

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

(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

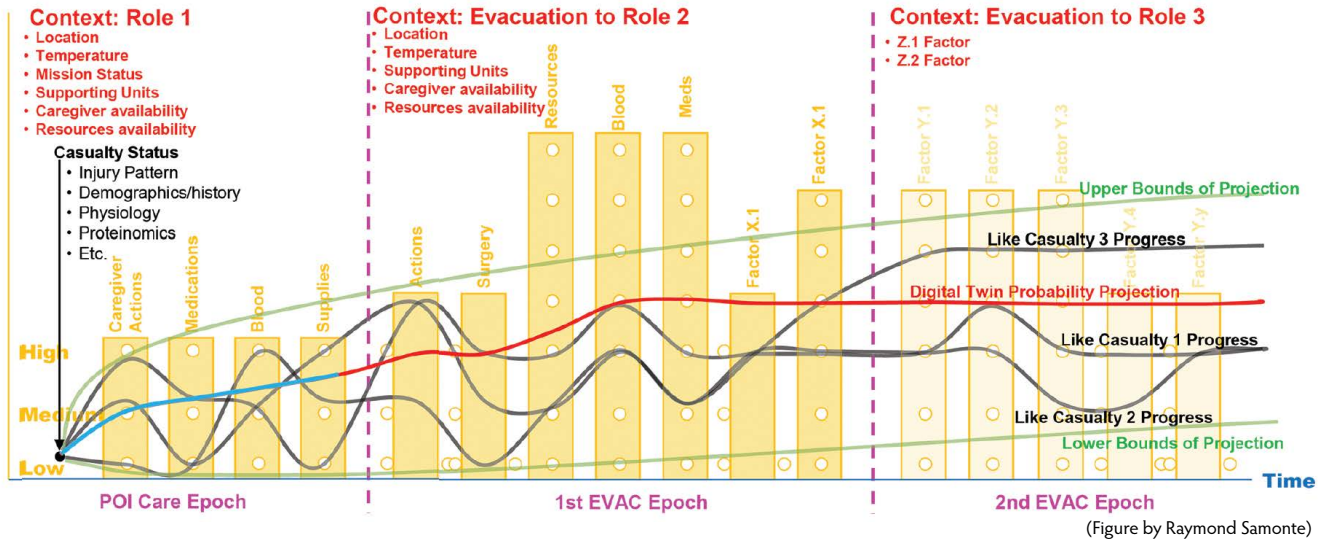


Figure 6. Casualty Digital Twinning Concept

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. ■

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Notes

1. Christian Brose, *The Kill Chain: Defending America in the Future of High-Tech Warfare* (New York: Hachette Books, 2020); Jennifer M. Gurney et al., "The 'Survival Chain': Medical Support to Military Operations on the Future Battlefield," *Joint Force Quarterly* 112 (1st Quarter, 2024): 94–99, <https://ndupress.ndu.edu/Media/News/News-Article-View/Article/3679354/the-survival-chain-medical-support-to-military-operations-on-the-future-battlef/>.

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. Mason H. Remondelli et al., "Casualty Care Implications of Large-Scale Combat Operations," *Journal of Trauma and Acute Care Surgery* 95, no. S2 (Supp. 1) (2023): S180, <https://doi.org/10.1097/ta.0000000000004063>; Aaron Epstein et al., "Putting Medical Boots on the Ground: Lessons from the War in Ukraine and Applications for Future Conflict with Near Peer Adversaries," *Journal of the American College of Surgeons* 237, no. 2 (2023): 364–73, <https://doi.org/10.1097/XCS.0000000000000707>.

4. William R. Hogan and Michael M. Wagner, "Accuracy of Data in Computer-Based Patient Records," *Journal of the American Medical Informatics Association* 4, no. 5 (September 1997): 342–55, <https://doi.org/10.1136/jamia.1997.0040342>; Nicole Gray Weiskopf and Chunhua Weng, "Methods and Dimensions of Electronic

Health Record Data Quality Assessment: Enabling Reuse for Clinical Research," *Journal of the American Medical Informatics Association* 20, no. 1 (January 2013): 144–51, <https://doi.org/10.1136/amia-jnl-2011-000681>; Xinggang Liu et al., "Improving ICU Risk Predictive Models through Automation Designed for Resiliency Against Documentation Bias," *Critical Care Medicine* 51, no. 3 (March 2023): 376–87, <https://doi.org/10.1097/CCM.00000000000005750>.

5. Jon B. Robinson et al., "Battlefield Documentation of Tactical Combat Casualty Care in Afghanistan" *U.S. Army Medical Department Journal* (April–September 2016): 87–94.

6. Laurie Lovett Novak et al., "Understanding the Information Needs and Context of Trauma Handoffs to Design Automated Sensing Clinical Documentation Technologies: Qualitative Mixed-Method Study of Military and Civilian Cases," *Journal of Medical Internet Research* 22, no. 9 (2020): e17978, <https://doi.org/10.2196/17978>; Sean M. Bloos et al., "Feasibility Assessment of a Pre-Hospital Automated Sensing Clinical Documentation System," *American Medical Informatics Association Annual Symposium Proceedings* 2019 (2019): 248–57; Brian J. Eastridge et al., "We Don't Know What We Don't Know: Prehospital Data in Combat Casualty Care," *U.S. Army Medical Department Journal* (April–June 2011): 11–15.

7. Matthew Schwall et al., "Waymo Public Road Safety Performance Data," arXiv, 30 October 2020, <https://doi.org/10.48550/arXiv.2011.00038>.

8. "B.A.T.M.A.N. Program: Battlefield-Assisted Trauma Distributed Observation Kit (BATDOK)," Air Force Research Laboratory, accessed 11 March 2024, <https://afresearchlab.com/technology/human-performance/batman-program/>.
9. "Human-Machine Teaming," Defense Innovation Marketplace, accessed 11 March 2024, <https://defenseinnovationmarketplace.dtic.mil/technology-interchange-meetings/autonomy-tim/human-machine-teaming/>; H. James Wilson and Paul R. Daugherty, "Collaborative Intelligence: Humans and AI Are Joining Forces," *Harvard Business Review*, July-August 2018, <https://hbr.org/2018/07/collaborative-intelligence-humans-and-ai-are-joining-forces>.
10. James C. Walliser et al., "Team Structure and Team Building Improve Human-Machine Teaming with Autonomous Agents," *Journal of Cognitive Engineering and Decision Making* 13, no. 4 (2019): 258–78, <https://doi.org/10.1177/1555343419867563>.
11. James Johnson, "Automating the OODA Loop in the Age of Intelligent Machines: Reaffirming the Role of Humans in Command-and-Control Decision-Making in the Digital Age," *Defence Studies* 23, no. 1 (2023): 43–67, <https://doi.org/10.1080/14702436.2022.2102486>.
12. Jeremy C. Pamplin et al., "Augmenting Clinical Performance in Combat Casualty Care: Telemedicine to Automation," in *Augmented Cognition: Users and Contexts*, ed. Dylan D. Schmorow and Cali M. Fidopiastis, part II (Gowerbestrasse, CH: Springer International, 2018), 326–38.
13. Riccardo Miotto et al., "Deep Patient: An Unsupervised Representation to Predict the Future of Patients from the Electronic Health Records," *Scientific Reports* 6, no. 1 (May 2016), <https://doi.org/10.1038/srep26094>; Devika Menon, Bharath Anand, and Chiranjil Lal Chowdhary, "Digital Twin: Exploring the Intersection of Virtual and Physical Worlds," *IEEE [Institute of Electronics and Electronic Engineers] Access* 11 (July 2023), 75152–72, <https://doi.org/10.1109/ACCESS.2023.3294985>.
14. Menon, Anand, and Chowdhary, "Digital Twin."
15. Epstein et al., "Putting Medical Boots on the Ground"; Joseph L. Votel et al., "Unconventional Warfare in the Gray Zone," *Joint Force Quarterly* 80, no. 1 (1st Quarter, January 2016): 101–9, <https://ndupress.ndu.edu/JFQ/Joint-Force-Quarterly-80/article/643108/unconventional-warfare-in-the-gray-zone/>; Jamie Riesberg, Doug Powell, and Paul Loos. "The Loss of the Golden Hour," *Special Warfare* 30, no. 1 (January-March 2017): 49–51, <https://prolongedfieldcare.org/2017/03/16/special-warfare-magazine-articles-loss-of-the-golden-hour-18d-the-lifeline/>.
16. Mark A. Milley, "Strategic Inflection Point: The Most Historically Significant and Fundamental Change in the Character of War Is Happening Now—While the Future Is Clouded in Mist and Uncertainty," *Joint Force Quarterly* 110, no. 9 (3rd Quarter, July 2023): 6–15, <https://ndupress.ndu.edu/JFQ/Joint-Force-Quarterly-110/Article/article/3447159/strategic-inflection-point-the-most-historically-significant-and-fundamental-ch/>.
17. Mary Ann Spott, Cynthia R. Kurkowski, and Zsolt Stockinger, "The Joint Trauma System: History in the Making," *Military Medicine* 183, no. S2 (2018): S4–7, <https://doi.org/10.1093/milmed/usy166>.
18. International Organization for Standardization (ISO) 9241-210:2019, "Ergonomics of Human-System Interaction: Part 210: Human-Centred Design for Interactive Systems" (Geneva: ISO, July 2019), <https://www.iso.org/standard/77520.html>.
19. Christopher Nemeth et al., "Support for ICU Resilience Using Cognitive Systems Engineering to Build Adaptive Capacity," *2014 IEEE International Conference on Systems, Man, and Cybernetics* (2014), 654–58, <https://doi.org/10.1109/SMC.2014.6973983>.
20. U.S. Army Futures Command, *Army Medical Modernization Strategy* (Austin, TX: U.S. Army Futures Command, May 2022), 7, https://www.army.mil/e2/downloads/rv7/about/2022_Army_Medical_Modernization_Strategy.pdf.
21. Abhijit Sen, "DevOps, DevSecOps, AIOPS-Paradigms to IT Operations," in *Evolving Technologies for Computing, Communication and Smart World: Proceedings of ETCCS*, ed. Pradeep Kumar Singh et al. (Singapore: Springer Singapore, 2021), 211–21.
22. Elaine Bochniewicz et al., *Playbook for Threat Modeling Medical Devices* (McLean, VA: MITRE Corporation; Arlington, VA: Medical Device Innovation Consortium, 2021), <https://www.mitre.org/sites/default/files/publications/Playbook-for-Threat-Modeling-Medical-Devices.pdf>.

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