Automating the Survival Chain and Revolutionizing Combat Casualty Care

Human-Technology Teaming on the Future Battlefield

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Like the concept of automating the "kill chain" that executes lethal force faster than the enemy, the "survival chain" can be automated to accelerate critical decisions about casualty care and maximally preserve combat power (see figure 1).[1] The accelerated execution of this medical construct through automation requires an uncomfortable paradigm shift for the Military Health System (MHS) that has achieved heroic casualty outcomes over the past twenty years of war but now faces a reckoning from challenges posed by large-scale combat operations against near-peer adversaries.[2] The challenges faced in this context—high frequency and volume of casualties; prolonged care in resource-limited settings; inadequate numbers of

Every second matters during the European Best Medic Competition, and neither Spc. Connor Ignozzi nor Spc. Carl Cleveland assigned to the Headquarters and Headquarters Troop, 1st Squadron, 1st Cavalry Regiment, 2nd Armored Brigade Combat Team, 1st Armored Division, waste any time as they assess a simulated rollover casualty in Grafenwöhr, Germany, on 7 December 2023. Artificial intelligence can enhance casualty care in a variety of ways to include casualty assessment, data transmission and processing, patient monitoring, and medical evacuation, to name just a few. (Photo by Spc. Trevares Johnson, U.S. Army)

trained medical providers; elevated potential for chemical, biological, radiological, nuclear, and directed energy events; increase in disease nonbattle injuries (e.g., endemic diseases, infection, and orthopedic injuries); and the near-constant threat of attack—demand a rethinking about how artificial intelligence, robotics, and human-technology teaming can accelerate the survival chain and facilitate commanders' forward momentum to achieve overmatch on the future battlefield.[3]

This new paradigm is a significant departure from current expectations of single casualties managed by multiple warfighters who are removed from the fight; it must evolve to a future state that maintains similar casualty outcomes but with fewer human resources needed to achieve them (see figure 2). The technologies necessary to achieve this require massive amounts of real-time data about casualty care that are accurate and reliably obtained in all care contexts at the sharp edge of medicine: the casualty-caregiver interaction.

The Data Problem

Unfortunately, the MHS does not collect such data. Like civilian health care, current data collection, focused on documentation for billing and historical accountability, is primarily human-derived, validated by humans for medical-legal purposes, and has been shown to be inaccurate and unreliable necessitating significant effort to transform it for research or machine-learning purposes.[4] Likewise, documentation is currently focused on longitudinal requirements (documentation of diagnosis, injuries, treatments, and outcomes). Records do not include real-time information about the context of care (number and type of caregivers, location, resources, mission requirements,

Automation Stack:	Sense	Understand	Decide	Act	Organize and Optimize	Measured Outcomes
Warfighter Or Casualty	Location Environment "Status" (position, movement, injuries, physiology, mental status, etc.)	"In the fight" (Optimal, Normal, Degraded) "Casualty" (Rapid RTD, Delayed RTD, EVAC Home) Trajectory (Better, Same, Worse)			Triage Category based on digital twin's probabilistic trajectory through the current system based on time, location, and resources (system level)	RTD Rate (immediate vs. delayed) Evacuation rate per injury pattern Survival Quality of Life Mission Success Commander Satisfaction
Caregiver Or Care Team	Location Environment "Status" (sleep, physiology, training, proficiency, etc.)	Numbers available Stress Task Saturation Expectations	Specific Treatment or Intervention or Additional Assessment Prioritization and Plan Next step	Provide LSI (e.g. TQ, Blood, Surgery, etc.) Provide Medication Document Provide non-LSI (e.g. bandage, package for transport, etc.) Coordinate Care	What needs to be done when, and by whom at a systems level? System Casualty Prioritization System Task Planning	Time on Priority Task Time on Non-Priority Task Number of Caregivers Needed/Casualty Caregiver Satisfaction
Resources *Local & System*	Location Blood Products Tourniquets IVs, bandages Medications Clinician Type and Number	Time-to-Resource Resupply Needs Triage Framework	Priority of Resupply Priority of Evacuation Priority of Platform	Execute resupply mission Execute MEDEVAC Mission Task Evacuation platform	Where should it be done? How to best *optimize* the probability of success at a systems level? Evacuation Prioritization Evacuation Location Evacuation Platform	Optimal time to task Minimal Resource Waste (less resupply, lest cost, etc.) Time to Resupply Commander Satisfaction

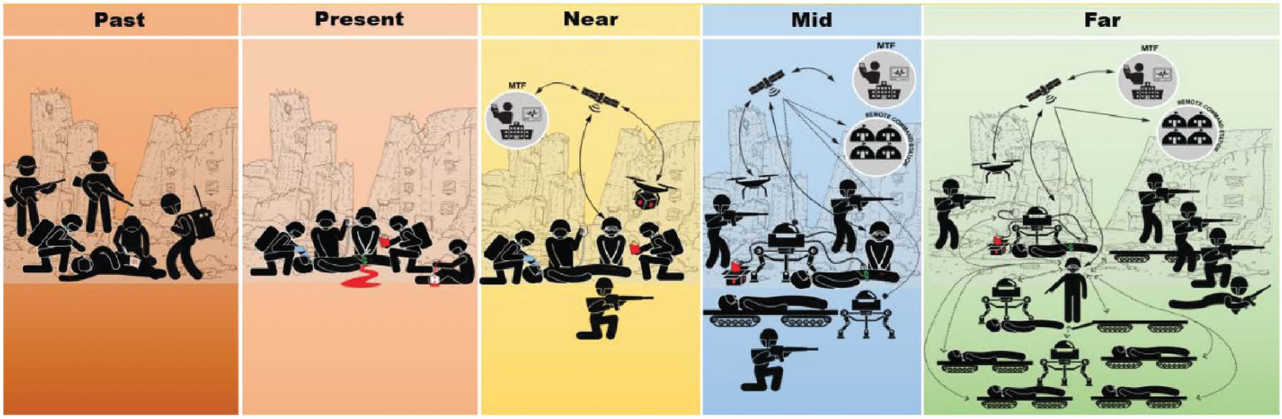
(Figure by Raymond Samonte)

Figure 1. The Survival Chain and the Automation Stack Paradigm

kinetic activity on the battlefield, etc.), or any data about clinicians'/care teams' actions and when they occur. In essence, these current data collection practices do not provide the type of information necessary for modernizing casualty care in the age of artificial intelligence (AI).

Lack of accurate and reliable data is a principal challenge to building trustworthy AI. Current data sources within the MHS include the electronic health record, Tactical Combat Casualty Care Card (DD Form 1380), and tape with handwritten notes that all require humans to complete at the expense of performing other casualty care tasks. Less than 20 percent of the thirty thousand casualties in Iraq and Afghanistan had any form of prehospital documentation because, when given the choice, task-saturated caregivers chose to return fire, provide casualty care, and perform other tasks over documentation (personal experience of the authors).[5] Furthermore, when documentation is completed, it is nearly always completed after casualty care and is thus delayed and often incorrect or biased.[6] Given these constraints, the entire Department of Defense (DOD) Joint Trauma System's Trauma Registry, collected between 2006 and 2023, is less than one gigabyte in size (personal knowledge of authors). For comparison, autonomously driving cars such as Waymo (Google Self-Driving Car Project), collect three gigabytes of data every minute from twenty-five sensors, which is a total of thirty-two terabytes of data daily (figure 3).[7]

In large-scale combat operations, human-inputted documentation will fail because humans will be task-saturated providing lifesaving care to casualties. Consequently, systems that rely upon data from electronic medical records and anticipated near-term digital documentation tools, such as the U.S. Air Force's Battlefield Assisted Trauma Distributed Observation



*N.B. size and configuration of robots, drones, and evacuation vehicles are notional and do not reflect teaming, future miniaturization, or multi-purpose functionality

(Figure by Raymond Samonte)

Figure 2. Human Resources Needed for Point of Injury Casualty Care over Time

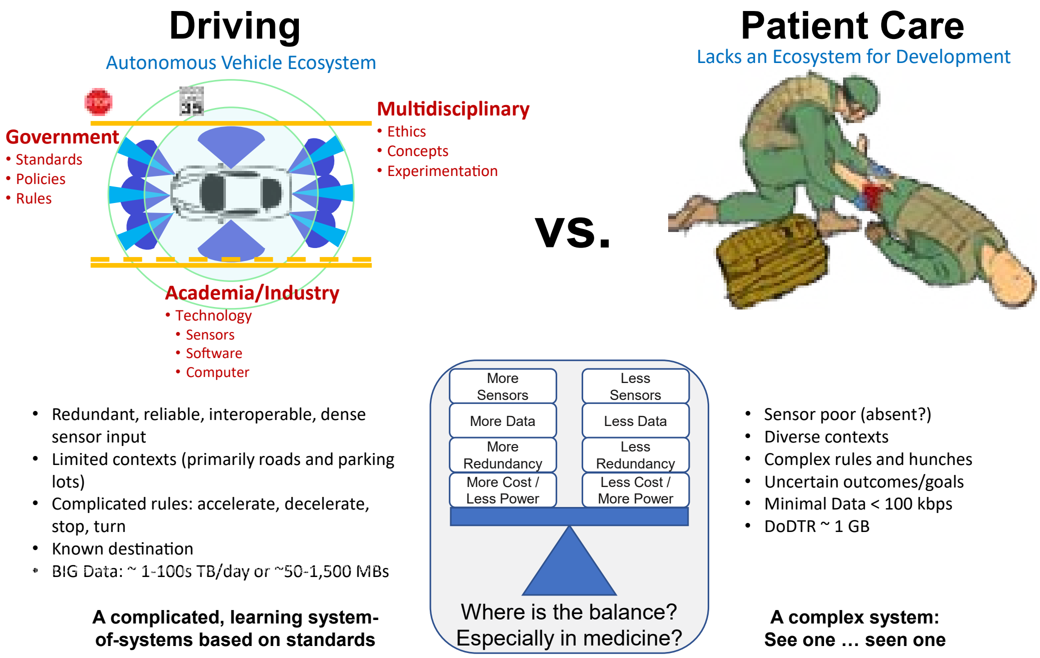
Kit (BATDOK), will not provide the information needed for optimal care, to learn passively and continuously, and they will not be available for real-time use.[8] Instead, accurate and reliable time-series data collected passively from sensors about casualty status, resource use/consumption, caregivers and their actions, and care context across the care continuum are needed. This foundational data set provides data for more precise predictive model development for triage, evacuation, logistic resupply, medical command and control, and medical force projection.

A New Paradigm: Automating the Survival Chain

Human-technology teaming alone achieves faster processes by fusing data, humans, and technology into solutions that optimize system performance.[9] Automating processes further improves performance and efficiency.[10] The survival chain model parallels the automation stack (compare figures 1 and 4). It is a framework for understanding how to create and accelerate human-technology teaming in casualty care. Like the observe, orient, decide, act loop, the automation stack begins with passive data collection using sensors.[11] We can then use data from these sensors to understand the 5 Ws of casualty care:

- *Who* is present in the care context (casualties and caregivers),
- *What* is wrong with the casualty (injuries, physiology, etc.) and *what* does the caregiver do about it (actions),
- *When* does the casualty's status change and *when* does a caregiver perform an action,
- *Where* is the care occurring (location, temperature, altitude, and environment), and
- *Why* does the casualty's status change and *why* does a caregiver perform an action (status and actions are tightly connected and correlated to available resources and care context)?

Clinicians combine sensing and understanding data into an *assessment* used to decide what clinical action to take. Intelligent (AI enhanced) and unintelligent (enhanced visualizations, rule-based decision trees, etc.) decision-support tools can improve clinical decision-making. Hardware (robotics and medical devices) and AI-based software can assist caregivers by offloading human tasks to machines. Similarly, treatments may be offloaded to intelligent or unintelligent machines. For example, current treatments that are commonly offloaded to unintelligent medical devices include the monitoring, intravenous fluid, and medication administration via intravenous pumps, and the use of mechanical ventilators for breathing assistance. In the future, robotics will help caregivers manage casualties by identifying them, monitoring them with physiologic sensors and imaging modalities, assisting them with surgery, aiding with lifesaving interventions, and intelligently tasking resupply and medical evacuation missions.[12] We imagine that these types of innovations will be particularly beneficial in environments contaminated by chemical, biological, radiological, nuclear, and directed energy threats.



(Figure by Raymond Samonte)

Figure 3. Comparison between Automating Driving and Automating Casualty Care

Optimizing the entire survival chain is necessary to manage casualties across the care continuum and achieve the best outcomes. Automation will provide future commanders with the necessary speed, agility, and resources to maintain overmatch and win. If we successfully obtain the data necessary for automation, we can also produce a curated dataset to digitally twin casualties. Producing digital twins involves creating a sophisticated digital replica of a real-world entity, such as a human, which can then be applied to service members and combat casualties.[13] By doing so, we can achieve even more efficiency and better outcomes.

Revolutionizing Combat Casualty Care with Digital Twins

Revolutionary change in casualty care, however, will come when data collected provides trustworthy predictive analytics about an *individual* casualty's future state and how to optimize it across time by efficiently matching needs to resources. These forecast models are *casualty digital twins* (CDTs).[14] To understand what happens at the point of care (e.g., under a bush, on a beachhead, or at the bedside) and produce real-time models to aid decisions and automate care, data must be passively collected (see figure 5). Real-time, passive data collection that provides for an accurate and reliable assessment of casualties, caregivers, and resources across the care continuum can iteratively evolve the survival chain and automate tasks at each step of the survival chain (e.g., documentation, triage, evacuation coordination).

Casualty digital twins provide the MHS with a unique opportunity to close the gap between the physical and digital worlds. Through digital replicas of casualties (twinning), the MHS gains access to the understanding of a casualty's projected (future) condition and needs by applying the learned experience of previously treated patients and adapting it as a continuously learning system (see figure 6). This virtual representation, infused with information about resource availability at echelon and operational considerations for evacuation that impact time, can form the basis for personalized, data-driven decisions that can optimize our battlefield trauma system's capability and capacity to manage large volumes of casualties. Casualty digital twins in turn lead to the development of decision-support tools and automation algorithms that facilitate

Automation Stack	Possible Solutions	Timeline (interim products)
Act • **AKA:** Treat, Intervene • **Concepts:** Reassessment, Physical Action **Human and/or Machine**	• Autonomous/remote controlled ICU • Autonomous/remote assisted MEDEVAC • Robotic assistance • Telesurgery in network limited environment	2028-2035
Decide • **Concepts:** Decision support, hypothesis testing, AoA/COAs **Human, HITL, HOTL, Machine**	• Precision resupply? • Intelligent triage of casualties, resources, evacuation? • Digital twinning	2026-2030
Understand • **AKA:** Orient, learn, "assess" • **Concepts:** Visualizations, dashboards, models, algorithms **Machine-Human, Machine**	• **First solution**: Automated documentation of the 1380 • Others: Casualty status, resource consumption, caregiver actions pre-Role 2	2025
Sense • **AKA:** Observe, "see," "assess," perceive • **Concepts:** Sensors and devices **Machine**	• Trusted (accurate, reliable) passive data collection in real time in all domains	2024

(Figure by Raymond Samonte)

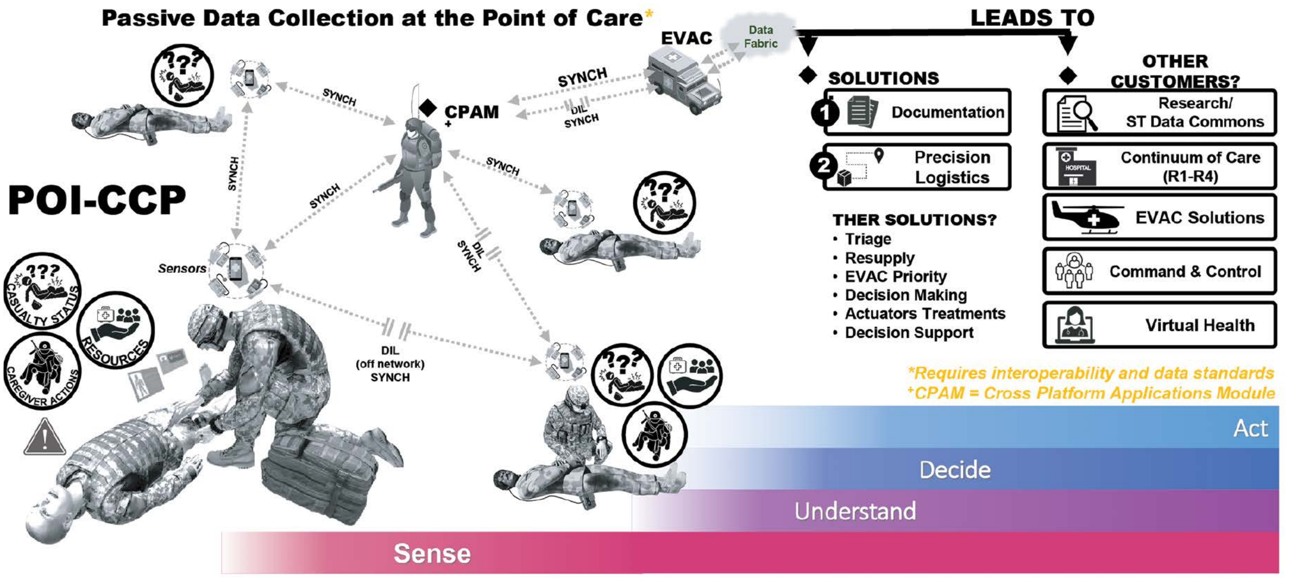
Figure 4. The Automation Stack and a Concept of Time to Achieve Solutions

faster, more accurate decisions and interventions tailored according to an individual casualty's needs and balanced with the needs of other casualties in the system, ultimately producing an optimized survival chain that assesses situations, makes faster decisions, and gives more appropriate treatments within the context of the resource availability across the care continuum to achieve the best outcomes.

AI-Enhanced Casualty Care

Currently, the MHS manages casualties across the care continuum in a linear fashion using the NATO roles of care guidelines (Roles 1-4). Doctrinally, this evacuation system has increasing capability and capacity at each level of care; in execution, however, it is asymmetric and requires significant communication and human input at all levels to be successful. In the future, the doctrinal roles of care are likely to be disrupted, which can lead to multiple points of failure. Primarily, it relies on rapid evacuation, proper communication, and freedom of maneuver. However, future warfare will preclude casualties from moving through a linear progression of battlefield care as has been seen in Africa and currently within Ukraine.[15] Advanced medical and surgical care, and the ability to hold patients for prolonged periods prior to evacuation, may be required much closer to the point of injury and networked across the battlespace to maintain system resiliency.

Recently, Gen. (Ret.) Mark A. Milley wrote, "The next conflict will be characterized by ubiquitous sensors with *mass data collection and processing ability* [emphasis added]."[16] To maintain optimal care through the survival chain, even amidst a disrupted medical support structure, requires that casualty digital twinning begins before a potential injury. Therefore, health



(Figure by Raymond Samonte)

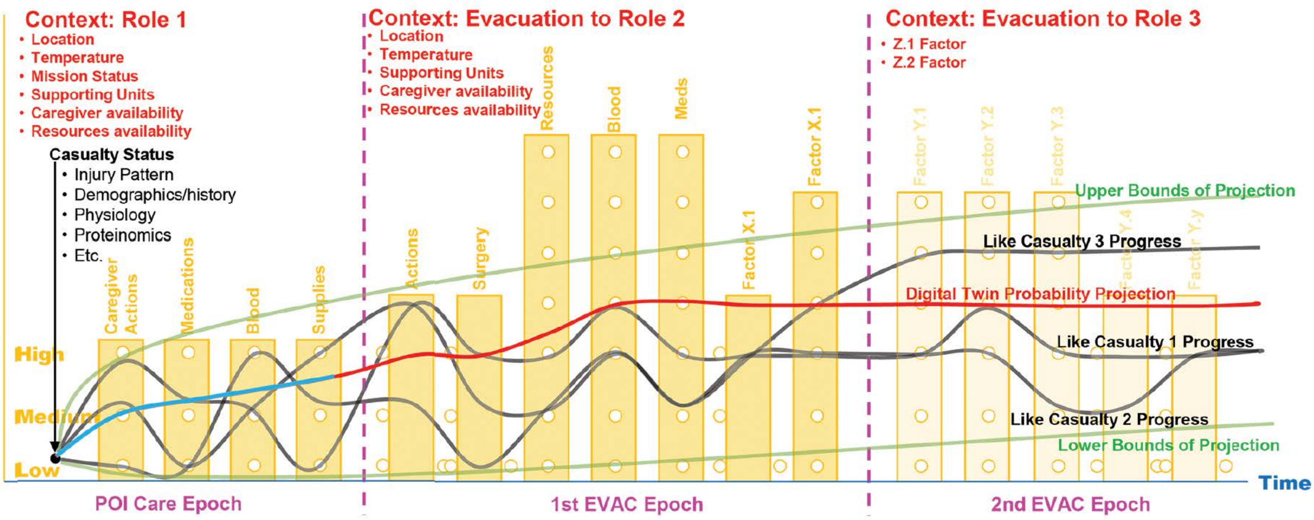
Figure 5. Passive Data Collection at the Edge and Possible Automation Solutions That Can Be Derived from It

data about warfighters *must* be collected from wearable sensors not only from casualties but also from warfighters in a *precasualty state*. We propose this precasualty state of health management as a new role of care, "Role 0." This role of care represents the majority of a warfighter's "life space" as well as their baseline health from which future AI will recognize variance as illness or injury. In this future state, the MHS will be responsible for helping commanders optimize health to avoid illness or injury and to return casualties to duty faster.

Consequently, a future state that incorporates "ubiquitous sensors with mass data collection and processing ability" will not only enable better Role 0 health and more rapid return to duty but will also combine with the predictive power of CDTs to optimize how casualties move through the evacuation chain.

Delivering casualty care utilizing CDTs will facilitate a better understanding of military medical support and enable evidence-based performance improvement made possible by the DOD Joint Trauma System. The predictive power of CDTs will evolve over time as part of a learning health-care system to optimize care on the twenty-first-century battlefield by rapidly influencing combat casualty care guidelines and reshaping how we train warfighters to deliver casualty care.[17] Ultimately, the following principles guide success:

- Data necessary to identify casualty conditions, track decision-making, treatments, resource consumption, and care synchronization is not the same as retrospective *documentation* of illness/injury patterns and treatment rendered. Documentation is *delayed*; data for care management must be real-time and include caregiver performance, which should not be captured in an individual patient's medical record.
- A single solution is unlikely to address the nuances of patient care in different contexts (e.g., care under fire versus in a helicopter versus in an operating room versus in an intensive care unit versus on a ship versus in the arctic). Different care domains necessitate different workflows, information needs, caregiver training, and experience. The technology solutions used to support care in various work domains must earn the trust of medical professionals through the incorporation of rigorous user-centered design that optimizes efficiency and effectiveness of use by different users in different contexts of use.[18] The approach to achieving success is not one solution but a system of solutions that is



(Figure by Raymond Samonte)

Figure 6. Casualty Digital Twinning Concept

interoperable (e.g., a secure, standards-based, plug-and-play "internet of medical things" built to operate as a system versus a series of disparate medical products integrated on an ad hoc basis).[19] This "system of systems approach requires increased coordination with diverse battlefield governance … common data standards and message formats … [to form] a continuous, seamless link between administrative and tactical systems through the continuum of DoD, VA, civilian hospitals, and coalition partners."[20]

- Solutions incorporated into the survival chain system must address care across the continuum and at each point within it to produce a comprehensive understanding of resource utilization and care synchronization. Research is still necessary to understand what data needs to move between echelons; at what frequency; according to what standard(s); and ultimately how data will be analyzed, visualized, and used for decision support, forecast model development, and automation. Ongoing research and rigorous application of user-centered design can continually assess and improve the value and effectiveness of data sources, models, algorithms, visualizations, and decision-support tools to accelerate the survival chain as novel and different sensors, tools, and visualizations become available.
- The sensors used on the battlefield must also be used during training. Utilizing these sensors to understand the care that trainees provide and getting trainees familiar with the decision-support tools that CDTs enable will dramatically impact training paradigms.
- It is essential to lower technical and administrative barriers for academia, industry, and DOD laboratories to enter this space. Doing so will generate collaboration and competition that iteratively enhances component parts of the system rather than utilizing single entities to develop and enhance the entire system. Current processes, especially with respect to authorities to operate on the network delay progress and choke innovation by conditioning research, development, interoperability testing, and iterative solution improvement on a linear process instead of a continuous, development-operations cycle nested within a cybersecurity framework (DevSecOps cycle).[21]
- Technology must be cyber secure from a hardware, software, and network perspective. Furthermore, the electronic signature of these devices must be consistent with military specifications to minimize the risk of identification and attack. Ensuring that components of the survival chain are built as part of an interoperable, standards-based, plug-and-play system of systems

allows proactive threat modeling and mitigation of risks.[22]

- Research and solution development across the MHS is fragmented due to competing perspectives, responsibilities, resource allocation, and multiple labs studying similar issues, which makes research dollars not prudently spent. For example, funding and accountability for care at the point of injury through Role 3 is assigned to the DOD services; whereas all care documentation and care beyond Role 3 is assigned to the Defense Health Agency. Similarly, resourcing of care is a logistics function that aims to improve gross resource availability, but not resource use at the individual casualty or caregiver level. Requirements generators, researchers, advanced developers, program managers, and policymakers can utilize the survival chain paradigm to piece together more consistently a medical system that optimizes decision-making, and therefore maximizes outcomes, over time and with the most modern technology. *A key question to ask is, What portion of the survival chain is a technology intended to improve and how does that improvement affect the other components of the chain?*

Conclusion

The scale, severity, and prolonged nature of combat casualty care in multidomain operations against near-peer adversaries requires modernizing the MHS. The survival chain is a concept that can help the MHS reframe battlefield medicine and iteratively develop technology solutions across the care continuum. A data and technology-enabled survival chain akin to a convergent kill chain requires passive data collection now that enables decision support and automated actions in the future. Progress is contingent on rapidly producing a foundational casualty care dataset—from training, research, and real-world care—made available to developers that will begin the process of automating the survival chain. ■

We would like to give special thanks to Mr. Raymond Samonte for help creating the figures and graphics in this manuscript. The views, opinions, and/or findings contained in this research/presentation/publication are those of the author(s)/company and do not necessarily reflect the views of the Department of Defense and should not be construed as an official DOD/Army position, policy, or decision unless so designated by other documentation. No official endorsement should be made.

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