of these assets augments the guerrilla/insurgent force with logistical movement and support.[193] The development of these relationships requires forward planning and building trust to strengthen commitment in a situation of high uncertainty.[194] These operational implications are not unique to assault forces, so building of these relationships will be instrumental in optimizing a medical support system.

D. IMPLICATIONS OF NETWORK DENSITY ON MEDICAL SUPPORT

Supporting medical assets are limited by the operational environment where they are located. These relationships between medical care and operational limitations are documented throughout guerrilla medicine literature, especially the Yugoslavian partisan effort in WWII. Some medical limitations based on the operational environment will be discussed in this section, although this is not an all-inclusive list.

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[192] Duke, Phillips, and Conover, "Challenges in Coalition Unconventional Warfare," 133–34; Grdovic, *A Leader's Handbook to Unconventional Warfare*, 9–12; Department of the Army, *Special Forces Unconventional Warfare*, 1–1.

[193] Department of the Army, Special Forces Unconventional Warfare, 1–1.

[194] Toshio Yamagishi, Karen S. Cook, and Motoki Watabe, "Uncertainty, Trust, and Commitment Formation in the United States and Japan," *American Journal of Sociology* 104, no. 1 (1998): 165–94, https://doi.org/10.1086/210005.

Time to treatment is one of the most influential factors in decreasing battlefield mortality. The "golden hour" evacuation standard set by Secretary Gates is exceedingly more difficult in denied environments with decreased permissiveness and freedom of movement. Therefore, treatment times will incur more delays with a higher impact on mortality as the freedom of movement decreases. This underscores the need for forward medical care in these environments to provide expeditious treatment of life-threatening injuries to the maximum extent possible. The variable "Mortality with Treatment Delays" in Figure 21 attempts to depict this concept. It is important to emphasize that once the patient moves zones from point of conflict towards the safe area, they have received some level of care to address immediate life-threats. Therefore, delays in the patient receiving treatment at the point of injury has a larger impact on their mortality than delays occurring away from the point of injury.

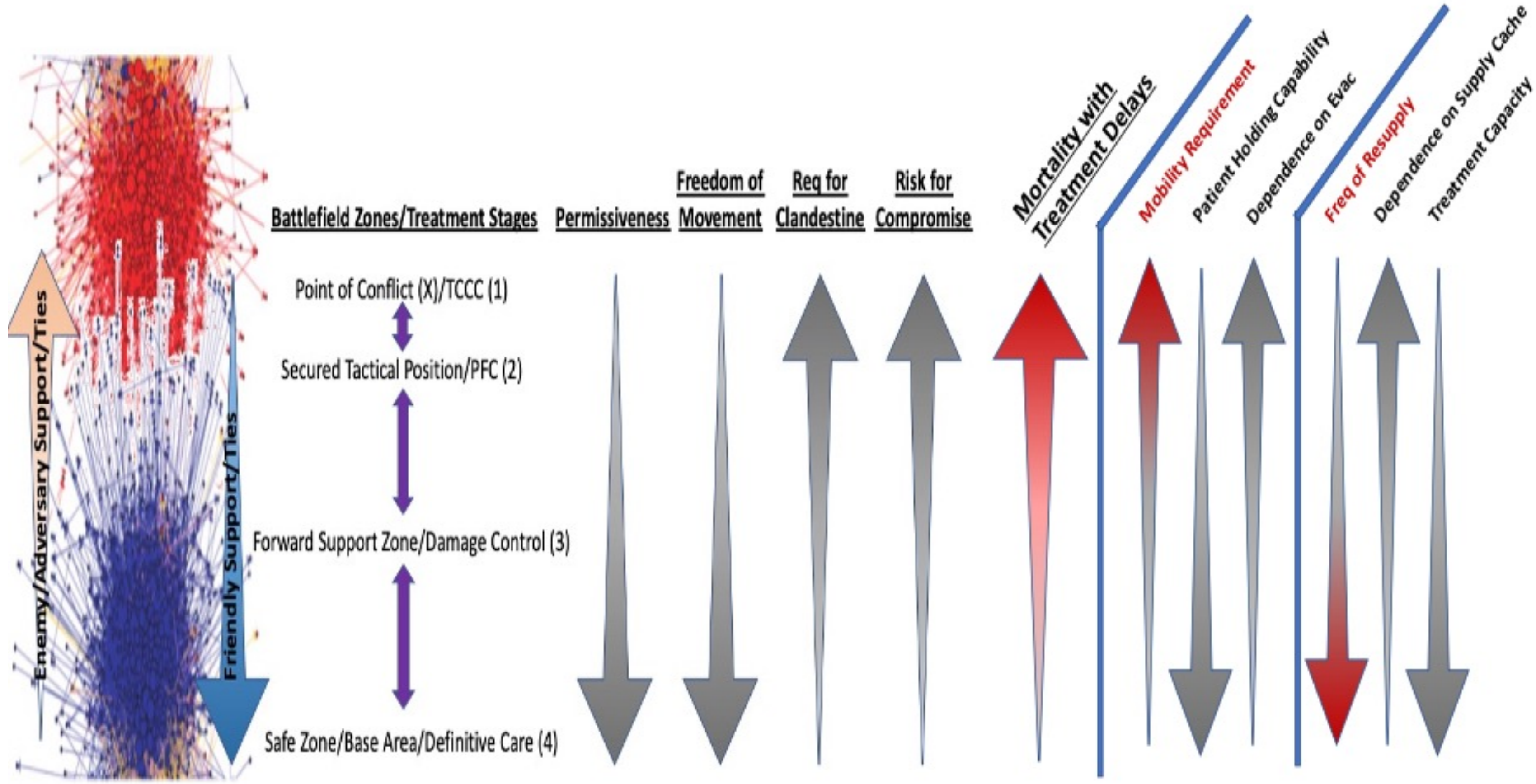
Due to the increased risk of compromise, forward located medical assets require the ability to move. The Yugoslavian partisan hospitals located closer to the areas of conflict were able to treat patients expeditiously and address acute life-threats, but they were at increased risk for compromise and had to change locations frequently.[195] This requirement to move ("Mobility Requirement") becomes less important the closer to a safe zone a medical asset is. As the requirement for mobility increases, the asset must remain small, decreasing its capacity to hold patients for extended periods ("Patient Holding Capacity"). Without a holding capacity, the patient must be evacuated to receive further, more advanced care ("Dependence on Evac").

The decreased freedom of movement also affects the ability of forward medical assets to acquire medical supplies. Logistical supply chains are a potential target and increasing the frequency of resupply in a denied environment increases the risk of compromise of not only the logistics assets, but of the assets themselves. Therefore, as the risk of compromise goes up towards the point of conflict, the "Frequency of Resupply" for the medical teams decreases. In addition, the medical team's "Requirement for Mobility" not only limits patient holding capacity, but also the ability to store supplies. Between these two limitations, the amount of medical supplies a team can have on-hand and can be

[195] Rogers, *Guerilla Surgeon*, 174.

replenished decreases the more forward they are. Medical supplies are a major limiting factor for providing treatment, especially for more critical patients. Therefore, the team's "Treatment Capacity" also goes down with an increased "Requirement for Mobility," ultimately affecting the ability to render timely treatment without delay. Historical guerrilla medical assets encountered these issues and stressed the importance of multiple supply caches across the area of operations.[196] As the "Requirement for Mobility" increases, the medical assets develop a higher "Dependence on Supply Caches."

[196] Farr, "Guerrilla Warfare Medicine: A Review of the Literature and the Problem," 20; Farr, *The Death of the Golden Hour and the Return of the Future Guerrilla Hospital*, 16; Farr, "American Guerrilla Warfare Medical Doctrine – The First Manuals: Lessons Learned," 27; Rogers, *Guerilla Surgeon*, 156.



The list is not all inclusive and only meant to provide examples of how a network can influence the implementation of a medical system in the GW/UW environment.

Figure 21. Secondary Medical Implications from Operational Considerations.[197]

[197] Adapted from Saint Leo University Library, "GLO 410: Systems Thinking - (Campion, Spring 2016): Chapter 3: Social Network Analysis."

Auxiliary and underground forces can facilitate evacuation of patients and movement of medical supplies in situations of increased risk of compromise and decreased freedom of movement. The ability to overcome these obstacles is instrumental to treating casualties. In addition to movement on the battlefield, utilizing auxiliary and underground medical personnel to augment the medical system and render care would decrease many of these operational impacts on medical care. SOCEUR has embraced this idea by approaching the development of a Baltic resistance medical system using the Resistance Operating Concept and whole-of-society approach.[198]

Based on these non-tangible characteristics of UW and its associated medical system, the table created in Chapter II can be expanded to better characterize each treatment stage. Table 3 has updated the original table to include degree of mobility and relative location to points of conflict.

		Holding Capability	
		None	**Present**
Required Skill	**Medic**	Treatment Stage 1 (TCCC)	Treatment Stage 2 (PFC)
	Physician	Treatment Stage 3 (Damage Control Resuscitation/Surgery)	Treatment Stage 4 (Definitive Care/Recovery)

On Battlefield

Away from Battlefield

High Mobility

Low Mobility

Implied variables of mobility and location are indicated by the blue and red arrows, respectively. Although assumed Stage 2 will be more mobile than Stage 4 and Stage 3 will be closer to the battlefield than Stage 4, these are dependent variables based on the tactical and operational environment.

Table 3. Proposed GW/UW Casualty Treatment Stages, Further Classified

[198] Hickman, Baker, and Erickson, "Survivability: Medical Support to Resistance," 18.

E. CONCLUSION

Social network analysis and network structures can help illustrate the concepts of UW. For these conflicts, an occupying force network has increased density in their strongholds, mandating the insurgent forces project forward into the occupied area to carry out harassing attacks. The increased occupying force network density, however, leads to increased risk of compromise, requirement for clandestine operations, and reliance on the underground and auxiliary forces.

These operational implications influence the employment of medical assets and their ability to render expedient, appropriate medical care. Decreased freedom of movement caused by increased opposition forces density mandate medical teams to be more mobile, decrease their footprint, set up supply caches, and depend on the clandestine movement of patients and supplies by the underground and auxiliary.

Network structures and analysis of the unique UW environment helps contextualize this dynamic paradigm. These networks can show not only military force networks, but the network and strength of population support for that force. A resistance relies on the support of underground and auxiliary forces amongst the population, which dictates that the occupying force have less than full support of that population. These non-tangible concepts and their implications on the battlefield are best illustrated by social network structures.

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V. SYSTEMS DYNAMICS MODELING FOR DEVELOPING A GW/UW MEDICAL SYSTEM DECISION SUPPORT TOOL

Based on the causal loop diagrams for a GW/UW medical system organized by the Casualty Treatment Stages, a system dynamics model was created to provide planners with a decision support tool. Each Treatment Stage was designed based on the tangible limitations identified by the systemic analysis in Chapter III, but non-tangible limitations still have an impact on the function of the model. This chapter describes the general design and function of the model for each treatment stage. The model explanation is geared towards potential users with user-interface screenshots for reference. A more detailed explanation of the design, mathematical equations, and close-up views of the model schematics can be found in the appendix and is cross-referenced in the chapter.

A. THE GW/UW MEDICAL SYSTEM DYNAMICS MODEL

This model of the endogenous GW/UW Medical System was created using Stella Architect© Version 2.1.2 (ISEE Systems).[199] The screenshots and graphs presented in this chapter are of the model created using this software. Its simulation is designed to run in hours as the treatment time of combat casualties is measured in hours rather than days or months. Figure 22 shows the complete model that was developed for a “big-picture” view, and Figure 23 highlights each Treatment Stage of the complete system.

As a decision support tool, the model was designed to be interactive for planners so that certain conditions can be changed to see the impact on battlefield mortality and attrition. Examples of such input requirements include casualty rates, injury severity distribution, availability of patient evacuation, evacuation times, treatment/processing times, supply shipment frequency, and supply cache capacity and quantity. Other data such as length of recovery for injuries was built into the system and can be changed, but not through the interface.

[199] ISEE Systems, Stella Architect.

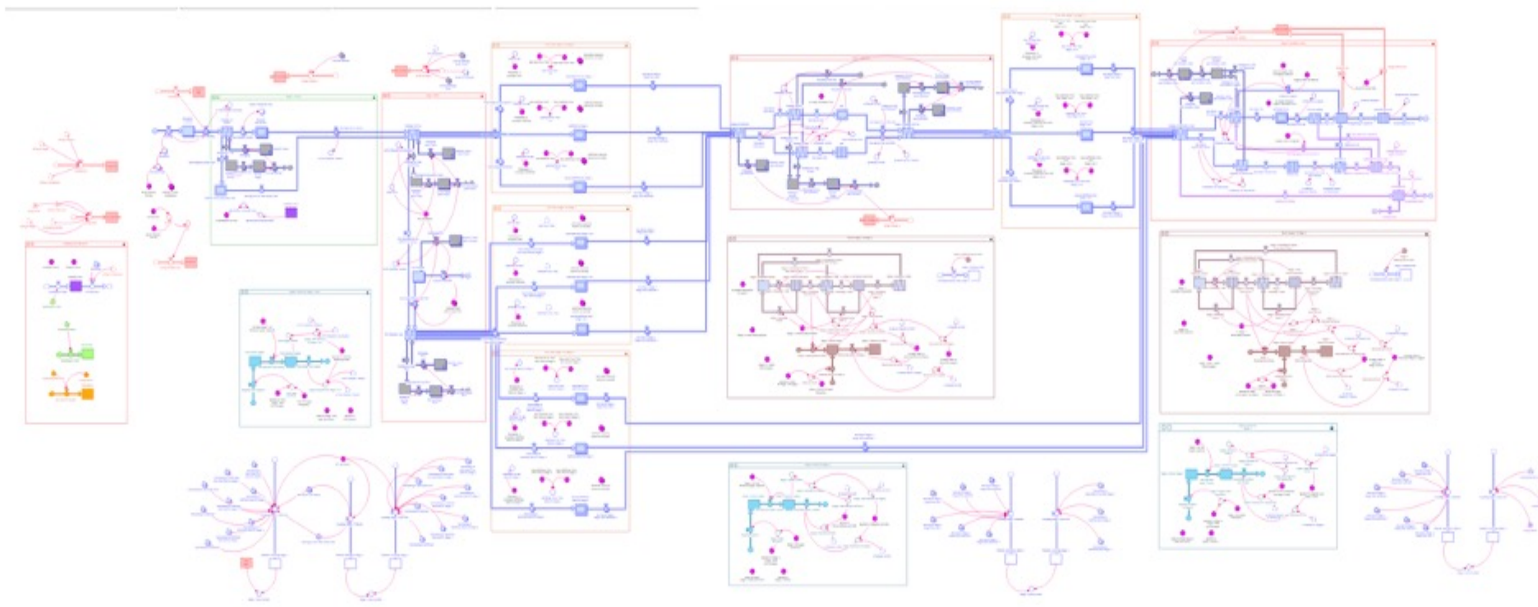

Figure 22. Complete Systems Dynamics Model for a GW/UW Medical System.[200]

200 Adapted from ISEE Systems, Stella Architect.

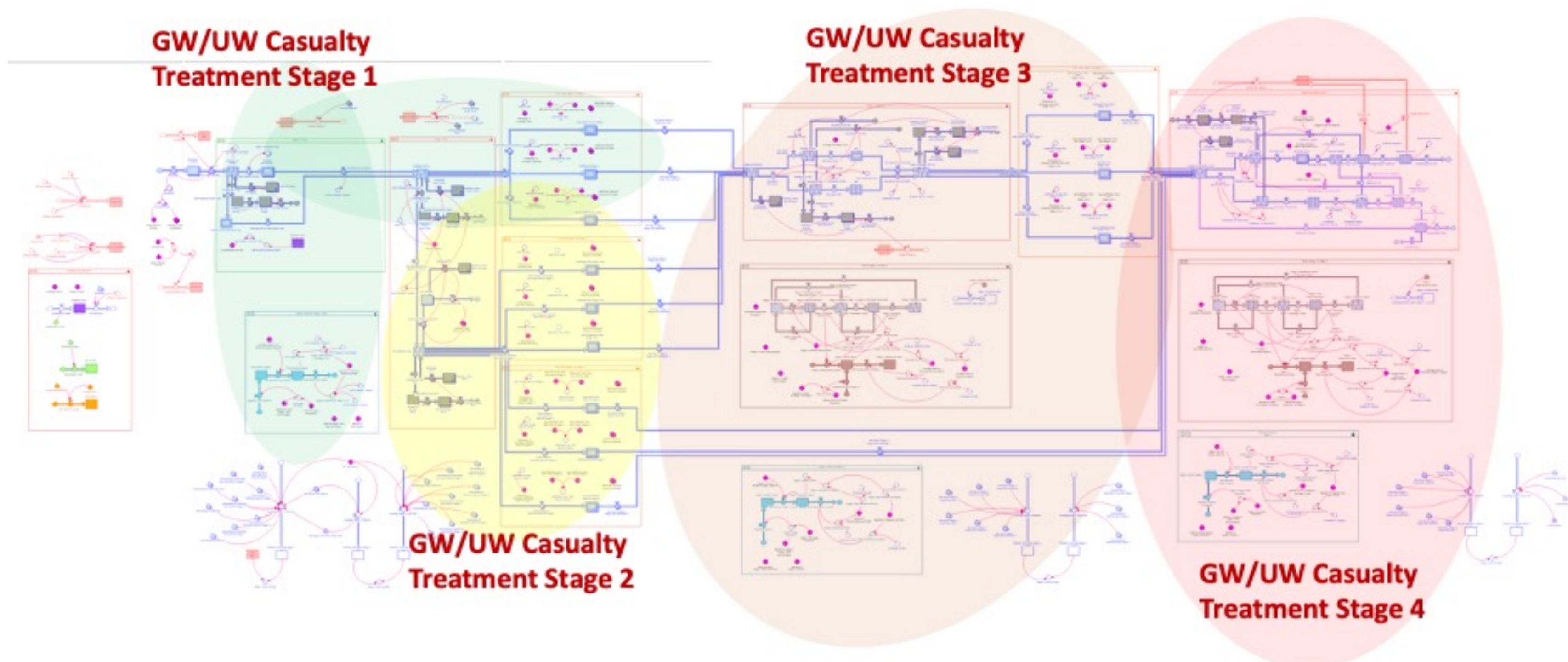

Figure 23. Complete Systems Dynamics Model with Highlighted Treatment Stages.[201]

201 Adapted from ISEE Systems, Stella Architect.

1. Initializing the System—Casualty Wounding Rates and Triage Priorities

On the first page of the interface, the user will input data that establishes the initial fighting force strength and average casualty statistics. The first data entry is the "Total Number of Forces," which are a series of text entries for the number of combat-ready coalition forces and partner forces. The second section is "Casualty Statistics" that uses inputs to create a random number of patients with a given injury severity distribution (Figure 24). The model was designed in this way for a few reasons critical to its function. First, the number of patients who are injured and present to a casualty collection point is random, not reproducible, but over the course of a conflict, follows a distribution of patients varying in severity. This severity variation can be determined by a multitude of factors, such as environment of conflict, emphasis on improvised explosive devices (IED) use vs small arms, effectiveness of the enemy, and their weapons. These factors are outside the scope of the model. The distribution of patient severity, however, is fundamental in the model's function because critical patients require faster treatment and are unlikely to return to the conflict compared to those with minimal injuries who will likely return within 72 hours.

The two inputs, "Average Number of Casualties Per Day" and "Distribution of Casualty Severity" denote data that the end-user will enter, either from historical data, from exercise data, or from collected data on an on-going conflict. These values were calculated using SOSTs' collected data on partner nation casualties from a 2019 Syria deployment.[202] The overall distribution of these patients is relatively consistent when comparing conflicts between Vietnam, Iraq, Afghanistan, and Syria, which allows initial estimates to be used

[202] Special Operations Surgical Team, "BLACK Patient Tracker 2019," June 2, 2019.

with moderate confidence in accuracy.[203] The KIA rate used in designing the model is based on the non-treatable, immediate life-threats reported from previous conflicts in Vietnam, Iraq and Afghanistan.[204]

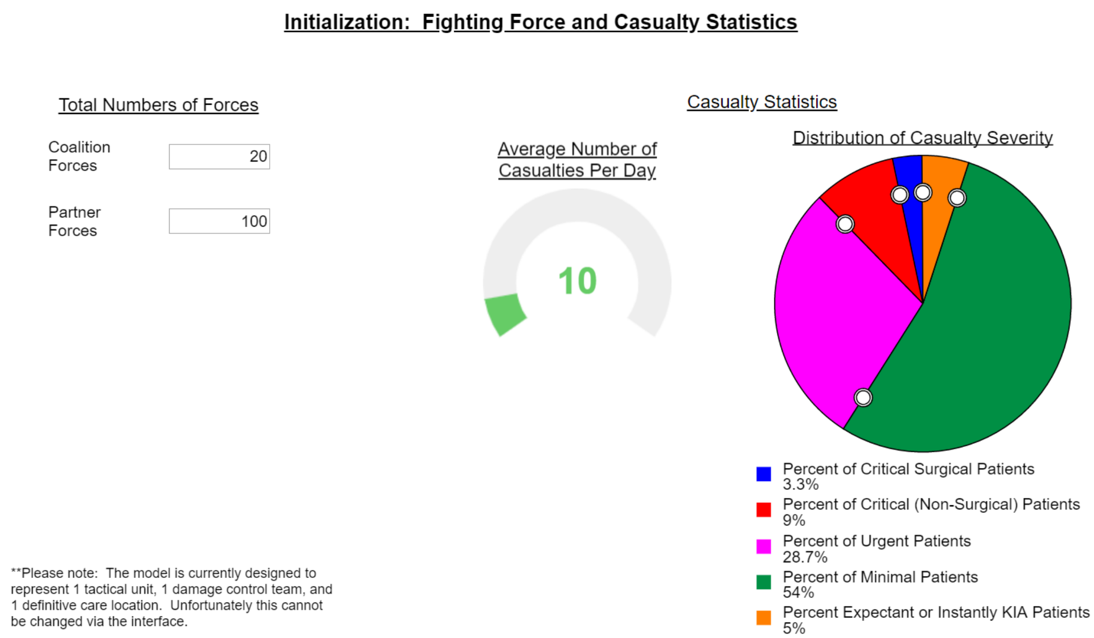

Figure 24. Initialization Interface.[205]

2. Casualty Treatment Stage 1

The interface in Figure 25 sets the variables for Casualty Treatment Stage 1. As illustrated in the causal loop diagrams, the training of unit members and of medics in TCCC

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[203] David A Blum and Nese F DeBruyne, *American War and Military Operations Casualties: Lists and Statistics*, CRS Report No. RL32492 (Washington, DC: Congressional Research Service, 2020); Hannah Fischer, *A Guide to U.S. Military Casualty Statistics: Operation Freedom's Sentinel, Operation Inherent Resolve, Operation New Dawn, Operation Iraqi Freedom, and Operation Enduring Freedom*, CRS Report No. RS22452 (Washington, DC: Congressional Research Service, 2015); Holcomb et al., "Understanding Combat Casualty Care Statistics," 400; Champion et al., "A Profile of Combat Injury," fig. 4.

[204] Holcomb et al., "Understanding Combat Casualty Care Statistics," 398–99; Champion et al., "A Profile of Combat Injury," S15-16; Kotwal et al., "Eliminating Preventable Death on the Battlefield," 1351.

[205] Adapted from ISEE Systems, Stella Architect.

are primary independent variables that contribute to this section of the system. The model currently only simulates one combat unit and does not factor in multiple combat units. The number of medics per unit is currently set at two but can be changed (not through the interface) to simulate an increase in medic training, which, as depicted in Chapter III, will increase the TCCC provided. This section also factors in unit members being trained in TCCC and able to care for less critical patients. The user can change the percentage of the fighting force (accounting for both partner forces and coalition) trained in TCCC. Changing this number also has an impact on TCCC treatment. Details of the model design for Stage 1 treatment can be found in the Appendix on page 131-135.

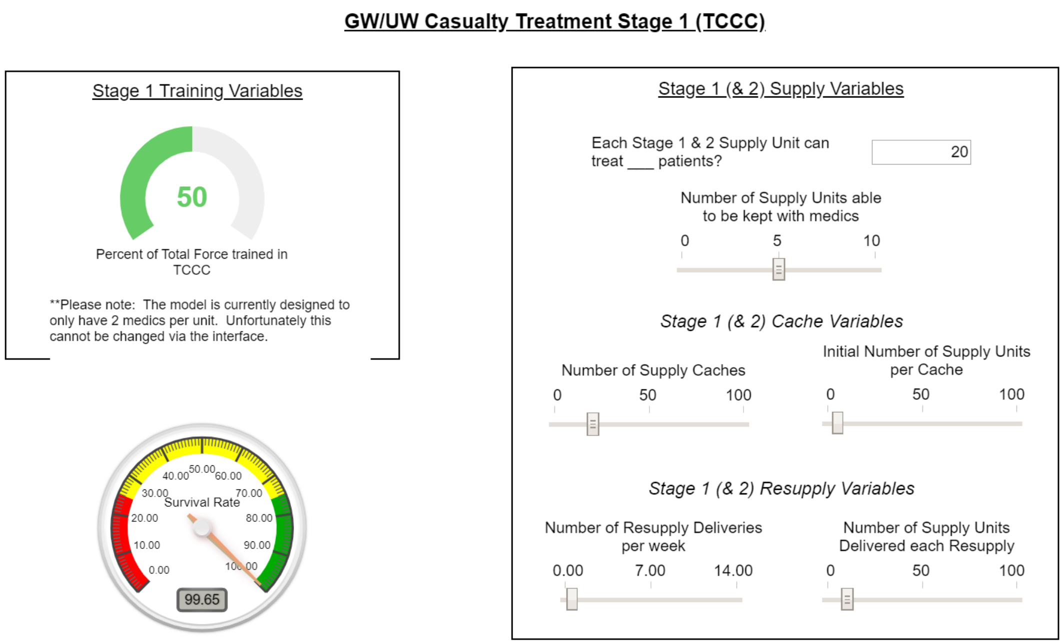

Figure 25. Casualty Treatment Stage 1 Interface.[206]

The model was designed to account for possible delays and constraints on the flow of patients. When patients of increased severity do not receive expeditious care, their clinical condition quickly decompensates. Operational planners have used the concept of a “golden hour” routinely in the last couple decades of conflict, to mean that a patient with a

206 Adapted from ISEE Systems.

traumatic injury is far more likely to survive if their life threatening injuries are addressed within an hour.[207] By factoring the worsening of patients into the model, casualty statistics will reflect more accurate values and end-users can identify the variables delaying care. Details of this function in the model can be found in the Appendix on page 135-136.

The TCCC treatment of patients by the medics is limited by the amount of medical supplies available. The supplies discussed here do not include individual first aid kits (IFAKs) and are specific to medic-level care. If no supplies are available, the medics are unable to treat patients who will begin to decompensate and eventually die without treatment. Based on historical recounts of guerrilla medicine and the emphasis on supply caches, the supply sectors in this model include such caches. For stages that are closer to areas of conflict, multiple small caches will be required as forward teams need to maintain high mobility to avoid capture. Also, the amount of supplies able to be kept on-hand will be less as the mobility requirement of the treatment teams increases. Based on the specific operational environment, the user can define the size of a supply unit, how many units can be carried by medics, the number of caches, the initial supplies per cache, frequency of resupply, and how much supplies is delivered on resupply. A more detailed description of the supply section can be found in the Appendix on page 137-141.

After treatment, either by medics or buddy care, patients move into a queue for evacuation and are prioritized based on severity. There are two classifications of evacuation platforms for patients. The first is casualty evacuation (CASEVAC), which is defined as any platform that does not have medical treatment capability (i.e., no medical personnel on the platform).[208] The second is MEDEVAC, defined as any platform that does have medical treatment capability.[209] Because MEDEVAC requires trained personnel to be considered a MEDEVAC platform, these are scarcer resources. CASEVACs, however, can

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207 Kotwal et al., "The Effect of a Golden Hour Policy on the Morbidity and Mortality of Combat Casualties," 16; Remick et al., "Defining the Optimal Time to the Operating Room May Salvage Early Trauma Deaths," 1257.

208 Department of the Army, *Medical Evacuation*, ATP 4-02 (Washington, DC: Department of the Army, 2019), sec. III.

209 Department of the Army, sec. III.

be any available transport mechanism. For this model, CASEVAC and MEDEVAC refer to ground platforms only and do not factor in helicopter evacuation. A denied environment will not have air superiority; therefore, any use of air assets will be at significant risk and would most likely be rotary wing aircraft. Dedicated rotary-wing MEDEVAC does not typically project forward into hostile environments, so this model assumes a non-MEDEVAC rotary wing asset, although significantly limited in its availability.

This model was designed to allow patients with minor injuries to be evacuated from Stage 1 to Stage 3 or 4. Patients with more significant injuries (classified Urgent, Critical, or Surgical Critical) are restricted to be evacuated to Stage 3 or stay to receive PFC from Stage 2. The data inputs for evacuation from Stage 1 to Stage 3 and from Stage 1 to Stage 4 are the same as from Stage 2 to Stage 3 and from Stage 2 to Stage 4, respectively, and are included in the Treatment Stage 2 interface (Figure 26 and 27). The interface allows for modifying variables for three different types of platforms: rotary wing (helicopter), CASEVAC, and MEDEVAC. Probabilities for the availability and success of each platform are used to account for the limited movement in denied environments as discussed in Chapter IV. The user inputs the probability for each platform (Figure 26), and through a series of logic equations, evacuation platforms become available to move patients based on that probability. More patient evacuations occur with platforms of higher probability. The user also determines the minimum and maximum transport time to the Stage 3 location (Figure 27), which further affects evacuation asset availability. This set up is utilized for evacuation at each stage of care. Further explanation on the design of the model's evacuation sectors can be found in the Appendix on page 142-144.

3. Casualty Treatment Stage 2

Treatment Stage 2 is defined by the use of PFC in which medics provide additional treatment of patients in the event of significant delays in evacuation from forward locations. Figure 26 depicts the interface that modifies variables for Stage 2 medical treatment. If medics are trained in PFC, then the toggle switch in the "Stage 2 Training Capability" should be on. If a system does not have Stage 2, then it should be turned off. A recent study reported a high mortality rate for critical patients within the first four hours of PFC.[210] If medics have been trained in PFC, then the amount of time patients can wait for evacuation without decompensating goes up to 4 hours. After these 4 hours, a PFC mortality rate is applied to these patients, and they are placed in line to be evacuated to Stage 4 rather than Stage 3. These patients will not decompensate until after 72 hours, the standard time quoted for PFC capabilities. The explanation of how this was designed can be found in the Appendix on page 146-157.

The recent study by Shackleford, et. al. also found that patients who survive 4 hours of PFC are not likely to require damage control treatment and can be transported to more definitive care.[211] Therefore, evacuation from Stage 2 can either be to Stage 3 or Stage 4, since patients who have undergone 4 hours of PFC can be transported directly to definitive care. Once patients have undergone 4 hours of care and are waiting for evacuation, they are prioritized based on severity and evacuated based on the next available evacuation platform, either to Stage 3 or 4. The evacuation computations for Stage 2 are set up in the same way as Stage 1 (evacuation from Stage 1 and Stage 2 to Stage 3 automatically use the same inputs). However, the probability of available platforms may be less and transport times increased for evacuation to Stage 4 given the increased distance. These variables can all be adjusted by the user in the interface (Figure 26 and 27).

The evacuation probabilities in Figure 26 can be used to simulate medical systems without Stage 3 and/or Stage 4 capabilities. If a given medical system cannot reach these levels of care, then all probabilities of evacuation should be set to "0." This halts any movement of patients to next level of care, achieving the same result as deleting the Stage 3 and 4 from the model.

One of the limitations of this model's design is that the medics for Stage 1 are the same for Stage 2, and the current design of the model assumes superior multitasking between the acute treatment and prolonged management of critical patients. In addition,

[210] Stacy A. Shackelford et al., "Case-Control Analysis of Prehospital Death and Prolonged Field Care Survival during Recent U.S. Military Combat Operations," *Journal of Trauma and Acute Care Surgery* 91, no. 2 (April 26, 2021): S186–93.

[211] Shackelford et al., S189-192.

the current structure of Stage 2 does not prevent the treatment of patients if supplies are low. The medical supply calcuations for Stage 1 do, however, account for patients being treated in Stage 2 for expending supplies, lowering the overall supplies available to medics. This slight inaccuracy will allow for patients to be treated in Stage 2 even if supplies are not available, which will falsely decrease the mortality rate for Stage 2.

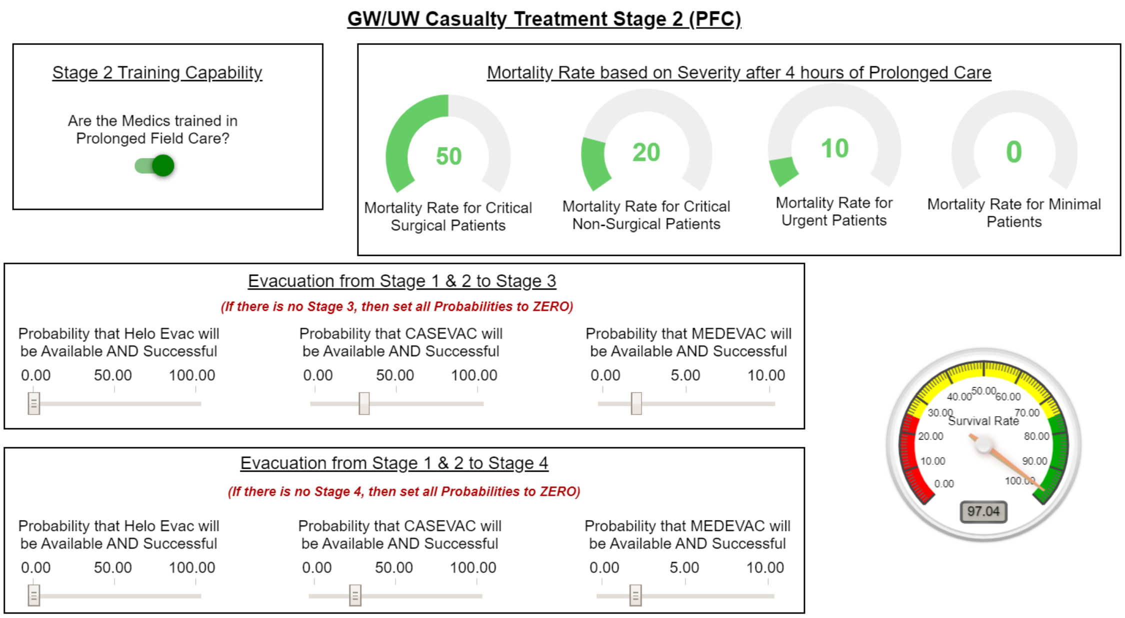

Figure 26. Casualty Treatment Stage 2 Interface.[212]

212 Adapted from ISEE Systems, Stella Architect.

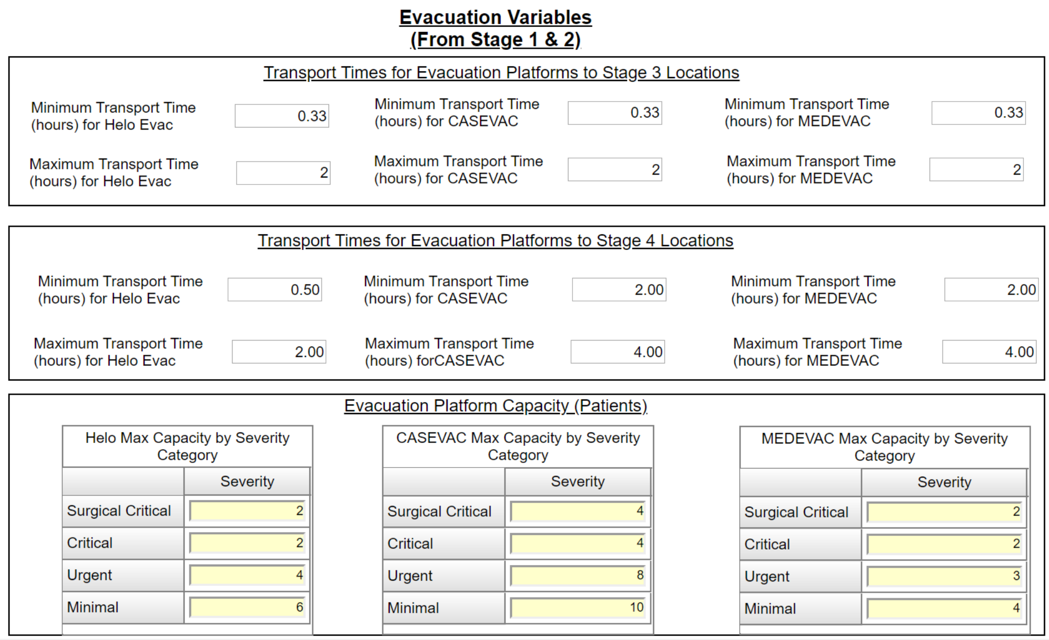

Figure 27. Evacuation Variables for Stage 1 & 2 Interface.[213]

4. Casualty Treatment Stage 3

The interfaces for GW/UW Casualty Treatment Stage 3 are shown in Figure 28 and 29. Per the causal loop diagrams from Chapter III, the number of surgical teams and the blood supply are primary contributers to this stage of the system. This model currently only depicts one AST and does not capture the training process. This is a limitation of the model and should be included in future modifications. The user can modify the "Average Time (hours) per Surgery" to account for inexperienced surgeons or teams. This time can also be modified to account for other variables such as types and numbers of injuries, injury severity, complexity of procedures, etc. Adjustment of "Average Time (hours) per Surgery" will increase the time patients are waiting for surgery. The model also includes a supply sector that was not originally depicted in the causal loop diagram.

213 Adapted from ISEE Systems, Stella Architect.

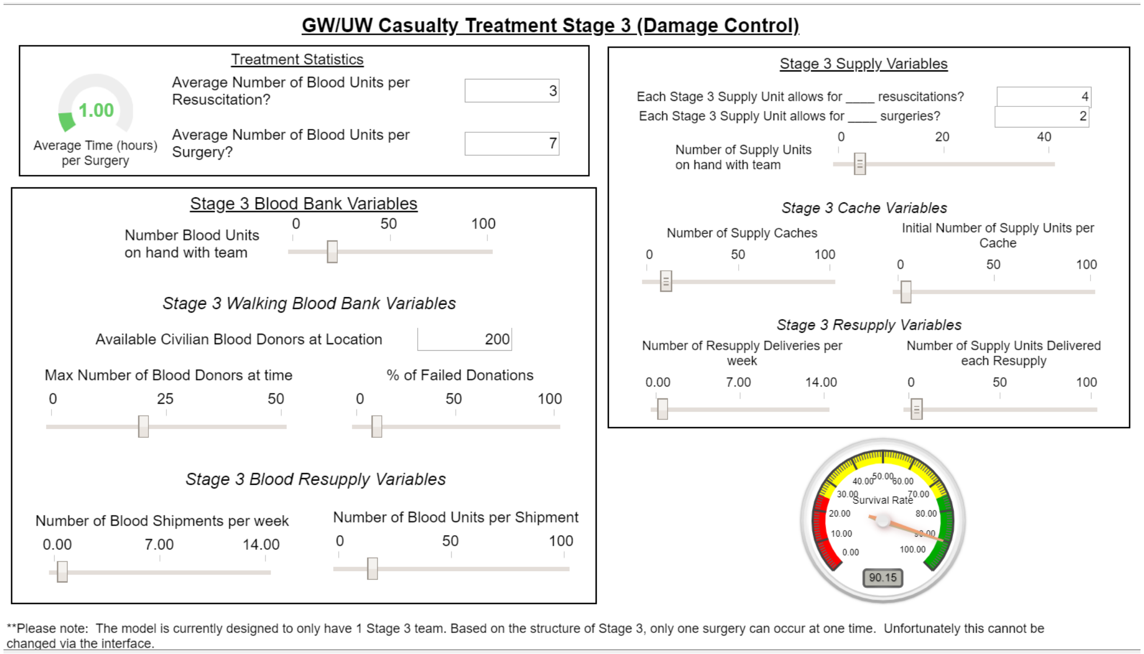

Figure 28. Casualty Treatment Stage 3 Interface.[214]

When patients arrive at Stage 3 from the myriad of evacuation platforms, they are again prioritized based on severity. Patients who have been designated as surgical in the initial classification will be seperated and placed in line for DCS. Given the size of these forward surgical teams, only one surgery can be performed at a time and the average surgery duration is set in the interface. The model is designed to account for a worsening patient condition with delays in surgery. Patients who cannot receive surgery within 1 hour after arriving to the Stage 3 location will die. This is not currently changeable through the interface and is based on the "golden hour."[215] Patients who do not require surgery will be in line for DCR. Given the size of the teams, only 8 patients can receive DCR at one time, and if they are waiting too long for care, they will decompensate further. The model does not take into consideration patients who have been treated and survived over 4 hours in Stage 2 who have a better chance of survival. It assumes these patients have worsened

[214] Adapted from ISEE Systems, Stella Architect.

[215] Kotwal et al., "The Effect of a Golden Hour Policy on the Morbidity and Mortality of Combat Casualties," 22–23; Remick et al., "Defining the Optimal Time to the Operating Room May Salvage Early Trauma Deaths," 1257.

during transport and treats them equally to be conservative in calcuations, but potentially this could falsely raise the death rate. Details of the model design for Stage 3 treatment can be found in the Appendix on page 160-165.

The ability of the team to perform DCR/DCS is limited by the amount of blood andmedical supplies available. The interface in Figure 28 has sections to alter inputs for these variables.

The concept of the blood supply system is similar to that of medical supplies described earlier for Stage 1, with limited storage capablity and difficulty of resupply given the denied environment. There are two differences for blood inventory, however. First, caches are less likely to be an option given the storage requirements for blood products, although this could be an avenue pursed by the teams that is not accounted for in the model. The second difference is that blood supply can be generated by drawing a unit from blood donors, known as a "walking blood bank." The walking blood bank is used down-range to increase the amount of available blood.[216] The amount of blood required and expended is calculated based on the flow of patients through Stage 3 and the average number of blood units used during a critical surgery or resuscitation, which can be changed on the interface. The initial data used in this model is based on the statistics from a forward surgical team's deployment.[217] A more detailed description on the modeling for blood supply and walking blood banks can be found in the Appendix on page 166-171.

The design for Stage 3 medical supplies closely mirrors that of Stage 1. Stage 3's medical supply establishes a supply unit specific to Stage 3 care that can allow the team to perform a defined number of DCRs and DCSs. It is currently set to the advertised number of surgeries and resuscitations that the SOST standard supply increment can support. This

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[216] Marshall Bahr et al., "Practical Considerations for a Military Whole Blood Program," *Military Medicine* 185, no. 7–8 (August 14, 2020): e1032–38, https://doi.org/10.1093/milmed/usz466; Andrew D. Fisher et al., "Low Titer Group O Whole Blood Resuscitation: Military Experience from the Point of Injury," *Journal of Trauma and Acute Care Surgery* 89, no. 4 (October 2020): 834–41, https://doi.org/10.1097/TA.0000000000002863; J. R. Hess and J. B. Holcomb, "Transfusion Practice in Military Trauma," *Transfusion Medicine* 18, no. 3 (2008): 143–50, https://doi.org/10.1111/j.1365-3148.2008.00855.x.

[217] Special Operations Surgical Team, "BLACK Patient Tracker 2019."

can be changed in the interface. The use of medical supplies on non-critical patients is relatively negligible at this stage and is not accounted for. Also, the delivery of medical supplies is slightly more frequent than that of Stage 1 given Stage 3's distance from point of conflict. This may change depending on the operating environment and can be modified in the interface. A more detailed description on the modeling for Stage 3's medical supply can be found in the Appendix on page 171-173.

Once patients are treated at Stage 3, they enter a queue for evacuation to Stage 4, prioritized based on their severity. Although further removed from the area of conflict, the environment still limits the movement of people and supplies, creating evacuation delays. Patients who are critical and have been waiting too long for evacuation and begin to decompensate, re-enter the triage for Stage 3 to receive more DCR/DCS. If the team is backed up, and patients wait too long to be re-treated, then they will die.

Evacuation from Stage 3 to Stage 4 (Figure 29) uses the same logic as that of Stages 1 and 2. Because Stage 3 teams are located further from the point of conflict, the end-user can adjust the probability of evacuation and the transport time accordingly to account for more freedom of movement.

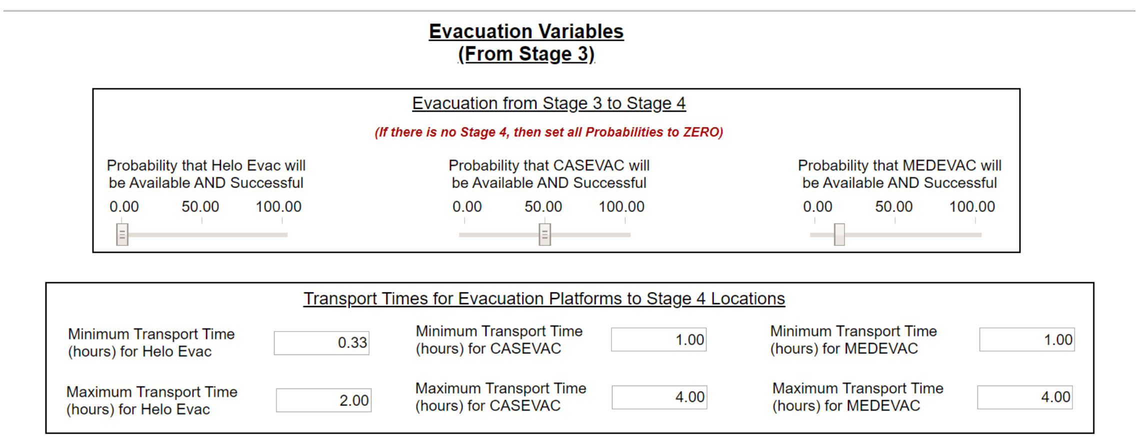

Figure 29. Evacuation Variables from Stage 3 Interface.[218]

[218] Adapted from ISEE Systems, Stella Architect.

5. Casualty Treatment Stage 4

GW/UW Casualty Treatment Stage 4 variables are modified by the interface shown in Figure 30. The primary contributers to this stage of the system, as seen in the causal loop diagram (Figure 8), are the number of guerrilla hospitals, medical personnel, and the blood supply. This model currently only depicts one hospital and does not capture the training process. Medical supplies were again accounted for even though not originally depicted in the causal loop diagram.

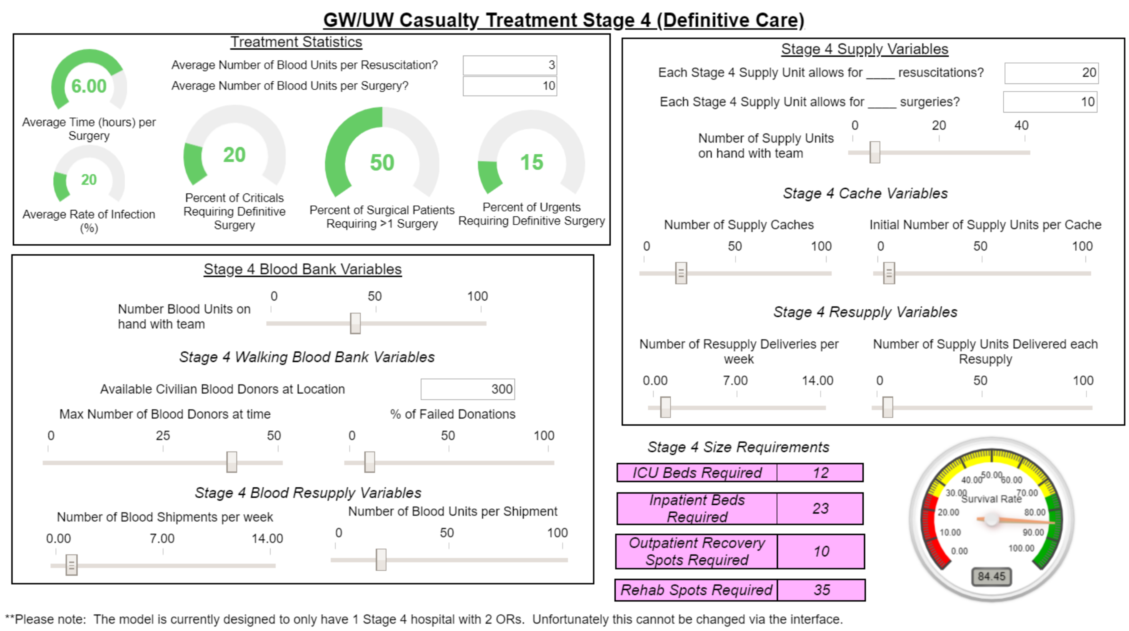

Figure 30. Casualty Treatment Stage 4 Interface.[219]

It is important to note that although terms such as “hospital,” “ICU,” “inpatient,” and “beds” are used to describe a Stage 4 location, it should not be assumed that a Stage 4 facility must look like a traditional hospital with all these treatment areas in one confined space. The guerrilla hospital, for example, may have a surgical suite and trauma bay and use auxillaries or citizens to provide post-surgical nursing care in the surrounding area.

[219] Adapted from: ISEE Systems, Stella Architect.

Regardless, this requires a more secure area with a strong, dense support network to house many patients in the community.

When patients arrive at Stage 4 from either Stage 2 or 3, they are again prioritized based on severity. Patients originally designated with a “Minimal” severity will be immediately sent to rehabilitation and bypass inpatient treatment. Patients who have been designated as “Surgical” in the initial classification will be seperated and placed in line for surgery. Stage 4 facilities can be slightly larger than Stage 3, and therefore the model allows for two operating rooms (ORs) for simultaneous surgeries. This can be changed to account for larger facilities, but cannot be done through the interface. Stage 4 surgeries require more time due to extensiveness of definitive surgeries, and the average surgery duration can be set through the interface. After surgery, patients either move to the intensive care unit (ICU) or into outpatient recovery (more routine surgeries). The non-surgical patients arriving at Stage 4 who require more than rehabilitation care enter the triage area for the trauma bay. After treatment in the trauma bay, critical patients are transferred to the ICU and non-critical patients are sent to outpatient recovery. Patients completing outpatient recovery will be placed in rehabilitation and returned to the force. Patients in the ICU move to inpatient recovery and, upon completion of inpatient recovery, are considered furloughed due to the seriousness of their injuries and cannot be returned to duty. This may falsely lower the number of able fighters as some may be able to return to the fight if it is a prolonged conflict. The explanation of the patient flow for Stage 4 can be found in the Appendix on page 178-187.

In designing the model, several errors occured when trying to limit the number of ICU and inpatient beds. While this reinforces the need for several Stage 4 facilities or a robust guerrilla hospital capacity as shown with the causal loop diagrams, it hindered the desired function of the model. Therefore, instead of setting these numbers, the model calculates the maximum number of patients in these wards at a time, determining the number of beds (and therefore, personnel) required. The same calculation is done for outpatient recovery and rehabilitation spots, although the local area is more likely to be used to house these patients to decrease the Stage 4 footprint and prevent compromise. If the model was able to depict multiple Stage 4 facilities, all the “bed” requirement numbers would decrease since patients would be spread across locations. These results are populated in the table on the interface.

Patients in Stage 4 are more likely to die from treatment complications, such as infection, rather than delay in care since they have “stood the test of time.” In the event Stage 4 is overwhelmed, however, the model still accounts for treatment delays, and patients will decompensate if they cannot receive care within 4 hours. The reason for the longer time is because patients arriving to Stage 4 have either “stood the test of time” with PFC at Stage 2, supporting the decision to bypass damage control treatment, or they have already received damage control treatment.[220] This will more likely occur when blood or medical supplies run low, preventing surgeries or treatment to continue. For patients in the ICU and inpatient beds, a fraction of patients die due to infection, which accounts for the majority of deaths at this stage.

The ability of the hospital to perform surgery and treat patients is limited by the amount of medical supplies and blood available. The blood supply and medical supply sectors are designed identically to that of Stage 3 and have the same interface data inputs (Figure 30). Some variables are going to have different values for Stage 4. For example, Stage 4’s location may allow for more frequent resupply deliveries, more caches, and more available blood donors. Stage 4 will also utilize more supplies and blood given the extent of the treatment received at this stage. All these variables can be adjusted by the user interface. Further explanation of Stage 4’s blood supply and medical supply can be found in the Appendix on page 187-192 and 192-194, respectively.

6. Casualty Statistics and Fighting Force Calculations

Military medicine uses casualty statistics to determine effectiveness of the medical system. There are four statistics used: Wounded in Action (WIA), KIA, DOW, and CFR.[221] These statistics are discussed in more det ail in the literature review of Chapter I.

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[220] Shackelford et al., “Case-Control Analysis of Prehospital Death and Prolonged Field Care Survival during Recent U.S. Military Combat Operations,” S190.

[221] Holcomb et al., “Understanding Combat Casualty Care Statistics,” 398.

CFR, although sometimes a more accurate statistic to determine if medical care can influence battlefield mortality, is not currently calculated in this model.[222] WIA is the total number of patients who were wounded, and in this model, does not include the number of fighters who instantaneously died. These are included in the KIA figures. KIA numbers reflect the number of patients who die prior to receiving medical care from reaching a "hospital," or in this model, Treatment Stage 3. DOW numbers reflect the number of patients who die after reaching Treatment Stage 3.

Casualty statistics are calculated so that they can be displayed in graphs when the model is run. "Total KIA" is the total number of patients who died before Stage 3. "Total KIA" receives input from two different portions of the model. The first input "Dying Instantly" represents patients who sustained such devastating wounds on the battlefield, they were dead on arrival to the medic. The two other inputs are the result of patients decompensating in Stage 1 or 2. "Died of Wounds" is calculated through input from both Stage 3 and 4 in which patients decompensated or died of infections. A more detailed explanation of the calculations can be found in the Appendix on page 195-197.

Another set of calculations the model provides as an output for the user is the "Fighting Force Numbers." These statistics include the available "Fighting Force," total patients "Recovered" from their injuries, and total patients "Furloughed" because of non-healed or long-term injury issues. While minimally injured patients may be able to be returned to duty prior to reaching Treatment Stage 4, the model was not designed to account for this possibility. This likely underestimates the number of "Recovered" patients and puts unnecessary strain on parts of the system, although these patients do not affect blood or supplies. A more detailed explanation of these calculations can be found in the Appendix, on page 198-200.

B. LIMITATIONS OF THE MODEL

Many of the limitations of the current model have been mentioned for each stage. The main limitations of the overall model will be noted here. First, this model only depicts

222 Holcomb et al., 398.

one battlefield unit (2 medics), one surgical team, and one hospital. These entities should be duplicated based on the number of combat units, surgical teams, and hospitals on the battlefield, but for simplicity, such scaling was not pursued.

The next limitation is that the evacuation platforms for Stage 1, 2, and 3 are the same platforms. The software would have required duplication of these sections, falsely increasing the number of evacuation platforms available and moving patients more frequently than would likely occur. This can be accounted for with lower probabilities being entered for the evacuation platforms.

Another limitation is that patients who receive care usually change from a higher severity level to a lower severity. This process over-complicated the model, and the rates at which this occurs are hard to decipher from the literature.

Finally, this model assumes a constant level of operations. Revolutionary fights or insurgencies go through phases in which operations ramp up and then slow down while the insurgent force is re-grouping or recovering.[223] The loss of a significant amount of people for fighting would likely halt operations until the force was ready to again conduct operations. This is not to say that there would not be periods of constant conflict, but it would not be standard for a pure unconventional, resistance type of conflict. In its current design, there are no delays or changes in operational tempo based on the fighting force size and/or wellness.

C. OVERVIEW OF THE MODEL RESULTS

This model was run using variable inputs based on my estimations and statistics from published medical literature and patient databases. The time frame simulated in the model is over the course of one month (750 hours). The model was run using the settings seen in the screenshots of the interface in Figures 24–30. Screenshots of the model's simulation results can be found in the Appendix on page 200-218. The main take-aways will be covered here.

[223] Johnson, *Revolutionary Change*, chap. 7.

Figure 31 is a graph of the "Fighting Force Numbers." When initializing the model with 120 fighters, the "Fighting Force" numbers decrease and eventually succumb to attrition prior to the month's end.

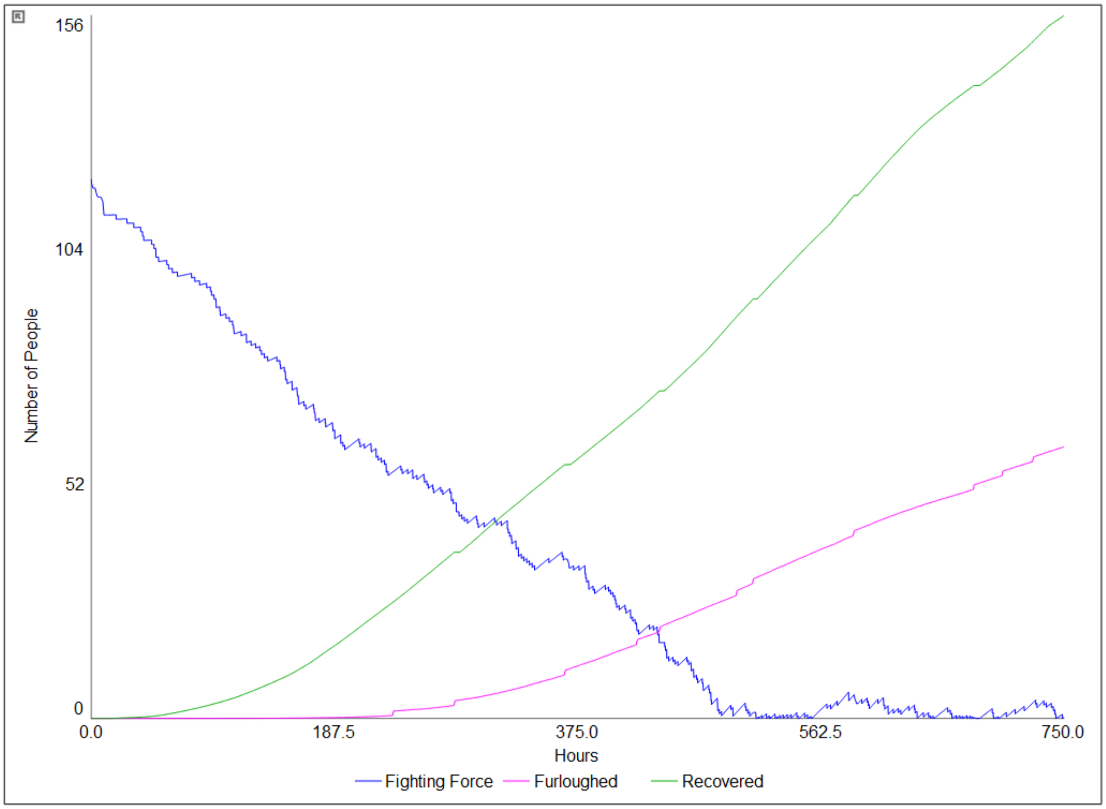

Figure 31. Graph of Fighting Force Results.[224]

Trends of the Casualty Statistics are shown in Figure. Most KIA patients are the result of dying instantaneously from untreatable wounds and the minority while waiting for evacuation at Stage 2. DOW numbers do not begin to rise significantly until later in the simulation run when Stage 3 treatment becomes overwhelmed and when Stage 4 patients begin dying of infection. One noteworthy limitation is that the simulation does not stop when the fighting force reaches attrition. Therefore, the WIA numbers rise above 120. In

224 Adapted from ISEE Systems, Stella Architect.

reality, WIA numbers will be higher than a fighting force as a result of collateral civilian deaths, even though this was not originally included in the systemic analysis.

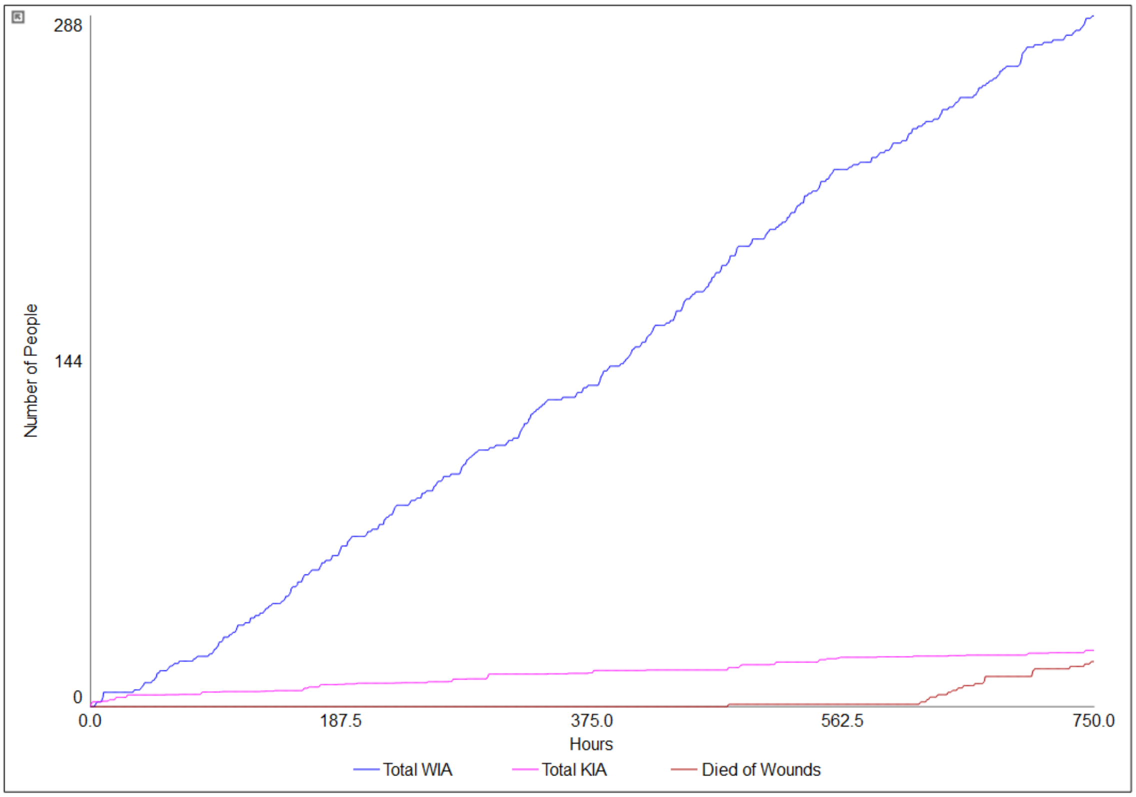

Figure 32. Graph of Casualty Statistics.[225]

Figure 33 is a graph of the deaths at each treatment stage. For this simulation, no preventable deaths occurred at Stage 1, but this does not include instantaneous deaths or untreatable injuries (included in "Instant KIA"). Stage 2's deaths rise relatively steadily due to the set mortality rate of those patients requiring PFC. Stage 3's deaths rise towards the end of the simulation when the team runs out of required tangible resources, and Stage 4's deaths rise due to infections. Further details of the results of each stage will be discussed further.

225 Adapted from ISEE Systems, Stella Architect.

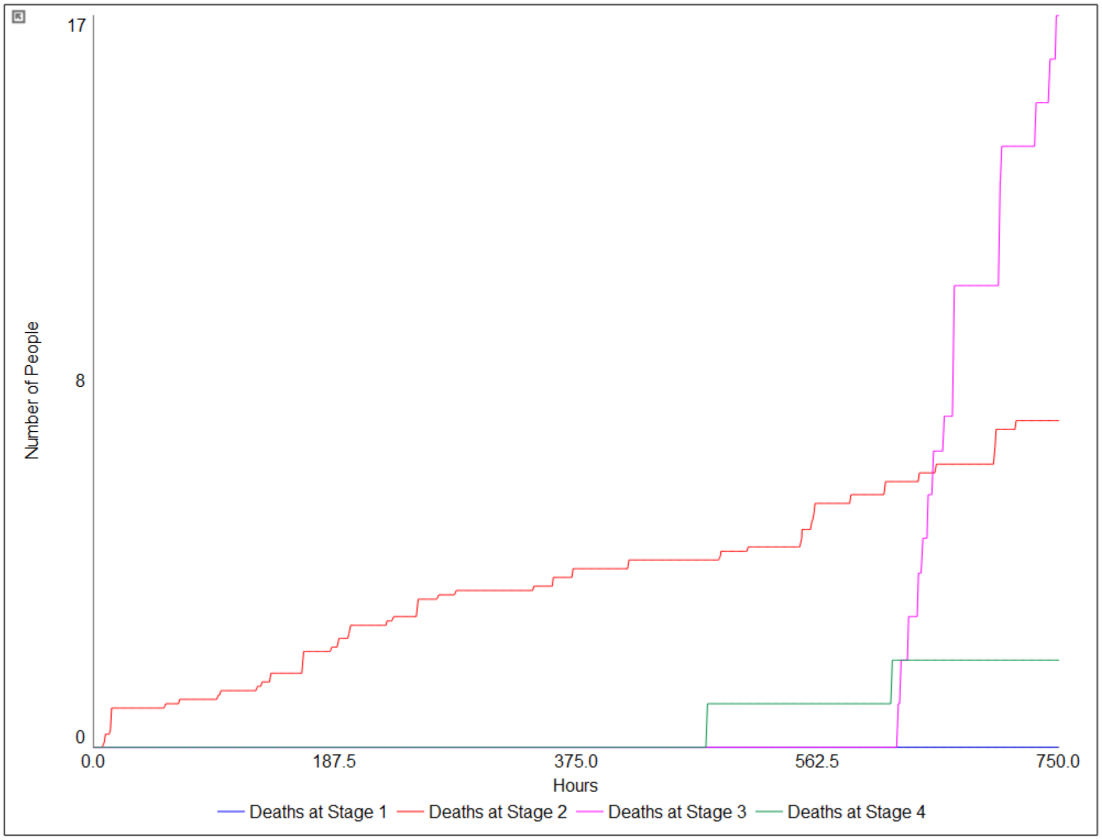

Figure 33. Graph of Deaths by Stage.[226]

Patients arrived at the Stage 1 casualty collection point at a rate that did not initially overwhelm the medics since 50% of the fighting force had been trained in TCCC. As time progressed, buddy care from a shrinking fighting force declined, an increased number of patients had to wait for care, and these patients' clinical conditions began to worsen. Figure 34 is a graph which includes the patients waiting for treatment by the medic, medical supplies, and deaths at Stage 1. The blue spike in the figure represents the increase in patients waiting for care and correlates with the time of attrition in Figure 31. This reinforces that having the fighting force trained in TCCC has a significant impact on the treatment of casualties and prevention of preventable death.

226 Adapted from ISEE Systems, Stella Architect.

The model assumed that medics could treat 20 patients with one unit of supplies, and they can carry 5 units with them. This is likely overexaggerated given the requirement for mobility at Stage 1. During this simulation's run, the medics (for both Stage 1 and 2) never ran out of supplies (orange line in Figure 34). At one point in the model, supplies did have to be moved from the supply caches. This demonstrates the importance of caches in this environment. The movement of supplies also corresponds with the increase in patients demanding treatment by medics and the lack of fighting force available to perform buddy care.

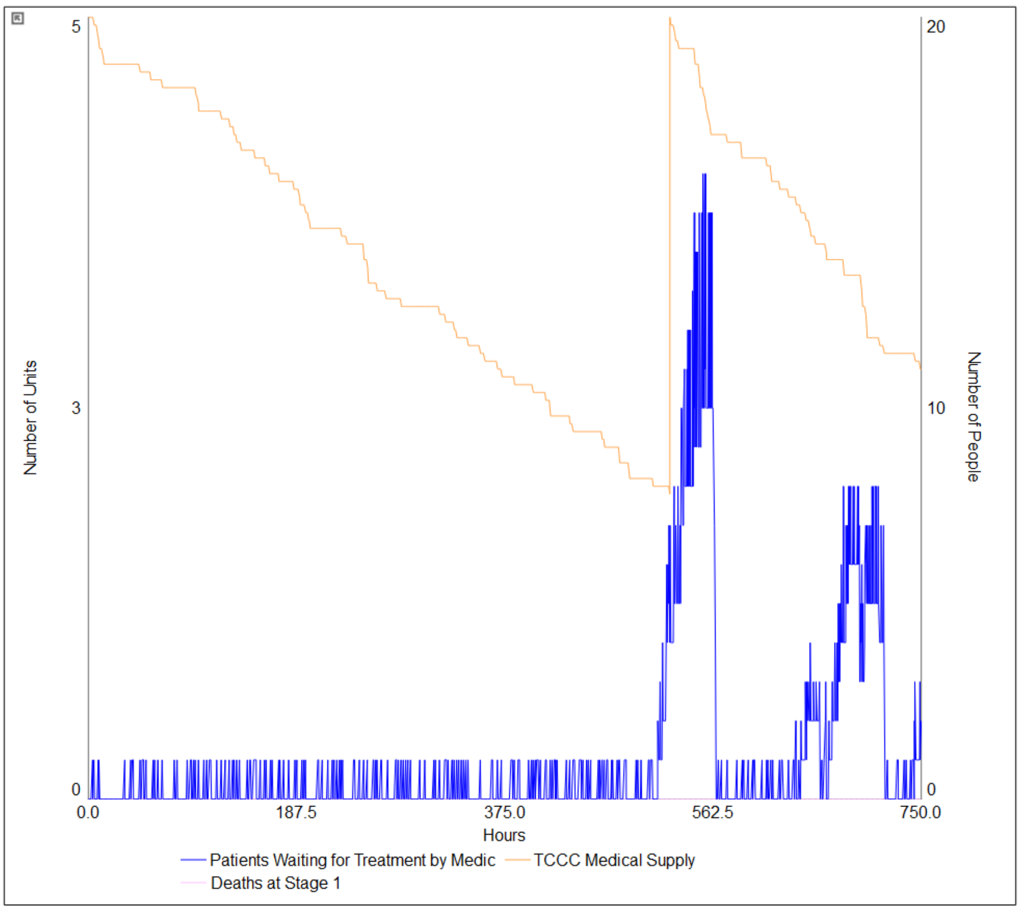

Figure 34. Graph of Stage 1 Limitations and Deaths.[227]

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227 Adapted from ISEE Systems, Stella Architect.

The availability of patient evacuation from Stage 1 to Stage 3 determines the need for PFC at Stage 2, and for this simulation the model was configured with the medics trained in PFC. The probability for rotary wing evacuation from Stage 1 was set to 0%, for CASEVAC to 30%, and for MEDEVAC to 2%.

The lack of adequate evacuation caused a build-up of patients that required PFC. Figure 35 is a graph of Stage 2 that includes the patients waiting on evacuation and requiring PFC, the patients who survived the first 4 hours of PFC, and deaths. The evacuation of patients from Stage 2 remains steady throughout the simulation, until a spike of patients who survived the first 4 hours of PFC occurs. This spike correlates with a slight increase in rise of deaths, suggesting evacuation did not occur fast enough. This may be due to the decrease in probability of CASEVAC from Stage 2 to Stage 4, which did not supply adequate evacuation to these patients. Most deaths at Stage 2 were accounted for by the set mortality rate of patients who received 4 hours of PFC.

Supplies were not included in Figure 35 as the model was not designed to affect treatment at Stage 2 based on supply inventory.

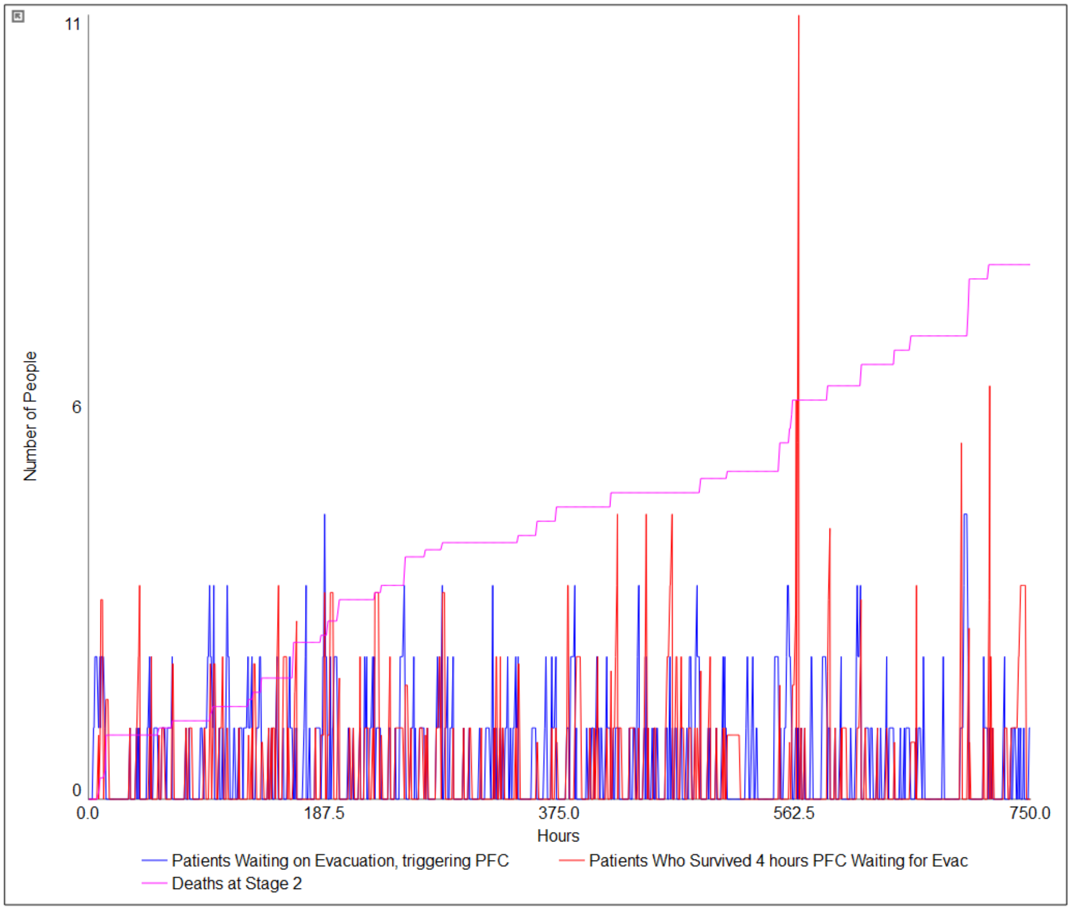

Figure 35. Graph of Stage 2 Limitations and Deaths.[228]

Patients arrived at Stage 3 at a rate that did not overwhelm the forward surgical team until the latter part of the month. Figure 36 is a graph of Stage 3 including patients waiting for surgery, patients waiting for resuscitation, medical supply, blood supply, and deaths. Late in the model, the number of patients waiting for resuscitation (red spikes) increases. This corresponds to the sharp decline of supply units (orange). When this occurs, the deaths at Stage 3 begin to rise (pink) because the team cannot perform any surgeries or resuscitations. The on-hand blood supply was also inadequate, requiring a walking blood bank to replenish supplies. This is represented by the multiple peaks/troughs of blood units (green). At a few points in time, the blood supply was so low that a second unit had to be

[228] Adapted from: ISEE Systems, Stella Architect.

drawn from donors. For the few times the blood supply reached zero and patients requiring treatment increased (green lows overlapping with red spikes in Figure 36), the walking blood bank was adequate and resumed treatment quickly. Ultimately, the walking blood bank was sufficient to treat patients. The medical supply, on the other hand, could not keep up with the demand even with multiple trips to caches, leading to a sustained inability to treat patients.

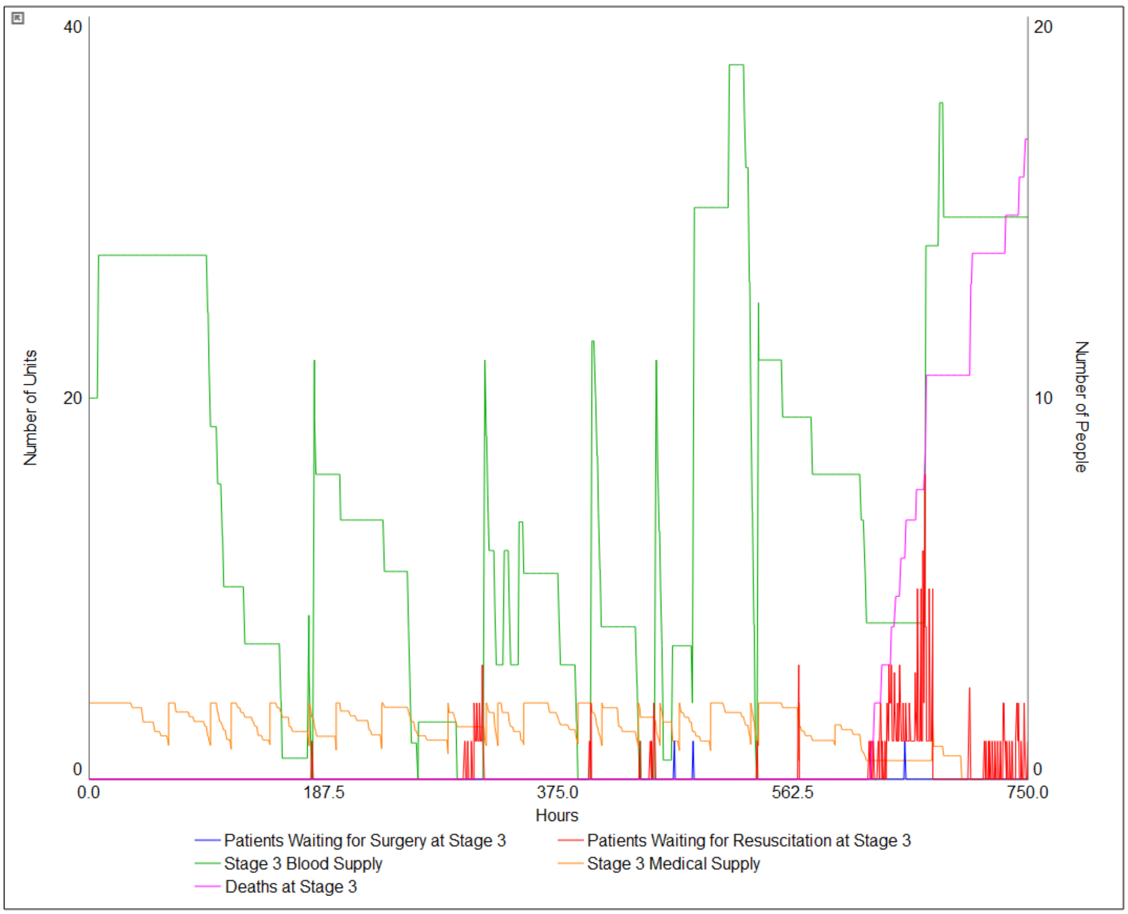

Figure 36. Graph of Stage 3 Limitations and Deaths.[229]

The increase in the probability of CASEVAC to 50% and of MEDEVAC to 15% was not sufficient to prevent worsening patient conditions. Patients were waiting for

[229] Adapted from ISEE Systems, Stella Architect.

evacuation from Stage 3 too long and began to decompensate, requiring further treatment from the team. The buildup of patients waiting for evacuation will have a negative impact on the mobility of the team and potentially compromise their position in a denied environment. This build-up in patients may be erroneous, however, since in reality there would likely be more than one Stage 3 team.

Patients arrived at Stage 4 at a rate that did not overwhelm the hospital until almost halfway into the simulated run. Figure 37 is a graph of Stage 4 including patients waiting for surgery, patients waiting for resuscitation, medical supply, blood supply, and deaths. It appears at times patients were awaiting treatment (red and blue spikes), the hospital had depleted their blood supply (green troughs), halting surgeries and treatment of patients in the trauma bay until blood could be collected by walking blood banks. At a few points in time, the blood supply was so low that a second unit had to be drawn from donors. The walking blood banks were able to re-establish patient treatment, preventing prolonged periods where patients were awaiting treatment. The medical supply was also sufficient to treat patients, only requiring a couple withdrawals from caches (orange) and did not halt Stage 4 treatment. The majority of Stage 4 DOW occurred over halfway into the simulation when deaths from infections rose.

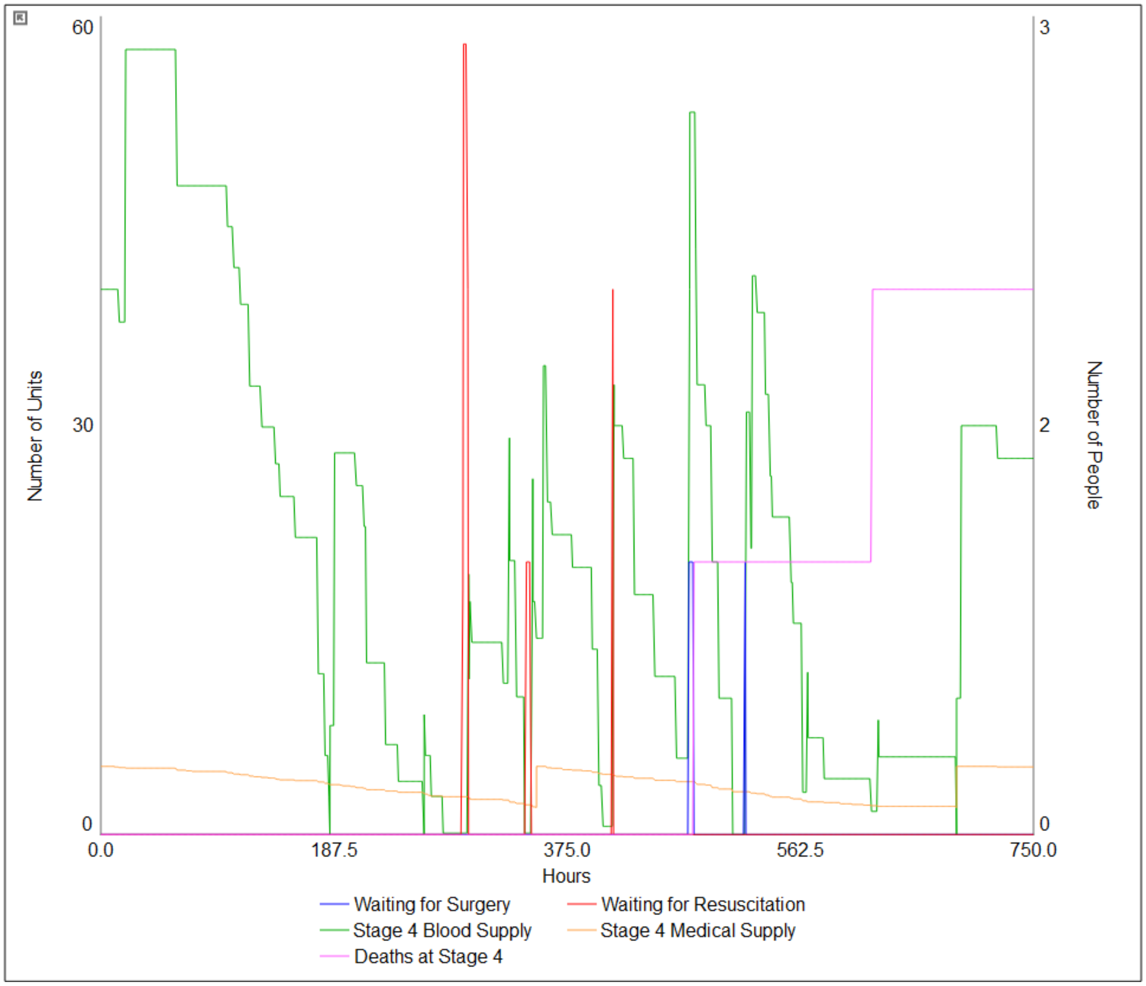

Figure 37. Graph of Stage 4 Limitations and Deaths.[230]

As mentioned previously, the Stage 4 model provides output based upon the maximum number of beds required at any given time. This can provide planners the scale required at Stage 4 to achieve an acceptable survival rate. Figure 33 shows the results from this simulation that dictate a total of 35 beds (12 ICU and 23 inpatient beds) with corresponding medical personnel needed. Another 45 spots (10 outpatient recovery and 35 rehabilitation) need to be acquired from the local area for patients with more minor injuries to recover before returning to the fight.

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230 Adapted from ISEE Systems, Stella Architect.

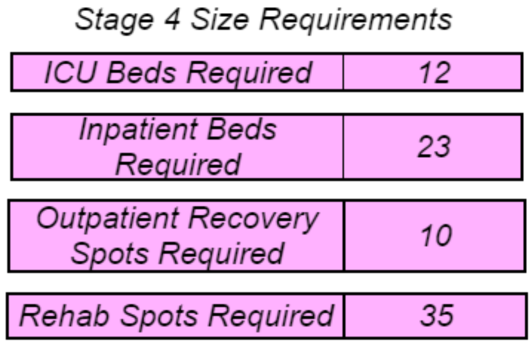

Figure 38. Outputs from Model Dictating Stage 4 Capacity Requirements.[231]

D. CONCLUSION

Based on the earlier systemic analysis, a system dynamic model was created to simulate an endogenous medical system based on the proposed Casualty Treatment Stages. While this research is focused on GW/UW conflicts, any future conflicts utilizing these treatment stages could be similarly modeled. The GW/UW Medical System Dynamics Model includes an interface that allows the end-user to modify several variables and to observe the impact this would have on patient flow and mortality. Several limitations, however, affect its functionality, and future versions should allow the user to modify the number of fighting units, Stage 3 teams, and Stage 4 hospitals available.

Although limited in function in its current state, the model reflects the cause-and-effect relationships depicted in the causal loop diagram. Patients were noted to have a delay in care and subsequent worsening in conditions primarily when awaiting evacuation. Evacuation, therefore, plays a large role in optimizing care and will rely on the ability to provide PFC at GW/UW Casualty Treatment Stage 2 to extend the "golden hour." Blood supply and medical supplies are also limiting factors in the ability of teams to treat patients and eventually caused attrition of the friendly force. Medical planners in the future will need to ensure that an auxiliary system supports the movement of blood, supplies, and most importantly, patients through the medical network in order to have the greatest mitigating impact on casualty statistics.

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[231] Adapted from ISEE Systems, Stella Architect.

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VI. DETERMINING THE HIGHEST ACHIEVABLE LEVEL OF CARE FOR A GIVEN CONFLICT

The research conducted has identified limitations that affect the development of a medical system in a denied environment. Up to this point, however, it has not provided planners a tool to determine to what treatment stage a medical system can realistically be developed for a given conflict. This chapter synthesizes the analyses conducted and develops such a decision tool. It is important to note that this tool identifies the *best possible* level of care that can be achieved for a given scenario based on two variables that cannot easily be modified: the existing capability of the indigenous forces, and whether there is a "safe zone" in the operating environment. Finally, I discuss the risk-to-force implications for medical systems that can only achieve treatment levels below Stage 4, which can aid mission commander risk assessments.

A. ESTABLISHMENT OF EXPECTED TIME HORIZONS

The treatment stages proposed in Chapter II can be classified based on medical skill level (Table 2). Even for medics, medical training is a time-intensive process, and the ability to train personnel was a tangible limitation identified in Chapter III's causal loop diagrams. Although the phases of UW accounts for training of partner forces, depending on the baseline medical capabilities of an indigenous population, the time requirement for training medical personnel can vary significantly.[232]

Figure 39 is a graphic representation of the estimated time requirements for establishing each treatment stage, primarily determined by the training of personnel. For each stage, there are two different time horizons, depending on the baseline medical capabilities of the indigenous guerrilla force. Green time ranges are for a force with a baseline medical capability, and orange time ranges are for forces with no established medical support. It is important to note that the "baseline medical capability" is relative to

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[232] Department of the Army, Unconventional Warfare Mission Planning Guide for the Special Forces Operational Detachment--Charlie Level, TC 18–01.3 (Fort Bragg, NC: Department of the Army, 2016), fig. 1.9-1.10.

the treatment stage's skill requirement (Table 2). For example, the green bar for Stage 1 is the time requirement for a force that has trained medics, but the green bar for Stage 3 assumes a force with trained physicians, specifically surgeons. The ranges for both categories are subject to cultural and language barriers, which may cause delays in normal training times. These time horizons were estimated based on my professional experience, knowledge of traditional training timelines, and involvement with medical education.

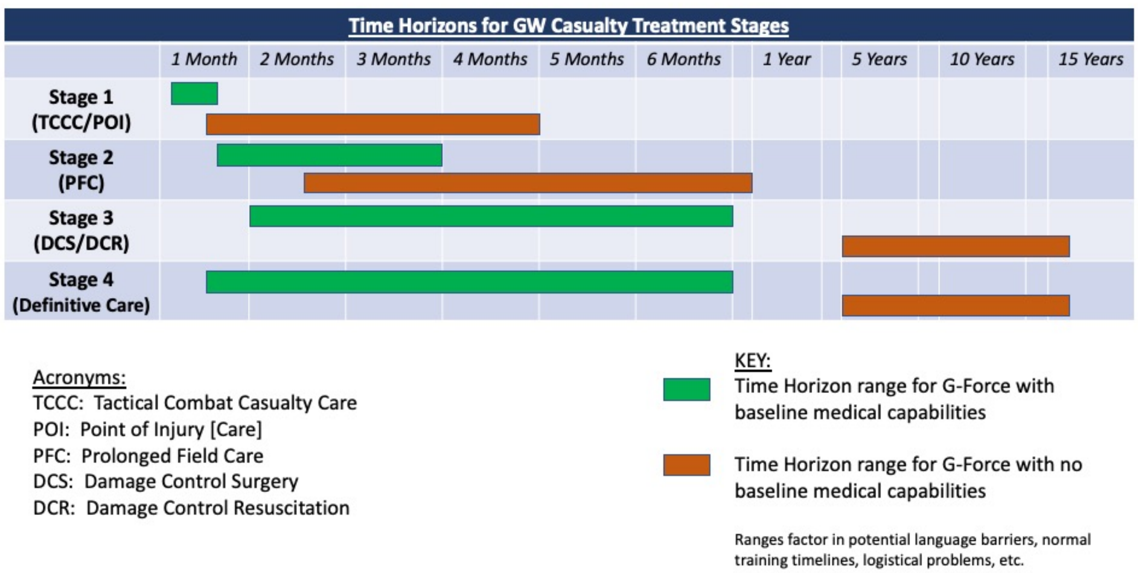

Figure 39. Time Horizons for the Establishment of Each GW/UW Casualty Treatment Stage

Training for Stage 1 personnel who already have basic medic training will be minimal and limited to specific TCCC training. While the length of TCCC courses for medics varies, training should be completed within two weeks. For a force without any trained medics, the time required to establish Stage 1 can vary between two weeks and 4 months. If time is limited, a "hybrid" Stage 1 can be created with the use of U.S. and coalition medics to treat more serious casualties and indigenous forces trained in basic TCCC for less critical patients. Training of unit members in basic TCCC skills could be accomplished in a couple weeks. However, if the desire is to train some indigenous forces to be medics, then several months of training would be required.

Stage 2 requires more in-depth training in resuscitative care for medics. Trained medics may be able to complete this training in as little as two weeks if they have a solid medical knowledge foundation. Training could take as long as three months for medics without an understanding of human physiology vital to resuscitating critically injured patients. For untrained personnel, training would require almost two months at a minimum but could take as long as a year.

Stage 3 and 4 both require a skill level of a trained physician, specifically a surgeon. Operating in an austere, clandestine environment, however, requires unique tactical and medical decision-making skills not inherent in medical training. Austere medicine and clandestine skill training could take up to 6 months. Since Stage 3 is closer to the point of conflict than Stage 4, training for even established surgeons used for Stage 3 care will take longer than training for Stage 4. For a population without any trained physicians, training would require five to fifteen years to reach full operational capability and would not be realistic for most conflicts.

B. AN ALGORITHM TO ESTABLISH TREATMENT GOALS

It is unrealistic to assume that every GW/UW scenario will be able to have a medical system with all four casualty treatment stages available. Dynamic, hostile environments, short-notice onsets, and political factors hamstring establishing such a complex system. Trying to establish an unrealistic level of care will waste time and resources that cannot be afforded, and therefore, realistic expectations need to be established for what the best possible level of care is for any given conflict.

Figure 40 provides a suggested algorithm for planners to establish the highest achievable treatment stage. The questions used to determine this maximum level of care are based on existing trained medical personnel, the presence of a “safe zone,” and whether there is time to train personnel. The basic definitions of each Treatment Stage are based on skill level and the type of care provided, with Stage 4 requiring a large enough holding capacity (and, therefore, “safe zone”) for convalescent care. If surgeons are not available and there is insufficient time to train them, then a medical system, by definition, cannot achieve higher than Stage 2 care. If surgeons are available, but there is no “safe zone” to allow for treating patients for extended periods, then surgical teams will need to focus on damage control treatment only, limiting treatment to Stage 3.

There are a couple of special circumstances provided in the algorithm that should be addressed. As Chapter II mentions, subcategories only complicate doctrine, and “Stage 3*” and “Stage 1*” are not meant to be considered sub-categories. Instead, they are meant to acknowledge that some goals of a treatment stage may be achieved through creative or “last ditch effort” methods. For example, if surgeons are not available, other physicians or medical providers may be able to perform DCR. This will not achieve the DCS required for Stage 3, leading to a higher mortality rate compared to a fully capable Stage 3. Stage 3* demonstrates ways to utilize medical personnel, which may provide some limited benefit to treatment of casualties. Stage 1* assumes there is only time to train an indigenous force on basic TCCC skills and will not have any indigenous medics, limiting the ability to address immediate life-threats in critical patients.

For any stage below Stage 4, the algorithm notes that some patients will require treatment “outside of the system.” Stages 1–3 are meant to address immediate life-threatening injuries but do not provide definitive care. Further care from specialized providers will have to be sought either outside the theater or through local hospital systems. Evacuating outside the theater is not realistic in a denied environment, but treatment through local hospital systems not considered part of the GW medical system would likely lead to compromise and/or capture of that patient.

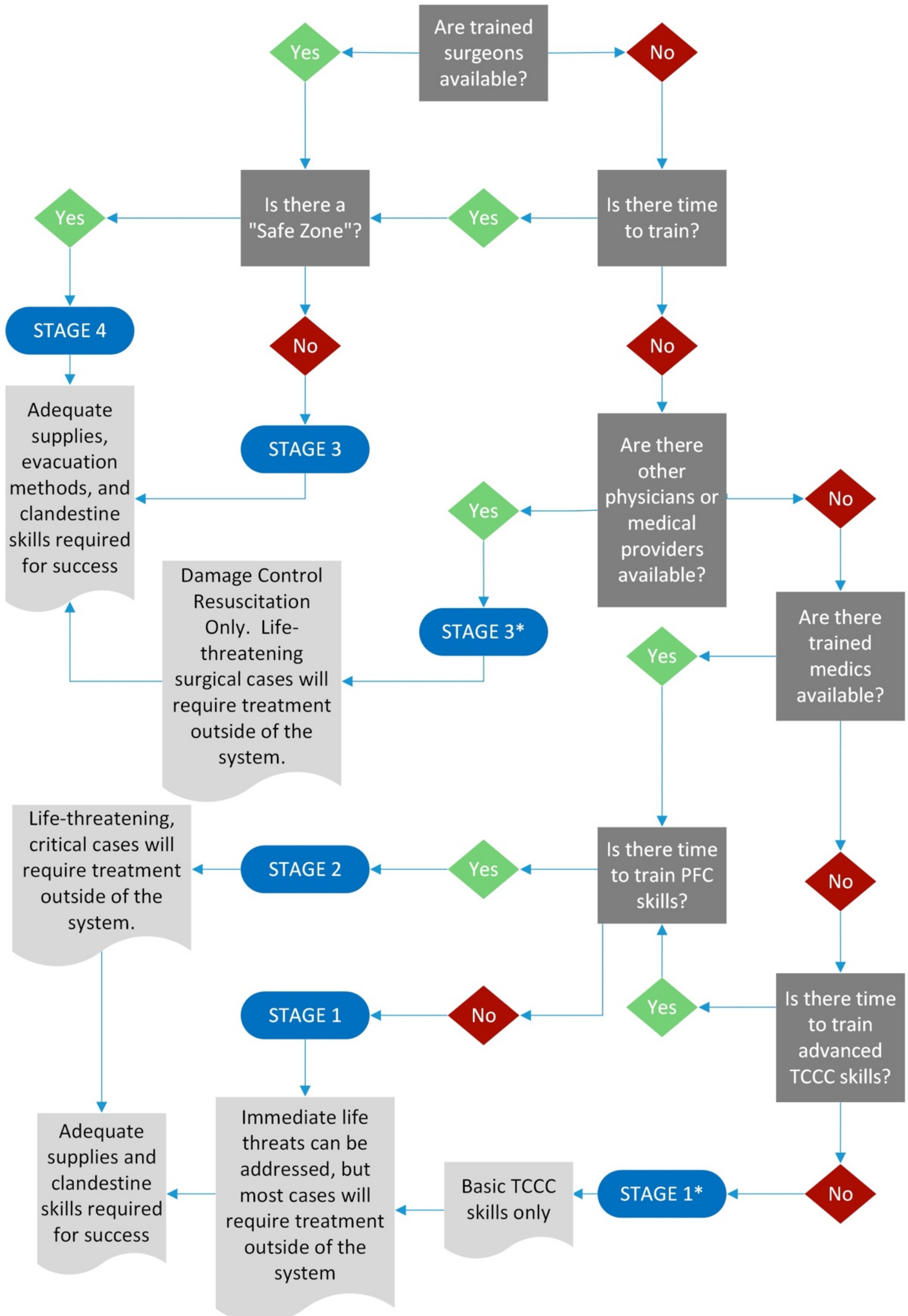

Figure 40. Algorithm to Establish the Highest Achievable Treatment Stage

The trade-off for not achieving treatment goals that provide life-saving care is increased mortality. The developed model from Chapter V was used to calculate the CFR for medical systems with different maximum levels of care. The CFR is calculated by dividing the Total KIA and DOW by the Total WIA and Instant KIA.

A limitation of the current model is that it does not account for improvement of patient conditions at each stage after treatment, e.g., recovery of Minimal or Urgent patients in Stages 1–3, or when no further care is required after simple Stage 3 interventions (such as a noncomplex amputation). In the model, although immediate life-threats are accounted for by Stages 1–3, patients are still forced through the whole system to receive definitive care, regardless of necessity. As a result, the model is not optimal for casualty statistic calculations, and the results presented here are meant for a relative comparison rather than their absolute values.

For a medical system achieving Casualty Treatment Stage 4 (i.e., completing definitive surgical treatment, post-surgical critical care, and recovery) the model calculated a CFR of 12.04%. This is comparable to the overall CFR of WWII and Vietnam.[233] In addition, attrition did not occur until late in the model (approximately 29 days). When the model inputs were adjusted to simulate a medical system up to Stage 3 (i.e., ending prior to definitive surgical treatment), the CFR rises to 41.20% with attrition occurring at 308.42 hours (13 days).

Regardless of the model's limitations, the significant rise in CFR in medical systems not achieving higher treatment levels underscores the need for advanced surgical care, even if this is achieved through local sources. Without advanced surgical care addressing immediate life-threatening NCTH and/or providing definitive surgery, the CFR rises to unsustainable levels.

Finally, the algorithm notes that regardless of what the maximum achievable level of care is, the ability to achieve that level is impacted by the other limitations addressed in this study. The algorithm is merely intended to help planners avoid time spent trying to

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[233] Holcomb et al., "Understanding Combat Casualty Care Statistics," Table 3.

reach a system with Stage 4 care if there is no way to achieve that goal. Further, it does not imply that the presence of trained medical personnel and a “safe zone” are alone necessary and sufficient for success.

C. CONCLUSION

Planners who are trying to develop a medical system for a GW/UW conflict must have realistic expectations regarding the level of care possible for that system. Time, energy, and resources can easily be wasted in trying to achieve an unattainable goal. Therefore, planners must assess the medical assets available to them, both coalition and partner forces. The lack of required skills and time to train those skills will ultimately dictate the best possible level of an indigenous medical system able to be reached. The decision tool proposed helps guide these decisions to avoid wasting precious resources on unrealistic goals.

It is expected that the denied environment will increase the likelihood of death and battlefield mortality, but failure to create a complete medical system comes at a cost. For each treatment stage not achieved, the CFR for a medical system increases, with significant increases if surgical care (Stages 3–4) is absent. In order to lower CFR, planners should consider other potential treatment alternatives for critically injured individuals, such as host nation medical facilities. In occupied territory, however, this might come at an unfeasible cost and require increased reliance on personnel recovery systems.

Regardless of the determined best possible level of care, this does not guarantee success in achieving that level. The other limitations discussed in this research, such as medical supplies, blood, and evacuation, still hinder the ability to treat patients, independent of the medical skills of personnel.

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VII. FUTURE RESEARCH AND POLICY RECOMMENDATIONS FOR OPTIMIZING UW MEDICAL SYSTEMS

There is a significant gap in research for guerrilla or unconventional medicine, and it has only begun to be addressed. Most of the literature and research that address the subject is based on historical recounts and the call for military medicine personnel to prepare for providing medical care in such environments. After the awakening monograph from Dr. Farr in 2017, there seemed to be a renewed interest in this subject but a lack of any foundational concepts to help guide the process.

This research study is merely a step towards closing that gap. My original ambition was to provide detailed instruction and guidance that operational teams could easily apply. Such a goal was futile without developing the basic concepts of how we should reframe our levels of care. In the process of this research, more questions and hurdles arose, creating the requirement for future research and policy adjustments.

A. FUTURE RESEARCH RECOMMENDATIONS

Several areas of future research are required for planners to be able to apply the foundational concepts of Casualty Treatment Stages in creating their GW/UW medical system. First, the system dynamics model needs to be enhanced to allow for scalability and to better simulate the operational tempo or pattern of an insurgency. An enhanced model could not only demonstrate the relative changes in mortality depending on the levels of care but could help planners determine the number of trained assets needed or decide when "regrouping" of the force needs to occur.

The medical community can also help research the best ways to train partner forces in battlefield care. There is research on the establishment of civilian trauma systems in developing countries, but little focused on providing medical training to personnel.[234]

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[234] Atkin et al., "The Evolution of an Integrated State Trauma System in Victoria, Australia," 1277–87; Latifi et al., "Trauma System Evaluation in Developing Countries," 1–8; Callese et al., "Trauma System Development in Low- and Middle-Income Countries," 300–307; Air Force Research Laboratory, "The Defense Institute for Medical Operations (DIMO)."

DIMO provides short trauma and disaster courses to foreign nations, but there is little published regarding the efficacy or validation of these courses. There is also little published on the use of the formalized TCCC courses for foreign national medics or basic operators. Such studies could help further refine the amount of time needed to train personnel, set realistic time constraints on planners, and provide sample curricula.

Although research into nuanced medical treatment procedures is useful to the development of medical practice, it will be of limited use in setting up a medical system tailored for a denied environment. Case reports or articles addressing treatment in resource-constrained environments, however, can help identify items that can be used for purposes other than their original intent. For example, for certain cases in the Middle East, an explosive ordinance device x-ray was used on patients to assist with medical decision making.[235] Although the use of such equipment on humans is not ideal, in resource constrained environments such as that of UW, this type of information will help planners better consolidate logistical requirements.

B. POLICY RECOMMENDATIONS

1. Improve Medical Interoperability

Unconventional warfare is conducted "through or with [indigenous forces]."[236] This demands interoperability between nations' military and civilian medical systems. Joint Publication 3-0 provides the operations definition of interoperability as the "…ability to act together coherently, effectively, and efficiently to achieve tactical, operational, and strategic objectives."[237] Even though building relationships and interoperability with partner forces is primarily focused on operations, intelligence, and logistical support, the

[235] Caitlin M Howard et al., "Making Use of Your Assets: Clinical Use of EOD Radiography in the Forward-Deployed Setting," *Journal of Special Operations Medicine* 21, no. 1 (Spring 2021): 87–89.

[236] Farr, The Death of the Golden Hour and the Return of the Future Guerrilla Hospital, 7.

[237] Joint Chiefs of Staff, *Joint Operations*, GL-10.

definition of interoperability is just as applicable to medical care.[238] To start emphasizing the importance of preparing an indigenous force medical system, the concepts developed in this research should be overlayed with the phases of UW so it does not become an after-thought.

Dr. James Derleth points out that key tactical interoperability challenges include strategic incongruencies, such as doctrinal differences.[239] This supports the idea that doctrine and interoperability are interwoven, explaining why NATO member states have medical doctrine closely aligned to NATO's. Because interoperability is dependent on doctrinal foundations, the first step to establishing medical interoperability for an unconventional conflict is agreeing upon applicable doctrinal definitions of medical care.

Another limitation for multinational civil-military medical interoperability is the variation amongst international medical standards, especially their legal restrictions, training standards, and medical practice guidelines. The development of TCCC is a poignant example of a U.S. military medical standard incongruent with typical civilian medical training for medical technicians. The skills taught to medics in TCCC include procedures such as cricothyrotomies (surgical airway access), which were controversial even within the military medical community until research supporting the improvement of mortality emerged.[240] The U.S. is not naïve to civilian and military medical training inconsistencies, but national governing authorities have reached a consensus to allow for the training, exercise, and execution of these advanced skills in preparation for future

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238 Duke, Phillips, and Conover, "Challenges in Coalition Unconventional Warfare," 133–34; Department of the Army, *Special Forces Unconventional Warfare*, 1.3-1.4; Grdovic, *A Leader's Handbook to Unconventional Warfare*, 10–12.

239 James Derleth, "Enhancing Interoperability: The Foundation for Effective NATO Operations," *NATO Review*, June 16, 2015, https://www.nato.int/docu/review/articles/2015/06/16/enhancing-interoperability-the-foundation-for-effective-nato-operations/index.html.

240 Robert Mabry et al., "Emergency Cricothyroidotomy in Tactical Combat Casualty Care," *Journal of Special Operations Medicine* 15, no. 3 (2015): 11–19.

crises. In fact, civilian medical systems have now adopted these skills for civilian tactical law enforcement teams.[241]

Medical interoperability becomes complicated with varying clinical protocols and legal restrictions between multiple nations. Well-documented medical practices that reduce preventable battlefield death, such as TCCC, should be considered for standardization across allies and partner nations to set a ubiquitous minimal medical standard that decreases mortality. This will require a collaborative effort across nations' health and defense departments to identify variations of practice, training standards, potential barriers to standardization among nation states.

2. Use of Comprehensive Defense Strategies

In December 2020, NATO Special Operations Headquarters (NSHQ) published Version 1 of the *Comprehensive Defence Handbook* to guide nations in establishing a whole-of-society approach to defense against potential security threats.[242] The concept uses SOF forces to train, educate, and advise the population making up a nation's comprehensive defense. This creates a body of volunteers trained to identify and respond to potential threats, multiplying the defense capabilities of a nation.

Both NATO and non-NATO nation states have recognized the value of having a comprehensive defense strategy and have started efforts to build such capabilities. Humanitarian efforts or crisis response has been identified as one of the potential benefits in mobilizing a larger force than just government officials. For example, having medical personnel trained and tasked for disaster response can allow medical assets to flex to disaster areas rather than rely on evacuation from a disaster area to established medical

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241 Kevin Gerold, Capt Mark Gibbons, and Sean Mckay, "The Relevance of Tactical Combat Casualty Care (TCCC) Guidelines to Civilian Law Enforcement Operations," *The Tactical Edge*, Fall 2009, 52–60.

242 Eric P. Wendt, "NSHQ Comprehensive Defence" (lecture, Naval Postgraduate School, Monterey, CA, October 5, 2021); NATO Special Operations Headquarters, *Comprehensive Defence Handbook*, I-A (Belgium: NATO Special Operations Headquarters, 2020), https://www.nshq.nato.int/nshq/library/nshq-comprehensive-defence-handbook-volume-1/.

facilities. Coincidently, preparation for these disaster responses by medical teams are similar to the training and preparation required for austere casualty treatment.

Nations that have incorporated medical assets into such comprehensive defense plans can provide a trained pool of assets for teams establishing a GW/UW medical system. Incorporating medical support into crisis response will reduce the amount of training required at the onset of a conflict or crisis. If a nation has not incorporated medical support in its comprehensive defense or crisis response preparations, special operations medical personnel should encourage consideration of doing so.

3. Use of Special Operations Medical Teams

The SOCEUR UW exercise in 2018 demonstrated that a medical system using only U.S. special operations surgical teams is not sustainable for any extended period in a resistance movement.[243] That is not to say, however, that these teams cannot be used to fill gaps temporarily or for purposes other than providing medical treatment. To maximize their contributions, these teams require specialized training for UW.

SOCOM has a range of medical personnel supporting its operations. Most medics are trained SOCOM tacticians who undergo a prolonged course of instruction for medical training. They are permanent parties assigned to their tactical units and receive the same tactical skills training as other operators. Medical teams designed to provide surgical or resuscitative capability to SOF missions, however, can be SOCOM assets or conventional assets tasked to support SOCOM. Those that are SOCOM assets are more likely to receive specialized training for unique operating environments than are the conventional assets, creating asymmetries in training standards between these teams.

As mentioned by historical recounts and identified in this research, training specific to operating in the denied environment of UW is critical. SOCOM is behind some of our NATO partners in emphasizing this training.[244] For SOCOM medical teams, courses

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[243] Hickman, Baker, and Erickson, "Survivability: Medical Support to Resistance," 18.

[244] Nedas Jasinkas, Regan Lyon, and Jay Baker, "Unconventional Warfare Medicine Is the Ultimate Prolonged Field Care," U.S. *Army Medical Department Journal*, (forthcoming).

tailored to operating and providing medical care in such environments should be incorporated into their training standards. This more in-depth training in special warfare is what should define special operations medical teams/personnel. It is even more imperative for conventional assets tasked to support SOCOM UW conflicts to receive training in clandestine skills, even if through more condensed courses of instruction.

Special operations medical personnel who have received training for UW operations can assist the development of a GW/UW medical system in more ways than by providing medical treatment. Physicians or other medical providers do not have to oversee creating a GW/UW medical system. They should be consulted, though, for Stage 3 and Stage 4 development. Physicians trained in the unique aspects of austere medicine and UW can help to identify indigenous medical personnel with required skillsets or cache requirements that may not be appreciated by non-physicians. SOCOM should emphasize training in Phase 0 preparations for their dedicated medical teams.[245]

4. Development of Operational Medicine Leaders

The 2017 National Defense Authorization Act (NDAA) called for a separation and differentiation between operational and in-garrison healthcare.[246] Some services made this distinction long before the NDAA, but others believed the two worlds were interchangeable. Although valuable for any medical officer, operational medical leaders require a cross-cultural competency to facilitate working within both the medical and operational realms. The development of this cross-cultural competency is a career-long process, and medical officers interested in, and dedicated to, integrating medicine with operations should be retained within this area of expertise.

Hesitancy towards integrating medical officers with operational staffs exist, on both sides. Operational officers do not necessarily feel that a medical officer will offer much insight. Medical officers believe that existing medical leadership can provide appropriate

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[245] Department of the Army, Unconventional Warfare Mission Planning Guide for the Special Forces Operational Detachment--Charlie Level, 1.2.

[246] Office of the Secretary of Defense, *2018 Final Report to Congress--Plan to Implement FY17 NDAA, Section 702* (Washington, DC: Department of Defense, 2018).

and sound recommendations should they arise. This type of disconnect exists because of the lack of operational medicine expertise. There is a deficit of medical officers well-versed enough in operations to provide valuable insight and to validate their need. In the meantime, operations staffs will utilize any available medical officer, who may or may not have an operational background. Medical officers may be able to provide the information needed, but by having a better understanding of operations, medical officers will potentially be able to provide more creative or more tailored advice to help the operators accomplish their goals.

Cross-cultural competency should be developed at all leadership levels and throughout a career. As we develop operational medicine leaders, opportunities to work with multiple services, agencies, and career fields from different perspectives need to be exploited. Assignments to an operations staff, joint professional military education program, executive officer position, Assistant Secretary of Defense or Headquarters staff, or a joint staff should be incorporated into a medical officer's career trajectory. These career broadening opportunities are just as important as hospital or medical leadership positions and foster better understanding of working with multiple stakeholders. Career paths that foster cross-cultural competency will develop more versatile and impactful medical officers, and the integration of these operational medical experts with operations officers is the best way to optimize battlefield care and mission accomplishment.

C. CONCLUSION

The foundational doctrine on which the medical community bases casualty care has little relevance in non-permissive environments. This research proposed new doctrine based on medical treatment rather than asset capability. Next, through systems analysis, it identified tangible limitations that play a significant role in the ability to deliver care, with personnel training being a rate-limiting constraint. Applying social network analysis, it employed sociograms to map non-tangible constraints of an unconventional conflict that demand clandestine training and impact the mobility of medical assets. A system dynamics model provided the means to simulate an endogenous GW/UW Medical System as a decision support tool for planners and the means to better analyze a proposed medical system's impact on mortality in a denied combat environment. Finally, a decision support algorithm was created based on the analysis performed to manage expectations regarding the best possible Casualty Treatment Stage achievable for a given scenario.

The strategic problem, however, still exists: *The U.S. has no known GW/UW medical network framework to use for establishing a medical system in such environments.* Based on the foundational concepts proposed in this study, more research is required to determine how best to address this. Because of the significant time requirement for medical training, development of validated courses of instruction for partner forces of differing skill levels will refine expectations for medical system development. Better system dynamics modeling will increase the fidelity of the tool for planners and could be validated in exercises.

Regardless of the research findings, the execution of developing a GW/UW medical system requires policy adjustments. Most importantly, significant differences in medical standards, protocols, legal, and ethical guidance between nations hinders the ability to train indigenous personnel prior to the onset of conflict. This will also be the hardest obstacle to overcome. A solution may be to apply NATO's Comprehensive Defence strategy as justification for early training in non-standard medical practices. U.S. medical teams expected to support special operations need to receive training in UW and clandestine skills to improve survivability. Finally, the integration of medical officers competent in operations, mission analysis, and planning can optimize the use of medical assets to ensure battlefield deaths are minimized and strategic objectives are achieved.

APPENDIX: DETAILED DESCRIPTION OF THE GW/UW MEDICAL SYSTEM DYNAMICS MODEL

The screenshots and equation tables presented in this appendix are from the model designed using Stella Architect © Version 2.1.2 (ISEE Systems).[247]

A. MODEL SETTINGS AND COLOR DESIGNATIONS

The run specifications settings of the model are listed in Table 4. the simulated duration runs from 0 to 750 hours (1 month) and has an integration calculation delta time (DT) of 0.02 hours. The integration method must be set to "Cycle Time" for patients to retain their designated attributes. The attribute function of the software was utilized to assign patients an injury severity or triage categorization using an array. The "Severity" array (Table 5) has four categories and associated attribute designation (in parentheses): Surgical Critical (1), Critical (2), Urgent (3), and Minimal (4). Any parts of the model restricted or prioritized by attribute use this array with lower numbered attributes being higher priority. If the model was not using "Cycle Time" as its integration method, the patients would lose their associated attributes when going through ovens or conveyors, preventing prioritization of care based on a patient's severity.

[247] Adapted from ISEE Systems, Stella Architect.

Run Specs	
Start Time	0
Stop Time	750
DT	0.02
Fractional DT	No
Save Interval	0.02
Sim Duration	2 seconds
Time Units	Hours
Pause Interval	0
Integration Method	Cycle Time
Keep all variable results	No
Run By	Run
Calculate loop dominance information	No

Table 4. Run Specs for the Overall Model.[248]

Array Dimension	Indexed by	Elements
Severity	Label (4)	Surgical_Critical
		Critical
		Urgent
		Minimal

Severity Array that dictates patient attributes for the rest of the model. The top label denotes "Attribute 1" with subsequent labels Attributes 2–4 respectively. This becomes important when priorities are assigned and when flows are restricted by attributes.

Table 5. Severity Array Categories.[249]

The icons with a blue fill and blue border represent the normal flow of patients. For blood supply sectors and walking blood banks, icons denoting the flow of blood donors have a blue fill and maroon border. Sections with a grey fill and blue border depict the process of re-evaluating and reclassifying of patients if their clinical status is worsening. Medical supply sectors use a teal fill and border. Icons in red are for casualty statistical calculations only. Converters wth a pink fill are variables to be filled in by the user and are the data inputs seen in the user interfaces. Converters with no fill are used for computation and logic series.

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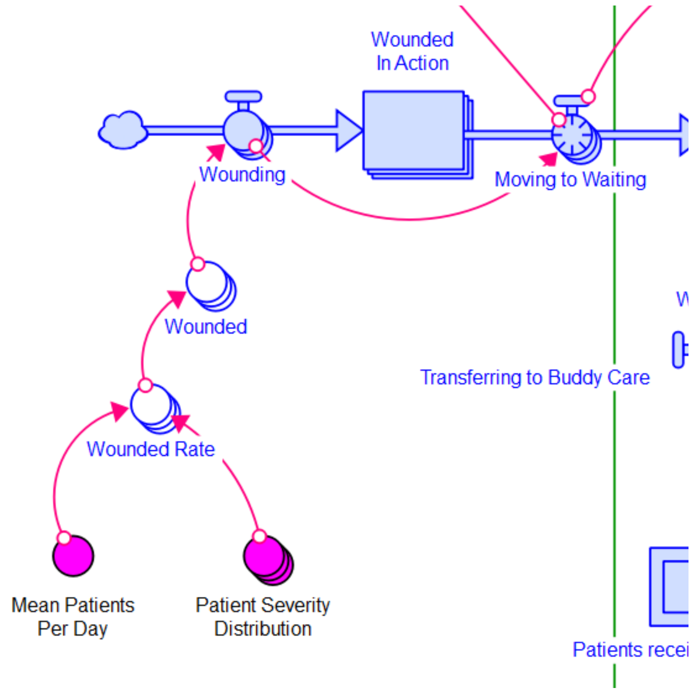
248 Adapted from ISEE Systems, Stella Architect.

249 Adapted from ISEE Systems, Stella Architect.

B. INITIALIZING THE SYSTEM—CASUALTY WOUNDING RATES AND TRIAGE PRIORITIES

The beginning of the system has a logic series which creates a random pulsed input of wounded patients for each time step (Figure 41). The two pink converters, "Mean Patients Per Day" and "Patient Severity Distribution" denote data that the user will enter in the interface. The data used is shown in Table 6. The Patient Severity Distribution values only add up 95% of those wounded, as 5% of total patients will be deceased or expectant and labeled "Killed in Action," which is tracked separately in the model. "Patient Severity Distribution" and "Mean Patients Per Day" are multiplied together in an arrayed (based on Severity) converter ("Wounded Rate") and divided by 24 to convert the number of patients per day to the number of patients per hour. The arrayed converter "Wounded" uses "Wounded Rate" in a POISSON distribution to vary the number of patients in a more realistic fashion. The "Wounded" converter is used in the "Wounding" arrayed (Severity) flow to PULSE casualties, simulating a group of patients being dropped off at a casualty collection point. The flow leads to an arrayed (Severity) non-negative stock, "Wounded In Action," which is initialized at 0. The outflow from this stock into the beginning of the medical care model time-stamps all the patients and assigns an Attribute Value based on the Severity element in the array they belong . The equations for these computations can be found in Table 7.



The initializing logic to create a varied number of patients with differing severities. Pink converters denote areas in that the end-user will enter numbers, either from historical data, from exercise data or from collected data on a current conflict.

Figure 41. Logic Series Establishing Patient Flow.[250]

[250] Adapted from ISEE Systems, Stella Architect.

	Equation	Units
Mean_Patients_Per_Day	10	People Per Day
Patient_Severity_Distribution[Surgical_Critical]	3.3	
Patient_Severity_Distribution[Critical]	9	
Patient_Severity_Distribution[Urgent]	28.7	
Patient_Severity_Distribution[Minimal]	54	

These numbers were calculated using collected data on partner nation casualties from a 2019 deployment to Syria.

Table 6. Data Input for Establishing Patient Flow.[251]

	Equation	Properties	Units	Annotation
Wounded[Severity]	POISSON(Wounded_Rate)		People	
Wounded_In_Action[Severity](t)	Wounded_In_Action[Severity](t - dt) + (Wounding[Severity] - Moving_to_Waiting[Severity]) * dt	INIT Wounded_In_Action[Severity] = 0	People	NON-NEGATIVE
Wounded_Rate[Severity]	((Patient_Severity_Distribution/100)*Mean_Patients_Per_Day)/24		People	
Wounding[Severity]	PULSE(Wounded)		People/Hours	UNIFLOW
Moving_to_Waiting[Severity]	Wounding	TIME STAMPED ATTRIBUTE VALUE = Severity INFLOW PRIORITY: 1	People/Hours	UNIFLOW

Table 7. Equations for Calculating Patient Flow.[252]

Figure 42 represents the calculation of patients who sustain non-survivable injuries that cause near-instantaneous death. As noted earlier, the "Patient Severity Distribution" values only add up to 95%; the remaining 5% of total patients was used as the initial value for "KIA percent." The "Mean Patients Per Day" is a ghost of the same converter used in calculating wounded patients. "KIA percent" is included in the severity distribution input on the interface. These converters are multiplied together in a non-arrayed converter ("KIA Rate") and divided by 24 to convert the number of patients per day to the number of patients per hour. The converter "KIAs" uses "KIA Rate" in a POISSON distribution to vary the

[251] Adapted from Special Operations Surgical Team, "BLACK Patient Tracker 2019"; ISEE Systems, Stella Architect.

[252] Adapted from ISEE Systems, Stella Architect.

number of patients in a more realistic fashion. The “KIAs” converter is used in the “Dying on Battlefield” flow to PULSE instantly dead casualties. The equations for this logic are listed in Table 8.

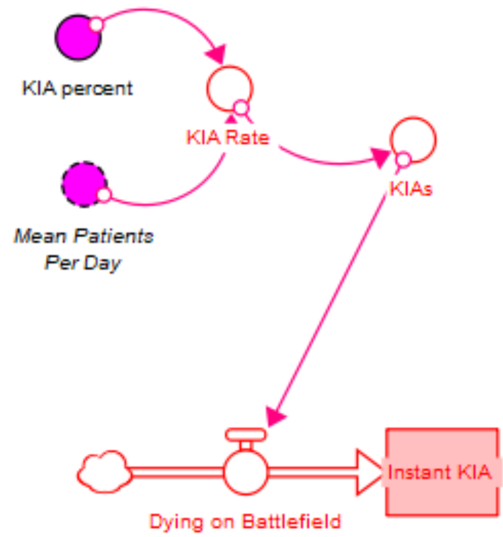


Figure 42. Logic Series for Instant KIAs.[253]

	Equation	Properties	Units	Annotation
Dying_on_Battlefield	PULSE(KIAs)		People/Hours	UNIFLOW
Instant_KIA(t)	Instant_KIA(t - dt) + (Dying_on_Battlefield) * dt	INIT Instant_KIA = 0	People	NON-NEGATIVE
KIA_percent	5		Per Day	
KIA_Rate	((KIA_percent/100)*Mean_Patients_Per_Day)/24		People Per Hour	
KIAs	POISSON(KIA_Rate)		People Per Hour	
Mean_Patients_Per_Day	10		People Per Day	

Table 8. Equations for Calculating Instant KIAs.[254]

[253] Adapted from ISEE Systems, Stella Architect.

[254] Adapted from ISEE Systems, Stella Architect.

C. GW/UW CASUALTY TREATMENT STAGE 1

The sector “Stage 1 (TCCC)” in Figure 43 represents the flow of patients in Stage 1 and will be described first. The equations for this section are depicted in Table 9. Patients arrive at a non-arrayed queue, “Waiting for Medic,” which is prioritized by attribute (Severity). Patients arriving with an attribute of 1 (Severity of “Surgical Critical”) are placed into the queue first. The initial value of the queue is 0 and the outflows use a round robin selection to move patients to the next open spot in the downstream ovens.

One downstream stock “Patient with Medics” is an arrayed (Medics = 2) oven with a CAPACITY of 1 because each medic can only treat one patient at a time. The oven’s initial value is 0 and the COOK TIME is based on the arrayed (Medics) converter “Medic Treatment Time.” “Medic Treatment Time” uses the ATTRMIN built-in to vary the COOK TIME based on patient severity (patients who are more critical will take a longer time to treat than those with less severe injuries). “Medic Treatment Time” uses the oven inflow “Transferring to Medic” in the ATTRMIN logic. For those patients with an attriute value “Surgical Critical” or “Critical” passing through “Transferring to Medic,” the value is set to 0.25 (15 minutes). For those with an attribute value “Urgent,” the value is set to 0.17 (10 minutes), and “Minimal” is 0.08 (5 minutes). The oven outflow “Moving to Evac Queue” again time-stamps the patients flowing because they have now received some, although not complete, treatment.

As noted in Table 9, the treatment of patients by the medics in “Patients with Medics” is limited by a stock “TCCC Medical Supply.” This stock belongs to the Sector “Supply Sector for Stage 1 and 2” and represents the amount of supply units the medics have on hand. The oven “Patients with Medics” uses an ARREST IF function. This function stops the oven if the value listed is anything other than 0. The equation used for this oven is TCCC_Medical_Supply < 1 THEN 1, ELSE 0, which means that if the medics have no supplies on hand, then a value of 1 is entered into ARREST IF. Because this value is not 0, the oven will arrest. The process for determining “TCCC Medical Supply” is discussed later in this section.

The second downstream stock from “Waiting for Medic” is “Patients receiving buddy care.” The equations for this portion of the sector are listed in Table 10. “Transferring to Buddy Care” is the queue outflow to this oven, which restricts flow by attributes 3 and 4 (Urgent and Minimal). Although some unit members may be comfortable with more serious patients, these patients will likely need treatment from the medics regardless. “Patients receiving buddy care” is a non-arrayed oven initialized at 0 and representing TCCC rendered by trained unit members. The CAPACITY is determined by the converter “Able Bodies for Buddy Care,” or the number of unit members who are trained in TCCC. The converter “% Unit trained in TCCC” is set by the user (currently 50%). The converter “Not Wounded Unit Members” subracts “Total WIA” from “Fighting Force” to return the number of bodies capable of rendering care. “Able Bodies for Buddy Care” multiplies “% Unit trained in TCCC” by “Not Wounded Unit Members.” This likely under-estimates the number of people able to render aid, but this can make up for the fact the model does not account for the number of people needed for defensive maneuvers. The COOK TIME is 0.17 (10 minutes) for all patients, assuming that unit members will not be as efficient as medics. The oven outflow “Moving to Evac from Buddy Care” timestamps the patients flowing because they have now received some, although not complete, treatment.

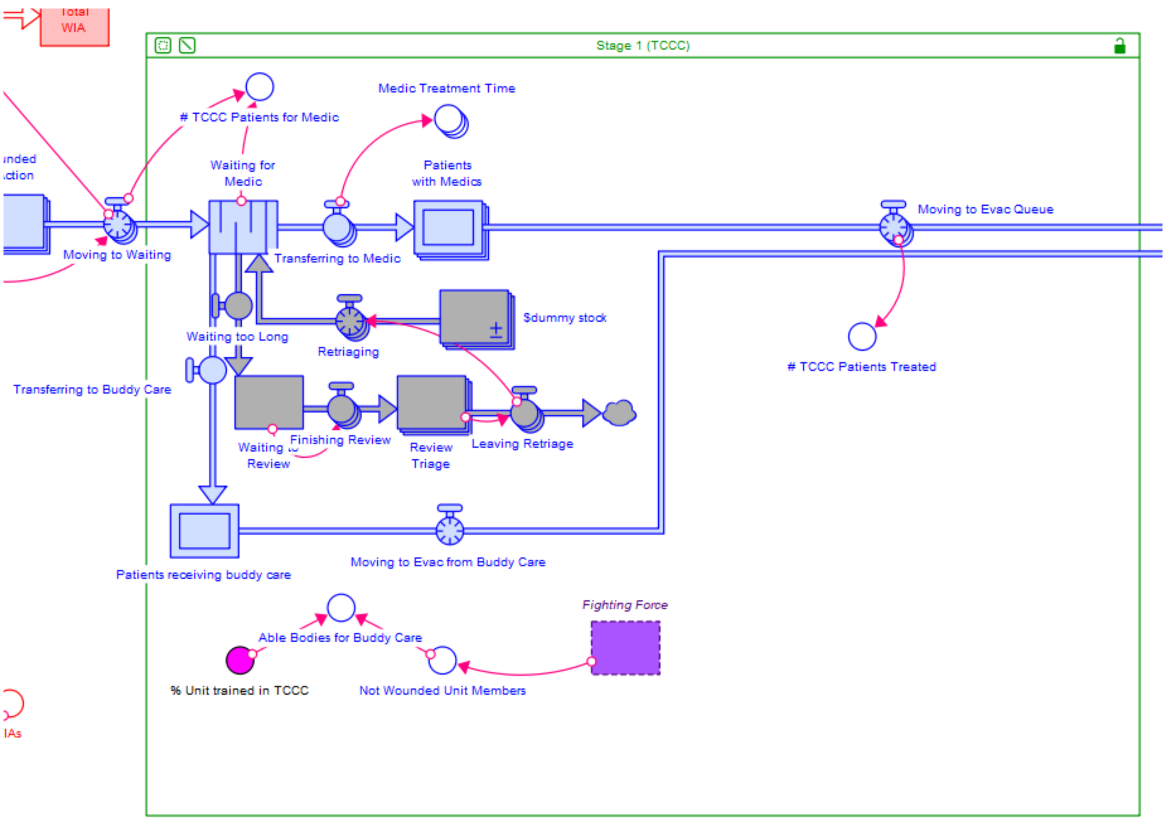


Figure 43. Casualty Treatment Stage 1, Patient Treatment Sector.[255]

255 Adapted from ISEE Systems, Stella Architect.

	Equation	Properties	Units	Annotation
"Stage_1_(TCCC)":				
"#_TCCC_Patients_for_Medic"	(Waiting_for_Medic-ATTRCOUNT(Waiting_for_Medic, Severity.Minimal))+(DT*(Moving_to_Waiting[Surgical_Critical]+Moving_to_Waiting[Critical]+Moving_to_Waiting[Urgent]))			
"#_TCCC_Patients_Treated"	DT*((ATTRCOUNT(Moving_to_Evac_Queue[1], Severity.Surgical_Critical, Severity.Urgent)+ATTRCOUNT(Moving_to_Evac_Queue[2], Severity.Surgical_Critical, Severity.Urgent)))			
Medic_Treatment_Time[Medics]	IF ATTRMIN(Transferring_to_Medic) = Severity.Surgical_Critical THEN 0.25 ELSE IF ATTRMIN(Transferring_to_Medic) = Severity.Critical THEN 0.25 ELSE IF ATTRMIN(Transferring_to_Medic) = Severity.Urgent THEN 0.17 ELSE 0.08			
Moving_to_Evac_Queue[Medics]	OVEN OUTFLOW	TIME STAMPED INFLOW PRIORITY: 1	People/Hours	
Patients_with_Medics[Medics](t)	Patients_with_Medics[Medics](t - dt) + (Transferring_to_Medic[Medics] - Moving_to_Evac_Queue[Medics]) * dt	INIT Patients_with_Medics[Medics] = 0 COOK TIME = Medic_Treatment_Time CAPACITY = 1 ARREST IF IF TCCC_Medical_Supply < 1 THEN 1 ELSE 0 <> 0 ACCEPT SINGLE BATCH SPLIT BATCHES	People	OVEN
Transferring_to_Medic[Medics]	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 1	People/Hours	
Waiting_for_Medic(t)	Waiting_for_Medic(t - dt) + (Moving_to_Waiting[Surgical_Critical] + Moving_to_Waiting[Critical] + Moving_to_Waiting[Urgent] + Moving_to_Waiting[Minimal] + Retriaging[Surgical_Critical] + Retriaging[Critical] + Retriaging[Urgent] + Retriaging[Minimal] - Transferring_to_Medic[1] - Transferring_to_Medic[2] - Transferring_to_Buddy_Care - Waiting_too_Long) * dt	INIT Waiting_for_Medic = 0 PRIORITIZE INFLOWS BASED ON ATTRIBUTE VALUES USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION	People	QUEUE

Table 9. Equations for Stage 1 Treatment by Medics.[256]

256 Adapted from ISEE Systems, Stella Architect.

	Equation	Properties	Units	Annotation
"Stage_1_(TCCC)":				
"%_Unit_trained_in_TCCC"	50			
Able_Bodies_for_Buddy_Care	INT(("%_Unit_trained_in_TCCC"/100)* Not_Wounded_Unit_Members)			
Moving_to_Evac_from_Buddy_Care	OVEN OUTFLOW	TIME STAMPED INFLOW PRIORITY: 7	People/Hours	
Not_Wounded_Unit_Members	Fighting_Force			
Patients_receiving_buddy_care(t)	Patients_receiving_buddy_care(t - dt) + (Transferring_to_Buddy_Care - Moving_to_Evac_from_Buddy_Care) * dt	INIT Patients_receiving_buddy_care = 0 COOK TIME = 0.17 CAPACITY = Able_Bodies_for_Buddy_Care FILL TIME = 0.1 ACCEPT SINGLE BATCH SPLIT BATCHES	People	OVEN
Transferring_to_Buddy_Care	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 RESTRICT BY ATTRIBUTE = 3,4 OUTFLOW PRIORITY: 3	People/Hours	

Table 10. Equations for Stage 1 Buddy Care.[257]

The model was designed to account for possible delays and limitations of flow of patients. When patients of increased severity do not receive expeditious care, their clinical condition quickly decompensates. Table 4 includes the equations for this series of logic. The queue "Waiting for Medics" has an outflow, "Waiting too Long," that uses the time-stamp given at "Moving to Waiting" to purge patients after 0.5 hours (30 minutes). This outflow is universal for all attributes, so even patients with a "Minimal" severity who have been waiting for 30 minutes will flow through this part of the system. The non-arrayed stock "Waiting to Review" is a placeholder for these purged patients. "Finishing Review" is an arrayed (Severity) flow that now sorts the patients by severity using the ATTRCOUNT function and value for "Waiting too Long." The patients, organized by severity, then enter the arrayed (Severity) stock "Review Triage." The arrayed (Severity) flow "Leaving Retriage" PULSEs the patients from "Review Triage," and the resulting flow rate is utilized to reclassify patients.

The most critical patients "Surgical Critical" and "Critical" who have been waiting too long for any treatment from the medics cannot be classified to a more severe category and will die from lack of treatment. This is accounted for by the non-arrayed flow, "Dying

[257] Adapted from ISEE Systems, Stella Architect.

at Stage 1," which is not included in the equations for Table 11, but is included later (Table 29). Patients labeled "Urgent" who have been waiting too long for treatment, however, will become more critical and require re-classification. This is done utilizing the arrayed (Severity) flow "Retriaging." The "$dummy stock" is used strictly to establish an array (Severity) of patients without previously assigned attributes and its initial value is 0.

"Retriaging" uses the values of "Leaving Retriage" to re-estabish patient attributes. The flow of patients from the Critical "$dummy stock" (ie. the patients who were previously Urgent, but now Critical) is equal to the flow of Urgent patients in "Leaving Retriage." The flow of patients from the Surgical Critical "$dummy stock" is 0 because patients are not reclassified into the Surgical Critical category. While some Urgent patients may need surgery, only a fraction would require more expeditious surgery and it would be difficult to accurately account for in this model. The flow of patients from the Urgent "$dummy stock" is 0 because the only less-severe category is Minimal, and these patients rarely decompensate to a higher priority. Finally, the flow of patients from the Minimal "$dummy stock" (ie. the patients who were previously Minimal and continue to be classified as such) is equal to the flow of Minimal patients in "Leaving Retriage." The flow "Retriaging" moves reclassified patients to "Waiting for Medic" and establishes a new time stamp.

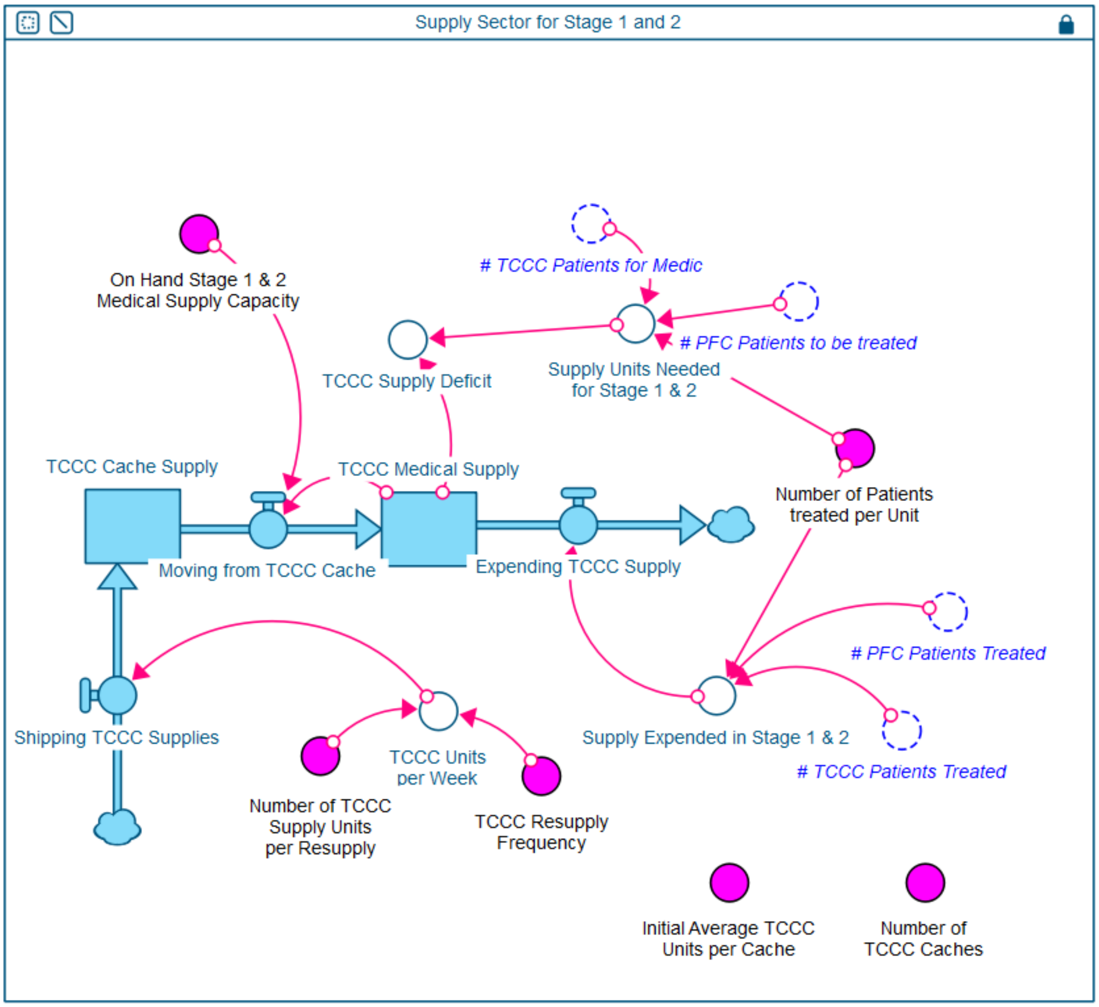
	Equation	Properties	Units	Annotation
"Stage_1_(TCCC)":				
$dummy_stock[Severity](t)	$dummy_stock[Severity](t - dt) + (- Retriaging[Severity]) * dt	INIT $dummy_stock[Severity] = 0	People	
Finishing_Review[Severity]	PULSE(ATTRCOUNT(Waiting_to_Review, Severity))		People/Hours	UNIFLOW
Leaving_Retriage[Severity]	PULSE(Review_Triage)		People/Hours	UNIFLOW
Retriaging[Severity]	IF Severity = Severity.Critical THEN Leaving_Retriage[Urgent] ELSE IF Severity = Severity.Surgical_Critical THEN 0 ELSE IF Severity = Severity.Urgent THEN 0 ELSE Leaving_Retriage	TIME STAMPED ATTRIBUTE VALUE = Severity INFLOW PRIORITY: 5	People/Hours	UNIFLOW
Review_Triage[Severity](t)	Review_Triage[Severity](t - dt) + (Finishing_Review[Severity] - Leaving_Retriage[Severity]) * dt	INIT Review_Triage[Severity] = 0	People	NON-NEGATIVE
Waiting_to_Review(t)	Waiting_to_Review(t - dt) + (Waiting_too_Long - Finishing_Review[Surgical_Critical] - Finishing_Review[Critical] - Finishing_Review[Urgent] - Finishing_Review[Minimal]) * dt	INIT Waiting_to_Review = 0	People	NON-NEGATIVE
Waiting_too_Long	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 PURGE AFTER AGE = 0.5 OUTFLOW PRIORITY: 4	People/Hours	

Table 11. Equations for Stage 1 Worsening Patient Conditions.[258]

The "Supply Sector for Stage 1 and 2" (Figure 44) depicts the system for medical supplies that has an effect on the treatment of patients in "Patients with Medics." This section utilizes a general concept of a TCCC Supply Unit. The number of patients that this unit is designed to treat can also be set using the converter "Number of Patients treated per Unit" (currently set to 20). The "On Hand Stage 1 & 2 Medical Supply Capacity" is the amount of supplies the forward combat medics can have on hand or carry with them and is currently set to 5. The "Initial Average TCCC Units per Cache" will vary depending on the size of available caches, and initially this was set to 5, assuming forward caches will have more limited space than those further from conflict. The "Number of TCCC Caches" will vary depending on operational environment. Initially this was set to 20 since the capacity for each cache was low and forward forces will have to be more mobile. "Initial Average

258 Adapted from ISEE Systems, Stella Architect.

TCCC Units per Cache" and "Number of TCCC Caches" are multiplied together to initialize the "TCCC Cache Supply" stock.



This supply sector represents the medical supplies for both Stage 1 and Stage 2.

Figure 44. Casualty Treatment Stage 1, Supply Sector.[259]

The "Number of TCCC Supply Units per Resupply" is the number of supply units typically delivered per each resupply movement (set by end-user) and is currently set to 10 (1 unit for half the caches). The "TCCC Resupply Frequency" is the number of resupply

259 Adapted from ISEE Systems, Stella Architect.

deliveries per week and is currently set to 0.5 to simulate a bi-weekly resupply. “TCCC Units per Week” multiplies “Number of TCCC Supply Units per Resupply” and “TCCC Resupply Frequency” to determine units per week. The flow “Shipping TCCC Supplies” uses the “TCCC Units per Week” in a PULSE with initial and recurring values of “TCCC Units per Week” and interval set to 168 hours (1 week). The resupply shipments are delivered to the cache sites to not compromise the medic positions.

The calculations of “TCCC Supply Deficit” rely on the number of patients waiting to be treated by the medic (“#TCCC Patients for Medic”), patients to be treated with PFC at Stage 2 (“#PFC Patients to be treated”), and the number of patients that can be treated per TCCC supply unit (“Number of Patients treated per Unit”). “#TCCC Patients for Medic” and “#PFC Patients to be treated” are ghost converter from Figure 43 and 46, respectively. Only “#TCCC Patients for Medic” will be explained in detail here; “#PFC Patients to be treated will be further explained in the section for Stage 2. “#TCCC Patients for Medic” calculates all the number of patients waiting, except for patients with a Minimal severity as these patients rarely require any use of supplies. The equation for this converter is included in Table 9 and uses ATTRCOUNT of the Minimal patients in Waiting for Medic to subtract from the total value of the stock then adds the number of Surgical Critical, Critical, and Urgent patients flowing through “Moving to Waiting.” Counting the number of patients in the queue alone would not account for those who “pass through” the queue to treatment. The combined values for the “#TCCC Patients for Medic” and “#PFC Patients to be treated” converters are divided by “Number of Patients treated per Unit” to determine “Supply Units Needed for Stage 1 & 2.” The “TCCC Supply Deficit” is calculated by subtracting the “TCCC Medical Supply” from the “Supply Units Needed for TCCC.” A positive number for “TCCC Supply Deficit” means there is not enough supply on hand to treat patients, and a negative number means there is adequate supply.

When there is a deficit of supplies, medics must move supplies to the “TCCC Medical Supply” stock from the “TCCC Cache Supply.” The flow “Moving from TCCC Cache” to “TCCC Medial Supply” is 0 unless the “TCCC Medical Supply” stock is < 2, which will trigger a PULSE of supply units to fill the “TCCC Medical Supply” to original capacity.

	Equation	Properties	Units	Annotation
Supply_Sector_for_Stage_1_and_2:				
Expending_TCCC_Supply	PULSE(Supply_Expended_in_Stage_1_&_2)			UNIFLOW
Initial_Average_TCCC_Units_per_Cache	5			
Moving_from_TCCC_Cache	IF TCCC_Medical_Supply < 2 THEN PULSE(On_Hand_Stage_1_&_2_Medical_Supply_Capacity-TCCC_Medical_Supply) ELSE 0			UNIFLOW
Number_of_Patients_treated_per_Unit	20			
Number_of_TCCC_Caches	20			
Number_of_TCCC_Supply_Units_per_Resupply	10		Units	
On_Hand_Stage_1_&_2_Medical_Supply_Capacity	5			
Shipping_TCCC_Supplies	PULSE(TCCC_Units_per_Week, TCCC_Units_per_Week, 168)			UNIFLOW
Supply_Expended_in_Stage_1_&_2	("#_TCCC_Patients_Treated"+"#_PFC_Patients_Treated")/Number_of_Patients_treated_per_Unit			
Supply_Units_Needed_for_Stage_1_&_2	("#_TCCC_Patients_for_Medic"+"#_PFC_Patients_to_be_treated")/Number_of_Patients_treated_per_Unit			
TCCC_Cache_Supply(t)	TCCC_Cache_Supply(t - dt) + (Shipping_TCCC_Supplies - Moving_from_TCCC_Cache) * dt	INIT TCCC_Cache_Supply = Initial_Average_TCCC_Units_per_Cache*Number_of_TCCC_Caches		NON-NEGATIVE
TCCC_Medical_Supply(t)	TCCC_Medical_Supply(t - dt) + (Moving_from_TCCC_Cache - Expending_TCCC_Supply) * dt	INIT TCCC_Medical_Supply = On_Hand_Stage_1_&_2_Medical_Supply_Capacity		NON-NEGATIVE
TCCC_Resupply_Frequency	0.5		Per Week	
TCCC_Supply_Deficit	Supply_Units_Needed_for_Stage_1_&_2 - TCCC_Medical_Supply			
TCCC_Units_per_Week	Number_of_TCCC_Supply_Units_per_Resupply *TCCC_Resupply_Frequency			

Table 12. Equations for Stage 1 and 2 Supply Sector.[260]

Supply expenditures are calculated based on the number of patients treated by the medic in Stage 1 ("#TCCC Patients Treated") and Stage 2 ("#PFC Patients Treated") and the number of patients who can be treated per TCCC supply unit ("Number of Patients treated per Unit"). "#TCCC Patients Treated" and "#PFC Patients Treated" are ghost converters from Figure 38 and Figure 41, respectively. Only "#TCCC Patients Treated" will be explained in detail here. This converter uses ATTRCOUNT to calculate the Surgical Critical, Critical, and Urgent patients flowing through "Moving to Evac Queue" (equations in Table 9). The value for the "#TCCC Patients Treated" converter is added to "#PFC Patients Treated" and is divided by "Number of Patients treated per Unit" to

[260] Adapted from ISEE Systems, Stella Architect.

determine “Supply Expended in Stage 1 & 2.” This converter is then used to PULSE flow through “Expending TCCC Supply.”

After patients complete treatment with the medics or by buddy care, they enter a non-arrayed queue, “Waiting for Evac” (seen in Figure 46), that prioritizes patients based on their clinical severity so more serious patients are evacuated first. Patients with lower severities will remain in the queue until higher priorities are evacuated. The queue is initialized at 0 and prioritizes patients on attributes. This queue is included in Stage 2 because its purge function of patients who are waiting too long for evacuation is determined by whether the medics are trained in PFC. If no medis are trained in PFC, patients will begin to decompensate after 30 minutes. The logic sequence determining the purge time is further explained in Stage 2’s section. The equations for reclassifying patients if PFC is not available can be found in Table 14 (Stage 2 equations) and will be explained next.

The queue “Waiting for Evac” has an outflow, “Waiting too long (post TCCC),” which uses the time-stamps given at “Moving to Evac Queue” and “Moving to Evac from Buddy Care” to purge patients after 30 minutes. This outflow is universal for all attributes, so even patients with a “Minimal” severity who have been waiting for 30 miuntes will flow through this part of the system. The non-arrayed stock “Waiting to Review (post TCCC)” is a placeholder for these purged patients. “Finishing Review (post TCCC)” is an arrayed (Severity) flow that now sorts the patients by severity using the ATTRCOUNT function and value for “Waiting too long (post TCCC).” The patients, organized by severity, then enter the arrayed (Severity) stock “Review Triage (post TCCC).” The arrayed (Severity) flow “Leaving Retriage (post TCCC)” PULSEs the patients from “Review Triage (post TCCC),” and the resulting flow rate is utilized to reclassify patients.

The most critical patients, “Surgical Critical” and “Critical,” who cannot be evacuated in a timely manner are unable to be classified to a more severe category and will die from lack of advanced treatment. This is accounted for by the non-arrayed flow, “Dying at Stage 2,” which is not included in the equations for Table 14, but is included later (Table 29). Patients labeled “Urgent” who have been waiting too long for treatment, however, will become more critical and require re-classification. This is done utilizing the arrayed (Severity) flow “Retriaging (post TCCC).” The “$dummy stock (post TCCC)” is used strictly to establish an array (Severity) of patients without previously assigned attributes and its initial value is 0.

If PFC is available, “Retriaging (post TCCC)” will be 0 through logic explained in the section for Stage 2. If Stage 2 is not available, “Retriaging (post TCCC)” uses the values of “Leaving Retriage (post TCCC)” to re-estabish patient attributes. The flow of patients from the Critical “$dummy stock (post TCCC)” (ie. the patients who were previously Urgent, but now Critical) is equal to the flow of Urgent patients in “Leaving Retriage (post TCCC).” The flow of patients from the Surgical Critical “$dummy stock (post TCCC)” is 0 because patients are not reclassified into the Surgical Critical category. The flow of patients from the Urgent “$dummy stock (post TCCC)” is 0 because the only less-severe category is Minimal, and these patients rarely decompensate to a higher priority. Finally, the flow of patients from the Minimal “$dummy stock (post TCCC)” (ie. the patients who were previously Minimal and continue to be classified as such) is equal to the flow of Minimal patients in “Leaving Retriage (post TCCC).” The flow “Retriaging (post TCCC)” moves reclassified patients to “Waiting for Evac” and establishes a new time stamp.

“Waiting for Evac” has another queue outflow, “Moving Minimals to either evac queue,” also included in Stage 2’s sector. This outflow is restricted by the Minimal attribute to enter another queue that has outputs to evacuation platforms going to Stage 3 or 4 since minimal patients do not require immediate treatment and should take whatever evacuation method is available.

Movement of patients from the non-arrayed queue “Waiting for Evac” is through arrayed flows using a round robin selection of available evacuation platforms depicted by arrayed ovens “Helicopter Evac to Stage 3” (arrayed by Severity), “CASEVAC to Stage 3” (arrayed by Severity), and “Ground MEDEVAC to Stage 3” (arrayed by Severity). The sector for moving patients from Stage 1 to Stage 3 is shown in Figure 45.

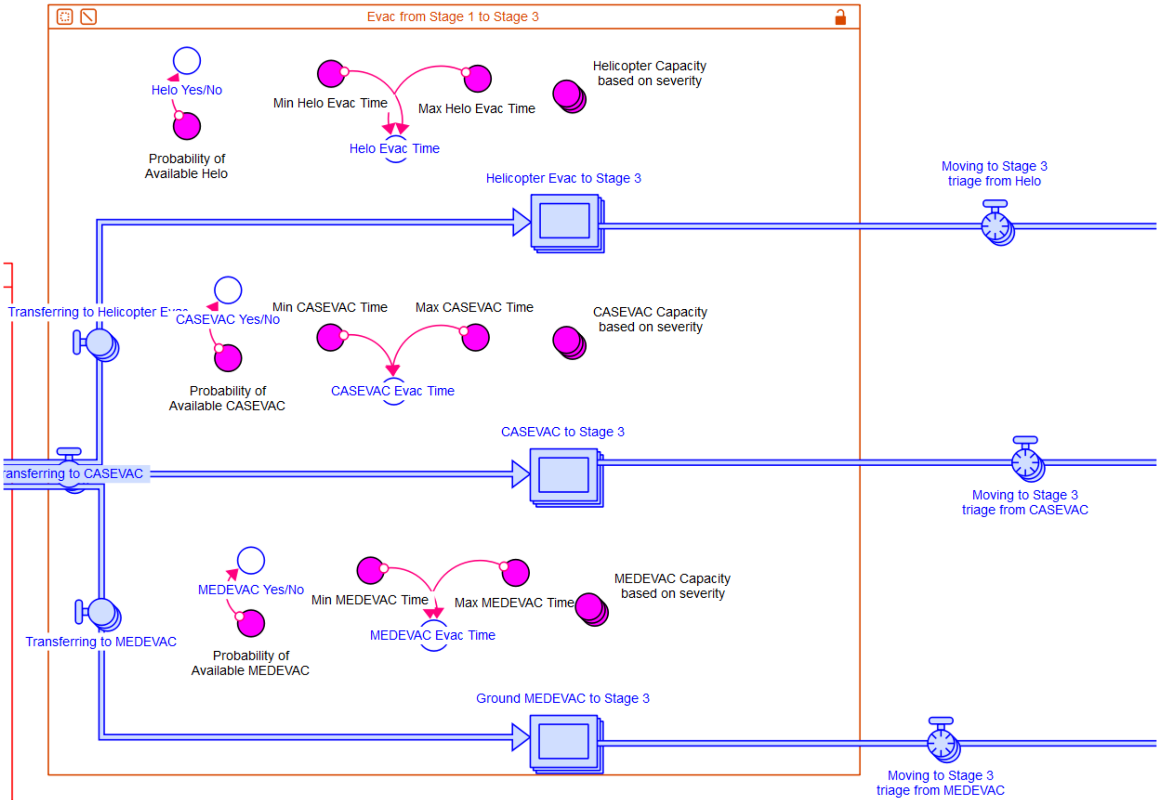


Figure 45. Casulty Treatment Stage 1, Evacuation Sector.[261]

Each oven in "Evac from Stage 1 to Stage 3" uses the same calculations with different values. Only the "CASEVAC to Stage 3" will be described in detail here. Table 13 includes the equations used for the arrayed ovens for this section of the model and can be referenced for the remainder of the ovens. "CASEVAC to Stage 3" has a COOK TIME that simulates the time it takes to transport a patient to the next level of care and is defined by "CASEVAC Evac Time." "CASEVAC Evac Time" is a converter that randomizes a number between the set values in converters "Min CASEVAC Time" and "Max CASEVAC Time." "CASEVAC Evac Time" is also utilized in the oven's CLEAN TIME (the time that the oven is not "cooking" or "filling") that simulates the CASEVAC platform returning to the front lines to pick up patients and again randomizes a value between the "CASEVAC Evac Time" and 4x the "CASEVAC Evac Time" (accounts for refueling,

261 Adapted from ISEE Systems, Stella Architect.

maintenance issues, operational environment delays, and platforms that have made multiple stops). The FILL TIME is 0.33 Hours (20 minutes) as evacuation platforms will not wait for patients to be loaded for longer than this amount of time due to the risk of compromise or targeting. The oven CAPACITY uses an arrayed (Severity) converter "CASEVAC Capacity based on Severity" designed for user input and currently set to 4 Surgical Critical patients, 4 Critical patients, 8 Urgent patients, and 10 Minimal patients. The variation of capacity based on severity is because more critical patients will be on a stretcher while less severe can potentially sit upright as normal passengers.

The limited freedom of movement in the GW/UW operating environment hinders evacuation and was accounted for in the "CASEVAC to Stage 3" oven's CAPACITY. An oven with a capacity of 0 will not accept any patients, and therefore, no flow will occur to the oven. As seen in Table 13, the oven capacities include the capacity converter a converter, "CASEVAC Yes/No," that will be either a 1 or 0, essentially functioning as a "on/off" switch for the oven capacity. "CASEVAC Yes/No" converter uses the MONTECARLO built-in that assigns a 1 or 0 based on a probability between 0–100, defined by "Probability of Available CASEVAC." "Probability of Available CASEVAC" is intended to be a value set by the user describing the probability (%) that a CASEVAC platform will be available at any given time for forward medics and is currently set to 30%. The current value for "Probability of Available Helo" is 0.01% as helicopters will give away the position of forces when employed and would only be used in dire situations in such environments. The modification of the probability converters will modify available evacuation platforms and have an impact on the evacuation wait times, increasing the need for PFC.

The oven outflow "Moving to Stage 3 triage from CASEVAC" timestamps patients for the upcoming queue "Waiting for DCR/DCS" at Treatment Stage 3.

	Equation	Properties	Units	Annotation
Evac_from_Stage_1_to_Stage_3:				
CASEVAC_Capacity_based_on_severity[Surgical_Critical]	4			
CASEVAC_Capacity_based_on_severity[Critical]	4			
CASEVAC_Capacity_based_on_severity[Urgent]	8			
CASEVAC_Capacity_based_on_severity[Minimal]	10			
CASEVAC_Evac_Time	RANDOM(Min_CASEVAC_Time, Max_CASEVAC_Time)			
CASEVAC_to_Stage_3[Severity](t)	CASEVAC_to_Stage_3[Severity](t - dt) + (Transferring_to_CASEVAC[Severity] - Moving_to_Stage_3_triage_from_CASEVAC[Severity]) * dt	INIT CASEVAC_to_Stage_3[Severity] = 0 COOK TIME = CASEVAC_Evac_Time CAPACITY = CASEVAC_Capacity_based_on_severity*"CASEVAC_Yes/No" FILL TIME = 0.33 CLEAN TIME = RANDOM (CASEVAC_Evac_Time, 4*CASEVAC_Evac_Time) ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
"CASEVAC_Yes/No"	MONTECARLO(Probability_of_Available_CASEVAC)			
Ground_MEDEVAC_to_Stage_3[Severity](t)	Ground_MEDEVAC_to_Stage_3[Severity](t - dt) + (Transferring_to_MEDEVAC[Severity] - Moving_to_Stage_3_triage_from_MEDEVAC[Severity]) * dt	INIT Ground_MEDEVAC_to_Stage_3[Severity] = 0 COOK TIME = MEDEVAC_Evac_Time CAPACITY = MEDEVAC_Capacity_based_on_severity*"MEDEVAC_Yes/No" FILL TIME = 0.33 CLEAN TIME = RANDOM (MEDEVAC_Evac_Time, 4*MEDEVAC_Evac_Time) ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
Helicopter_Capacity_based_on_severity[Surgical_Critical]	2			
Helicopter_Capacity_based_on_severity[Critical]	2			
Helicopter_Capacity_based_on_severity[Urgent]	4			
Helicopter_Capacity_based_on_severity[Minimal]	6			
Helicopter_Evac_to_Stage_3[Severity](t)	Helicopter_Evac_to_Stage_3[Severity](t - dt) + (Transferring_to_Helicopter_Evac[Severity] - Moving_to_Stage_3_triage_from_Helo[Severity]) * dt	INIT Helicopter_Evac_to_Stage_3[Severity] = 0 COOK TIME = Helo_Evac_Time CAPACITY = Helicopter_Capacity_based_on_severity*"Helo_Yes/No" FILL TIME = 0.33 CLEAN TIME = RANDOM (Helo_Evac_Time, 4*Helo_Evac_Time) ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
Helo_Evac_Time	RANDOM(Min_Helo_Evac_Time, Max_Helo_Evac_Time)			
"Helo_Yes/No"	MONTECARLO(Probability_of_Available_Helo)			
Max_CASEVAC_Time	2			
Max_Helo_Evac_Time	2			
Max_MEDEVAC_Time	2			
MEDEVAC_Capacity_based_on_severity[Surgical_Critical]	2			
MEDEVAC_Capacity_based_on_severity[Critical]	2			
MEDEVAC_Capacity_based_on_severity[Urgent]	3			
MEDEVAC_Capacity_based_on_severity[Minimal]	4			
MEDEVAC_Evac_Time	RANDOM(Min_MEDEVAC_Time, Max_MEDEVAC_Time)			
"MEDEVAC_Yes/No"	MONTECARLO(Probability_of_Available_MEDEVAC)			
Min_CASEVAC_Time	0.33			
Min_Helo_Evac_Time	0.33			
Min_MEDEVAC_Time	0.33			
Probability_of_Available_CASEVAC	30			
Probability_of_Available_Helo	0.01			
Probability_of_Available_MEDEVAC	2			
Transferring_to_CASEVAC[Severity]	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 5	People/Hours	
Transferring_to_Helicopter_Evac[Severity]	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 1	People/Hours	
Transferring_to_MEDEVAC[Severity]	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 9	People/Hours	

Table 13. Equations for Stage 1 Evacuation Sector.[262]

D. GW/UW CASUALTY TREATMENT STAGE 2

Casualty Treatment Stage 2 is initiated by the user indicating whether the medica are trained in PFC through the converter "PFC available?" This can easily be done through the interface with a toggle switch. If the switch is "ON" (PFC is available), then the converter value will be 1. If "OFF" (PFC not available), then the value will be 0. This converter is used in multiple logic series to affect the treatment and flow of patients thorugh Stage 2, depicted in Figure 46 and equations in Table 14.

Patients who have received Stage 1 treatment enter the non-arrayed quue, "Waiting for Evac," at which point the determination for PFC or Stage 2 treatment begins. As mentioned previously, the queue has a purge function to account for worsening clinical conditions. The outflow "Waiting too long (post TCCC)" purge time is dictated by the converter "Purge Time," that uses logic based on "PFC Available?" If "PFC Available?" is 1, then the purge time is 4 hours, otherwise it is 30 minutes. The 4 hours was determined based on a retrospective review on PFC from recent conflicts that demonstrated patients living past 4 hours could likely survive without the need for damage control care.[263] Therefore, patients with less than 4 hours of PFC needed to move to Stage 3, while those who survived longer than 4 hours could be moved to Stage 3 or 4 depending on available evacuation. PFC patients with less than 4 hours of treatment flow through the same evacuation sector as Stage 1 patients (Figure 40 and Table 13). The logic for this sector will not be explained again here.

After 4 hours, patients receiving PFC move through "Waiting to Review (post TCCC)" and "Review Triage (post TCCC)" with the same logic used for patients were worsening (same logic as the processes in Stage 1). If Stage 2 care is available, however, patients are not re-classified through "Retriaging (post TCCC)" and are placed back into the "Waiting for Evac" queue. This is controled with an IF/THEN series of logic for the flow "Retriaging (post TCCC)," which states that IF "PFC Available?"=1, THEN 0,

[262] Adapted from ISEE Systems, Stella Architect.

[263] Shackelford et al., "Case-Control Analysis of Prehospital Death and Prolonged Field Care Survival during Recent U.S. Military Combat Operations," S190.

shutting off flow. Conversely, “Continuing PFC” uses similar logic that states IF “PFC Available?”=1, THEN “Leaving Retriage (post TCCC)” ELSE 0. This flows patients into a non-negative stock, “PFC Patients” and does not recategorize the patient’s severity as it is assumed the PFC is preventing their status from worsening. This is likely a false assumption and is accounted for through the arrayed (Severity) flow “Dying PFC patients.” The user can set a mortality rate for the initial 4 hours of PFC based on severity through the arrayed converter “Mortality Rate after 4 hours PFC.” The current settings are listed in Table 15 and are roughly based on data from the recent PFC article.[264] “Dying PFC patients” has an outflow priority from “PFC Patients” of 1 and multiplies the mortality rate percent for each severity category by “Continuing PFC” to remove patients who will likely succumb to their injuries during PFC. The second priority ouflow from “PFC Patients” is the arrayed (Severity) flow “Surviving initial 4 hours PFC,” which sends the remaining patients not flowing through “Dying PFC patients” into the queue “PFC Patients >4hrs.” Patients are re-timestamped when they enter this queue.

Although patients who have survived the initial 4 hours of PFC have less of a need for emergent care, their clinical condition can still worsen with time. The equations for this portion of the model is included in Table 16. The queue “PFC Patients >4hr” has an outflow, “Waiting too long (PFC),” that uses the time-stamp given at “Surviving initial 4 hours PFC” to purge patients after 36 hours. This outflow is universal for all attributes, so even patients with a “Minimal” severity who have been waiting for 36 hours will flow through this part of the system. The non-arrayed stock “Waiting to Review (PFC)” is a placeholder for these purged patients. “Finishing Review (PFC)” is an arrayed (Severity) flow that now sorts the patients by severity using the ATTRCOUNT function and value for “Waiting too long (PFC).” The patients, organized by severity, then enter the arrayed (Severity) stock “Review Triage (PFC).” The arrayed (Severity) flow “Leaving Retriage (PFC)” PULSEs the patients from “Review Triage (PFC),” and the resulting flow rate is utilized to reclassify patients.

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264 Shackelford et al., S190.

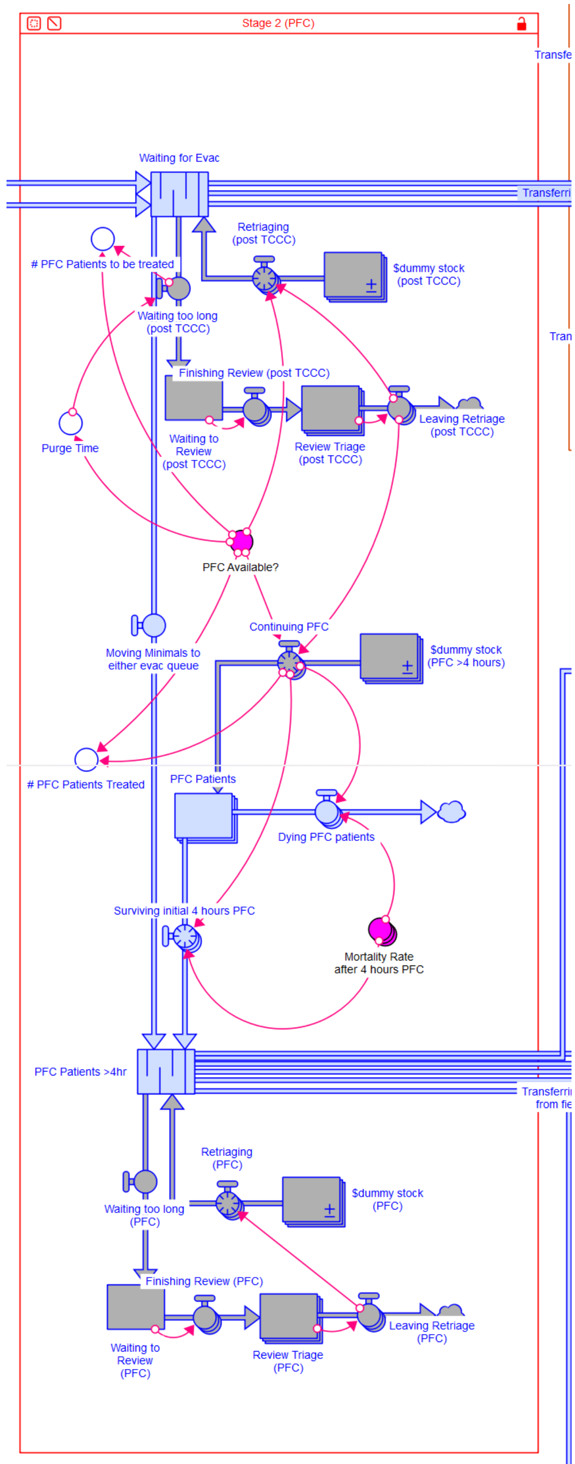

Figure 46. Casualty Treatment Stage 2, Patient Treatment Sector.[265]

[265] Adapted from ISEE Systems, Stella Architect.

	Equation	Properties	Units	Annotation
"Stage_2_(PFC)":				
"#_PFC_Patients_to_be_treated"	(DT*("Waiting_too_long_(post_TCCC)"-ATTRCOUNT("Waiting_too_long_(post_TCCC)", Severity.Minimal)))*PFC_Available?			
"#_PFC_Patients_Treated"	(DT*(Continuing_PFC[Surgical_Critical]+Continuing_PFC[Critical]+Continuing_PFC[Urgent]))*PFC_Available?			
"$dummy_stock_(PFC_>4_hours)"[Severity](t)	"$dummy_stock_(PFC_>4_hours)"[Severity](t - dt) + (- Continuing_PFC[Severity]) * dt	INIT "$dummy_stock_(PFC_>4_hours)"[Severity] = 0	People	
"$dummy_stock_(post_TCCC)"[Severity](t)	"$dummy_stock_(post_TCCC)"[Severity](t - dt) + (- "Retriaging_(post_TCCC)"[Severity]) * dt	INIT "$dummy_stock_(post_TCCC)"[Severity] = 0	People	
Continuing_PFC[Severity]	IF PFC_Available?=1 THEN "Leaving_Retriage_(post_TCCC)" ELSE 0	TIME STAMPED ATTRIBUTE VALUE = Severity	People/Hours	UNIFLOW
Dying_PFC_patients[Severity]	(Mortality_Rate_after_4_hours_PFC/100)* Continuing_PFC	OUTFLOW PRIORITY: 1	People/Hours	UNIFLOW
"Finishing_Review_(post_TCCC)"[Severity]	PULSE(ATTRCOUNT("Waiting_to_Review_(post_TCCC)", Severity))		People/Hours	UNIFLOW
"Leaving_Retriage_(post_TCCC)"[Severity]	PULSE("Review_Triage_(post_TCCC)")		People/Hours	UNIFLOW
Moving_Minimals_to_either_evac_queue	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 RESTRICT BY ATTRIBUTE = 4 INFLOW PRIORITY: 5 OUTFLOW PRIORITY: 13	People/Hours	
PFC_Patients[Severity](t)	PFC_Patients[Severity](t - dt) + (Continuing_PFC[Severity] - Dying_PFC_patients[Severity] - Surviving_initial_4_hours_PFC[Severity]) * dt	INIT PFC_Patients[Severity] = 0	People	NON-NEGATIVE
Purge_Time	IF PFC_Available?=1 THEN 4 ELSE 0.5			
"Retriaging_(post_TCCC)"[Severity]	IF PFC_Available?=0 THEN (IF Severity = Severity.Critical THEN "Leaving_Retriage_(post_TCCC)"[Urgent] ELSE IF Severity = Severity.Surgical_Critical THEN 0 ELSE IF Severity = Severity.Urgent THEN 0 ELSE "Leaving_Retriage_(post_TCCC)") ELSE 0	TIME STAMPED ATTRIBUTE VALUE = Severity INFLOW PRIORITY: 3	People/Hours	UNIFLOW
"Review_Triage_(post_TCCC)"[Severity](t)	"Review_Triage_(post_TCCC)"[Severity](t - dt) + ("Finishing_Review_(post_TCCC)"[Severity] - "Leaving_Retriage_(post_TCCC)"[Severity]) * dt	INIT "Review_Triage_(post_TCCC)"[Severity] = 0	People	NON-NEGATIVE
Surviving_initial_4_hours_PFC[Severity]	((100-Mortality_Rate_after_4_hours_PFC)/100)* Continuing_PFC	TIME STAMPED ATTRIBUTE VALUE = Severity INFLOW PRIORITY: 6 OUTFLOW PRIORITY: 2	People/Hours	UNIFLOW
Waiting_for_Evac(t)	Waiting_for_Evac(t - dt) + (Moving_to_Evac_Queue[1] + Moving_to_Evac_Queue[2] + "Retriaging_(post_TCCC)"[Surgical_Critical] + "Retriaging_(post_TCCC)"[Critical] + "Retriaging_(post_TCCC)"[Urgent] + "Retriaging_(post_TCCC)"[Minimal] + Moving_to_Evac_from_Buddy_Care -	INIT Waiting_for_Evac = 0 PRIORITIZE INFLOWS BASED ON ATTRIBUTE VALUES USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION	People	QUEUE
"Waiting_to_Review_(post_TCCC)"(t)	"Waiting_to_Review_(post_TCCC)"(t - dt) + ("Waiting_too_long_(post_TCCC)" - "Finishing_Review_(post_TCCC)"[Surgical_Critical] - "Finishing_Review_(post_TCCC)"[Critical] - "Finishing_Review_(post_TCCC)"[Urgent] - "Finishing_Review_(post_TCCC)"[Minimal]) * dt	INIT "Waiting_to_Review_(post_TCCC)" = 0	People	NON-NEGATIVE
"Waiting_too_long_(post_TCCC)"	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 PURGE AFTER AGE = Purge_Time OUTFLOW PRIORITY: 14	People/Hours	

Table 14. Equations for Stage 2 Patient Treatment.[266]

	Equation
Mortality_Rate_after_4_hours_PFC[Surgical_Critical]	50
Mortality_Rate_after_4_hours_PFC[Critical]	20
Mortality_Rate_after_4_hours_PFC[Urgent]	10
Mortality_Rate_after_4_hours_PFC[Minimal]	0

Table 15. Values for Mortality Rate by Severity for PFC.[267]

The most critical patients "Surgical Critical" and "Critical" who have been waiting too long for evacuation cannot be classified to a more severe category and will die from lack of treatment. This is accounted for by the non-arrayed flow "Dying at Stage 2," which is not included in the equations for Table 16, but is included later (Table 29). Patients labeled "Urgent" who have been waiting too long for treatment, however, will become more critical and require re-classification. This is done utilizing the arrayed (Severity) flow "Retriaging (PFC)." The "$dummy stock (PFC)" is used strictly to establish an array (Severity) of patients without previously assigned attributes and its initial value is 0.

"Retriaging" uses the values of "Leaving Retriage (PFC)" to re-estabish patient attributes. The flow of patients from the Critical "$dummy stock (PFC)" (ie. the patients who were previously Urgent, but now Critical) is equal to the flow of Urgent patients in "Leaving Retriage (PFC)." The flow of patients from the Surgical Critical "$dummy stock (PFC)" is 0 because patients are not reclassified into the Surgical Critical category. The flow of patients from the Urgent "$dummy stock (PFC)" is 0 because the only less-severe category is Minimal, and these patients rarely decompensate to a higher priority. Finally, the flow of patients from the Minimal "$dummy stock (PFC)" (ie. the patients who were previously Minimal and continue to be classified as such) is equal to the flow of Minimal patients in "Leaving Retriage (PFC)." The flow "Retriaging (PFC)" moves reclassified patients to "PFC Patients >4hr" and establishes a new time stamp.

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266 Adapted from ISEE Systems, Stella Architect.

267 Adapted from ISEE Systems, Stella Architect.

	Equation	Properties	Units	Annotation
"$dummy_stock_(PFC)"[Severity](t)	"$dummy_stock_(PFC)"[Severity](t - dt) + (- "Retriaging_(PFC)"[Severity]) * dt	INIT "$dummy_stock_(PFC)"[Severity] = 0	People	
"Finishing_Review_(PFC)"[Severity]	PULSE(ATTRCOUNT("Waiting_to_Review_(PFC)", Severity))		People/Hours	UNIFLOW
"Leaving_Retriage_(PFC)"[Severity]	PULSE("Review_Triage_(PFC)")		People/Hours	UNIFLOW
Moving_Minimals_to_either_evac_queue	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 RESTRICT BY ATTRIBUTE = 4 INFLOW PRIORITY: 5 OUTFLOW PRIORITY: 13	People/Hours	
"PFC_Patients_>4hr"(t)	"PFC_Patients_>4hr"(t - dt) + ("Retriaging_(PFC)"[Surgical_Critical] + "Retriaging_(PFC)"[Critical] + "Retriaging_(PFC)"[Urgent] + "Retriaging_(PFC)"[Minimal] + Moving_Minimals_to_either_evac_queue + Surviving_initial_4_hours_PFC[Surgical_Critical] + Surviving_initial_4_hours_PFC[Critical] +	INIT "PFC_Patients_>4hr" = 0 USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION	People	QUEUE
"Retriaging_(PFC)"[Severity]	IF Severity = Severity.Critical THEN "Leaving_Retriage_(PFC)"[Urgent] ELSE IF Severity = Severity.Surgical_Critical THEN 0 ELSE IF Severity = Severity.Urgent THEN 0 ELSE "Leaving_Retriage_(PFC)"	TIME STAMPED ATTRIBUTE VALUE = Severity INFLOW PRIORITY: 1	People/Hours	UNIFLOW
"Review_Triage_(PFC)"[Severity](t)	"Review_Triage_(PFC)"[Severity](t - dt) + ("Finishing_Review_(PFC)"[Severity] - "Leaving_Retriage_(PFC)"[Severity]) * dt	INIT "Review_Triage_(PFC)"[Severity] = 0	People	NON-NEGATIVE
Surviving_initial_4_hours_PFC[Severity]	((100-Mortality_Rate_after_4_hours_PFC)/100)* Continuing_PFC	TIME STAMPED ATTRIBUTE VALUE = Severity INFLOW PRIORITY: 6 OUTFLOW PRIORITY: 2	People/Hours	UNIFLOW
"Waiting_to_Review_(PFC)"(t)	"Waiting_to_Review_(PFC)"(t - dt) + ("Waiting_too_long_(PFC)" - "Finishing_Review_(PFC)"[Surgical_Critical] - "Finishing_Review_(PFC)"[Critical] - "Finishing_Review_(PFC)"[Urgent] - "Finishing_Review_(PFC)"[Minimal]) * dt	INIT "Waiting_to_Review_(PFC)" = 0	People	NON-NEGATIVE
"Waiting_too_long_(PFC)"	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 PURGE AFTER AGE = 36 OUTFLOW PRIORITY: 9	People/Hours	

Table 16. Equations for Stage 2 Worsening Patient Conditions.[268]

Because the Stage 2 treatment is depicted by other means than using ovens and conveyors, there is no "ARREST" logic to prevent treatment if the "TCCC Medical

[268] Adapted from ISEE Systems, Stella Architect.

Supply" runs out. This is a limitation of the system that may allow for a greater flow of patients through Stage 2 than could otherwise be treated. PFC patients are counted towards the amount of TCCC supplies needed and expended, however.

In the previous section, the calculations of "TCCC Supply Deficit" were explained, and the converter "#PFC Patients to be treated" was utilized in those calculations. "#PFC Patients to be treated" uses ATTRCOUNT of all patients flowing through "Waiting too long (post TCCC)" when PFC is available ("PFC Available?"=1). One of the limitations of using this method is that patients being treated for 3 hours and 59 minutes (prior to the 4-hour purge time) will not be counted towards needed supplies. It should also be noted that the logic does not exclude Minimal patients to simplify the equations since Minimal patients are moved to a different queue for evacuation to Stage 3 or 4.

"Supply Expended in Stage 1 & 2" was noted earlier to use a converter "#PFC Patients Treated." "#PFC Patients Treated" adds the number of Surgical Critical, Critical, and Urgent patients flowing through the arrayed flow "Continuing PFC" (equations in Table 14). Again, the logic does not exclude Minimal patients for simplicity.

Evacuation of patients from "PFC Patients >4hr" uses the same platforms as the evacuation sector for Stage 1, but patients can move to either Stage 3 or Stage 4. Because the software only allows for one inflow to an oven, the Stage 1 evacuation sector (Figure 40) could not be utilized again for these patients. Instead, a copy of the sector was made, creating the "Evac from Stage 2 to Stage 3" sector (Figure 47).

Movement of patients from the non-arrayed queue "PFC Patients >4hr" is through arrayed flows using a round robin selection of available evacuation platforms depicted by arrayed ovens "Helicopter Evac to Stage 3" (arrayed by Severity), "CASEVAC to Stage 3" (arrayed by Severity), and "Ground MEDEVAC to Stage 3" (arrayed by Severity).

Each oven in "Evac from Stage 2 to Stage 3" uses the same calculations with different values. Only the "CASEVAC from Stage 2 to 3" will be described in detail here. Table 17 includes the equations used for the arrayed ovens for this section of the model and can be referenced for the remainder of the ovens. "CASEVAC from Stage 2 to 3" has a COOK TIME that simulates the time it takes to transport a patient to the next level of care and is defined by the ghost converter “CASEVAC Evac Time” from the evacuation sector for Stage 1. “CASEVAC Evac Time” is also utilized in the oven’s CLEAN TIME, which simulates the CASEVAC platform returning to the front lines to pick up patients and again randomizes a value between the “CASEVAC Evac Time” and 4x the “CASEVAC Evac Time.” The FILL TIME is 0.33 Hours (20 minutes). The oven CAPACITY uses an arrayed (Severity) converter “CASEVAC Capacity based on Severity” designed for user input and currently set to 4 Surgical Critical patients, 4 Critical patients, 8 Urgent patients, and 10 Minimal patients.

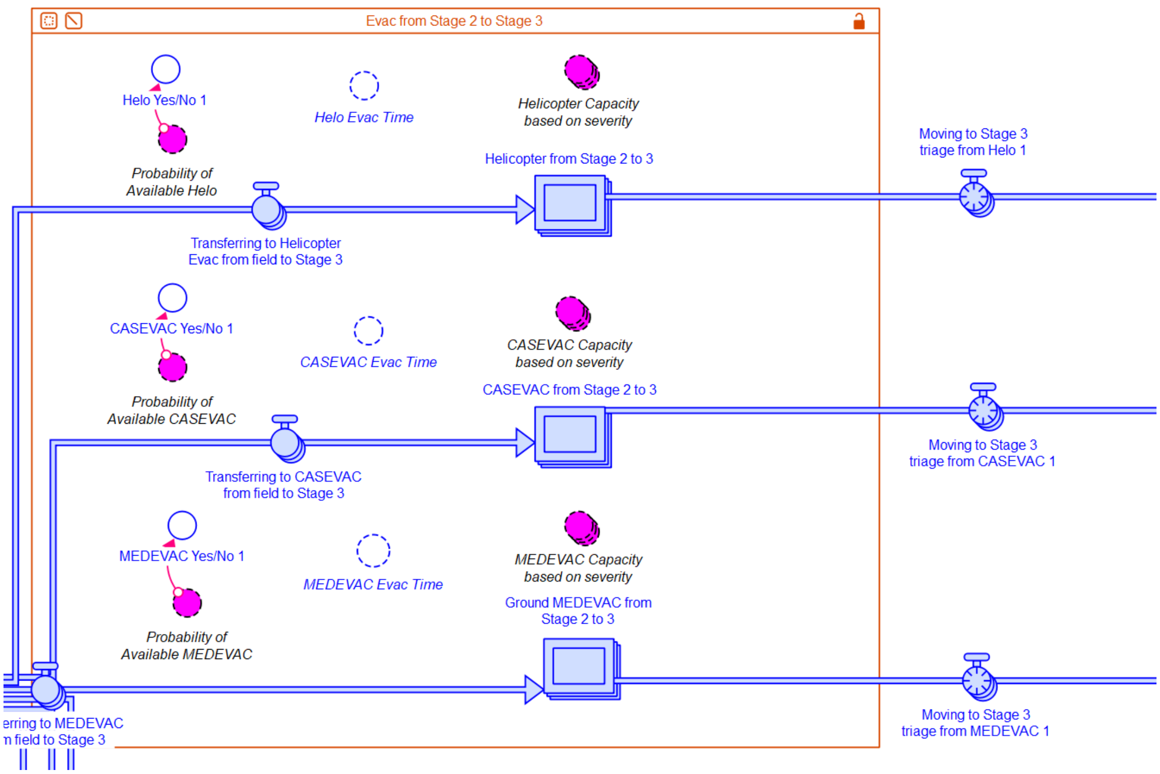

Figure 47. Casualty Treatment Stage 2, Evacuation Sector to Stage 3.[269]

269 Adapted from ISEE Systems, Stella Architect.

	Equation	Properties	Units	Annotation
Evac_from_Stage_2_to_Stage_3:				
CASEVAC_from_Stage_2_to_3[Severity](t)	CASEVAC_from_Stage_2_to_3[Severity](t - dt) + (Transferring_to_CASEVAC_from_field_to_Stage_3[Severity] - Moving_to_Stage_3_triage_from_CASEVAC_1[Severity]) * dt	INIT CASEVAC_from_Stage_2_to_3[Severity] = 0 COOK TIME = CASEVAC_Evac_Time CAPACITY = CASEVAC_Capacity_based_on_severity *"CASEVAC_Yes/No_1" FILL TIME = 0.33 CLEAN TIME = RANDOM (CASEVAC_Evac_Time, 4*CASEVAC_Evac_Time) ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
"CASEVAC_Yes/No_1"	MONTECARLO(Probability_of_Available_CASEVAC)			
Ground_MEDEVAC_from_Stage_2_to_3[Severity](t)	Ground_MEDEVAC_from_Stage_2_to_3[Severity](t - dt) + (Transferring_to_MEDEVAC_from_field_to_Stage_3[Severity] - Moving_to_Stage_3_triage_from_MEDEVAC_1[Severity]) * dt	INIT Ground_MEDEVAC_from_Stage_2_to_3[Severity] = 0 COOK TIME = MEDEVAC_Evac_Time CAPACITY = MEDEVAC_Capacity_based_on_severity *"MEDEVAC_Yes/No_1" FILL TIME = 0.33 CLEAN TIME = RANDOM (MEDEVAC_Evac_Time, 4*MEDEVAC_Evac_Time) ARREST IF "MEDEVAC_Yes/No" <> 0 ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
Helicopter_from_Stage_2_to_3[Severity](t)	Helicopter_from_Stage_2_to_3[Severity](t - dt) + (Transferring_to_Helicopter_Evac_from_field_to_Stage_3[Severity] - Moving_to_Stage_3_triage_from_Helo_1[Severity]) * dt	INIT Helicopter_from_Stage_2_to_3[Severity] = 0 COOK TIME = Helo_Evac_Time CAPACITY = Helicopter_Capacity_based_on_severity *"Helo_Yes/No_1" FILL TIME = 0.33 CLEAN TIME = RANDOM (Helo_Evac_Time, 4*Helo_Evac_Time) ARREST IF "Helo_Yes/No" <> 0 ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
"Helo_Yes/No_1"	MONTECARLO(Probability_of_Available_Helo)			
"MEDEVAC_Yes/No_1"	MONTECARLO(Probability_of_Available_MEDEVAC)			
Transferring_to_CASEVAC_from_field_to_Stage_3[Severity]	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 18	People/Hours	
Transferring_to_Helicopter_Evac_from_field_to_Stage_3[Severity]	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 22	People/Hours	

Table 17. Equations for Evacuation from Stage 2 to Stage 3.[270]

[270] Adapted from ISEE Systems, Stella Architect.

Because the modeling software does not allow multiple flows into a single oven, there is a false increase in the number of evacuation platforms. This increase can be accounted for by adjusting the probability of available evacuation platforms, but this adjustment cannot prevent the simultaneous evacuation of patients by the same platform in two different parts of the model. To reduce the chances of this error, the "Evac from Stage 2 to Stage 3" sector generates its own on/off switch for the platforms. The converters "Helo Yes/No 1," "CASEVAC Yes/No 1," and "MEDEVAC Yes/No 1" were created for this sector rather than using ghost converters from Stage 1's evacuation sector. These converters use the MONTECARLO built-in, assigning a 1 or 0 based on a probability between 0–100. The probability inputs utilize the probabilities defined by ghost converters from "Evac from Stage 1 to Stage 3" because the probability is the same. Because the MONTECARLO converters are not ghost converters from Stage 1's evacuation, they will generate 1s or 0s independently of those in Stage 1, even while using the same probability input.

The oven outflow from this sector timestamps patients for the upcoming non-arrayed queue "Waiting for DCR/DCS" at Treatment Stage 3, where they are prioritized based on severity.

The round robin selection in "PFC Patients >4hr" allows patients to be transported to Stage 4 if transport becomes available. Patient prioritized for transport move through arrayed flows to the arrayed (Severity) ovens "Helicopter Evac direct to Stage 4," "CASEVAC direct to Stage 4," and "Ground MEDEVAC direct to Stage 4." The sector for moving patients from Stage 2 to Stage 4 is shown in Figure 43.

Each oven in "Evac from Stage 2 to Stage 4" uses the same calculations with different values. Only the "CASEVAC direct to Stage 4" will be described here. Table 18 includes the equations used for the arrayed ovens for this section of the model and can be referenced for the remainder of the ovens. "CASEVAC direct to Stage 4" has a COOK TIME that simulates the time it takes to transport a patient to the next level of care and is defined by "CASEVAC Evac Time direct to Stage 4." "CASEVAC Evac Time direct to Stage 4" is a converter that randomizes a number between the set values in converters "Min CASEVAC Time from field to Stage 4" and "Max CASEVAC Time from field to Stage

4." "CASEVAC Evac Time direct to Stage 4" is also utilized in the oven's CLEAN TIME randomizes a value between the "CASEVAC Evac Time direct to Stage 4" and 4x the "CASEVAC Evac Time direct to Stage 4." The FILL TIME is 0.33 Hours (20 minutes). The oven CAPACITY uses the arrayed (Severity) ghost converter "CASEVAC Capacity based on Severity."

The reduced availability of patient transport is accounted for in the oven capacities. As seen in Table 18, the oven capacities include "CASEVAC Capacity based on Severity" and a converter, "CASEVAC Yes/No direct to Stage 4," that will be either a 1 or 0, essentially functioning as a "on/off" switch for the oven capacity. "CASEVAC Yes/No direct to Stage 4" converter uses the MONTECARLO built-in that assigns a 1 or 0 based on a probability between 0–100, defined by "Probability of Available CASEVAC direct to Stage 4." "Probability of Available CASEVAC direct to Stage 4" is set by the user describing the probability (%) that a CASEVAC platform will be available at any given time for forward medics and is currently set to 25%. The probability was set lower due to the increased distance required to travel and the increased risk for compromise of those platforms.

The oven outflow "Moving to Stage 4 triage from CASEVAC 1" (not identified in Figure 48) timestamps patients for the upcoming queue "Waiting for Definitive Care" at Treatment Stage 4.

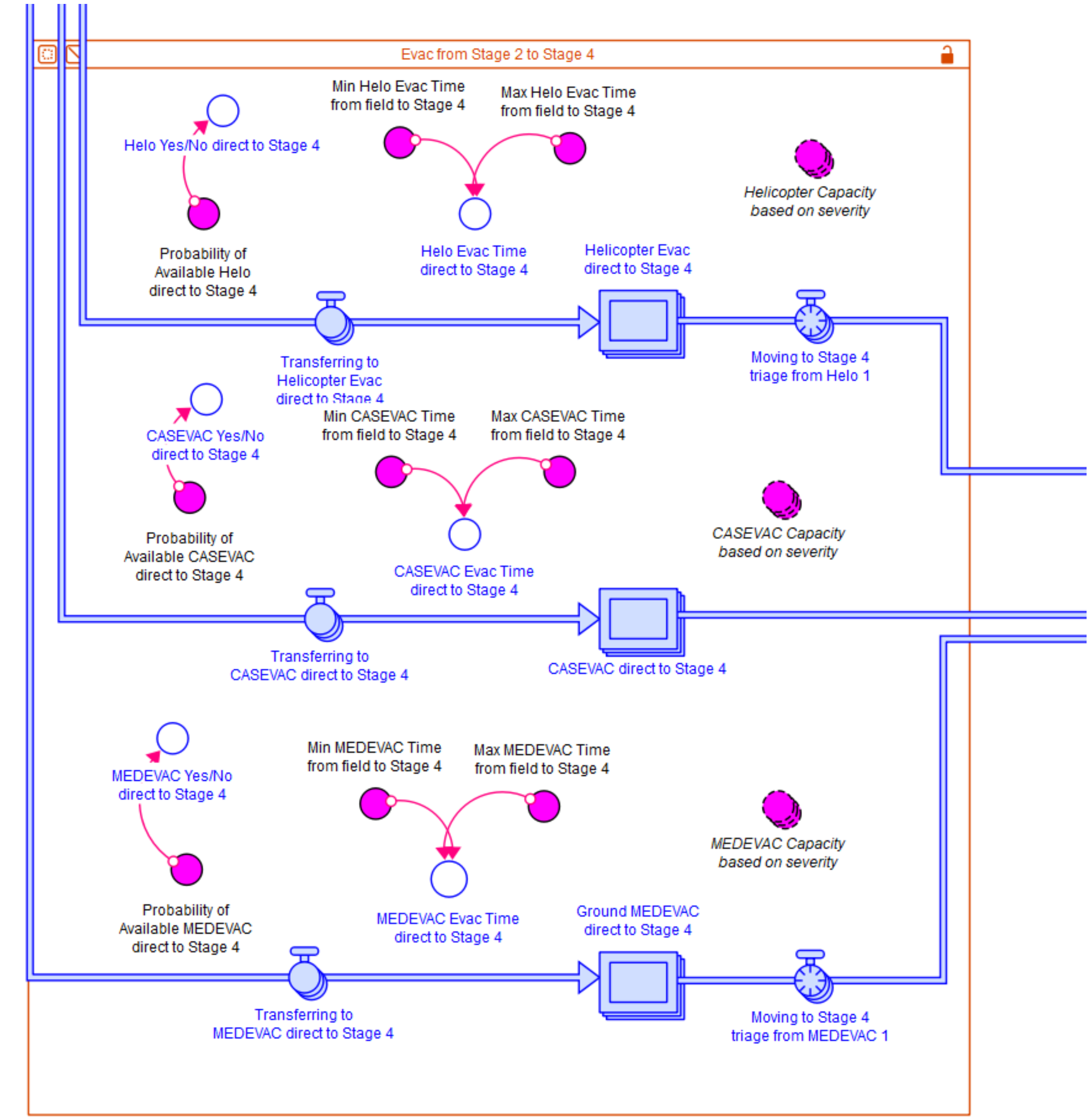

Figure 48. Casualty Treatment Stage 2, Evacuation Sector to Stage 4.[271]

[271] Adapted from ISEE Systems, Stella Architect.

	Equation	Properties	Units	Annotation
Evac_from_Stage_2_to_Stage_4:				
CASEVAC_direct_to_Stage_4[Severity](t)	CASEVAC_direct_to_Stage_4[Severity](t - dt) + (Transferring_to_CASEVAC_direct_to_Stage_4[Severity] - Moving_to_Stage_4_triage_from_CASEVAC_1[Severity]) * dt	INIT CASEVAC_direct_to_Stage_4[Severity] = 0 COOK TIME = CASEVAC_Evac_Time_direct_to_Stage_4 CAPACITY = CASEVAC_Capacity_based_on_severity*"CASEVAC_Yes/No_direct_to_Stage_4" FILL TIME = 0.33 CLEAN TIME = RANDOM (CASEVAC_Evac_Time_direct_to_Stage_4, 4*CASEVAC_Evac_Time_direct_to_Stage_4) ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
CASEVAC_Evac_Time_direct_to_Stage_4	RANDOM(Min_CASEVAC_Time_from_field_to_Stage_4, Max_CASEVAC_Time_from_field_to_Stage_4)			
"CASEVAC_Yes/No_direct_to_Stage_4"	MONTECARLO(Probability_of_Available_CASEVAC_direct_to_Stage_4)			
Ground_MEDEVAC_direct_to_Stage_4[Severity](t)	Ground_MEDEVAC_direct_to_Stage_4[Severity](t - dt) + (Transferring_to_MEDEVAC_direct_to_Stage_4[Severity] - Moving_to_Stage_4_triage_from_MEDEVAC_1[Severity]) * dt	INIT Ground_MEDEVAC_direct_to_Stage_4[Severity] = 0 COOK TIME = MEDEVAC_Evac_Time_direct_to_Stage_4 CAPACITY = MEDEVAC_Capacity_based_on_severity*"MEDEVAC_Yes/No_direct_to_Stage_4" FILL TIME = 0.33 CLEAN TIME = RANDOM (MEDEVAC_Evac_Time_direct_to_Stage_4, 4*MEDEVAC_Evac_Time_direct_to_Stage_4) ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
Helicopter_Evac_direct_to_Stage_4[Severity](t)	Helicopter_Evac_direct_to_Stage_4[Severity](t - dt) + (Transferring_to_Helicopter_Evac_direct_to_Stage_4[Severity] - Moving_to_Stage_4_triage_from_Helo_1[Severity]) * dt	INIT Helicopter_Evac_direct_to_Stage_4[Severity] = 0 COOK TIME = Helo_Evac_Time_direct_to_Stage_4 CAPACITY = Helicopter_Capacity_based_on_severity*"Helo_Yes/No_direct_to_Stage_4" FILL TIME = 0.33 CLEAN TIME = RANDOM (Helo_Evac_Time_direct_to_Stage_4, 4*Helo_Evac_Time_direct_to_Stage_4) ARREST IF "Helo_Yes/No" <> 0 ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
Helo_Evac_Time_direct_to_Stage_4	RANDOM(Min_Helo_Evac_Time_from_field_to_Stage_4, Max_Helo_Evac_Time_from_field_to_Stage_4)			
"Helo_Yes/No_direct_to_Stage_4"	MONTECARLO(Probability_of_Available_Helo_direct_to_Stage_4)			
Max_CASEVAC_Time_from_field_to_Stage_4	4			
Max_Helo_Evac_Time_from_field_to_Stage_4	2			
Max_MEDEVAC_Time_from_field_to_Stage_4	4			
MEDEVAC_Evac_Time_direct_to_Stage_4	RANDOM(Min_MEDEVAC_Time_from_field_to_Stage_4, Max_MEDEVAC_Time_from_field_to_Stage_4)			
"MEDEVAC_Yes/No_direct_to_Stage_4"	MONTECARLO(Probability_of_Available_MEDEVAC_direct_to_Stage_4)			
Min_CASEVAC_Time_from_field_to_Stage_4	2			
Min_Helo_Evac_Time_from_field_to_Stage_4	0.5			
Min_MEDEVAC_Time_from_field_to_Stage_4	2			
Moving_to_Stage_4_triage_from_Helo_1[Severity]	OVEN OUTFLOW	TIME STAMPED INFLOW PRIORITY: 17	People/Hours	
Moving_to_Stage_4_triage_from_MEDEVAC_1[Severity]	OVEN OUTFLOW	TIME STAMPED INFLOW PRIORITY: 25	People/Hours	
Probability_of_Available_CASEVAC_direct_to_Stage_4	25			
Probability_of_Available_Helo_direct_to_Stage_4	0			
Probability_of_Available_MEDEVAC_direct_to_Stage_4	2			
Transferring_to_CASEVAC_direct_to_Stage_4[Severity]	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 10	People/Hours	
Transferring_to_Helicopter_Evac_direct_to_Stage_4[Severity]	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 1	People/Hours	
Transferring_to_MEDEVAC_direct_to_Stage_4[Severity]	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 5	People/Hours	

Table 18. Equations for Evacuation from Stage 2 to Stage 4.[272]

E. GW/UW CASUALTY TREATMENT STAGE 3

Figures 49–52 make up the GW/UW Casualty Treatment Stage 3. As seen in the causal loop diagrams, the number of surgical teams and the blood supply are the primary contributers to this section of the system. This model currently only depicts one austere surgical team and does not capture the training process. It does, however, include a supply sector that was not originally depicted in the causal loop diagram that affects every component and is not unique.

The sector "Stage 3 (DCR/DCS)" in Figure 49 will be described first, and the equations for this section are in Table 19.

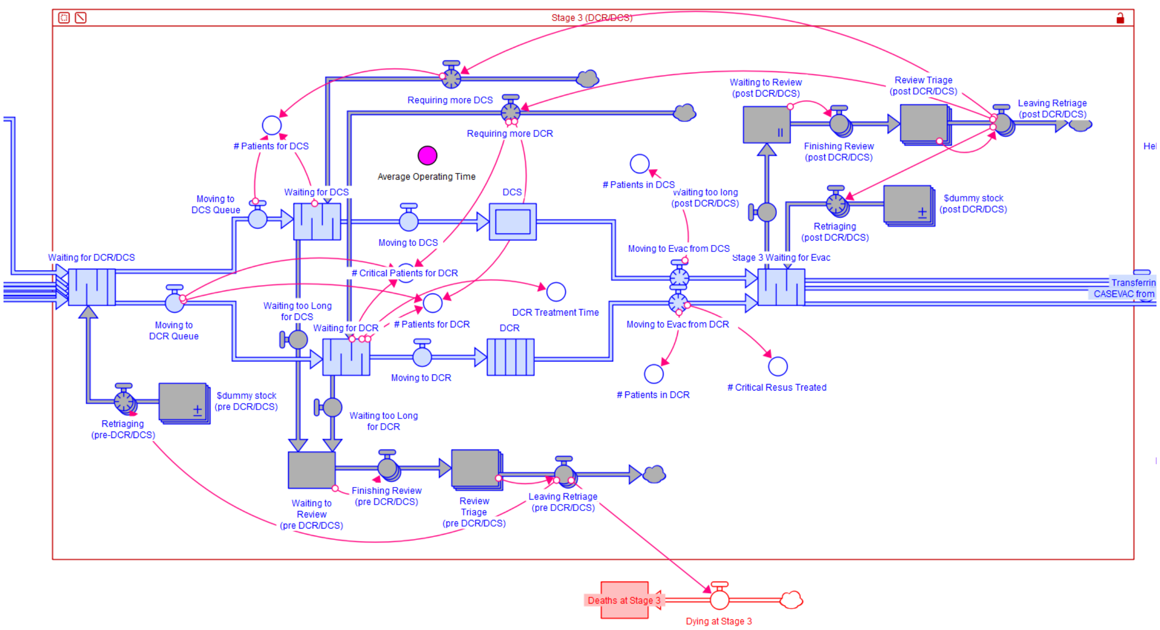

Figure 49. Casualty Treatment Stage 3, Patient Treatment Sector.[273]

Patients arrive at a non-arrayed queue, "Waiting for DCR/DCS" (full equation not included in Table 19), which is prioritized by attribute (Severity). Patients arriving with an

[272] Adapted from ISEE Systems, Stella Architect.

[273] Adapted from ISEE Systems, Stella Architect.

attribute of 1 (Severity of "Surgical Critical") are placed into the queue first. Because only Surgical Critical patients will require DCS, the patients must be divided up into different queues "Waiting for DCS" (those requiring surgery) and "Waiting for DCR" (all others). This is done by restricting the outflows from "Waiting for DCR/DCS" based on the appropriate attributes. "Moving to DCS Queue" is restricted by attribute 1 (Surgical Critical) and "Moving to DCR Queue" is restrictd to attributes 2–4 (Critical to Minimal). If these patients were not separated in this fashion, then because higher priority patients are at the front of the queue, if there were any higher priortity patients waiting for the DCS oven, no patients would flow to the DCR conveyor. The initial value of these queues is 0 and the inflows of patients are prioritized based on attribute (Severity).

The downstream stock from "Waiting for DCS" is a non-arrayed oven ("DCS") because each surgical team only has one operating element. The "DCS" oven has a CAPACITY of 1 because each operating element can only operate on one patient at a time. The oven's initial value is 0 and the COOK TIME is based on the converter "Average Operating Time" that can be set by the end-user based on performance data for a given surgical team and is currently set to 0.75 hours (45 minutes). The "DCS" CLEAN TIME has been set to 0.08 hours (5 minutes) to allow for the movement of patients to/from the operating table and resetting surgical and anesthesia equipment. The oven outflow "Moving to Evac from DCS" again time-stamps the patients because they have now received DCS but not definitive care.

The stock downstream from "Waiting for DCR" is a non-arrayed conveyor ("DCR") because the resuscitation team continuously treats patients while starting the resuscitation of others. The "DCR" conveyor's initial value is 0, CAPACITY is 8, and the TRANSIT TIME is based on the converter "DCR Treatment Time," which is determined by the severity of patients to be treated. "DCR Treatment Time" uses the ATTRMIN built-in to vary the TRANSIT TIME based on patient severity (patients who are more critical will take a longer time to treat than those with less severe injuries). "DCR Treatment Time" uses the "Waiting for DCR" queue value with ATTRMIN logic. For those patients with an attriute value "Critical" waiting in "Waiting for DCR," the value is set to 0.5 hours (30 minutes). For those with an attribute value "Urgent," the value is set to 0.17 hours (10 minutes), and “Minimal” is 0.08 (5 minutes). The conveyor outflow “Moving to Evac from DCR” again time-stamps the patients because they have now received needed resuscitation but not definitive care.

As noted in Table 19, the treatment of patients in the oven “DCS” and the conveyor “DCR” is limited by “Stage 3 Blood Supply” and “Stage 3 Medical Supply.” These converters belong to the sectors “Blood Supply for Stage 3” and “Supply Sector for Stage 3” and represents the amount of blood and supply units, respectively, available for use for treatment. “DCS” and “DCR” use an ARREST IF function. This function stops the oven if the value listed is anything other than 0. The equation used for this oven is IF “Stage 3 Blood Supply” < 1 OR “Stage 3 Medical Supply” < 1 THEN 1 ELSE 0, which means that if there is no on-hand blood or medical supplies, then a value of 1 is entered into ARREST IF. Because this value is not 0, the oven and conveyor will arrest. This arrest likely occurs too late in the process, specifically for blood inventory as most patients will require more than one unit of blood in surgery or resuscitation. The processes for determining “Stage 3 Blood Supply” and “Stage 3 Medical Supply” are discussed later in this section.

The non-arrayed queue “Waiting for Evac (post DCS/DCR)” (full equation not included in Table 19) prioritizes patients treated by the medics based on their clinical severity so they are placed on an evacuation platform first. Patients with lower severities will remain in the queue until higher priorities are evacuated. The queue is initialized at 0, prioritizes patients on attributes, and uses a round robin selection for evacuation platforms (discussed later).

	Equation	Properties	Units	Annotation
"Stage_3_(DCR/DCS)":				
"#_Critical_Patients_for_DCR"	ATTRCOUNT(Waiting_for_DCR, Severity.Critical)+(DT*ATTRCOUNT(Moving_to_DCR_Queue, Severity.Critical))+(DT*ATTRCOUNT(Requiring_more_DCR, Severity.Critical))		People	
"#_Critical_Resus_Treated"	DT*ATTRCOUNT(Moving_to_Evac_from_DCR, Severity.Critical)		People	
"#_Patients_for_DCR"	Waiting_for_DCR+(DT*Moving_to_DCR_Queue)+(DT*Requiring_more_DCR)			
"#_Patients_for_DCS"	Waiting_for_DCS+(DT*Moving_to_DCS_Queue)+(DT*Requiring_more_DCS)			
"#_Patients_in_DCR"	DT*ATTRCOUNT(Moving_to_Evac_from_DCR, Severity.Critical, Severity.Minimal)			
"#_Patients_in_DCS"	DT*ATTRCOUNT(Moving_to_Evac_from_DCS, Severity.Critical, Severity.Minimal)			
Average_Operating_Time	0.75		Hours	
DCR(t)	DCR(t - dt) + (Moving_to_DCR - Moving_to_Evac_from_DCR) * dt	INIT DCR = 0 TRANSIT TIME = DCR_Treatment_Time CAPACITY = 8 ARREST IF IF Stage_3_Blood_Supply < 1 OR Stage_3_Medical_Supply < 1 THEN 1 ELSE 0 <> 0 DISCRETE ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	CONVEYOR
DCR_Treatment_Time	IF ATTRMIN(Waiting_for_DCR) = Severity.Critical THEN 0.5 ELSE IF ATTRMIN(Waiting_for_DCR) = Severity.Urgent THEN 0.17 ELSE 0.08			
DCS(t)	DCS(t - dt) + (Moving_to_DCS - Moving_to_Evac_from_DCS) * dt	INIT DCS = 0 COOK TIME = Average_Operating_Time CAPACITY = 1 CLEAN TIME = 0.08 ARREST IF IF Stage_3_Blood_Supply < 1 OR Stage_3_Medical_Supply < 1 THEN 1 ELSE 0 <> 0 ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
Moving_to_DCR	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 2	People /Hours	
Moving_to_DCR_Queue	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 RESTRICT BY ATTRIBUTE = 2,3,4 INFLOW PRIORITY: 1 OUTFLOW PRIORITY: 2	People /Hours	
Moving_to_DCS	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 1	People /Hours	
Moving_to_DCS_Queue	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 RESTRICT BY ATTRIBUTE = 1 INFLOW PRIORITY: 1 OUTFLOW PRIORITY: 1	People /Hours	
Moving_to_Evac_from_DCR	CONVEYOR OUTFLOW	TIME STAMPED INFLOW PRIORITY: 2	People /Hours	
Moving_to_Evac_from_DCS	OVEN OUTFLOW	TIME STAMPED INFLOW PRIORITY: 1	People /Hours	
Stage_3_Waiting_for_Evac(t)	Stage_3_Waiting_for_Evac(t - dt) + (Moving_to_Evac_from_DCS + Moving_to_Evac_from_DCR + "Retriaging_(post_DCR/DCS)"[Surgical_Critical] + "Retriaging_(post_DCR/DCS)"[Critical] + "Retriaging_(post_DCR/DCS)"[Urgent] + "Retriaging_(post_DCR/DCS)"[Minimal] - "Waiting_too_long_(post_DCR/DCS)" - Transferring_to_Helicopter_Evac_from_Stage_3[Surgical_Criti	INIT Stage_3_Waiting_for_Evac = 0 PRIORITIZE INFLOWS BASED ON ATTRIBUTE VALUES USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION	People	QUEUE
Waiting_for_DCR(t)	Waiting_for_DCR(t - dt) + (Moving_to_DCR_Queue + Requiring_more_DCR - Waiting_too_Long_for_DCR - Moving_to_DCR) * dt	INIT Waiting_for_DCR = 0 USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION	People	QUEUE
"Waiting_for_DCR/DCS"(t)	"Waiting_for_DCR/DCS"(t - dt) + ("Retriaging_(pre-DCR/DCS)"[Surgical_Critical] + "Retriaging_(pre-DCR/DCS)"[Critical] + "Retriaging_(pre-DCR/DCS)"[Urgent] + "Retriaging_(pre-DCR/DCS)"[Minimal] + Moving_to_Stage_3_triage_from_Helo[Surgical_Critical] + Moving_to_Stage_3_triage_from_Helo[Critical] + Moving_to_Stage_3_triage_from_Helo[Urgent] + Moving_to_Stage_3_triage_from_Helo[Minimal] + Moving_to_Stage_3_triage_from_CASEVAC[Surgical_Critical]	INIT "Waiting_for_DCR/DCS" = 0 PRIORITIZE INFLOWS BASED ON ATTRIBUTE VALUES USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION	People	QUEUE
Waiting_for_DCS(t)	Waiting_for_DCS(t - dt) + (Moving_to_DCS_Queue + Requiring_more_DCS - Moving_to_DCS - Waiting_too_Long_for_DCS) * dt	INIT Waiting_for_DCS = 0 PRIORITIZE INFLOWS BASED ON ATTRIBUTE VALUES USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION	People	QUEUE

Table 19. Equations for Stage 3 Medical Treatment.[274]

The decompensation of patients using grey stocks and flows, and Table 20 includes the equations for these processes described next.

The queues "Waiting for DCS" and "Waiting for DCR" have the outflows "Waiting too Long for DCS" and "Waiting to Long for DCR," respectively. These outflows use the time-stamp given at the flows from evacuation to purge patients after 1 hour and lead to "Waiting to Review (pre DCR/DCS)." These outflows are universal for all attributes in the queues, so even patients in "Waiting for DCR" with a "Minimal" severity who have been waiting for 1 hour will go through this system. The non-arrayed stock "Waiting to Review (pre-DCR/DCS)" is a placeholder for these purged patients from both queues "Waiting for DCS" and "Waiting for DCR." "Finishing Review" is an arrayed (Severity) flow that sorts the patients by severity using the ATTRCOUNT function and value of "Waiting to Review (pre DCR/DCS)." The patients, now organized by severity, enter the arrayed (Severity) stock "Review Triage (pre DCR/DCS)." The arrayed (Severity) flow "Leaving Retriage (pre DCR/DCS)" PULSEs the patients from "Review Triage (pre DCR/DCS)," and the resulting flow rate is utilized to reclassify patients.

The most critical patients, "Surgical Critical" and "Critical," who have been waiting too long for DCR/DCS cannot be classified to a more severe category and will die from lack of treatment. This is accounted for by the non-arrayed flow "Dying at Stage 3," which is not included in the equations for Table 20, but is included later (Table 29). Patients labeled "Urgent" who have been waiting too long for treatment, however, will become more critical and require re-classification. This is done utilizing the arrayed (Severity) flow "Retriaging (pre-DCR/DCS)." The "$dummy stock (pre DCR/DCS)" is used strictly to establish an array (Severity) of patients without previously assigned attributes and its initial value is 0.

"Retriaging (pre-DCR/DCS)" uses the values of "Leaving Retriage (pre DCR/DCS)" to re-estabish patient attributes. The flow of patients from the Critical "$dummy stock (pre-DCR/DCS)" (i.e., the patients who were previously Urgent, but now Critical) is equal to the flow of Urgent patients in "Leaving Retriage (pre-DCR/DCS)." The flow of patients from the Surgical Critical "$dummy stock (pre-DCR/DCS)" is 0 because patients are not reclassified into the Surgical Critical category. While some Urgent patients may need surgery, only a fraction would require more expeditious surgery and this would be difficult to accurately account for in this model. The flow of patients from the Urgent "$dummy stock (pre-DCR/DCS)" is 0 because the only less-severe category is Minimal, and these patients rarely decompensate to a higher priority. Finally, the flow of patients from the Minimal "$dummy stock(pre-DCR/DCS)" (i.e., the patients who were previously Minimal and continue to be classified as such) is equal to the flow of Minimal patients in "Leaving Retriage (pre-DCR/DCS)." The flow "Retriaging (pre DCR/DCS)" moves reclassified patients to "Waiting for DCR/DCS" and establishes a new time stamp.

The second point of the DCR/DCS sector that reclassifies patients is at the "Stage 3 Waiting for Evac" queue, which has outflow "Waiting to Long (post DCR/DCS)." This outflow uses the time-stamp given at the flows "Moving to Evac from DCS" and "Moving to Evac from DCR" to purge patients after 1 hour and leads to "Waiting to Review (post DCR/DCS)." From here, the process is the same as the logic for "Waiting to Review (pre-DCR/DCS)" and will not be described here. However, the most critical patients, "Surgical Critical" and "Critical," who have been waiting too long for evacuation after DCR/DCS cannot be classified to a more severe category. They do, however, have the means for further advanced treatment. "Requiring more DCS" and "Requiring more DCR" account for the Surgical Critical and Critical patients, respectively, moving through "Leaving Retriage (post DCR/DCS)." "Requiring more DCS" and "Requiring more DCR" re-stamp times, assign attributes, and move the patients to "Waiting for DCS" and "Waiting for DCR." They will not necessarily move to the front of the line if there are other high-priority patients waiting, which is a limitation of the system. Should the patients be waiting another hour in those queues, they will be subject to "Waiting too Long for DCS" and "Waiting too Long for DCR" purging outflows. Through this process, they will further decompensate and die.

	Equation	Properties	Units	Annotation
"$dummy_stock_(post_DCR/DCS)"[Severity](t)	"$dummy_stock_(post_DCR/DCS)"[Severity](t - dt) + (- "Retriaging_(post_DCR/DCS)"[Severity]) * dt	INIT "$dummy_stock_(post_DCR/DCS)"[Severity] = 0	People	
"$dummy_stock_(pre_DCR/DCS)"[Severity](t)	"$dummy_stock_(pre_DCR/DCS)"[Severity](t - dt) + (- "Retriaging_(pre-DCR/DCS)"[Severity]) * dt	INIT "$dummy_stock_(pre_DCR/DCS)"[Severity] = 0	People	
"Finishing_Review_(post_DCR/DCS)"[Severity]	PULSE(ATTRCOUNT("Waiting_to_Review_(post_DCR/DCS)", Severity))		People /Hours	UNIFLOW
"Finishing_Review_(pre_DCR/DCS)"[Severity]	PULSE(ATTRCOUNT("Waiting_to_Review_(pre_DCR/DCS)", Severity))		People /Hours	UNIFLOW
"Leaving_Retriage_(post_DCR/DCS)"[Severity]	PULSE("Review_Triage_(post_DCR/DCS)")		People /Hours	UNIFLOW
"Leaving_Retriage_(pre_DCR/DCS)"[Severity]	PULSE("Review_Triage_(pre_DCR/DCS)")		People /Hours	UNIFLOW
Requiring_more_DCR	"Leaving_Retriage_(post_DCR/DCS)"[Critical]	TIME STAMPED ATTRIBUTE VALUE = Severity.Critical INFLOW PRIORITY: 2	People /Hours	UNIFLOW
Requiring_more_DCS	"Leaving_Retriage_(post_DCR/DCS)"[Surgical_Critical]	TIME STAMPED ATTRIBUTE VALUE = Severity.Surgical_Critical INFLOW PRIORITY: 2	People /Hours	UNIFLOW
"Retriaging_(post_DCR/DCS)"[Severity]	IF Severity = Severity.Critical THEN "Leaving_Retriage_(post_DCR/DCS)"[Urgent] ELSE IF Severity = Severity.Surgical_Critical THEN 0 ELSE IF Severity = Severity.Urgent THEN 0 ELSE "Leaving_Retriage_(post_DCR/DCS)"	TIME STAMPED ATTRIBUTE VALUE = Severity INFLOW PRIORITY: 3	People /Hours	UNIFLOW
"Retriaging_(pre-DCR/DCS)"[Severity]	IF Severity = Severity.Critical THEN "Leaving_Retriage_(pre_DCR/DCS)"[Urgent] ELSE IF Severity = Severity.Surgical_Critical THEN 0 ELSE IF Severity = Severity.Urgent THEN 0 ELSE "Leaving_Retriage_(pre_DCR/DCS)"	TIME STAMPED ATTRIBUTE VALUE = Severity INFLOW PRIORITY: 1	People /Hours	UNIFLOW
"Review_Triage_(post_DCR/DCS)"[Severity](t)	"Review_Triage_(post_DCR/DCS)"[Severity](t - dt) + ("Finishing_Review_(post_DCR/DCS)"[Severity] - "Leaving_Retriage_(post_DCR/DCS)"[Severity]) * dt	INIT "Review_Triage_(post_DCR/DCS)"[Severity] = 0	People	NON-NEGATIVE
"Review_Triage_(pre_DCR/DCS)"[Severity](t)	"Review_Triage_(pre_DCR/DCS)"[Severity](t - dt) + ("Finishing_Review_(pre_DCR/DCS)"[Severity] - "Leaving_Retriage_(pre_DCR/DCS)"[Severity]) * dt	INIT "Review_Triage_(pre_DCR/DCS)"[Severity] = 0	People	NON-NEGATIVE
"Waiting_to_Review_(post_DCR/DCS)"(t)	"Waiting_to_Review_(post_DCR/DCS)"(t - dt) + ("Waiting_too_long_(post_DCR/DCS)" - "Finishing_Review_(post_DCR/DCS)"[Surgical_Critical] - "Finishing_Review_(post_DCR/DCS)"[Critical] - "Finishing_Review_(post_DCR/DCS)"[Urgent] - "Finishing_Review_(post_DCR/DCS)"[Minimal]) * dt	INIT "Waiting_to_Review_(post_DCR/DCS)" = 0	People	NON-NEGATIVE
"Waiting_to_Review_(pre_DCR/DCS)"(t)	"Waiting_to_Review_(pre_DCR/DCS)"(t - dt) + (Waiting_too_Long_for_DCS + Waiting_too_Long_for_DCR - "Finishing_Review_(pre_DCR/DCS)"[Surgical_Critical] - "Finishing_Review_(pre_DCR/DCS)"[Critical] - "Finishing_Review_(pre_DCR/DCS)"[Urgent] - "Finishing_Review_(pre_DCR/DCS)"[Minimal]) * dt	INIT "Waiting_to_Review_(pre_DCR/DCS)" = 0	People	NON-NEGATIVE
"Waiting_too_long_(post_DCR/DCS)"	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 PURGE AFTER AGE = 1 OUTFLOW PRIORITY: 1	People /Hours	
Waiting_too_Long_for_DCR	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 PURGE AFTER AGE = 1 OUTFLOW PRIORITY: 1	People /Hours	
Waiting_too_Long_for_DCS	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 PURGE AFTER AGE = 1 OUTFLOW PRIORITY: 2	People /Hours	

Table 20. Equations for Stage 3 Worsening Patient Conditions.[275]

The "Blood Supply for Stage 3" sector (Figure 50) depicts the system for blood acquisition treatment of patients for a Stage 3 team. There is not a cache for blood as the

[275] Adapted from ISEE Systems, Stella Architect.

storage of blood is not logistically feasible away from the forward teams. Equations are included in Table 21.

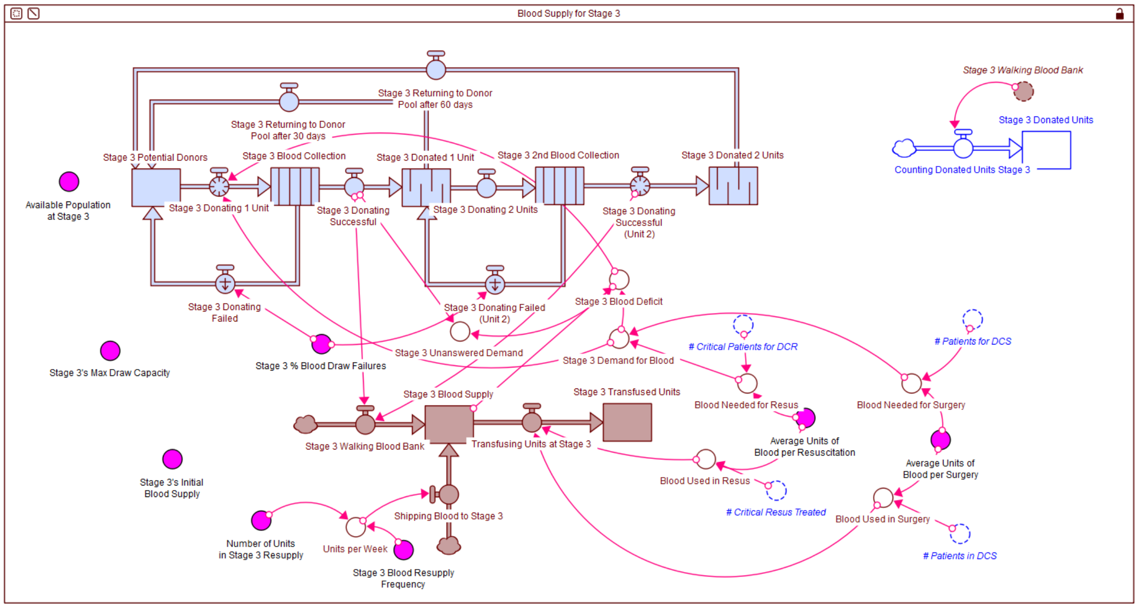

Figure 50. Casualty Treatment Stage 3, Blood Supply Sector.[276]

The pink converter "Stage 3's Initial Blood Supply" is entered by the user based on the operational environment of the surgical team and is currently set to 20 units. This number will be limited based on the holding capacity for blood, not accounted for in this model. This converter determines the initial value of "Stage 3 Blood Supply" for the surgical team represented in this sector. The "Number of Units in Stage 3 Resupply" is the number of blood units typically delivered per each resupply movement (set by user) and is currently set to 15 units. The "Stage 3 Blood Resupply Frequency" is the number of blood deliveries per week (set by user) and is currently set to 1. "Units per Week" multiplies "Number of Units in Stage 3 Resupply" and "Stage 3 Blood Resupply Frequency" to determine blood units per week. The flow "Shipping Blood to Stage 3" uses the "Units per

[276] Adapted from ISEE Systems, Stella Architect.

Week" in a PULSE with an initial and recurring values of "Units per Week" at an interval set to 168 hours (1 week).

The "Stage 3 Blood Supply" stock is drained by the flow "Transfusing Units at Stage 3," which PULSEs the sum of units from "Blood Used in Surgery" and "Blood Used in Resus." These converters are calculated based on the average units of blood used and the number of patients receiving resuscitation or surgery. The average units of blood used per surgery and per resuscitation is set by the user using the converters "Average Units of Blood per Surgery" (currently set to 7) and "Average Units of Blood per Resuscitation" (currently set to 3). "Blood Used in Surgery" multiplies the "Average Units of Blood per Surgery" by the ghost converter "# Patients in DCS." "# Patients in DCS" can be found in Figure 49 and tallies the total number of patients from "Moving to Evac from DCS." "Blood Used in Resus" multiplies the "Average Units of Blood per Resus" by the value of the ghost converter "# Critical Resus Treated." "# Critical Resus Treated" can be found in Figure 49 and uses the ATTRCOUNT function to count the number of Critical patients in the "Moving to Evac from DCR" flow. Urgent and Minimal patients are not accounted for because their injuries do not require blood transfusions.

"Stage 3 Blood Deficit" converter determines the need for a walking blood bank and requires a series of calculations. "Stage 3 Blood Deficit" is calculated by subtracting the "Stage 3 Blood Supply" from "Stage 3 Demand for Blood." A positive number for "Stage 3 Blood Deficit" means there is not enough blood on hand to treat patients, and a negative number means there is an adequate blood supply. "Stage 3 Demand for Blood" is determined by the converters "Blood Needed for Surgery" and "Blood Needed for Resus." These converters multiply the average units of blood used and the number of anticipated patients requiring resuscitation or surgery. "Blood Needed for Surgery" multiplies the "Average Units of Blood per Surgery" by "# Patients for DCS" (ghost converter from Figure 49). "# Patients for DCS" calculates the total number of patients moving through the flows "Moving to DCS Queue" and "Requiring more DCS" and patients held in the queue "Waiting for DCS" for a given timestep. "Blood Needed for Resuscitation" multiplies the "Average Units of Blood per Resus" by "# Critical Patients for DCR" (ghost converter from Figure 49). "# Critical Patients for DCR" uses the ATTRCOUNT function to calculate the total number of Critical patients per timestep moving through the flows "Moving to DCR Queue" and "Requiring more DCS" and patients held in the queue "Waiting for DCR."

In the event "Stage 3 Blood Deficit" is > 0, the process for a walking blood bank begins (blue filled flows and stocks in Figure 50, equations in Table 21). The process starts with the non-negative stock of "Stage 3 Potential Donors," initialized by the "Available Population at Stage 3" and the Minimal patients in "Waiting for DCR," calculated by the ATTRCOUNT function. Minimal patients receiving treatment or who have moved to the evacuation queue are not included as the priority for them is to receive treatment or evacuation rather than to donate blood. If "Stage 3 Blood Deficit" is > 0, then the flow "Stage 3 Donating 1 Unit" PULSEs the value of "Stage 3 Demand for Blood." While "Stage 3 Demand for Blood" likely accounts for more blood than the deficit, the extra donors counter the failure rate of donation and allow for extra blood to have on-hand. "Stage 3 Donating 1 Unit" timestamps patients and moves them to a conveyor "Stage 3 Blood Collection." The "Stage 3 Blood Collection" CAPACITY is limited by "Stage 3's Max Draw Capacity," representing the number of simultaneous blood collections the team can handle. This converter is to be set by the user and is currently 20. The TRANSIT TIME is 0.5 hours (30 minutes), which accounts for the set up and collection of a unit of blood from one person. There is a leak ("Stage 3 Donating Failed") from the conveyor that represents patients who do not complete a donation due to passing out or failure of the collection materials. The leakage zone is throughout the conveyor and the fraction is equal to the "Stage 3 % Blood Draw Failures" converter (set by user, currently 10%). Donors who are not leaked from the conveyor then move through "Stage 3 Donating Successful" to a queue "Stage 3 Donated 1 Unit." Donors will wait in this queue until either a 2nd unit of blood is needed (described later) or 30 days have passed. After 30 days, they can go back to the regular pool of people.

	Equation	Properties	Units	Annotation
Blood_Supply_for_Stage_3:				
Available_Population_at_Stage_3	200		People	
Average_Units_of_Blood_per_Resuscitation	3		Units	
Average_Units_of_Blood_per_Surgery	7		Units	
Blood_Needed_for_Resus	Average_Units_of_Blood_per_Resuscitation*("#_Critical_Patients_for_DCR")		Units	
Blood_Needed_for_Surgery	Average_Units_of_Blood_per_Surgery*("#_Patients_for_DCS")		Units	
Blood_Used_in_Resus	Average_Units_of_Blood_per_Resuscitation*"#_Critical_Resus_Treated"		Units	
Blood_Used_in_Surgery	Average_Units_of_Blood_per_Surgery*"#_Patients_in_DCS"		Units	
Counting_Donated_Units_Stage_3	Stage_3_Walking_Blood_Bank			UNIFLOW
Number_of_Units_in_Stage_3_Resupply	15		Units	
Shipping_Blood_to_Stage_3	PULSE(Units_per_Week, Units_per_Week, 168)		Units/Hours	UNIFLOW
Stage_3_%_Blood_Draw_Failures	10			
Stage_3_2nd_Blood_Collection(t)	Stage_3_2nd_Blood_Collection(t - dt) + (Stage_3_Donating_2_Units - "Stage_3_Donating_Successful_(Unit_2)" - "Stage_3_Donating_Failed_(Unit_2)") * dt	INIT Stage_3_2nd_Blood_Collection = 0 TRANSIT TIME = 0.5 INFLOW LIMIT = IF Stage_3_Unanswered_Demand > 0 THEN Stage_3_Unanswered_Demand ELSE 0 CAPACITY = Stage_3's_Max_Draw_Capacity DISCRETE ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	CONVEYOR
Stage_3_Blood_Collection(t)	Stage_3_Blood_Collection(t - dt) + (Stage_3_Donating_1_Unit - Stage_3_Donating_Successful - Stage_3_Donating_Failed) * dt	INIT Stage_3_Blood_Collection = 0 TRANSIT TIME = 0.5 CAPACITY = Stage_3's_Max_Draw_Capacity CONTINUOUS ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	CONVEYOR
Stage_3_Blood_Deficit	(Stage_3_Demand_for_Blood)-Stage_3_Blood_Supply			
Stage_3_Blood_Resupply_Frequency	0.5		Per Week	
Stage_3_Blood_Supply(t)	Stage_3_Blood_Supply(t - dt) + (Stage_3_Walking_Blood_Bank + Shipping_Blood_to_Stage_3 - Transfusing_Units_at_Stage_3) * dt	INIT Stage_3_Blood_Supply = Stage_3's_Initial_Blood_Supply	Units	NON-NEGATIVE
Stage_3_Demand_for_Blood	(Blood_Needed_for_Surgery+Blood_Needed_for_Resus)		Units	
Stage_3_Donated_1_Unit(t)	Stage_3_Donated_1_Unit(t - dt) + (Stage_3_Donating_Successful + "Stage_3_Donating_Failed_(Unit_2)" - Stage_3_Returning_to_Donor_Pool_after_30_days - Stage_3_Donating_2_Units) * dt	INIT Stage_3_Donated_1_Unit = 0	People	QUEUE
Stage_3_Donated_2_Units(t)	Stage_3_Donated_2_Units(t - dt) + ("Stage_3_Donating_Successful_(Unit_2)" - Stage_3_Returning_to_Donor_Pool_after_60_days) * dt	INIT Stage_3_Donated_2_Units = 0	People	QUEUE
Stage_3_Donated_Units(t)	Stage_3_Donated_Units(t - dt) + (Counting_Donated_Units_Stage_3) * dt	INIT Stage_3_Donated_Units = 0		NON-NEGATIVE
Stage_3_Donating_1_Unit	IF Stage_3_Blood_Deficit > 0 THEN PULSE(Stage_3_Demand_for_Blood) ELSE 0	TIME STAMPED	People/Hours	UNIFLOW
Stage_3_Donating_2_Units	QUEUE OUTFLOW	OUTFLOW PRIORITY: 2	People/Hours	
Stage_3_Donating_Failed	LEAKAGE OUTFLOW	LEAKAGE FRACTION = (Stage_3_%_Blood_Draw_Failures)/100 LINEAR LEAKAGE LEAK ZONE = 0% to 100% LEAK INTEGERS	People/Hours	
"Stage_3_Donating_Failed_(Unit_2)"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = (2*Stage_3_%_Blood_Draw_Failures)/100 LINEAR LEAKAGE LEAK ZONE = 0% to 100% LEAK INTEGERS INFLOW PRIORITY: 2	People/Hours	
Stage_3_Donating_Successful	CONVEYOR OUTFLOW	INFLOW PRIORITY: 1	People/Hours	
"Stage_3_Donating_Successful_(Unit_2)"	CONVEYOR OUTFLOW	TIME STAMPED	People/Hours	
Stage_3_Potential_Donors(t)	Stage_3_Potential_Donors(t - dt) + (Stage_3_Returning_to_Donor_Pool_after_30_days + Stage_3_Returning_to_Donor_Pool_after_60_days + Stage_3_Donating_Failed - Stage_3_Donating_1_Unit) * dt	INIT Stage_3_Potential_Donors = Available_Population_at_Stage_3 + ATTRCOUNT(Waiting_for_DCR, Severity.Minimal)	People	NON-NEGATIVE
Stage_3_Returning_to_Donor_Pool_after_30_days	QUEUE OUTFLOW	PURGE AFTER AGE = 1440 OUTFLOW PRIORITY: 1	People/Hours	
Stage_3_Returning_to_Donor_Pool_after_60_days	QUEUE OUTFLOW	PURGE AFTER AGE = 1440	People/Hours	
Stage_3_Transfused_Units(t)	Stage_3_Transfused_Units(t - dt) + (Transfusing_Units_at_Stage_3) * dt	INIT Stage_3_Transfused_Units = 0	Units	NON-NEGATIVE
Stage_3_Unanswered_Demand	Stage_3_Blood_Deficit - Stage_3_Donating_Successful		Units	
Stage_3_Walking_Blood_Bank	Stage_3_Donating_Successful + "Stage_3_Donating_Successful_(Unit_2)"		Units/Hours	UNIFLOW
Stage_3's_Initial_Blood_Supply	20		Units	
Stage_3's_Max_Draw_Capacity	20			
Transfusing_Units_at_Stage_3	PULSE(Blood_Used_in_Surgery+Blood_Used_in_Resus)		Units/Hours	UNIFLOW
Units_per_Week	Number_of_Units_in_Stage_3_Resupply*Stage_3_Blood_Resupply_Frequency		Units	

Table 21. Equations for Stage 3 Blood Supply.[277]

The completed blood draws ("Stage 3 Donating Successful") are then used in re-evaluating the deficit. "Stage 3 Unanswered Demand" is a converter that subtracts "Stage 3 Donating Successful" from "Stage 3 Blood Deficit." If "Stage 3 Unanswered Demand" is > 0, then flow to "Stage 3 2nd Blood Collection" begins. This conveyor's INFLOW LIMIT prevents unnecessary collection of 2 units through an IF/THEN logic series. If "Stage 3 Unanswered Demand" > 0, then the limit is the value of "Stage 3 Unanswered Demand." Otherwise, the Inflow Limit is 0. The "Stage 3 2nd Blood Collection" CAPACITY is limited by "Stage 3's Max Draw Capacity." representing the number of simultaneous blood collections the team can handle. The TRANSIT TIME is 0.5 hours (30 minutes). There is a leak ("Stage 3 Donating Failed (Unit 2)") from the conveyor that represents patients who do not complete donating a second unit due to passing out or failure of the collection materials. The leakage zone is throughout the conveyor and the fraction is equal to 2 x the "Stage 3 % Blood Draw Failures" converter because failures become more common with second units. Patients then move through "Stage 3 Donating Successful (Unit 2)" to the final queue "Stage 3 Donated 2 Units" and are re-timestamped. Donors will wait in this queue until 60 days have passed.[278] After 60 days, they can go back to the regular pool of potential donors.

Blood collected from the walking blood bank is added to the "Stage 3 Blood Supply" by the flow "Stage 3 Walking Blood Bank." This flow's value is the sum of the flows "Stage 3 Donating Successful" and "Stage 3 Donating Successful (Unit 2)." "Stage 3 Walking Blood Bank" is used as the flow value for "Counting Donated Units Stage 3." This flow leads to the stock "Stage 3 Donated Units" that can provide the end-user with information regarding the amount of blood collected from walking blood banks.

The "Supply Sector for Stage 3" (Figure 51 and Table 22) depicts the system for medical supplies that has an effect on the treatment of patients in "DCR" and "DCS." The pink converters "Initial Average Stage 3 Units per Cache," "Number of Stage 3 Caches,"

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277 Adapted from ISEE Systems, Stella Architect.

278 Bahr et al., "Practical Considerations for a Military Whole Blood Program," e1032-1038; Fisher et al., "Low Titer Group O Whole Blood Resuscitation," 834–41.

and "Stage 3 On Site Medical Supply Capacity" are values entered by the user. This section utilizes the general construct of a Stage 3 Supply Unit. The number of patients this unit is designed to treat can also be set by the end-user using the converters "Number of Resuscitations per Unit" (currently set to 4) and "Number of Surgeries per Unit" (currently set to 2). The "Stage 3 On Site Medical Supply Capacity" is the amount of supplies the forward surgical team can have on hand and is currently set to 4. The "Initial Average Stage 3 Units per Cache" will vary depending on the size of available caches (set to 4), and the "Number of Stage 3 Caches" will vary depending on the operational environment (set to 10). "Initial Average Stage 3 Units per Cache" and "Number of Stage 3 Caches" are multiplied together to initialize the "Stage 3 Cache Supply" stock.

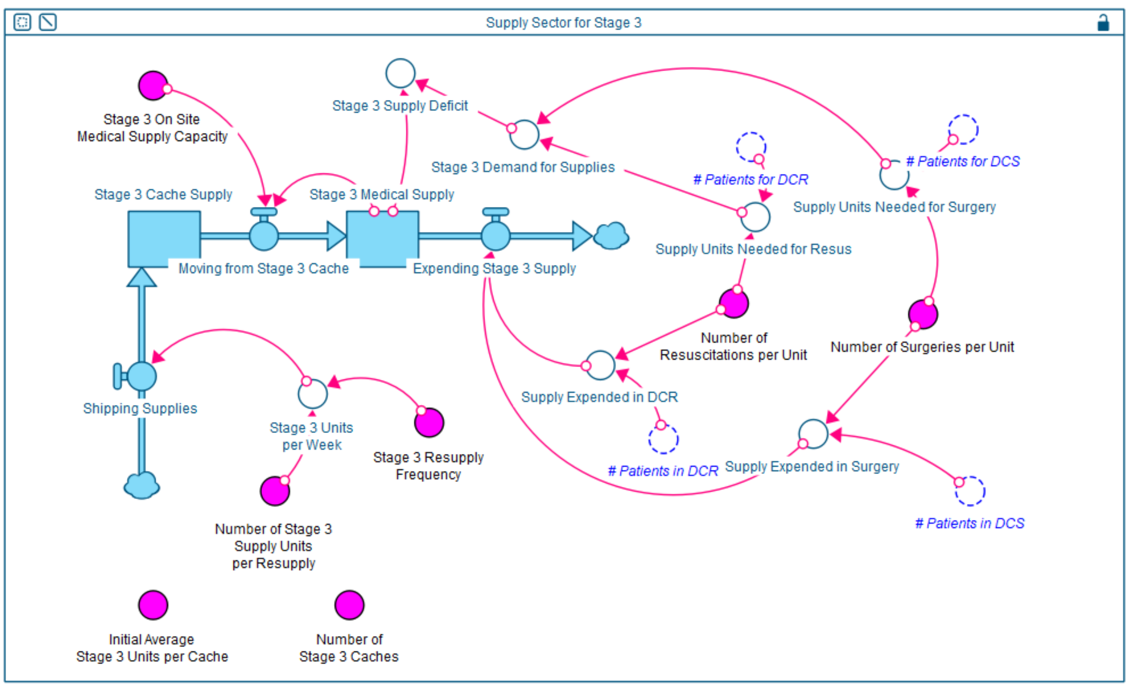

Figure 51. Casualty Treatment Stage 3, Medical Supply Sector.[279]

The "Number of Stage 3 Supply Units per Resupply" is the number of supply units typically delivered per each resupply movement (set by user) and is currently set to 4 units.

279 Adapted from ISEE Systems, Stella Architect.

The "Stage 3 Resupply Frequency" is the number of resupply deliveries per week (set by user) and is currently set to 0.5. "Stage 3 Units per Week" multiplies "Number of Stage 3 Supply Units per Resupply" and "Stage 3 Resupply Frequency" to determine units per week. The flow "Shipping Supplies" uses the "Stage 3 Units per Week" in a PULSE with an initial and recurring values of "Stage 3 Units per Week" at an interval set to 168 hours (1 week).

The calculations of "Stage 3 Supply Deficit" subtracts the "Stage 3 Medical Supply" from "Stage 3 Demand for Supplies." A positive number for "Stage 3 Supply Deficit" means there are not enough supplies on hand to treat patients, and a negative number means there is an adequate amount of supplies. "Stage 3 Demand for Supplies" is determined by the converters for "Supply Units Need for Resus" and "Supply Units Needed for Surgery." These converters multiply the average number of patients treated per supply unit by the number of anticipated patients requiring resuscitation or surgery. "Supply Units Needed for Resuscitation" divides "# Patients for DCR" by the "Number of Resuscitations per Unit." "# Patients for DCR" is a ghost converter from Figure 49 that calculates the total number of patients per timestep moving through the flows "Moving to DCR Queue" and "Requiring more DCS" and held in the queue "Waiting for DCR." Urgent and Minimal patients are included in this calculation to account for soft medical supplies used (gauze, ace wraps, etc.), although this could falsely increase the demand. "Supply Units Needed for Surgery" divides "# Patients for DCS" (ghost converter from Figure 49) by "Number of Surgeries per Unit." "# Patients for DCS" calculates the total number of patients moving through the flows "Moving to DCS Queue" and "Requiring more DCS" and patients held in the queue "Waiting for DCS" for a given timestep. "Stage 3 Demand for Supplies" adds the "Supply Units needed for Resuscitation" and "Supply Units Needed for Surgery." The "Supply Deficit" subtracts the "Stage 3 Medical Supply" from "Demand for Supplies."

When there is a deficit of supplies, supplies must be moved to the "Stage 3 Medical Supply" stock from the "Stage 3 Cache Supply." The flow "Moving from Stage 3 Cache" to "Stage 3 Medial Supply" is 0 unless the "Stage 3 Medical Supply" stock is < 2, which will trigger a PULSE of supply units to fill the "Stage 3 Medical Supply" to original capacity.

	Equation	Properties	Units	Annotation
Supply_Sector_for_Stage_3:				
Expending_Stage_3_Supply	PULSE(Supply_Expended_in_Surgery+Supply_Expended_in_DCR)		Units/Hours	UNIFLOW
Initial_Average_Stage_3_Units_per_Cache	4			
Moving_from_Stage_3_Cache	IF Stage_3_Medical_Supply < 2 THEN PULSE(Stage_3_On_Site_Medical_Supply_Capacity-Stage_3_Medical_Supply) ELSE 0		Units/Hours	UNIFLOW
Number_of_Resuscitations_per_Unit	4		People	
Number_of_Stage_3_Caches	10			
Number_of_Stage_3_Supply_Units_per_Resupply	4		Units	
Number_of_Surgeries_per_Unit	2			
Shipping_Supplies	PULSE(Stage_3_Units_per_Week, Stage_3_Units_per_Week, 168)		Units/Hours	UNIFLOW
Stage_3_Cache_Supply(t)	Stage_3_Cache_Supply(t - dt) + (Shipping_Supplies - Moving_from_Stage_3_Cache) * dt	INIT Stage_3_Cache_Supply = Initial_Average_Stage_3_Units_per_Cache*Number_of_Stage_3_Caches	Units	NON-NEGATIVE
Stage_3_Demand_for_Supplies	(Supply_Units_Needed_for_Surgery+Supply_Units_Needed_for_Resus)		Units	
Stage_3_Medical_Supply(t)	Stage_3_Medical_Supply(t - dt) + (Moving_from_Stage_3_Cache - Expending_Stage_3_Supply) * dt	INIT Stage_3_Medical_Supply = Stage_3_On_Site_Medical_Supply_Capacity	Units	NON-NEGATIVE
Stage_3_On_Site_Medical_Supply_Capacity	4			
Stage_3_Resupply_Frequency	0.5		Per Week	
Stage_3_Supply_Deficit	Stage_3_Demand_for_Supplies - Stage_3_Medical_Supply			
Stage_3_Units_per_Week	Number_of_Stage_3_Supply_Units_per_Resupply*Stage_3_Resupply_Frequency			
Supply_Expended_in_DCR	"#_Patients_in_DCR"/Number_of_Resuscitations_per_Unit		Units	
Supply_Expended_in_Surgery	"#_Patients_in_DCS"/Number_of_Surgeries_per_Unit		Units	
Supply_Units_Needed_for_Resus	("#_Patients_for_DCR")/Number_of_Resuscitations_per_Unit		Units	
Supply_Units_Needed_for_Surgery	("#_Patients_for_DCS")/Number_of_Surgeries_per_Unit		Units	

Table 22. Equations for Stage 3 Supply Sector.[280]

Casualty Treatment Stage 3 is also affected by the "Evac from Stage 3 to Stage 4" sector (Figure 52) as it causes the delays of evacuation, forcing patients to move through "Waiting too long (post DCR/DCS)." The same platforms described in previous evacuation sectors are used in this sector. Movement of patients from the non-arrayed queue "Waiting for Evac (post DCR/DCS)" (Figure 49) is through arrayed flows using a round robin selection of available evacuation platforms depicted by arrayed ovens "Helicopter Evac from Stage 3 to 4" (arrayed by and Severity), "CASEVAC to from Stage 3 to 4" (arrayed by Severity), and "Ground MEDEVAC from Stage 3 to 4" (arrayed by Severity).

280 Adapted from ISEE Systems, Stella Architect.

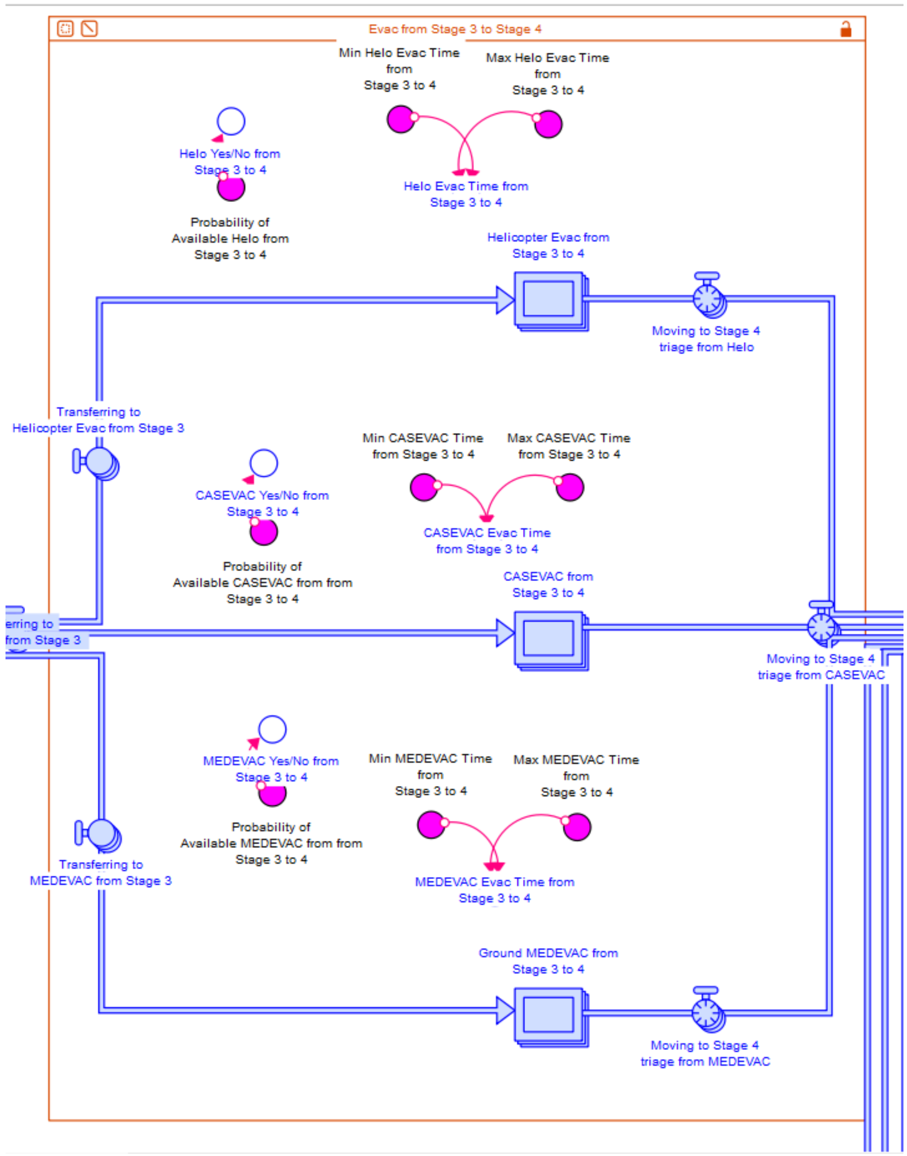

Figure 52. Casualty Treatment Stage 3, Evacuation Sector.[281]

Each oven in "Evac from Stage 3 to Stage 4" uses the same calculations with different values. Only the "CASEVAC from Stage 3 to 4" will be described here. Table 23 includes the equations used for the arrayed ovens in this sector and can be referenced for the remainder of the ovens. "CASEVAC from Stage 3 to 4" has a COOK TIME that simulates the time it takes to transport a patient to the next level of care defined by

281 Adapted from ISEE Systems, Stella Architect.

"CASEVAC Evac Time from Stage 3 to 4." "CASEVAC Evac Time from Stage 3 to 4" is a converter that randomizes a number between the set values in converters "Min CASEVAC Time from Stage 3 to 4" and "Max Helo CASEVAC Time from Stage 3 to 4." "CASEVAC Evac Time from Stage 3 to 4" is also utilized in the oven's CLEAN TIME, which randomizes a value between the "CASEVAC Evac Time from Stage 3 to 4" and 4 times the "CASEVAC Evac Time from Stage 3 to 4." The FILL TIME is 0.33 Hours (20 minutes). The oven CAPACITY uses the same arrayed (Severity) converter "CASEVAC Capacity based on Severity" as used for the other evacuation sectors since they are the same platforms with the same space.

The reduced availability of patient transport is also accounted for in the oven capacities. As seen in Table 23, the "CASEVAC from Stage 3 to 4" oven capacity includes "CASEVAC Capacity based on Severity" and a converter, "CASEVAC Yes/No from Stage 3 to 4," that will be either a 1 or 0, essentially functioning as a "on/off" switch for the oven capacity. "CASEVAC Yes/No from Stage 3 to 4" converter uses the MONTECARLO built-in that assigns a 1 or 0 based on a probability between 0–100, defined by "Probability of Available CASEVAC from Stage 3 to 4." "Probability of Available CASEVAC from Stage 3 to 4" is the probability that a CASEVAC will be available at any given time for the forward surgical teams and is set by the user. This probability is different than the probability at the previous stages given the different location of Stage 3 has a different operating environment and other variables affecting evacuation availability. The set probabilities for evacuation platforms will have an impact on the evacuation wait times, putting increased strain on teams with limited treatment resources and holding capability.

The oven outflow "Moving to Stage 4 triage from CASEVAC" timestamps patients for the upcoming queue "Waiting for Definitive Care" at Treatment Stage 4.

	Equation	Properties	Units	Annotation
Evac from Stage 3 to Stage 4:				
CASEVAC_Evac_Time_from_Stage_3_to_4	RANDOM(Min_CASEVAC_Time_from_Stage_3_to_4, Max_CASEVAC_Time_from_Stage_3_to_4)			
CASEVAC_from_Stage_3_to_4[Severity](t)	CASEVAC_from_Stage_3_to_4[Severity](t - dt) + (Transferring_to_CASEVAC_from_Stage_3[Severity] - Moving_to_Stage_4_triage_from_CASEVAC[Severity]) * dt	INIT CASEVAC_from_Stage_3_to_4[Severity] = 0 COOK TIME = CASEVAC_Evac_Time_from_Stage_3_to_4 CAPACITY = CASEVAC_Capacity_based_on_severity*"CASEVAC_Yes/No_from_Stage_3_to_4" FILL TIME = 0.33 CLEAN TIME = RANDOM (CASEVAC_Evac_Time_from_Stage_3_to_4, 4*CASEVAC_Evac_Time_from_Stage_3_to_4) ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
"CASEVAC_Yes/No_from_Stage_3_to_4"	MONTECARLO(Probability_of_Available_CASEVAC_from_from_Stage_3_to_4)			
Ground_MEDEVAC_from_Stage_3_to_4[Severity](t)	Ground_MEDEVAC_from_Stage_3_to_4[Severity](t - dt) + (Transferring_to_MEDEVAC_from_Stage_3[Severity] - Moving_to_Stage_4_triage_from_MEDEVAC[Severity]) * dt	INIT Ground_MEDEVAC_from_Stage_3_to_4[Severity] = 0 COOK TIME = MEDEVAC_Evac_Time_from_Stage_3_to_4 CAPACITY = MEDEVAC_Capacity_based_on_severity*"MEDEVAC_Yes/No_from_Stage_3_to_4" FILL TIME = 0.33 CLEAN TIME = RANDOM (MEDEVAC_Evac_Time_from_Stage_3_to_4, 4*MEDEVAC_Evac_Time_from_Stage_3_to_4) ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
Helicopter_Evac_from_Stage_3_to_4[Severity](t)	Helicopter_Evac_from_Stage_3_to_4[Severity](t - dt) + (Transferring_to_Helicopter_Evac_from_Stage_3[Severity] - Moving_to_Stage_4_triage_from_Helo[Severity]) * dt	INIT Helicopter_Evac_from_Stage_3_to_4[Severity] = 0 COOK TIME = Helo_Evac_Time_from_Stage_3_to_4 CAPACITY = Helicopter_Capacity_based_on_severity*"Helo_Yes/No_from_Stage_3_to_4" FILL TIME = 0.33 CLEAN TIME = RANDOM (Helo_Evac_Time_from_Stage_3_to_4, 4*Helo_Evac_Time_from_Stage_3_to_4) ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
Helo_Evac_Time_from_Stage_3_to_4	RANDOM(Min_Helo_Evac_Time_from_Stage_3_to_4, Max_Helo_Evac_Time_from_Stage_3_to_4)			
"Helo_Yes/No_from_Stage_3_to_4"	MONTECARLO(Probability_of_Available_Helo_from_Stage_3_to_4)			
Max_CASEVAC_Time_from_Stage_3_to_4	4			
Max_Helo_Evac_Time_from_Stage_3_to_4	2			
Max_MEDEVAC_Time_from_Stage_3_to_4	4			
MEDEVAC_Evac_Time_from_Stage_3_to_4	RANDOM(Min_MEDEVAC_Time_from_Stage_3_to_4, Max_MEDEVAC_Time_from_Stage_3_to_4)			
"MEDEVAC_Yes/No_from_Stage_3_to_4"	MONTECARLO(Probability_of_Available_MEDEVAC_from_from_Stage_3_to_4)			
Min_CASEVAC_Time_from_Stage_3_to_4	1			
Min_Helo_Evac_Time_from_Stage_3_to_4	0.33			
Min_MEDEVAC_Time_from_Stage_3_to_4	1			
Moving_to_Stage_4_triage_from_CASEVAC[Severity]	OVEN OUTFLOW	TIME STAMPED INFLOW PRIORITY: 9	People/Hours	
Moving_to_Stage_4_triage_from_Helo[Severity]	OVEN OUTFLOW	TIME STAMPED INFLOW PRIORITY: 5	People/Hours	
Moving_to_Stage_4_triage_from_MEDEVAC[Severity]	OVEN OUTFLOW	TIME STAMPED INFLOW PRIORITY: 13	People/Hours	
Probability_of_Available_CASEVAC_from_from_Stage_3_to_4	50			
Probability_of_Available_Helo_from_Stage_3_to_4	0.01			
Probability_of_Available_MEDEVAC_from_from_Stage_3_to_4	15			
Transferring_to_Helicopter_Evac_from_Stage_3[Severity]	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 2	People/Hours	
Transferring_to_MEDEVAC_from_Stage_3[Severity]	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 10	People/Hours	

Table 23. Equations for Evacuation from Stage 3 to 4.[282]

F. GW/UW CASUALTY TREATMENT STAGE 4

Figures 53–55 make up CasualtyTreatment Stage 4. As seen in the causal loop diagrams, the number of hospitals, medical personnel, and the blood supply are the primary contributers to this section of the system. This model currently only depicts one hospital and does not capture the training process. It does, however, include a supply sector that was not originally depicted in the causal loop diagram.

The "Stage 4 (Definitive Care)" sector in Figure 53 will be described first, and the equations for this section are depicted in Table 24–26.

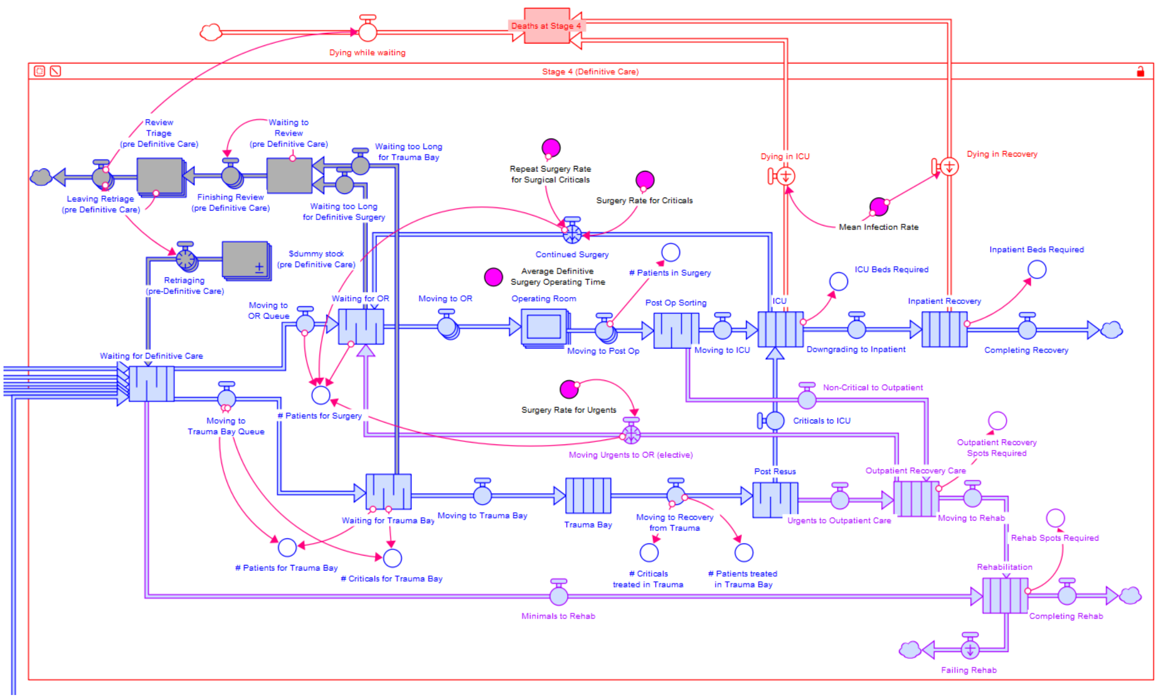

Figure 53. Casualty Treatment Stage 4, Patient Treatment Sector.[283]

Patients arrive to a non-arrayed queue "Waiting for Definitive Care" (full equation not included in Table 24), which is prioritized by attribute (Severity). Patients arriving with an attribute of 1 (Severity of "Surgical Critical") are placed into the queue first. Because

283 Adapted from ISEE Systems, Stella Architect.

only Surgical Critical patients will require surgery, the patients must be divided up into different queues “Waiting for OR” (those requiring surgery) and “Waiting for Trauma Bay” (Criticals and Urgents). This is done by restricting the outflows from “Waiting for Definitive Care” based on the appropriate attributes. “Moving to OR Queue” is restricted by attribute 1 (Surgical Critical) and “Moving to Trauma Bay Queue” is restrictd to attributes 2–3 (Critical to Urgent). The initial value of these queues is 0 and the inflows of patients are prioritized based on attribute (Severity). An additional outflow “Minimals to Rehab” restricts by attribute 4 (Minimals) and leads to the “Rehabilitation” conveyor (described later).

The downstream stock from “Waiting for OR” is an arrayed (ORs Per Hospital) oven, “Operating Room.” Each “Operating Room” oven has a CAPACITY of 1 because only one patient can be operated on at a time. The oven’s initial value is 0 and the COOK TIME is based on the converter “Average Definitive Surgery Operating Time,” which can be set by a user and is currently set to 6 hours (definitive surgery cases are much more extensive than damage control). The “Operating Room” CLEAN TIME is set to 0.5 hours (30 minutes) to allow for the movement of patients to/from the operating table and resetting surgical and anesthesia equipment. The oven outflow “Moving to Post Op” leads to queue “Post Op Sorting,” where patients are moved to different levels of recovery care depending on their condition. The recovery process will be described later in this section.

The downstream stock from “Waiting for Trauma Bay” is a non-arrayed conveyor (“Trauma Bay”) because the resuscitation team continuously treats patients while starting the resuscitation of others. The “Trauma Bay” conveyor has a CAPACITY of 8 patients. The conveyor’s initial value is 0 and the TRANSIT TIME is based on a normal distribution with a mean time of 0.5 hours (30 minutes) and a standard deviation of 0.25 hours (15 minutes). The conveyor outflow “Moving to Recovery from Trauma” leads to the queue “Post Resus” that prioritizes inflows based on attributes and moves patients to different levels of recovery care depending on their condition.

	Equation	Properties	Units	Annotation
"Stage_4_(Definitive_Care)":				
"#_Criticals_for_Trauma_Bay"	ATTRCOUNT(Waiting_for_Trauma_Bay, Severity.Critical)+(DT*ATTRCOUNT(Moving_to_Trauma_Bay_Queue, Severity.Critical))			
"#_Criticals_treated_in_Trauma"	DT*ATTRCOUNT(Moving_to_Recovery_from_Trauma, Severity.Critical)			
"#_Patients_for_Surgery"	ATTRCOUNT(Waiting_for_OR, Severity.Surgical_Critical, Severity.Minimal)+(DT*Moving_to_OR_Queue)+(DT*Continued_Surgery)+(DT*"Moving_Urgents_to_OR_(elective)")			
"#_Patients_for_Trauma_Bay"	Waiting_for_Trauma_Bay+(DT*Moving_to_Trauma_Bay_Queue)			
"#_Patients_in_Surgery"	(ATTRCOUNT(Moving_to_Post_Op[1], Severity.Surgical_Critical, Severity.Minimal)+ATTRCOUNT(Moving_to_Post_Op[2], Severity.Surgical_Critical, Severity.Minimal))*DT			
"#_Patients_treated_in_Trauma_Bay"	DT*ATTRCOUNT(Moving_to_Recovery_from_Trauma, Severity.Surgical_Critical, Severity.Minimal)			
Average_Definitive_Surgery_Operating_Time	6		Hours	
Moving_to_OR[ORs_per_Hospital]	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 1	People/ Hours	
Moving_to_OR_Queue	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 RESTRICT BY ATTRIBUTE = 1 INFLOW PRIORITY: 1 OUTFLOW PRIORITY: 1	People/ Hours	
Moving_to_Post_Op[ORs_per_Hospital]	OVEN OUTFLOW		People/ Hours	
Moving_to_Recovery_from_Trauma	CONVEYOR OUTFLOW		People/ Hours	
Moving_to_Trauma_Bay	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 OUTFLOW PRIORITY: 2	People/ Hours	
Moving_to_Trauma_Bay_Queue	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 RESTRICT BY ATTRIBUTE = 2,3 OUTFLOW PRIORITY: 2	People/ Hours	
Operating_Room[ORs_per_Hospital](t)	Operating_Room[ORs_per_Hospital](t - dt) + (Moving_to_OR[ORs_per_Hospital] - Moving_to_Post_Op[ORs_per_Hospital]) * dt	INIT Operating_Room[ORs_per_Hospital] = 0 COOK TIME = NORMAL (Average_Definitive_Surgery_Operating_Time, 1) CAPACITY = 1 CLEAN TIME = 0.5 ARREST IF IF Stage_4_Blood_Supply < 1 OR Stage_4_Medical_Supply < 1 THEN 1 ELSE 0 <> 0 ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	OVEN
Post_Op_Sorting(t)	Post_Op_Sorting(t - dt) + (Moving_to_Post_Op[1] + Moving_to_Post_Op[2] - Moving_to_ICU - "Non-Critical_to_Outpatient") * dt	INIT Post_Op_Sorting = 0	People	QUEUE
Post_Resus(t)	Post_Resus(t - dt) + (Moving_to_Recovery_from_Trauma - Criticals_to_ICU - Urgents_to_Outpatient_Care) * dt	INIT Post_Resus = 0	People	QUEUE
Trauma_Bay(t)	Trauma_Bay(t - dt) + (Moving_to_Trauma_Bay - Moving_to_Recovery_from_Trauma) * dt	INIT Trauma_Bay = 0 TRANSIT TIME = NORMAL (0.5, 0.25) CAPACITY = 8 ARREST IF IF Stage_4_Blood_Supply < 1 OR Stage_4_Medical_Supply < 1 THEN 1 ELSE 0 <> 0 DISCRETE ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	CONVEYOR
Waiting_for_Definitive_Care(t)	Waiting_for_Definitive_Care(t - dt) + ("Retriaging_(pre-Definitive_Care)"[Surgical_Critical] + "Retriaging_(pre-Definitive_Care)"[Critical] + "Retriaging_(pre-Definitive_Care)"[Urgent] + "Retriaging_(pre-Definitive_Care)"[Minimal] + Moving_to_Stage_4_triage_from_Helo[Surgical_Critical] +	INIT Waiting_for_Definitive_Care = 0 PRIORITIZE INFLOWS BASED ON ATTRIBUTE VALUES USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION	People	QUEUE
Waiting_for_OR(t)	Waiting_for_OR(t - dt) + (Moving_to_OR_Queue + Continued_Surgery + "Moving_Urgents_to_OR_(elective)" - Moving_to_OR[1] - Moving_to_OR[2] - Waiting_too_Long_for_Definitive_Surgery) * dt	INIT Waiting_for_OR = 0 PRIORITIZE INFLOWS BASED ON ATTRIBUTE VALUES USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION	People	QUEUE
Waiting_for_Trauma_Bay(t)	Waiting_for_Trauma_Bay(t - dt) + (Moving_to_Trauma_Bay_Queue - Waiting_too_Long_for_Trauma_Bay - Moving_to_Trauma_Bay) * dt	INIT Waiting_for_Trauma_Bay = 0 USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION	People	QUEUE

Table 24. Equations for Stage 4 Patient Treatment.[284]

As noted in Table 24, the treatment of patients in the oven “Operating Room” and the conveyor “Trauma Bay” is limited by converters “Stage 4 Blood Supply” and “Stage 4

[284] Adapted from ISEE Systems, Stella Architect.

Medical Supply." These converters belong to the sectors "Blood Supply for Stage 4" and "Supply Sector for Stage 4," respectively, and represent the amount of blood and supply units available for treating patients. "Operating Room" and "Trauma Bay" use an ARREST IF function. This function stops the oven if the value listed is anything other than 0. The equation used for this oven is "Stage 4 Blood Supply" OR "Stage 4 Medical Supply" < 1 THEN 1, which means that if there are no blood or supplies available, then a value of 1 is entered into ARREST IF. Because this value is not 0, the oven will arrest. This arrest likely occurs too late in the process, specifically for blood inventory, as most patients will require more than one unit of blood in surgery or resuscitation. The processes for determining "Stage 4 Blood Supply" and "Stage 4 Medical Supply" are discussed later in this section.

Patients' clinical conditions can worsen waiting for treatment in the OR and Trauma Bay. Table 25 includes the equations for this process. The queues "Waiting for OR" and "Waiting for Trauma Bay" have outflows "Waiting too Long for Definitive Surgery" and "Waiting to Long for Trauma Bay," respectively. These outflows use the timestamp given at the evacuation oven outflows to purge patients after 1 hour to "Waiting to Review (pre Definitive Care)." The non-arrayed stock "Waiting to Review (pre-Definitive Care)" is a placeholder for these purged patients from both queues "Waiting for OR" and "Waiting for Trauma Bay." "Finishing Review (pre Definitive Care)" is an arrayed (Severity) flow that now sorts the patients by severity using the ATTRCOUNT function and values from "Waiting to Review (pre Definitive Care)." The patients, now organized by severity, enter the arrayed (Severity) stock "Review Triage (pre Definitive Care)." The arrayed (Severity) flow "Leaving Retriage (pre Definitive Care)" PULSEs the patients from "Review Triage (pre Definitive Care)," and the resulting flow rate is utilized to reclassify patients.

The most critical patients "Surgical Critical" and "Critical" who have been waiting too long for definitive care cannot be classified to a more severe category and will die from lack of treatment. This is accounted for by the non-arrayed flow "Dying while waiting." Patients labeled "Urgent" who have been waiting too long for treatment, however, will become more critical and require re-classification. This is done utilizing the arrayed (Severity) flow "Retriaging (pre-Definitive Care)." The "$dummy stock (pre Definitive

Care)" is used strictly to establish an array (Severity) of patients without previously assigned attributes and its initial value is 0.

	Equation	Properties	Units	Annotation
"Stage_4_(Definitive_Care)":				
"$dummy_stock_(pre_Definitive_Care)"[Severity](t)	"$dummy_stock_(pre_Definitive_Care)"[Severity](t - dt) + (- "Retriaging_(pre-Definitive_Care)"[Severity]) * dt	INIT "$dummy_stock_(pre_Definitive_Care)"[Severity] = 0	People	
"Finishing_Review_(pre_Definitive_Care)"[Severity]	PULSE(ATTRCOUNT("Waiting_to_Review_(pre_Definitive_Care)", Severity))		People/ Hours	UNIFLOW
"Leaving_Retriage_(pre_Definitive_Care)"[Severity]	PULSE("Review_Triage_(pre_Definitive_Care)")		People/ Hours	UNIFLOW
"Retriaging_(pre-Definitive_Care)"[Severity]	IF Severity = Severity.Critical THEN "Leaving_Retriage_(pre_Definitive_Care)"[Urgent] ELSE IF Severity = Severity.Surgical_Critical THEN 0 ELSE IF Severity = Severity.Urgent THEN 0 ELSE "Leaving_Retriage_(pre_Definitive_Care)"	TIME STAMPED ATTRIBUTE VALUE = Severity INFLOW PRIORITY: 1	People/ Hours	UNIFLOW
"Review_Triage_(pre_Definitive_Care)"[Severity](t)	"Review_Triage_(pre_Definitive_Care)"[Severity](t - dt) + ("Finishing_Review_(pre_Definitive_Care)"[Severity] - "Leaving_Retriage_(pre_Definitive_Care)"[Severity]) * dt	INIT "Review_Triage_(pre_Definitive_Care)"[Severity] = 0	People	NON-NEGATIVE
"Waiting_to_Review_(pre_Definitive_Care)"(t)	"Waiting_to_Review_(pre_Definitive_Care)"(t - dt) + (Waiting_too_Long_for_Definitive_Surgery + Waiting_too_Long_for_Trauma_Bay - "Finishing_Review_(pre_Definitive_Care)"[Surgical_Critical] - "Finishing_Review_(pre_Definitive_Care)"[Critical] - "Finishing_Review_(pre_Definitive_Care)"[Urgent] - "Finishing_Review_(pre_Definitive_Care)"[Minimal]) * dt	INIT "Waiting_to_Review_(pre_Definitive_Care)" = 0	People	NON-NEGATIVE
Waiting_too_Long_for_Definitive_Surgery	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 PURGE AFTER AGE = 4 OUTFLOW PRIORITY: 3	People/ Hours	
Waiting_too_Long_for_Trauma_Bay	QUEUE OUTFLOW	USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 PURGE AFTER AGE = 4 OUTFLOW PRIORITY: 1	People/ Hours	

Table 25. Equations for Stage 4 Worsening Patient Conditions.[285]

"Retriaging (pre-Definitive Care)" uses the values of "Leaving Retriage (pre Definitive Care)" to re-estabish patient attributes. The flow of patients from the Critical "$dummy stock (pre Definitive Care)" (i.e., the patients who were previously Urgent, but now Critical) is equal to the flow of Urgent patients in "Leaving Retriage (pre Definitive Care)." The flow of patients from the Surgical Critical "$dummy stock (pre Definitive Care)" is 0 because patients are not reclassified into the Surgical Critical category. While some Urgent patients may need surgery, only a fraction would require more expeditious

[285] Adapted from ISEE Systems, Stella Architect.

surgery and it would be difficult to accurately account this for in the model. The flow of patients from the Urgent "$dummy stock (pre Definitive Care)" is 0 because the only less-severe category is Minimal, and these patients were removed from "Waiting for Definitive Care" before the retriaging process could take place.

After treatment in the "Operating Room" and "Trauma Bay," patients progress through the recovery process. The equations for this part of the Stage 4 patient treatment sector are listed in Table 26. Post-surgical patients in "Post Op Sorting" and patients in "Post Resus" are either sent to the conveyors "ICU" or "Outpatient Recovery Care." "Moving to ICU" (from "Post Op Sorting") and "Criticals to ICU" (from "Post Resus") restrict flow by attribute so only Surgical Critical or Critical patients flow to the "ICU." "Non-Critical to Outpatient Care" (from "Post Op Sorting") and "Urgents to Outpatient Care" (from "Post Resus") restrict flow by attribute so only Urgent patients flow to "Outpatient Recovery Care" immediately after treatment.

Setting a CAPACITY for the "ICU" conveyor created significant issues with the flow of patients, limiting the usefulness of the model. Instead, no CAPACITY was set and a macro was used to calculate the number of ICU beds needed as an output value for the end-user. The converter "ICU Beds Required" uses the macro MAXIMUM, which returns the maximum value that the conveyor reached during the model's run. This does not represent the total number of patients treated in the ICU but the most patients in the ICU at one time. The "ICU" conveyor's initial value is 0 and the TRANSIT TIME is based on a normal distribution with an average 72 hours (3 days) and standard deviation of 12 hours. There is a leak fraction "Continued Surgery" for patients who have to have multiple surgeries to fully recover. This leak occurs over the first half of the conveyor and has a fraction based on patient severity. For patients who are Surgical Critical, the leak fraction is 0.5 and for all others (Critical patients), it is 0.2. This is because those who required surgery initially will most likely require at least one more. A smaller number of patients who did not require initial surgery will require surgery while in the ICU.

The conveyor outflow "Downgrading to Inpatient" leads to another conveyor "Inpatient Recovery" for continued, but less critical treatment. The "Inpatient Recovery" conveyor cannot have a CAPACITY set because it is downstream of another conveyor and is a limitation of this model. Instead, a macro was used to calculate the number of inpatient beds needed as an output value for the end-user. The converter “Inpatient Beds Required” uses the macro MAXIMUM, which returns the maximum value that the conveyor reached during the model’s run. This does not represent the total number of patients treated as inpatients but the most patients in the inpatient ward at one time. The conveyor’s initial value is 0 and the TRANSIT TIME is based on a normal distribution with an average 168 hours (1 weeks) and standard deviation of 50 hours. Once patients complete their inpatient treatment in the “Inpatient Recovery” conveyor, the outflow “Completing Recovery” removes them from the system. Because these patients have a higher severity of injuries, the likelihood they can completely recover and return to the conflict is low.

The conveyors “ICU” and “Inpatient Recovery” both have leak fractions that simulate patients dying from wound infections. These leaks are “Dying in ICU” and “Dying in Recovery” and lead to “Deaths at Stage 4.” These leaks occurs over the full duration of the conveyors and have a fraction based on “Mean Infection Rate,” which is intended to be set by the user and is currently valued at 20%.[286] The leak fraction for “Dying in ICU” is 0.2 x “Mean Infection Rate,” meaning 20% of patients who get infected in the ICU will die. The leak fraction for “Dying in Recovery” is 0.1 x “Mean Infection Rate,” meaning 10% of patients who get infected as inpatients will die. These leak fractions are overexaggerated from reported numbers, but current data is from a robust combat casualty treatment system.[287]

The “Outpatient Recovery Care” conveyor receives Urgent patients from “Post Op Sorting” and “Post Resus.” This conveyor represents beds that may either be in the hospital or in the surrounding community to help decrease the space required. Setting a CAPACITY created significant issues with the flow of patients, limiting the usefulness of the model. Instead, no CAPACITY was set and a macro was used to calculate the number of outpatient

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286 Christopher J. Dente et al., “Towards Precision Medicine: Accurate Predictive Modeling of Infectious Complications in Combat Casualties,” *Journal of Trauma and Acute Care Surgery* 83, no. 4 (October 2017): 609–16, https://doi.org/10.1097/TA.0000000000001596.

287 Clinton K. Murray et al., “Infections Complicating the Care of Combat Casualties During Operations Iraqi Freedom and Enduring Freedom,” *Journal of Trauma and Acute Care Surgery* 71, no. 1 (July 2011): S62-73, https://doi.org/10.1097/TA.0b013e3182218c99.

beds required as an output value for the end-user. The converter “Outpatient Recovery Beds Required” uses the macro MAXIMUM, which returns the maximum value that the conveyor reached during the model’s run. This does not represent the total number of patients treated as outpatients, but the most patients in “Outpatient Recovery Care” at one time. The “Outpatient Recovery Care” conveyor’s initial value is 0 and the TRANSIT TIME is 336 hours (2 weeks). There is a leak fraction “Moving Urgents to OR (elective)” for patients who may require surgeries for fractures or other non-emergent conditions. This leak occurs over the first half of the conveyor and has a fraction based on the converter “Surgery Rate for Urgents.” This is a value set by the user and is currently set to 15%.

The conveyor outflow “Moving to Rehab” leads to another conveyor “Rehabilitation” for physical therapy-type treatment and ideally represents spots in the surrounding community. While in a GW/UW environment, this may seem extravagant, therapy can treat many orthopedic injuries that would otherwise prevent the mobility of a warfighter. The “Rehabilitation” conveyor cannot have a CAPACITY set because it is downstream of another conveyor and is a limitation of this model. Instead, a macro was used to calculate the number of rehabilitation spots needed as an output value for the end-user. The converter “Rehab Spots Required” uses the macro MAXIMUM, which returns the maximum value that the conveyor reached during the model’s run. This does not represent the total number of therapy patients but the most patients in therapy at one time. The conveyor’s initial value is 0 and the TRANSIT TIME is 168 hours (1 week). Once patients complete their therapy, the outflow “Completing Rehab” removes them from the system to return to the conflict. There is a leak fraction “Failing Rehab” for patients who have permanent orthopedic injuries that prevent their combat readiness. This leak occurs over the full duration of the conveyor and has a fraction of 0.3.

	Equation	Properties	Units	Annotation
"Stage_4_(Definitive_Care)":				
Completing_Recovery	CONVEYOR OUTFLOW		People/ Hours	
Completing_Rehab	CONVEYOR OUTFLOW		People/ Hours	
Continued_Surgery	LEAKAGE OUTFLOW	LEAKAGE FRACTION = IF Severity.Surgical_Critical THEN (Repeat_Surgery_Rate_for_Surgical_Criticals/100) ELSE (Surgery_Rate_for_Criticals/100) LINEAR LEAKAGE LEAK ZONE = 0% to 50% LEAK INTEGERS TIME STAMPED INFLOW PRIORITY: 2 OUTFLOW PRIORITY: 2	People/ Hours	
Criticals_to_ICU	QUEUE OUTFLOW	CONVEYOR FILL = EVENLY ACROSS CONVEYOR RESTRICT BY ATTRIBUTE = 2 INFLOW PRIORITY: 2 OUTFLOW PRIORITY: 1	People/ Hours	
Downgrading_to_Inpatient	CONVEYOR OUTFLOW	OUTFLOW PRIORITY: 1	People/ Hours	
Dying_in_ICU	LEAKAGE OUTFLOW	LEAKAGE FRACTION = 0.2*(Mean_Infection_Rate/100) LINEAR LEAKAGE LEAK ZONE = 0% to 100% LEAK INTEGERS OUTFLOW PRIORITY: 3	People/ Hours	
Dying_in_Recovery	LEAKAGE OUTFLOW	LEAKAGE FRACTION = 0.1*(Mean_Infection_Rate/100) LINEAR LEAKAGE LEAK ZONE = 0% to 100% LEAK INTEGERS	People/ Hours	
Failing_Rehab	LEAKAGE OUTFLOW	LEAKAGE FRACTION = 0.3 LINEAR LEAKAGE LEAK ZONE = 0% to 100% LEAK INTEGERS	People/ Hours	
ICU(t)	ICU(t - dt) + (Moving_to_ICU + Criticals_to_ICU - Downgrading_to_Inpatient - Continued_Surgery - Dying_in_ICU) * dt	INIT ICU = 0 TRANSIT TIME = NORMAL (72, 12) DISCRETE ACCEPT SINGLE BATCH SPLIT BATCHES	People	CONVEYOR
ICU_Beds_Required	MAXIMUM(ICU)			
Inpatient_Beds_Required	MAXIMUM(Inpatient_Recovery)			
Inpatient_Recovery(t)	Inpatient_Recovery(t - dt) + (Downgrading_to_Inpatient - Completing_Recovery - Dying_in_Recovery) * dt	INIT Inpatient_Recovery = 0 TRANSIT TIME = NORMAL(168, 50) DISCRETE ACCEPT MULTIPLE BATCHES	People	CONVEYOR
Mean_Infection_Rate	20		Hours	
Minimals_to_Rehab	QUEUE OUTFLOW	CONVEYOR FILL = EVENLY ACROSS CONVEYOR USE DISPATCH PRIORITIES AND ROUND ROBIN SELECTION DISPATCH PRIORITY = 0 RESTRICT BY ATTRIBUTE = 4 INFLOW PRIORITY: 2 OUTFLOW PRIORITY: 3	People/ Hours	
Moving_to_ICU	QUEUE OUTFLOW	RESTRICT BY ATTRIBUTE = 1,2 INFLOW PRIORITY: 1 OUTFLOW PRIORITY: 1	People/ Hours	
Moving_to_Rehab	CONVEYOR OUTFLOW	INFLOW PRIORITY: 1	People/ Hours	
"Moving_Urgents_to_OR_(elective)"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = Surgery_Rate_for_Urgents/100 LINEAR LEAKAGE LEAK ZONE = 0% to 50% LEAK INTEGERS TIME STAMPED INFLOW PRIORITY: 3	People/ Hours	
"Non-Critical_to_Outpatient"	QUEUE OUTFLOW	CONVEYOR FILL = EVENLY ACROSS CONVEYOR RESTRICT BY ATTRIBUTE = 3 INFLOW PRIORITY: 2 OUTFLOW PRIORITY: 2	People/ Hours	
Urgents_to_Outpatient_Care	QUEUE OUTFLOW	CONVEYOR FILL = EVENLY ACROSS CONVEYOR INFLOW PRIORITY: 1 OUTFLOW PRIORITY: 2	People/ Hours	
Outpatient_Recovery_Care(t)	Outpatient_Recovery_Care(t - dt) + (Urgents_to_Outpatient_Care + "Non-Critical_to_Outpatient" - Moving_to_Rehab - "Moving_Urgents_to_OR_(elective)") * dt	INIT Outpatient_Recovery_Care = 0 TRANSIT TIME = 336 DISCRETE ACCEPT SINGLE BATCH SPLIT BATCHES	People	CONVEYOR
Outpatient_Recovery_Spots_Required	MAXIMUM(Outpatient_Recovery_Care)			
Rehab_Spots_Required	MAXIMUM(Rehabilitation)			
Rehabilitation(t)	Rehabilitation(t - dt) + (Moving_to_Rehab + Minimals_to_Rehab - Completing_Rehab - Failing_Rehab) * dt	INIT Rehabilitation = 0 TRANSIT TIME = 168 DISCRETE ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	CONVEYOR
Repeat_Surgery_Rate_for_Surgical_Criticals	50			
Surgery_Rate_for_Criticals	20			
Surgery_Rate_for_Urgents	15			

Table 26. Equations for Stage 4 Patient Recovery Care.[288]

The “Blood Supply for Stage 4” sector (Figure 54) depicts the system for blood acquisition treatment of patients for a Stage 4 hospital. There is not a cache for blood as the storage of blood is not logistically feasible away from the hospital. Equations are included in Table 27.

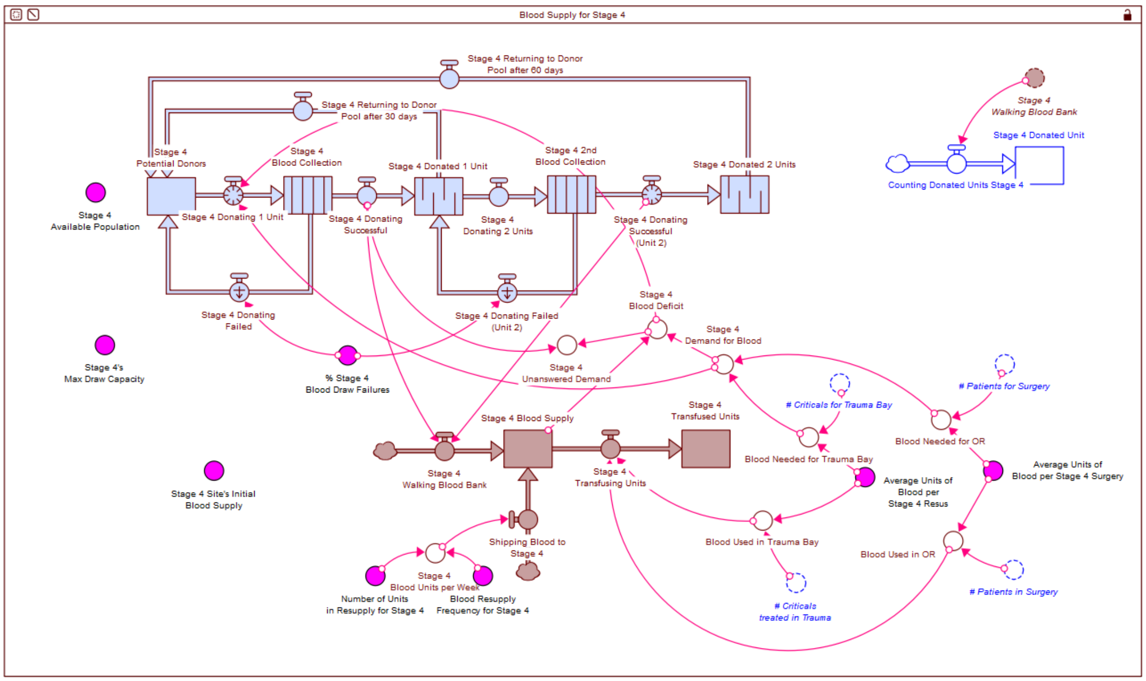

Figure 54. Casualty Treatment Stage 4, Blood Supply Sector.[289]

The pink converter “Stage 4 Site’s Initial Blood Supply” is entered by the user based on the operational environment of the surgical team and is currently set to 40 units. This converter determines the initial value of “Stage 4 Blood Supply” for the hospital represented in this stage. The “Number of Units in Resupply for Stage 4” is the number of blood units typically delivered per each resupply movement (set by user) and is currently set to 20 units. The “Blood Resupply Frequency for Stage 4” is the number of blood deliveries per week (set by user) and is currently set to 1. “Stage 4 Blood Units per Week”

289 Adapted from ISEE Systems, Stella Architect.

multiplies “Number of Units in Resupply for Stage 4” and “Blood Resupply Frequency for Stage 4” to determine blood units per week. The flow “Shipping Blood to Stage 4” uses the “Stage 4 Blood Units per Week” in a PULSE with an initial and recurring values of “Stage 4 Blood Units per Week” with an interval set to 168 hours (1 week).

The “Stage 4 Blood Supply” stock is drained by the flow “Stage 4 Transfusing Units,” which PULSEs the sum of units from “Blood Used in OR” and “Blood Used in Trauma Bay.” These converters are calculated based on the average units of blood used and the number of patients receiving resuscitation or surgery. The average units of blood used per surgery and per resuscitation are set by the user for the converters “Average Units of Blood per Stage 4 Surgery” (currently set to 10) and “Average Units of Blood per Stage 4 Resus” (currently set to 3). “Blood Used in OR” multiplies the “Average Units of Blood per Stage 4 Surgery” by the ghost converter “# Patients in Surgery.” “# Patients in Surgery” can be found in Figure 53 and tallies the total number of patients from “Moving to Post Op.” “Blood Used in Trauma Bay” multiplies the “Average Units of Blood per Stage 4 Resus” by the value of the ghost converter “# Criticals treated in Trauma.” “# Criticals treated in Trauma” can be found in Figure 53 and uses the ATTRCOUNT function to count the number of Critical patients in the “Moving to Recovery from Trauma” flow. Urgent and Minimal patients are not accounted for because their injuries do not require blood transfusions.

	Equation	Properties	Units	Annotation
Blood_Supply_for_Stage_4:				
"%_Stage_4_Blood_Draw_Failures"	10			
Average_Units_of_Blood_per_Stage_4_Resus	3			
Average_Units_of_Blood_per_Stage_4_Surgery	10			
Blood_Needed_for_OR	Average_Units_of_Blood_per_Stage_4_Surgery*("#_Patients_for_Surgery")			
Blood_Needed_for_Trauma_Bay	Average_Units_of_Blood_per_Stage_4_Resus*"#_Criticals_for_Trauma_Bay"			
Blood_Resupply_Frequency_for_Stage_4	1		Per Week	
Blood_Used_in_OR	Average_Units_of_Blood_per_Stage_4_Surgery*"#_Patients_in_Surgery"			
Blood_Used_in_Trauma_Bay	Average_Units_of_Blood_per_Stage_4_Resus*"#_Criticals_treated_in_Trauma"			
Counting_Donated_Units_Stage_4	Stage_4_Walking_Blood_Bank			UNIFLOW
Number_of_Units_in_Resupply_for_Stage_4	20		Units	
Shipping_Blood_to_Stage_4	PULSE(Stage_4_Blood_Units_per_Week, Stage_4_Blood_Units_per_Week, 168)			UNIFLOW
Stage_4_2nd_Blood_Collection(t)	Stage_4_2nd_Blood_Collection(t - dt) + (Stage_4_Donating_2_Units - "Stage_4_Donating_Successful_(Unit_2)" - "Stage_4_Donating_Failed_(Unit_2)") * dt	INIT Stage_4_2nd_Blood_Collection = 0 TRANSIT TIME = 0.5 INFLOW LIMIT = IF Stage_4_Unanswered_Demand > 0 THEN Stage_4_Unanswered_Demand+5 ELSE 0 CAPACITY = Stage_3's_Max_Draw_Capacity DISCRETE ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	CONVEYOR
Stage_4_Available_Population	300			
Stage_4_Blood_Collection(t)	Stage_4_Blood_Collection(t - dt) + (Stage_4_Donating_1_Unit - Stage_4_Donating_Successful - Stage_4_Donating_Failed) * dt	INIT Stage_4_Blood_Collection = 0 TRANSIT TIME = 0.5 CAPACITY = Stage_3's_Max_Draw_Capacity CONTINUOUS ACCEPT MULTIPLE BATCHES SPLIT BATCHES	People	CONVEYOR
Stage_4_Blood_Deficit	(Stage_4_Demand_for_Blood)-Stage_4_Blood_Supply			
Stage_4_Blood_Supply(t)	Stage_4_Blood_Supply(t - dt) + (Stage_4_Walking_Blood_Bank + Shipping_Blood_to_Stage_4 - Stage_4_Transfusing_Units) * dt	INIT Stage_4_Blood_Supply = Stage_4_Site's_Initial_Blood_Supply		NON-NEGATIVE
Stage_4_Blood_Units_per_Week	Number_of_Units_in_Resupply_for_Stage_4*Blood_Resupply_Frequency_for_Stage_4			
Stage_4_Demand_for_Blood	(Blood_Needed_for_OR+Blood_Needed_for_Trauma_Bay)			
Stage_4_Donated_1_Unit(t)	Stage_4_Donated_1_Unit(t - dt) + (Stage_4_Donating_Successful + "Stage_4_Donating_Failed_(Unit_2)" - Stage_4_Returning_to_Donor_Pool_after_30_days - Stage_4_Donating_2_Units) * dt	INIT Stage_4_Donated_1_Unit = 0	People	QUEUE
Stage_4_Donated_2_Units(t)	Stage_4_Donated_2_Units(t - dt) + ("Stage_4_Donating_Successful_(Unit_2)" - Stage_4_Returning_to_Donor_Pool_after_60_days) * dt	INIT Stage_4_Donated_2_Units = 0	People	QUEUE
Stage_4_Donated_Unit(t)	Stage_4_Donated_Unit(t - dt) + (Counting_Donated_Units_Stage_4) * dt	INIT Stage_4_Donated_Unit = 0		NON-NEGATIVE
Stage_4_Donating_1_Unit	IF Stage_4_Blood_Deficit > 0 THEN PULSE(Stage_4_Demand_for_Blood+5) ELSE 0	TIME STAMPED	People/Hours	UNIFLOW
Stage_4_Donating_2_Units	QUEUE OUTFLOW	OUTFLOW PRIORITY: 2	People/Hours	
Stage_4_Donating_Failed	LEAKAGE OUTFLOW	LEAKAGE FRACTION = "%_Stage_4_Blood_Draw_Failures"/100 LINEAR LEAKAGE LEAK ZONE = 0% to 100% LEAK INTEGERS	People/Hours	
"Stage_4_Donating_Failed_(Unit_2)"	LEAKAGE OUTFLOW	LEAKAGE FRACTION = (2*"%_Stage_4_Blood_Draw_Failures")/100 LINEAR LEAKAGE LEAK ZONE = 0% to 100% LEAK INTEGERS INFLOW PRIORITY: 2	People/Hours	
Stage_4_Donating_Successful	CONVEYOR OUTFLOW	INFLOW PRIORITY: 1	People/Hours	
"Stage_4_Donating_Successful_(Unit_2)"	CONVEYOR OUTFLOW	TIME STAMPED	People/Hours	
Stage_4_Potential_Donors(t)	Stage_4_Potential_Donors(t - dt) + (Stage_4_Returning_to_Donor_Pool_after_30_days + Stage_4_Returning_to_Donor_Pool_after_60_days + Stage_4_Donating_Failed - Stage_4_Donating_1_Unit) * dt	INIT Stage_4_Potential_Donors = Stage_4_Available_Population + Rehabilitation	People	NON-NEGATIVE
Stage_4_Returning_to_Donor_Pool_after_30_days	QUEUE OUTFLOW	PURGE AFTER AGE = 1440 OUTFLOW PRIORITY: 1	People/Hours	
Stage_4_Returning_to_Donor_Pool_after_60_days	QUEUE OUTFLOW	PURGE AFTER AGE = 1440	People/Hours	
Stage_4_Site's_Initial_Blood_Supply	40			
Stage_4_Transfused_Units(t)	Stage_4_Transfused_Units(t - dt) + (Stage_4_Transfusing_Units) * dt	INIT Stage_4_Transfused_Units = 0		NON-NEGATIVE
Stage_4_Transfusing_Units	PULSE(Blood_Used_in_OR+Blood_Used_in_Trauma_Bay)			UNIFLOW
Stage_4_Unanswered_Demand	Stage_4_Blood_Deficit - (DT*Stage_4_Donating_Successful)			
Stage_4_Walking_Blood_Bank	Stage_4_Donating_Successful + "Stage_4_Donating_Successful_(Unit_2)"			UNIFLOW
Stage_4's_Max_Draw_Capacity	40			

Table 27. Equations for Stage 4 Blood Supply.[290]

"Stage 4 Blood Deficit" converter determines the need for a walking blood bank and requires a series of calculations. "Stage 4 Blood Deficit" is calculated by subtracting the "Stage 4 Blood Supply" from "Stage 4 Demand for Blood." A positive number for "Stage 4 Blood Deficit" means there is not enough blood on hand to treat patients, and a negative number means there is an adequate blood supply. "Stage 4 Demand for Blood" is determined by the converters "Blood Needed for OR" and "Blood Needed for Trauma Bay." These converters multiply the average units of blood used and the number of anticipated patients requiring resuscitation or surgery. "Blood Needed for OR" multiplies the "Average Units of Blood per Stage 4 Surgery" by "# Patients for Surgery" (ghost converter from Figure 48). "# Patients for Surgery" calculates the total number of patients moving through the flows "Moving to OR Queue," Moving Urgents to OR (elective)," and "Continued Surgery" and patients held in the queue "Waiting for OR" for a given timestep. "Blood Needed for Trauma Bay" multiplies the "Average Units of Blood per Stage 4 Resus" by "# Criticals for Trauma Bay" (ghost converter from Figure 53). "# Criticals for Trauma Bay" uses the ATTRCOUNT function to calculate the total number of Critical patients per timestep moving through the flow "Moving to Trauma Bay Queue" and patients held in the queue "Waiting for Trauma Bay."

In the event "Stage 4 Blood Deficit" is > 0, the process for a walking blood bank begins (blue filled flows and stocks in Figure 54, equations in Table 27). The process starts with an initial non-negative stock of "Stage 4 Potential Donors," initialized by the "Stage 4 Available Population" and the patients in "Rehabilitation." If "Stage 4 Blood Deficit" is > 0, then the flow "Stage 4 Donating 1 Unit" PULSEs the value of "Stage 4 Demand for Blood." While "Stage 4 Demand for Blood" likely accounts for more blood than the deficit, the extra donors counter the failure rate of donation and allow for extra blood to have on-hand. "Stage 4 Donating 1 Unit" timestamps patients and moves them to a conveyor "Stage 4 Blood Collection." The "Stage 4 Blood Collection" CAPACITY is limited by "Stage 4's Max Draw Capacity," representing the number of simultaneous blood collections the hospital can handle. This converter is to be set by the user and is currently 40. The TRANSIT TIME is 0.5 hours (30 minutes), which accounts for the set up and collection of a unit of blood from one person. There is a leak ("Stage 4 Donating Failed") from the conveyor that represents patients who do not complete a donation due to passing out or failure of the collection materials. The leakage zone is throughout the conveyor and the fraction is equal to the "% Stage 4 Blood Draw Failures" converter (set by user, currently 10%). Donors who are not leaked from the conveyor then move through "Stage 4 Donating Successful" to a queue "Stage 4 Donated 1 Unit." Donors will wait in this queue until either a 2nd unit of blood is needed (described later) or 30 days have passed. After 30 days, they can go back to the pool of potential donors.

The completed blood draws ("Stage 4 Donating Successful") are then used in re-evaluating the deficit. "Stage 4 Unanswered Demand" is a converter that subtracts "Stage 4 Donating Successful" from "Stage 4 Blood Deficit." If "Stage 4 Unanswered Demand" is > 0, then flow to "Stage 4 2nd Blood Collection" begins. This conveyor's INFLOW LIMIT prevents unnecessary collection of 2 units through an IF/THEN logic series. If "Stage 4 Unanswered Demand" > 0, then the limit is the value of "Stage 4 Unanswered Demand." Otherwise, the Inflow Limit is 0. The "Stage 4 2nd Blood Collection" CAPACITY is limited by "Stage 4's Max Draw Capacity." representing the number of simultaneous blood collections the team can handle. The TRANSIT TIME is 0.5 hours (30 minutes). There is a leak ("Stage 4 Donating Failed (Unit 2)") from the conveyor that represents patients who do not complete donating a second unit due to passing out or failure of the collection materials. The leakage zone is throughout the conveyor and the fraction is equal to 2 x the "% Stage 4 Blood Draw Failures" converter because failures become more common with second units. Patients then move through "Stage 4 Donating Successful (Unit 2)" to the final queue "Stage 4 Donated 2 Units" and are re-timestamped. Donors will wait in this queue until 60 days have passed.[291] After 60 days, they can go back to the regular pool of potential donors.

Blood collected from the walking blood bank is added to the "Stage 4 Blood Supply" by the flow "Stage 4 Walking Blood Bank." This flow's value is the sum of the flows "Stage 4 Donating Successful" and "Stage 4 Donating Successful (Unit 2)." "Stage

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[291] Bahr et al., "Practical Considerations for a Military Whole Blood Program," e1032-1038; Fisher et al., "Low Titer Group O Whole Blood Resuscitation," 834–41.

4 Walking Blood Bank" is used as the flow value for "Counting Donated Units Stage 4." This flow leads to the stock "Stage 4 Donated Units" that can provide the end-user with information regarding the amount of blood collected from walking blood banks.

The "Supply Sector for Stage 4" (Figure 55 and Table 28) depicts the system for medical supplies that has an effect on the treatment of patients in "Trauma Bay" and "Operating Room." The pink converters "Initial Average Stage 4 Units per Cache," "Number of Stage 4 Caches," and "Stage 4 On Site Medical Supply Capacity" are values entered by the user. This section utilizes the general construct of a Stage 4 Supply Unit. The number of patients that this unit is designed to treat can also be set by the end-user using the converters "Number of Resuscitations per Stage 4 Unit" (currently set to 20) and "Number of Surgeries per Stage 4 Unit" (currently set to 10). The "Stage 4 On Site Medical Supply Capacity" is the amount of supplies the hospital can have on hand and is currently set to 5. The "Initial Average Stage 4 Units per Cache" will vary depending on the size of available caches (set to 5), and the "Number of Stage 4 Caches" will vary depending on the operational environment (set to 20). "Initial Average Stage 4 Units per Cache" and "Number of Stage 4 Caches" are multiplied together to initialize the "Stage 4 Cache Supply" stock.

The "Number of Stage 4 Supply Units per Resupply" is the number of supply units typically delivered per each resupply movement (set by user) and is currently set to 5 units. The "Stage 4 Resupply Frequency" is the number of resupply deliveries per week (set by user) and is currently set to 1. "Stage 4 Supply Units per Week" multiplies "Number of Stage 4 Supply Units per Resupply" and "Stage 4 Resupply Frequency" to determine units per week. The flow "Shipping Supplies to Stage 4" uses the "Stage 4 Supply Units per Week" in a PULSE with an initial and recurring values of "Stage 4 Supply Units per Week" with a repetition interval set to 168 hours (1 week).

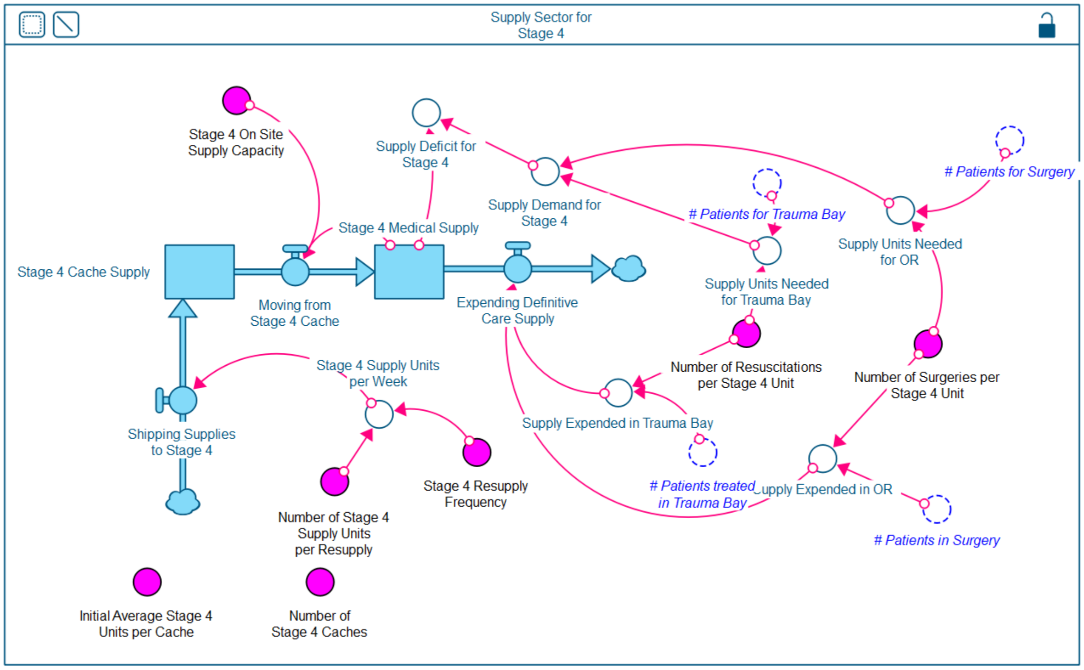

Figure 55. Casualty Treatment Stage 4, Medical Supply Sector.[292]

The calculations of "Supply Deficit for Stage 4" subtracts the "Stage 4 Medical Supply" from "Supply Demand for Stage 4." A positive number for "Supply Deficit for Stage 4" means there is not enough supplies on hand to treat patients, and a negative number means there is an adequate amount of supplies. "Supply Demand for Stage 4" is determined by adding the converter values for "Supply Units Need for Trauma Bay" and "Supply Units Needed for OR." These converters multiply the average number of patients treated per supply unit by the number of anticipated patients requiring resuscitation or surgery. "Supply Units Needed for Trauma Bay" divides "# Patients for Trauma Bay" by the "Number of Resuscitations per Stage 4 Unit." "# Patients for Trauma Bay" is a ghost converter from Figure 53 that calculates the total number of patients per timestep moving through the flow "Moving to Trauma Bay Queue" and held in the queue "Waiting for Trauma Bay." Urgent patients are included in this calculation to account for soft medical supplies used (gauze, ace wraps, etc.). "Supply Units Needed for OR" divides "# Patients

292 Adapted from ISEE Systems, Stella Architect.

for Surgery" (ghost converter from Figure 53) by "Number of Surgeries per Stage 4 Unit." "# Patients for Surgery" calculates the total number of patients moving through the flows "Moving to OR Queue," Moving Urgents to OR (elective)," and "Continued Surgery" and patients held in the queue "Waiting for OR" for a given timestep.

	Equation	Properties	Units	Annotation
Supply_Sector_for_Stage_4:				
Expending_Definitive_Care_Supply	PULSE(Supply_Expended_in_OR+Supply_Expended_in_Trauma_Bay)			UNIFLOW
Initial_Average_Stage_4_Units_per_Cache	5			
Moving_from_Stage_4_Cache	IF Stage_4_Medical_Supply < 2 THEN PULSE(Stage_4_On_Site_Supply_Capacity-Stage_4_Medical_Supply) ELSE 0			UNIFLOW
Number_of_Resuscitations_per_Stage_4_Unit	20			
Number_of_Stage_4_Caches	20			
Number_of_Stage_4_Supply_Units_per_Resupply	5		Units	
Number_of_Surgeries_per_Stage_4_Unit	10			
Shipping_Supplies_to_Stage_4	PULSE(Stage_4_Supply_Units_per_Week, Stage_4_Supply_Units_per_Week, 168)			UNIFLOW
Stage_4_Cache_Supply(t)	Stage_4_Cache_Supply(t - dt) + (Shipping_Supplies_to_Stage_4 - Moving_from_Stage_4_Cache) * dt	INIT Stage_4_Cache_Supply = Initial_Average_Stage_4_Units_per_Cache*Number_of_Stage_4_Caches		NON-NEGATIVE
Stage_4_Medical_Supply(t)	Stage_4_Medical_Supply(t - dt) + (Moving_from_Stage_4_Cache - Expending_Definitive_Care_Supply) * dt	INIT Stage_4_Medical_Supply = Stage_4_On_Site_Supply_Capacity		NON-NEGATIVE
Stage_4_On_Site_Supply_Capacity	5			
Stage_4_Resupply_Frequency	1		Per Week	
Stage_4_Supply_Units_per_Week	Number_of_Stage_4_Supply_Units_per_Resupply*Stage_4_Resupply_Frequency			
Supply_Deficit_for_Stage_4	Supply_Demand_for_Stage_4 - Stage_4_Medical_Supply			
Supply_Demand_for_Stage_4	(Supply_Units_Needed_for_OR+Supply_Units_Needed_for_Trauma_Bay)			
Supply_Expended_in_OR	("#_Patients_in_Surgery")/Number_of_Surgeries_per_Stage_4_Unit		Units	
Supply_Expended_in_Trauma_Bay	"#_Patients_treated_in_Trauma_Bay"/Number_of_Resuscitations_per_Stage_4_Unit			
Supply_Units_Needed_for_OR	("#_Patients_for_Surgery")/Number_of_Surgeries_per_Stage_4_Unit			
Supply_Units_Needed_for_Trauma_Bay	"#_Patients_for_Trauma_Bay"/Number_of_Resuscitations_per_Stage_4_Unit			

Table 28. Equations for Stage 4 Medical Supply Sector.[293]

When there is a deficit of supplies, supplies must be moved to the "Stage 4 Medical Supply" stock from the "Stage 4 Cache Supply." The flow "Moving from Stage 4 Cache" to "Stage 4 Medial Supply" is 0 unless the "Stage 4 Medical Supply" stock is < 2, which will trigger a PULSE of supply units to fill the "Stage 4 Medical Supply" to original capacity.

[293] Adapted from ISEE Systems, Stella Architect.

G. CASUALTY STATISTICS AND FIGHTING FORCE CALCULATIONS

Figures 56–58 depict the calculations of WIA, KIA, and DOW, respectively, and Table 29 includes the equations used.

Figure 56 illustrates how "Total WIA" is counted. "Total WIA" is a non-negative stock that is initialized at 0. The flow "Counting WIA" is the sum of all patients moving through each arrayed flow in "Moving to Waiting." This captures all the patients wounded entering the system. This does not account for those patients instantaneously KIA or with non-survivable injuries. The process for computing Instant KIAs was discussed earlier in the appendix (Figure 42 and Table 8).

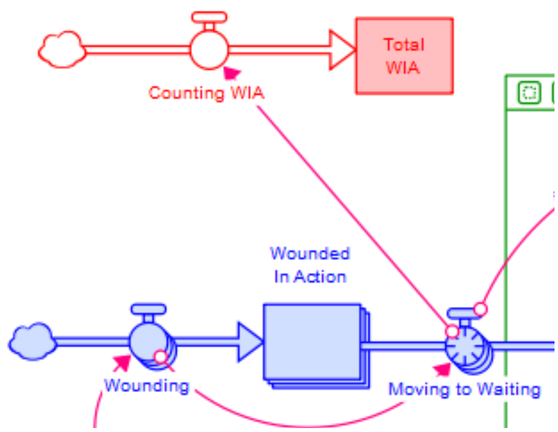

Figure 56. Model for Total Wounded in Action Calculations.[294]

"Total KIA" has an inflow "Counting KIA" that sums the ghost converters representing flows of patients dying prior to Stage 3 from different portions of the model. The first input "Dying on Battlefield" is ghost converter from the flow seen in Figure 42. "Dying at Stage 1" is a non-arrayed flow that is based on the values of "Leaving Retriage" for Surgical Critical and Critical patients who were decompensating while waiting for treatment from a medic.

[294] Adapted from ISEE Systems, Stella Architect.

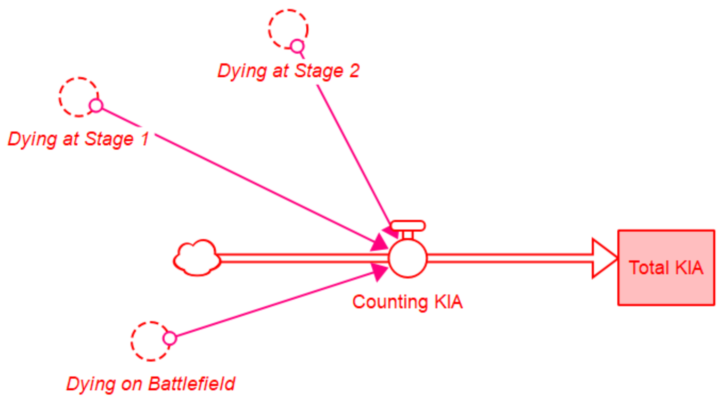

Figure 57. Model for Total Killed in Action Calculations.[295]

"Dying at Stage 2" is a non-arrayed flow that is based on several values in Stage 2. Figure 58 illustrates the portion of the model that calculates this flow and the equation for the flow can be found in Table 29. The converter "PFC Available?" is used in an IF/THEN logic series to determine how "Dying at Stage 2" is calculated. If "PFC Available?" is 1 (Stage 2 is present), then the value of "Dying at Stage 2" is the sum of the flow of patients of all severities from "Dying PFC patients" and of flows for decompensating Surgical Critical and Critical patients in "Leaving Retriage (PFC)." "Leaving Retriage (post TCCC)" is not included in this calculation because when PFC is available, this flow moves patients to PFC treatment and deaths are accounted for at other locations. If "PFC Available?" is 0 (Stage 2 is not present), then the value of "Dying at Stage 2" is equal to the sum of the flows for decompensating Surgical Critical and Critical patients in "Leaving Retriage (post TCCC)" and in "Leaving Retriage (PFC)." This is the last point where decompensating patients have not yet reached a hospital and will be classified as KIA (vice DOW).

[295] Adapted from ISEE Systems, Stella Architect.

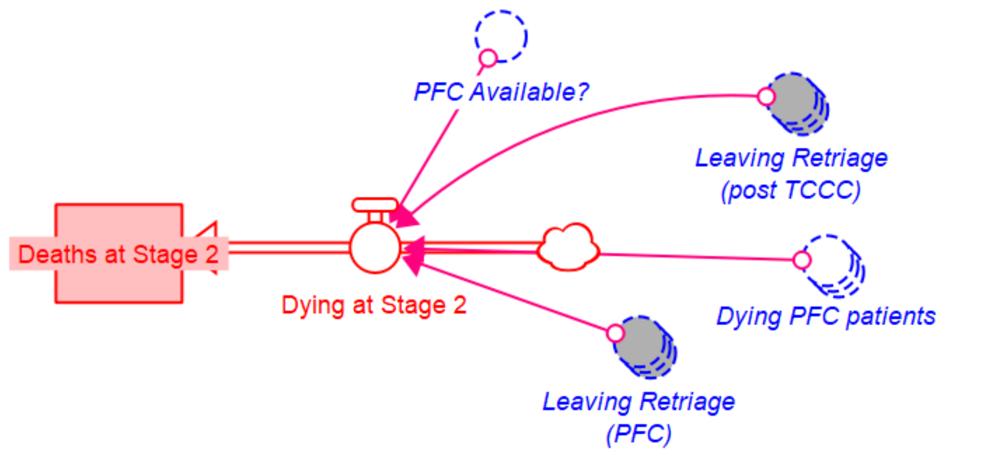

Figure 58. Model for Stage 2 Killed in Action Calculations.[296]

"Died of Wounds" (Figure 59) uses input from both Treatment Stages 3 and 4 in which patients decompensated or died of infections. "Counting DOW" is a non-arrayed uniflow to "Died of Wounds" based on several ghost converters from Stages 3 and 4.

The non-arrayed flows "Dying at Stage 3" and "Dying while waiting" occurred when Surgical Critical or Critical patients in queue to be treated decompensated after a given amount of time. These flows are based on the the values of "Leaving Retriage (pre-DCR/DCS)" and "Leaving Retriage (Pre-Definitive Care)" for Surgical Critical and Critical patients who were decompensating. The flows "Dying in ICU" and "Dying in Recovery" are leak fractions similating patients dying from infections.

[296] Adapted from ISEE Systems, Stella Architect.

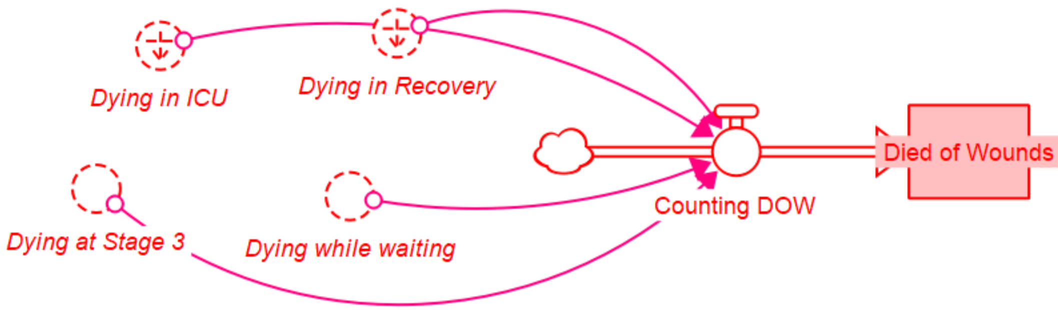

Figure 59. Model for Total Died of Wounds Calculations.[297]

	Equation	Properties	Units	Annotation
Counting_DOW	Dying_in_Recovery+Dying_while_waiting+Dying_in_ICU+Dying_at_Stage_3		People/Hours	UNIFLOW
Counting_KIA	Dying_at_Stage_2+Dying_at_Stage_1+Dying_on_Battlefield		People/Hours	UNIFLOW
Counting_WIA	Moving_to_Waiting[Surgical_Critical]+Moving_to_Waiting[Critical]+Moving_to_Waiting[Urgent]+Moving_to_Waiting[Minimal]			UNIFLOW
Died_of_Wounds(t)	Died_of_Wounds(t - dt) + (Counting_DOW) * dt	INIT Died_of_Wounds = 0	People	NON-NEGATIVE
Dying_at_Stage_1	Leaving_Retriage[Surgical_Critical] + Leaving_Retriage[Critical]		People/Hours	UNIFLOW
Dying_at_Stage_2	IF PFC_Available?=1 THEN (Dying_PFC_patients[Surgical_Critical]+Dying_PFC_patients[Critical]+Dying_PFC_patients[Urgent]+Dying_PFC_patients[Minimal]+"Leaving_Retriage_(PFC)"[Surgical_Critical]+"Leaving_Retriage_(PFC)"[Critical]) ELSE ("Leaving_Retriage_(post_TCCC)"[Surgical_Critical] + "Leaving_Retriage_(post_TCCC)"[Critical]+"Leaving_Retriage_(PFC)"[Surgical_Critical]+"Leaving_Retriage_(PFC)"[Critical])		People/Hours	UNIFLOW
Dying_at_Stage_3	"Leaving_Retriage_(pre_DCR/DCS)"[Surgical_Critical] + "Leaving_Retriage_(pre_DCR/DCS)"[Critical]		People/Hours	UNIFLOW
Dying_on_Battlefield	PULSE(KIAs)		People/Hours	UNIFLOW
Dying_while_waiting	"Leaving_Retriage_(pre_Definitive_Care)"[Surgical_Critical]+"Leaving_Retriage_(pre_Definitive_Care)"[Critical]		People/Hours	UNIFLOW
Instant_KIA(t)	Instant_KIA(t - dt) + (Dying_on_Battlefield) * dt	INIT Instant_KIA = 0	People	NON-NEGATIVE
Total_KIA(t)	Total_KIA(t - dt) + (Counting_KIA) * dt	INIT Total_KIA = 0	People	NON-NEGATIVE
Total_WIA(t)	Total_WIA(t - dt) + (Counting_WIA) * dt	INIT Total_WIA = 0		NON-NEGATIVE

Table 29. Equations for Casualty Statistics.[298]

The "Fighting Force Numbers" Sector (Figure 60) calculates the available "Fighting Force," total patients "Recovered" from their injuries, and total patients "Furloughed" due to non-healed or long-term injury issues. Equations are included in Table 30.

"Fighting Force" is a non-negative stock with an initial value based on the sum of converters "Coalition Forces" and "Partner Forces," which are set by the user (currently 20

[297] Adapted from ISEE Systems, Stella Architect.

[298] Adapted from ISEE Systems, Stella Architect.

and 100, respectively). The “Fighting Force” has the input “Returning to Fight,” which is calculated using the ghost converter of the flow “Returning to Force” used to populate the non-negative stock “Recovered.” The outflow from “Fighting Force” is “Leaving Force,” calculated by the sum of all patients in the ghost converters representing the arrayed flow “Wounding” and the “Died Instantly” flow.

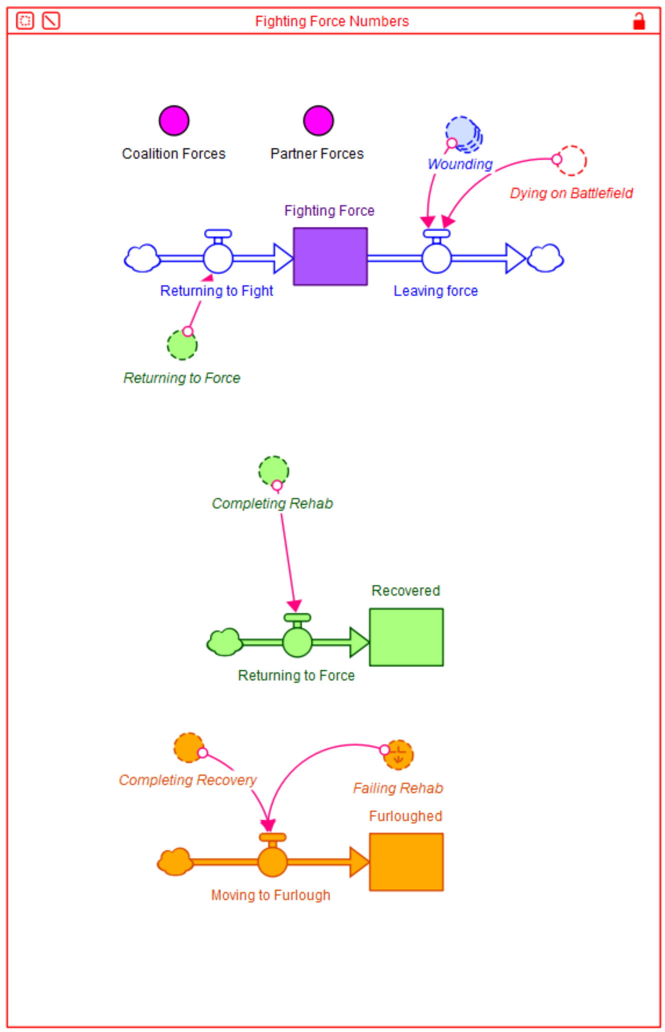

Figure 60. Model for Fighting Force Calculations.[299]

299 Adapted from ISEE Systems, Stella Architect.

"Recovered" is a non-negative stock, initialized at 0. It has a single inflow, "Returning to Force," which is equal to the ghost converter of the flow "Completing Rehab." "Furloughed" is a non-negative stock, initialized at 0. It has a single inflow, "Moving to Furlough," which is equal to the sum of the ghost converters of the leak "Failing Rehab" and flow "Completing Recovery." While Minimal patients may be able to be returned to duty prior to reaching Treatment Stage 4, the model was not currently set for this to be considered and is a limitation of the model. This likely underestimates the number of "Recovered" patients and puts unnecessary strain on parts of the system, although Minimal patients do not account for blood units or supply units.

	Equation	Properties	Units	Annotation
Fighting_Force_Numbers:				
Coalition_Forces	20			
Fighting_Force(t)	Fighting_Force(t - dt) + (Returning_to_Fight - Leaving_force) * dt	INIT Fighting_Force = Coalition_Forces+Partner_Forces	People	NON-NEGATIVE
Furloughed(t)	Furloughed(t - dt) + (Moving_to_Furlough) * dt	INIT Furloughed = 0	People	NON-NEGATIVE
Leaving_force	Wounding[Surgical_Critical]+Wounding[Critical]+Wounding[Urgent]+Wounding[Minimal]+Dying_on_Battlefield		People/Hours	UNIFLOW
Moving_to_Furlough	Failing_Rehab+Completing_Recovery		People/Hours	UNIFLOW
Partner_Forces	100			
Recovered(t)	Recovered(t - dt) + (Returning_to_Force) * dt	INIT Recovered = 0	People	NON-NEGATIVE
Returning_to_Fight	Returning_to_Force		People/Hours	UNIFLOW
Returning_to_Force	Completing_Rehab		People/Hours	UNIFLOW

Table 30. Equations for Fighting Force Calculations.[300]

H. SIMULATION RUN RESULTS BY SECTOR

This model was run using variable inputs based on my estimations and statistics from published medical literature and patient databases. The time frame simulated in the model is one month (750 hours). A graphical representation of the Casualty Statistics results was included in Chapter V. Figure 61 shows the screenshots of the model that totals by stage/cause of death for KIA and DOW patients. Most KIA patients are the result of dying instantaneously from untreatable wounds and the minority from waiting for

[300] Adapted from ISEE Systems, Stella Architect.

evacuation at Stage 2. Although some DOW patients die at Stage 3, DOW numbers do not begin to rise significantly until later in the model when patients begin dying of infection.

Figure 62 shows the screenshot of simulation results for the "Fighting Force Numbers" sector. When initializing with 120 fighters, the "Fighting Force" numbers decrease and eventually succumb to attrition prior to the month's end.

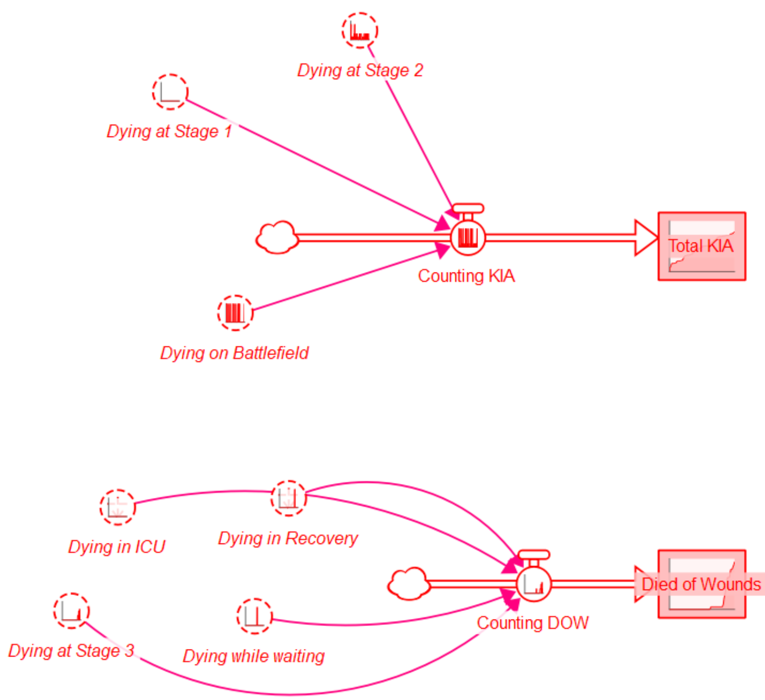

Figure 61. Model Screenshot Results of KIA and DOW Calculations.[301]

301 Adapted from ISEE Systems, Stella Architect.

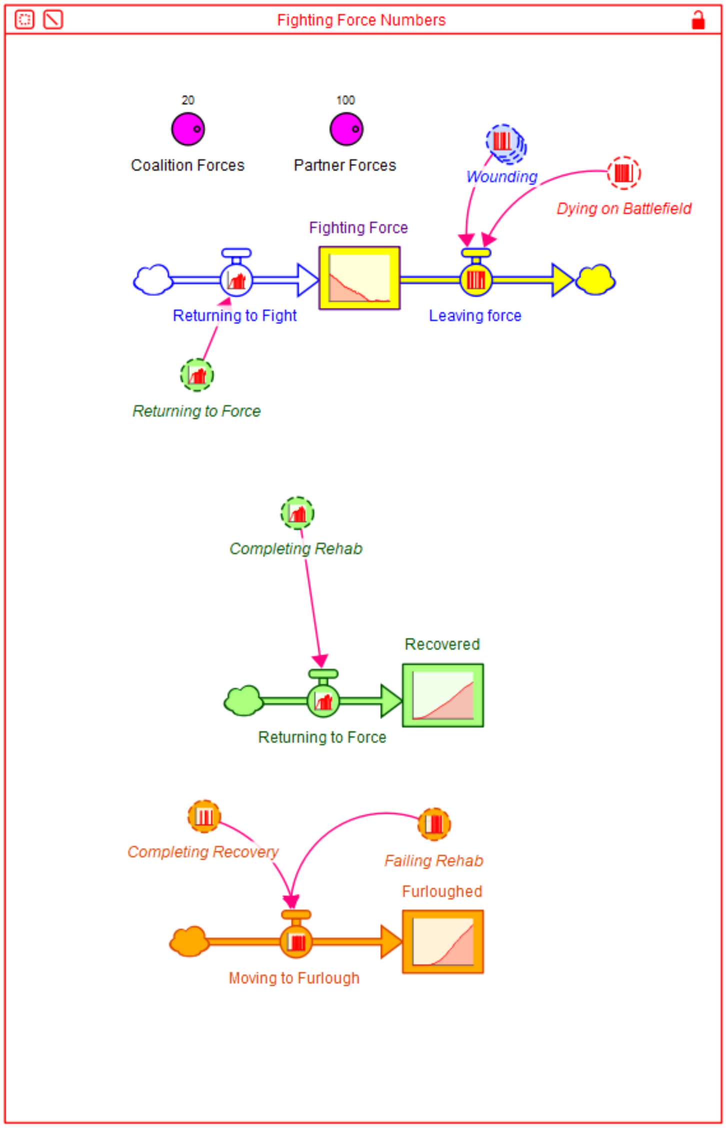

Figure 62. Model Screenshot Results for Fighting Force.[302]

The remainder of the results of the model will be based on the order the model was described in the preceding sections.

Figure 63 is a model screenshot that shows the results of patient care at Stage 1. Patients arrived at the casualty collection point at a rate that did not overwhelm the medics since 50% of the fighting force had been trained in TCCC. Just over halfway into the

302 Adapted from ISEE Systems, Stella Architect.

simulation, spikes can be seen in “Waiting for Review” as the system became overwhelmed due to the lack of buddy care available patients began to worsen while waiting for medics. Despite the worsening of patient conditions, there were no deaths at Stage 1.

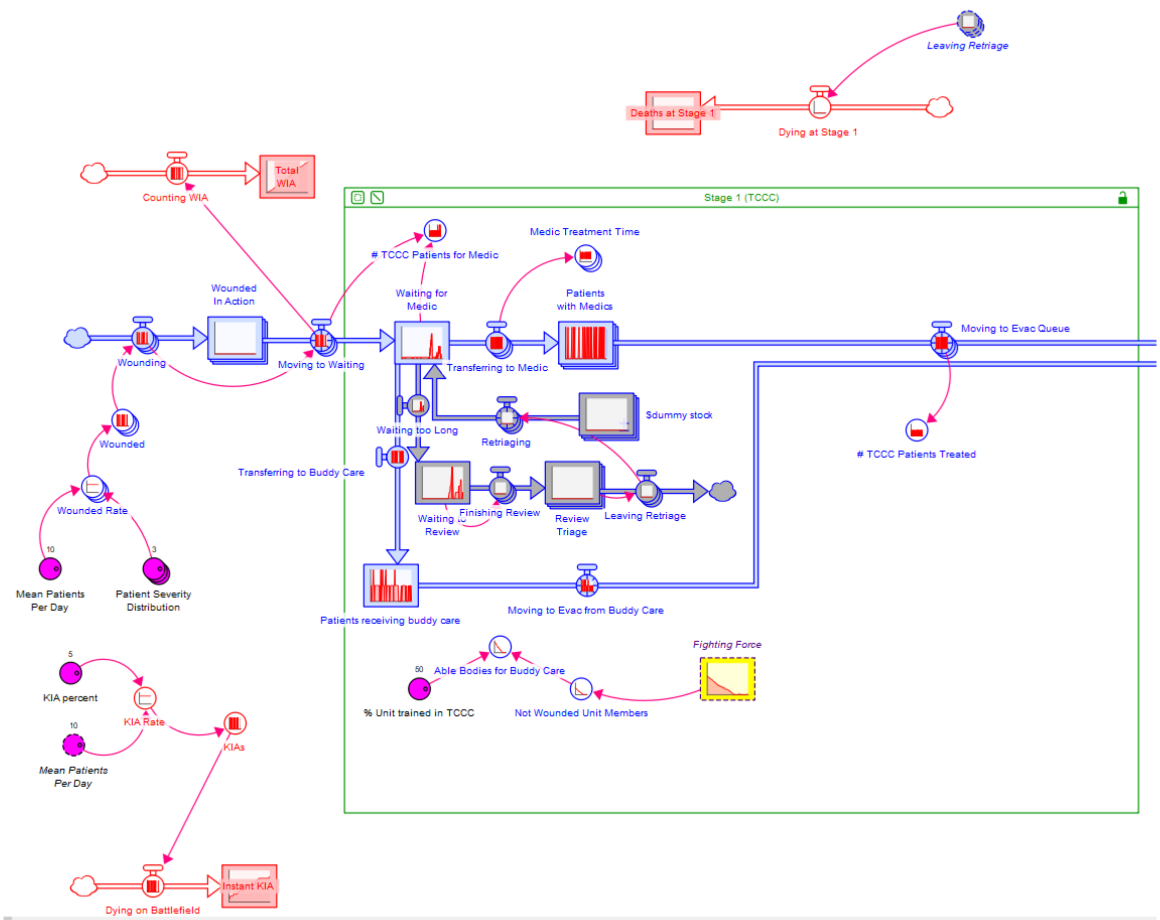

Figure 63. Model Screenshot Results of Stage 1 Patient Care.[303]

Figure 64 is a model screenshot that depicts the use of medical supplies by Stage 1 and Stage 2. Again, Stage 2 treatment is not inhibited by lack of supplies, but during the simulation’s run, the medics never ran out of supplies. It was assumed that medics can treat 20 patients with one unit of supplies, and they can carry 5 units with them. This is likely overexaggerated given the requirement for mobility at Stage 1. At one point in the model,

303 Adapted from ISEE Systems, Stella Architect.

supplies did have to be moved from the supply caches (red spike in “Moving from TCCC Cache”).

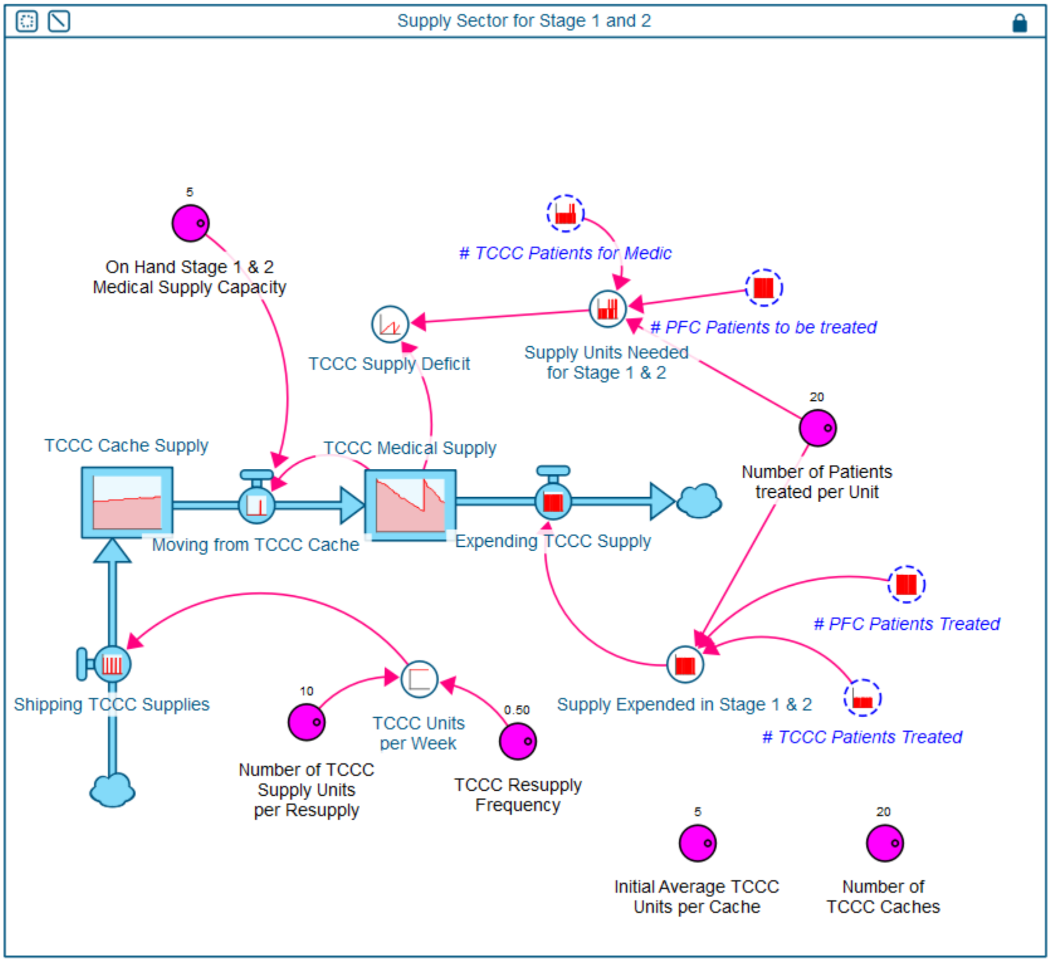

Figure 64. Model Screenshot Results of Stage 1 Medical Supplies.[304]

Figure 65 shows the model screenshots for frequency of evacuation from Stage 1 to 3, which directly effects the number of patients requiring PFC at Stage 2. The probability for rotary wing evacuation was set to 0%, for CASEVAC to 30%, and for MEDEVAC to 2%. The red spikes seen for each evacuation platform correlate with this probability and depict CASEVAC as the most frequent evacuation platform.

304 Adapted from ISEE Systems, Stella Architect.

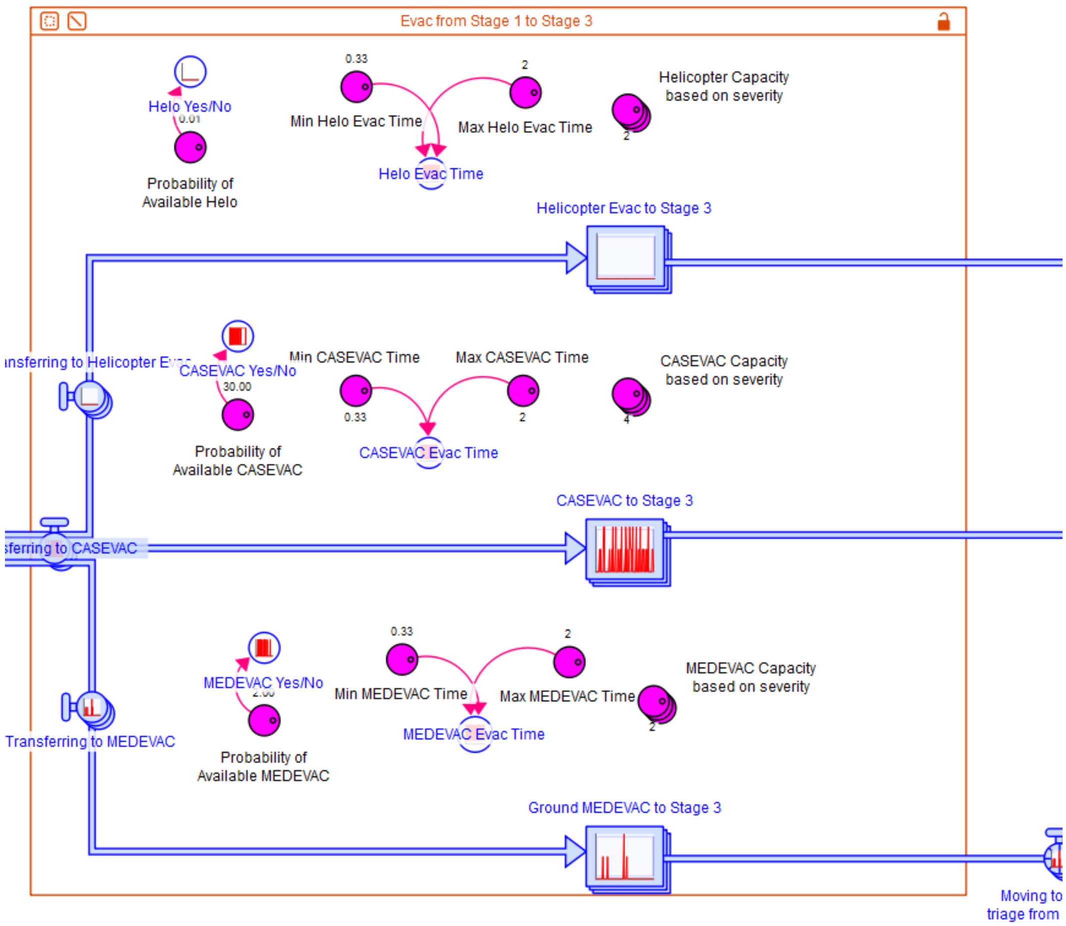

Figure 65. Model Screenshot Results of Evacuation from Stage 1 to Stage 3.[305]

The model was configured with the medics trained in PFC. There is a build-up of patients in "Waiting for Evac" (Figure 66) due to the infrequent availability of evacuation platforms seen in Figure 65. As a result, patients required PFC. As expected, a percentage of patients did not survive past 4 hours of PFC (red spikes in "Dying PFC Patients"), and this was the primary contributor for deaths at Stage 2. Those who survived past 4 hours entered the queue "PFC Patients > 4hr" to be evacuated to either Stage 3 or 4 (Figure 67).

305 Adapted from ISEE Systems, Stella Architect.

While the probability of CASEVAC to Stage 4 decreased to 25%, it is still the most prominent evacuation platform, as seen by the red spikes.

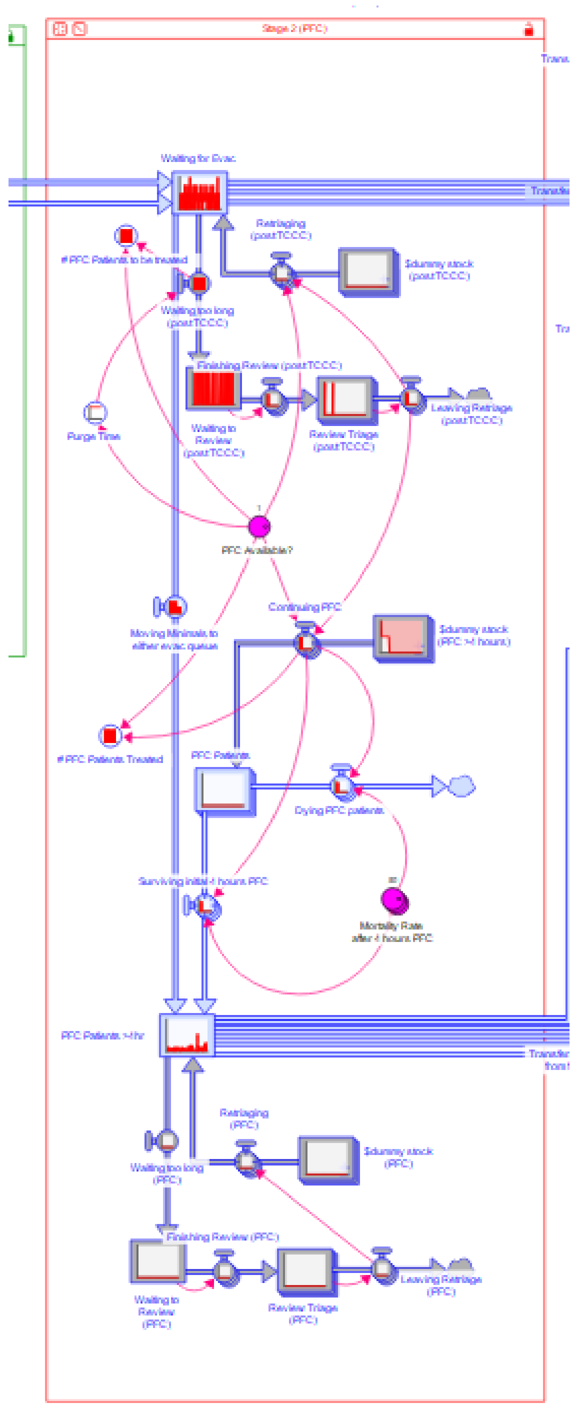

Figure 66. Model Screenshot Results of Stage 2 Patient Care.[306]

306 Adapted from ISEE Systems, Stella Architect.

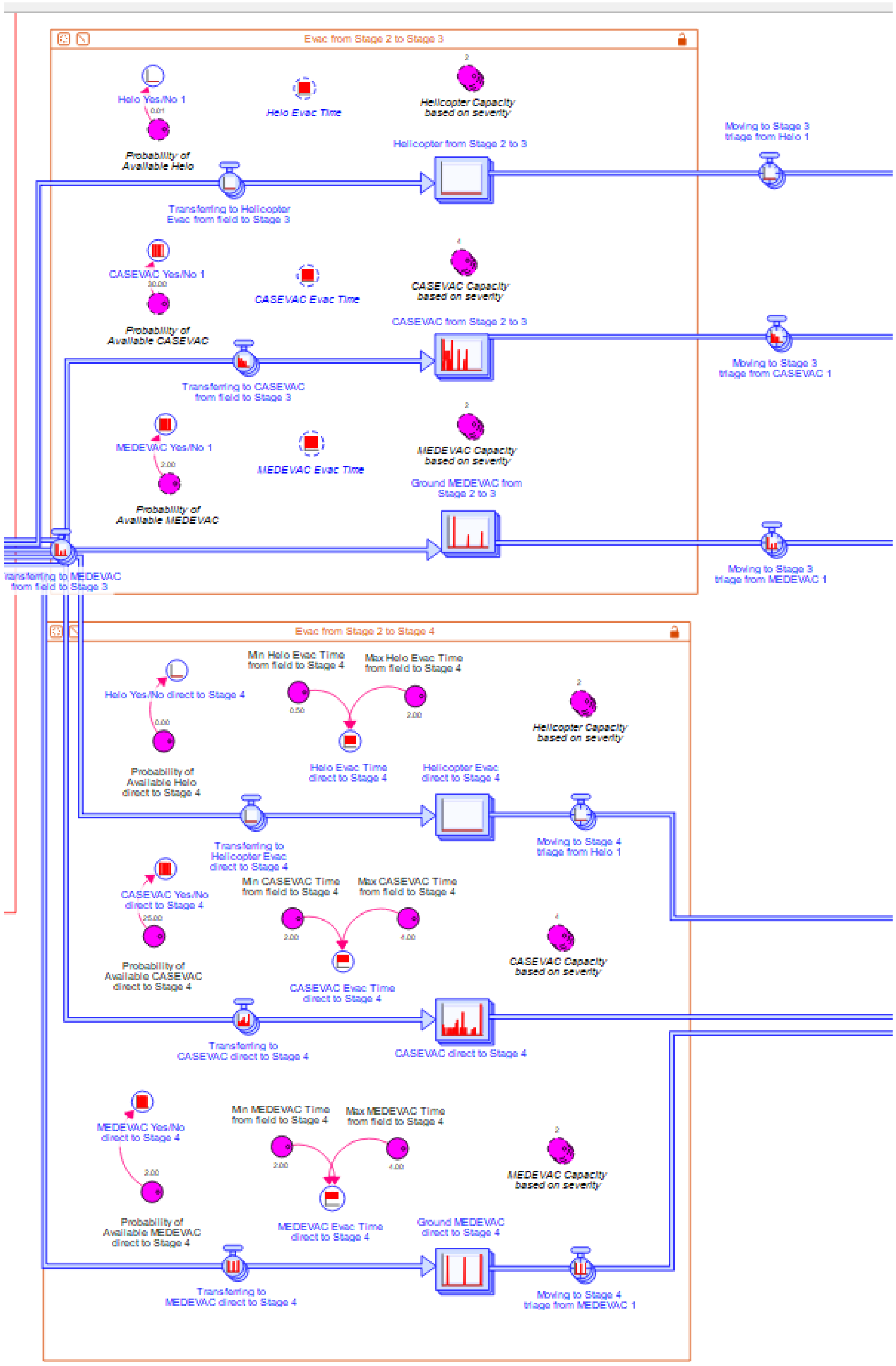

Figure 67. Model Screenshot Results of Evacuation from Stage 2 to Stages 3 and 4.[307]

[307] Adapted from ISEE Systems, Stella Architect.

The model screenshot of patient care results for Stage 3 are shown in Figure 63. Patients arrived at Stage 3 at a rate that did not overwhelm the forward surgical team until the latter part of the simulation. At that time, the team ran out of medical supplies (Figure 70), which prevented any surgeries or resuscitations from taking place and causing patients to decompensate. The lack of supplies was the reason for the spike in deaths at Stage 3 at the end of the month. The on-hand blood supply was also inadequate, requiring a walking blood bank to replenish supplies (Figure 69). At a few points in time, the blood supply was so low that a second unit had to be drawn from donors. The walking blood bank was sufficient to treat patients, however, and was not the reason Stage 3 treatment was arrested.

On the right-hand side of Figure 68, there are red spikes indicating decompensating patients who have been waiting for evacuation too long. These patients required retreatment by the team, certainly adding to the team increase in patients waiting for treatment towards the latter part of the simulation. The worsening of conditions was a result of unavailable evacuation platforms (Figure 71), even though the probability of CASEVAC increased to 50% and of MEDEVAC to 15%. This was not sufficient to prevent worsening patient conditions.

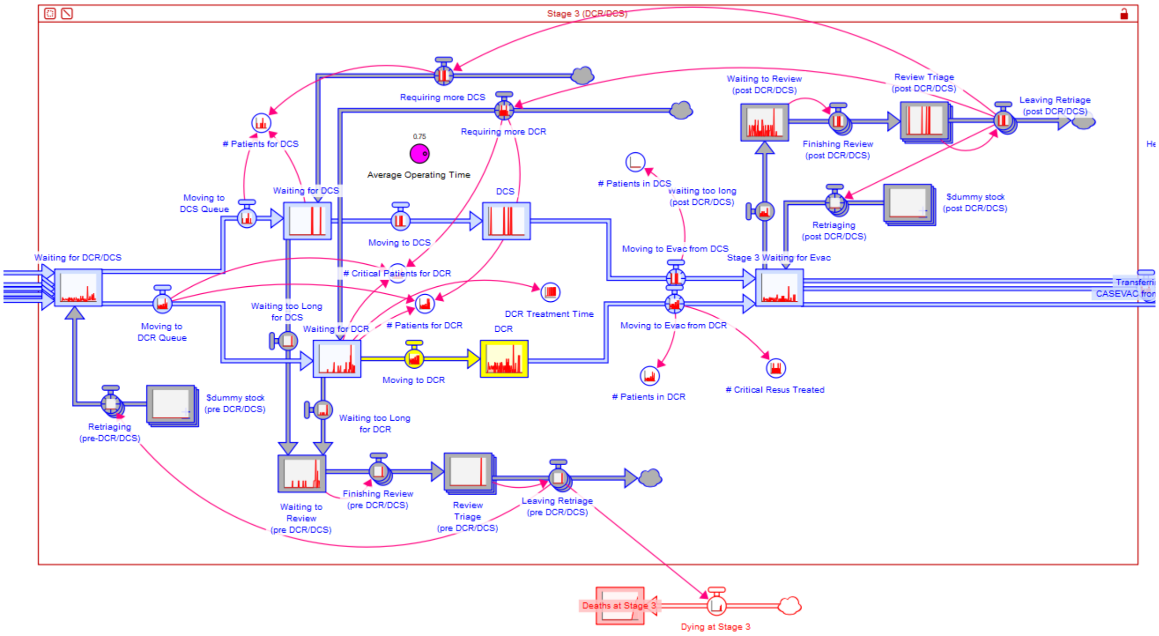

Figure 68. Model Screenshot Results of Stage 3 Patient Care.[308]

[308] Adapted from ISEE Systems, Stella Architect.

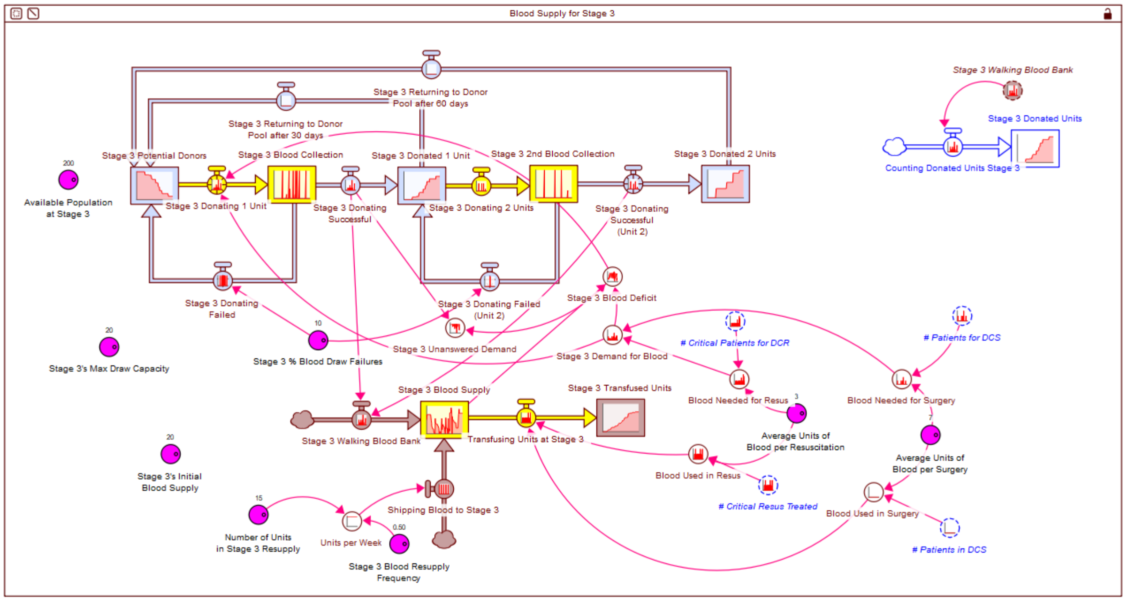

Figure 69. Model Screenshot Results for Stage 3 Blood Supply.[309]

309 Adapted from ISEE Systems, Stella Architect.

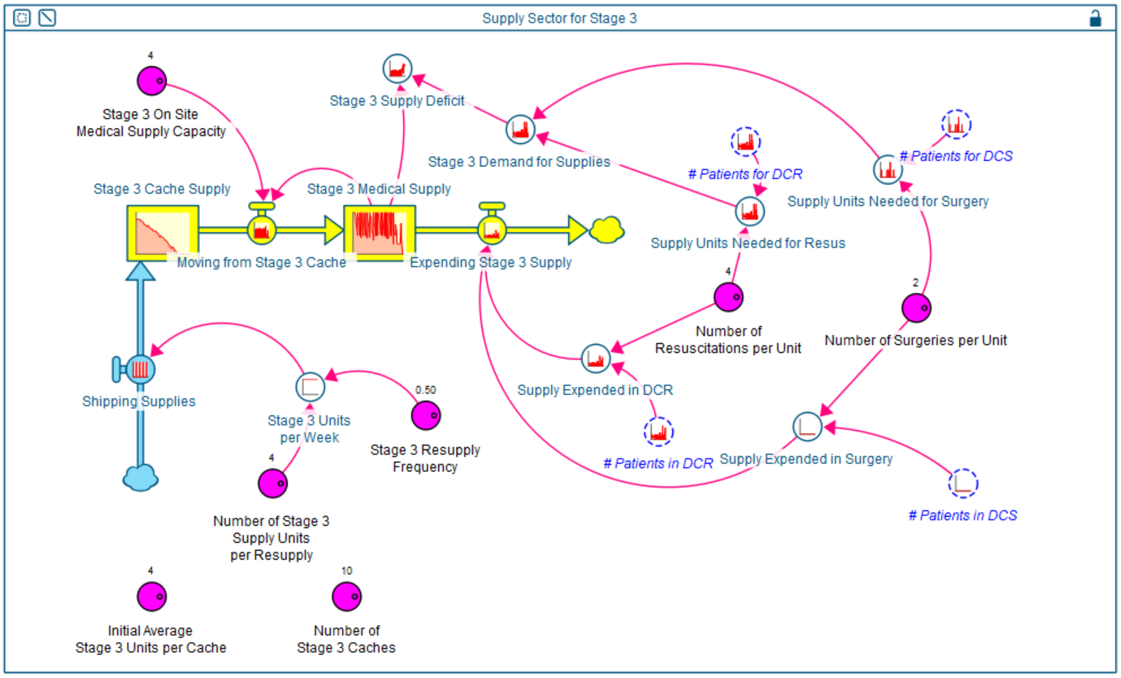

Figure 70. Model Screenshot Results for Stage 3 Medical Supplies.[310]

310 Adapted from ISEE Systems, Stella Architect.

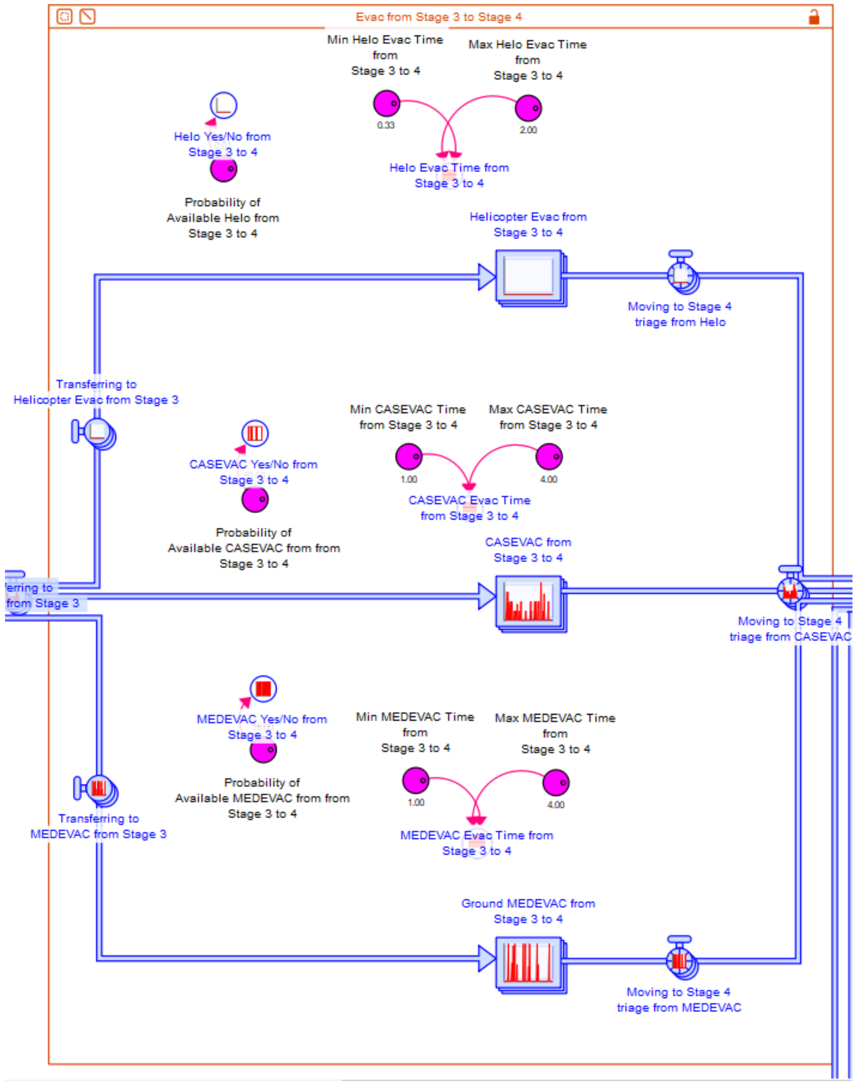

Figure 71. Model Screenshot Results for Evacuation from Stage 3 to Stage 4.[311]

Model screenshots for patient care results at Stage 4 are shown in Figure 72. Patients arrived at Stage 4 at a rate that did not overwhelm the hospital until almost halfway into the simulation when spikes were seen in “Waiting to Review (post Definitive Care).” Some of the Stage 4 DOW casualties occurred because of waiting to long for treatment,

311 Adapted from ISEE Systems, Stella Architect.

but the majority occurred approximately two weeks into the simulation when death from infections rose.

The Stage 4 model provides output on what the maximum number of beds are required at any given time. The converters calculating the MAXIMUM for “ICU” and “Inpatient Recovery” reached their peaks about halfway into the simulation and returned values of 12 and 23, respectively. This suggests that a total of 35 beds with corresponding medical personnel will be needed for the model to function as it did in the simulation. The converters calculating the MAXIMUM for “Outpatient Recovery Care” peaked early and resulted a value of 10. The converter calculating the MAXIMUM for “Rehabilitation” continued to rise until late in the simulation and resulted a value of 35. Therefore, space for rest and physical therapy for 45 people at a given time needs to be acquired, potentially through the local area, for patients with more minor injuries to recover and return to the fight.

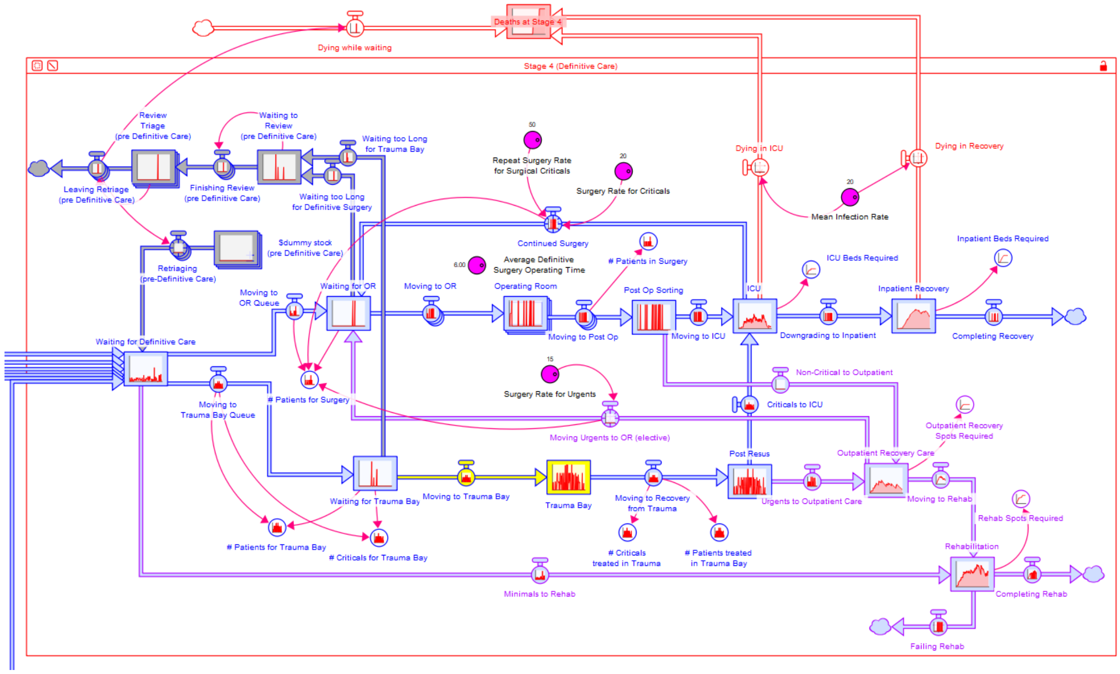

Figure 72. Model Screenshot Results of Stage 4 Patient Care.[312]

The “Stage 4 Blood Supply” was quickly depleted, requiring the initiation of walking blood banks. It appears that at times patients were waiting on treatment, the hospital had depleted their blood supply (“Stage 4 Blood Supply” in Figure 73), halting surgeries and treatment of patients in the trauma bay until blood could be collected by walking blood banks. At one point in time, the blood supply was so low that a second unit had to be drawn from donors (red spikes seen in “Stage 4 2nd Blood Donation” in Figure 73).

312 Adapted from ISEE Systems, Stella Architect.

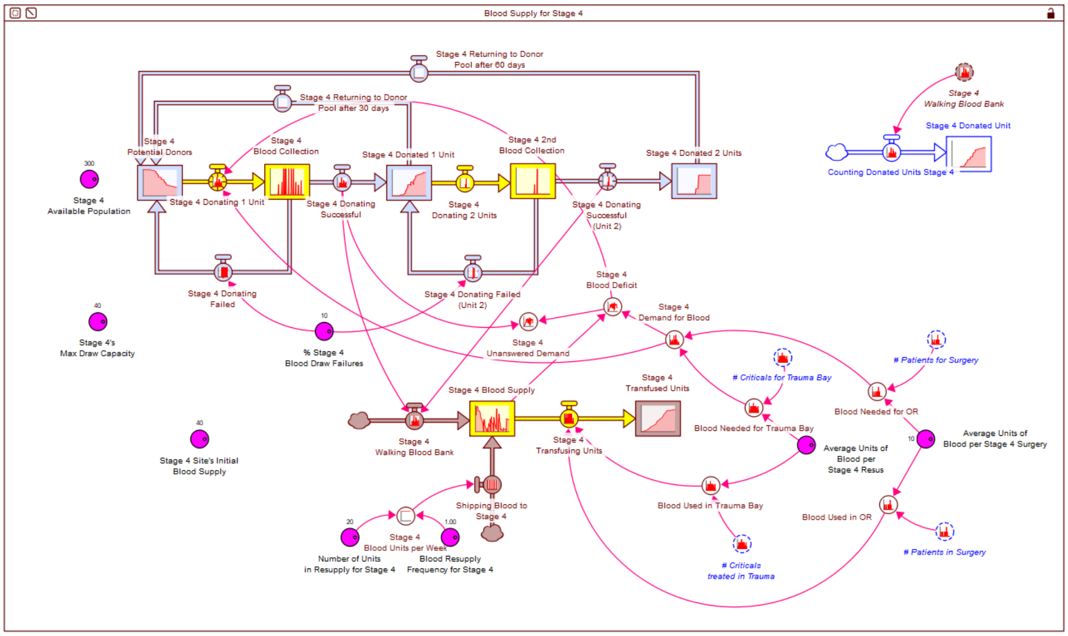

Figure 73. Model Screenshot Results for Stage 4 Blood Supply.[313]

The medical supplies were sufficient to treat patients, only required a couple withdrawals from caches, and did not halt Stage 4 treatment (Figure 74).

313 Adapted from ISEE Systems, Stella Architect.

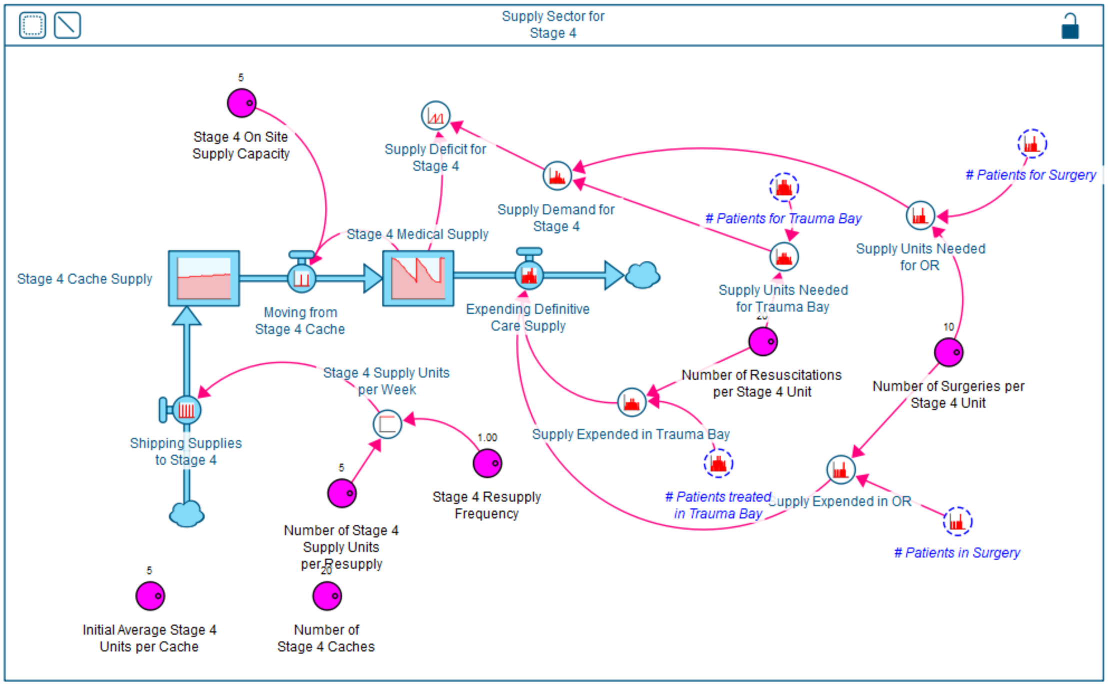

Figure 74. Model Screenshot Results for Stage 4 Medical Supplies.[314]

314 Adapted from ISEE Systems, Stella Architect.

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