U.S. Army Soldiers assigned to the 62nd Medical Brigade participate in a field training exercise, coordinating the movement of blood supplies during medical operations at Joint Base Lewis-McChord, Washington, Jan. 30, 2026. (U.S. Army photo by Spc. Fabian Jones)

Advancing Blood Production and Distribution

Leveraging AI in the Expeditionary Care Environment

By Andrew Hall, Michael Carrillo, Garrion Jackson, Jennifer H. Hall, and Ryan Comes

Blood is critical to casualty care, and managing the blood supply chain in expeditionary environments presents unique logistic challenges, especially in nonpermissive environments. Ensuring the availability of blood in resource-limited, remote settings far from established medical infrastructure requires sophisticated coordination.

Colonel Andrew Hall, USAF, is the Commander of the Keesler Surgical Operations Squadron, 359th Medical Wing, Keesler Air Force Base, Mississippi. Michael Carrillo is Clinical Associate Professor, Department of Marketing, at the Warrington College of Business, University of Florida, Gainesville. Lieutenant Colonel Garrion Jackson, USA, is Chief of Medical Logistics in the Logistics Directorate of Western Hemisphere Command, Fort Bragg, North Carolina. Colonel Jennifer H. Hall, USAF, is Deputy Commander of the 81st Training Wing, Keesler Air Force Base, Mississippi. Major Ryan Comes, USAF, is Officer in Charge at the Keesler Blood Donor Center, 359th Medical Wing, Keesler Air Force Base, Mississippi.

Unique aspects of its supply chain include the acquisition of blood, precise identification of the blood needed, and the viability of the product over time. Since blood must be donated rather than manufactured, it requires a dedicated effort to replenish existing supplies. Recipients have varied blood types, and only a few are universally compatible, which increases the need for precise metrics on expected use. Given that blood is subject to strict temperature requirements and a limited shelf life, time becomes a vital component to the supply chain. While the combatant commands each manage blood in distinct environments, they share a common goal of ensuring that they have sufficient supply on hand delivered rapidly to personnel in the field who require it. This common goal demands that each combatant command be able to maximize product availability and remaining shelf life within the expeditionary environment.

The blood supply chain is an interagency effort in which the synchronization of various agencies can affect the speed and accuracy of delivery. The production, transportation, and delivery of blood involve multiple agencies, all prioritizing successful delivery in expeditionary settings. For example, the U.S. Food and Drug Administration approves blood products collected by the Armed Services Blood Program at federal installations. Once approved, the blood is transported to various locations worldwide and used by the Department of War (DOW), Department of State, and other agencies to treat eligible hemorrhaging patients.

The most in-demand blood product in military settings is low-titer type O whole blood (LTOWB) because of its near-universal compatibility with potential recipients. Whole blood is generally preferred for trauma-related resuscitation because it reduces the volume of blood needed for treatment and leads to better clinical outcomes.[1] LTOWB is especially valuable because it is universally compatible, meaning it can be given to any patient regardless of the patient's blood type. In contrast, other types of whole blood are type-specific and must be matched to the recipient's blood type (for example, type A blood can be given only to a patient with type A blood). Currently, LTOWB has a maximum shelf life of 35 days from collection. Delivery of the product takes time, and any delays in delivery can reduce the remaining shelf life at the point of use, which increases the need for precise and efficient delivery.

Given blood's critical importance and limited supply, it must be allocated judiciously to areas of potential need. Currently, at a time of relative peace, there is a twofold timing problem. First, as lack of continuous need in the field has resulted in sporadic use, the amount of blood expiring on shelves has increased. Second, at the same time, combatant commands have faced unmet requests because of supply shortfalls. Second, combatant commands have faced unmet requests because of supply shortfalls.[2] This amplifies the need to have increases in precision and accuracy in the timing of the acquisition of blood (donations) relative to the delivery at the point of need in the field. Because a blood donor can safely donate only every 56 days, donations made during periods of surplus are at risk of being wasted. As donations decrease because of a perceived surplus, by the time donations resume, the product has expired—placing the supply in a deficit. These challenges highlight opportunities for improvement as the military prepares for future conflicts.

Combatant Command Portion of the Blood Supply Chain

In conjunction with the challenges of acquisition and shelf life, the blood supply chain is further complicated by the nature of the point of delivery: austere, contested environments. Delivery from the United States to combatant command areas of responsibilities is relatively simple compared to delivery *within* an area of responsibility. The expeditionary medical environment is characterized by austerity. In the expeditionary environment, limited resources are available, and all actions support the operational mission.[3] At forward positions, the resources to care for both traumatic and nontraumatic injuries are limited in comparison to in-garrison environments. Additionally, medical supplies compete for space with other essential military supplies like ammunition and food, adding another layer of logistic complexity.

Blood products hold a special status in supply prioritization because of their

A U.S. Army HH-60M Black Hawk MEDEVAC helicopter and aircrew assigned to C Company, 2nd Battalion, 4th General Support Aviation Battalion, conduct a medical evacuation flight to retrieve blood within the U.S. Central Command area of responsibility, December 21, 2025. (U.S. Air Force photo by Tech. Sgt. Drew Schumann)

Table 1. Summary of key applications and benefits in blood management

Application	Description	Potential Use Case in Blood Management
Supply Chain and Logistics	AI enhances the supply chain by predicting demand, managing inventory, and optimizing logistics.	Digital twins simulate blood distribution to optimize delivery based on predictive needs.
Automation and Efficiency	AI automates tasks, reducing manual efforts and improving accuracy in blood management.	UAVs** autonomously deliver blood to remote or high-risk areas, guided by real-time data from digital twins.
Tracking and Monitoring	RFID* and digital twins enable real-time tracking of blood supplies, monitoring location, temperature, and other critical parameters.	RFID tags integrated with digital twins allow real-time blood storage and transport monitoring, reducing spoilage.

*RFID = radio-frequency identification.

**UAV = unmanned aerial vehicle.

Source: Compiled by the authors.

critical role in resuscitating hemorrhaging patients. Unlike other war reserve materiel, blood cannot be forward-staged far in advance of a crisis or conflict and must therefore be constantly transported into theater. The process of collection, testing, and shipment to a distribution point in an area of responsibility takes time and consumes usable shelf life outside the utilization area. Ideally, handling time before delivery would be minimized to maximize the remaining shelf life at the point of use. Yet even with special status, blood must compete for transportation resources that could be used for other military operations.

During the conflicts in Iraq and Afghanistan, the blood supply chain flowed when the United States maintained air supremacy, allowing direct access to forces in any location. In addition, there were long periods of relatively low-intensity combat operations where the simultaneous need for blood supply was limited. In the future, the military is expected to operate in nonpermissive environments where aerial access is limited and even at times denied. Under the operating concept of agile combat employment in large-scale combat operations (LSCO), the forces are more distributed and operate out of more austere base conditions. With fewer fixed locations that have the requisite facilities and equipment needed to store blood, the resiliency of the blood chain is uncertain compared to the experiences in Iraq and Afghanistan.[4] The introduction of mobility into the supply chain can saturate mental models with data, resulting in human errors. Improved information processing would minimize handling time and maximize remaining shelf life at the point of usage.

Innovative solutions are needed to address the unpredictability of demand and the logistic challenges of storing and transporting blood to combat zones. One promising innovation is artificial intelligence (AI). AI has already transformed industries such as healthcare, pharmaceuticals, and food logistics, and its potential application in blood management is gaining attention.[5] This article explores how AI can help create a more efficient blood production and distribution system, improve utilization, and extend shelf life in expeditionary settings (see table 1).

Artificial Intelligence

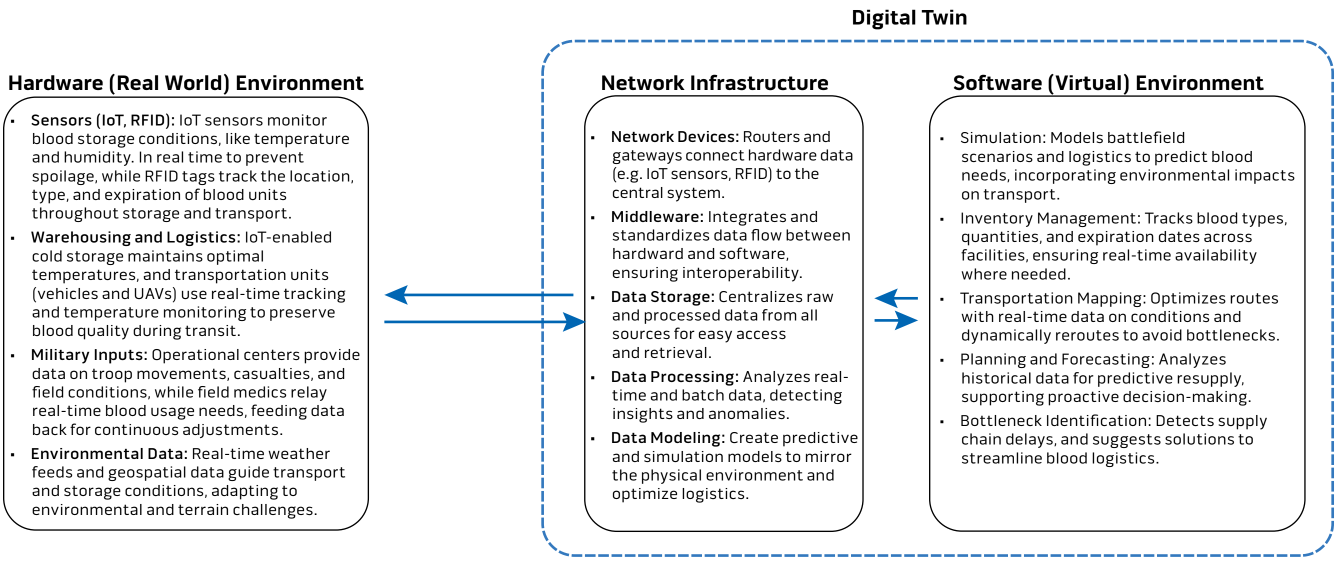
AI refers to the science and engineering of creating machines capable of intelligent processes.[6] In this context, intelligence involves the computational aspect of achieving objectives in the physical world. Because there are multiple forms of intelligence, various types of AI and underlying technologies are required to make them function effectively (see table 2). Different types of AI can be applied to address discrete problems. At the core of AI is

Table 2. Examples of types of artificial intelligence technologies in blood management

AI Technology	Purpose	Areas of Use	Potential Use Case in Blood Management
Machine Learning (ML)	Automate the learning process by enabling systems to learn from data without explicit programming.	Predictive analytics, demand forecasting, and supply chain optimization	ML predicts blood supply needs based on casualty rates, troop movements, and historical data.
Deep Learning	Utilize neural networks with multiple layers to analyze complex data sets, such as images, speech, and text.	Image and voice recognition, pattern detection, and medical diagnostics	Deep learning helps predict optimal blood usage during emergencies.
Reinforcement Learning (RL)	AI learns from feedback to optimize actions over time through trial and error.	Autonomous vehicles, decisionmaking, robotics	RL can continuously improve blood distribution strategies based on battlefield feedback.
Edge AI	AI processes data at the network's edge, close to data sources, for real-time decisionmaking.	Real-time monitoring and remote sensing	Edge AI processes data from sensors on blood storage units, ensuring real-time alerts for temperature changes.
Generative AI	AI systems generate new data or content based on learned patterns.	Content creation, simulation, and training models	Generative AI simulates battlefield scenarios to optimize blood logistics strategies before deployment.

Source: Compiled by the authors.

Figure 1.



Source: Authors.

the data it relies on to make initial decisions and learn over time. While AI is not expected to make decisions independently, it serves as decision support for humans. AI can quickly analyze vast amounts of data without emotional bias, enhancing human decisionmaking through improved information processing.

Key AI Applications in Blood Management

1. Predictive Analytics for Blood Supply Needs

One of AI's most promising applications in blood management is its ability to predict blood needs by analyzing troop movements, historical casualty data, and other operational conditions. Traditional supply chain management is often reactive, responding to immediate demands, or, when anticipatory, highly inefficient because of the excessive supply allocated to account for uncertain needs in remote areas. AI can transform this approach by analyzing vast datasets to forecast where and how much blood will be required. This ensures that appropriate quantities of blood are positioned at suitable locations, optimizing allocation and improving utilization rates.

A critical emerging concept to enhance predictive capabilities is the digital twin (figure 1).[7] In military blood management, a digital twin could simulate the real-world environment of battlefields, bases, or medical facilities in real time.[8] It is a live virtual model of the physical environment, kept synchronized through a continuous stream of real-time data, that planners can use to test decisions before acting. The model captures variables such as weather, troop movements, casualty rates, and resource availability. A digital twin can predict blood needs at various locations under different conditions by modeling different operational scenarios. For example, if a military unit prepares for a major operation in a remote area, the digital twin could simulate expected casualty rates, operational tempo, and environmental challenges, such as difficult terrain or severe weather. AI would then use this simulation to forecast blood demand, determine where it should be stored, and identify the optimal supply routes for timely delivery.

AI-driven predictive models have already shown success in health care and pharmaceutical supply chains, forecasting the need for medical supplies, medications, and equipment. By learning from historical patterns and integrating real-time data, AI can reduce the risk of shortages or overstocking, enhancing the overall efficiency of supply chains.[9] These models optimize inventory by ensuring that resources are available when and where needed, an approach that can be seamlessly applied to military blood logistics.

2. Managing Blood Transportation

AI can quickly and continuously analyze data that a human would find difficult to process. In military blood logistics, AI systems can optimize transport routes by considering environmental and logistical factors while accounting for blood products' temperature and shelf life. In food and health care logistics industries, AI-powered solutions dynamically adjust routes based on real-time traffic, weather, and operational constraints, significantly reducing delays.[10] Similarly, AI can prevent blood spoilage in military settings by adjusting routes in response to road conditions, geographical challenges, or hostile activity. When integrated with technologies such as RFID and UAVs, AI-driven route optimization can ensure safe and timely delivery of blood products. This integration is expected to minimize delays, preserving more of the blood's shelf life at forward locations.

Radio-frequency identification (RFID) is a technology that provides real-time data to support AI-driven

U.S. Soldiers assigned to the 703rd Brigade Support Battalion, 2nd Armored Brigade Combat Team, 3rd Infantry Division conduct a blood transport exercise as part of Spartan Focus at Fort Stewart, Georgia, February 14, 2026. (U.S. Army photo by Staff Sgt. Anthony Herrera)

decisionmaking. When combined with passive RFID tagging for each unit of blood, AI systems can track blood type, expiration date, and location in real time.[11] By analyzing data from RFID systems, AI can further enhance efficiency by predicting usage patterns and dynamically reallocating blood supplies to areas of higher demand, especially during kinetic events.[12] This approach reduces waste, streamlines the supply chain, and ensures that blood reaches the areas of greatest need with minimal delay.[13,]

Unmanned aerial vehicles (UAVs) have demonstrated their potential to quickly deliver medical supplies to remote or hard-to-reach areas, overcoming logistic challenges posed by damaged infrastructure or hostile environments. By integrating AI into UAV operations, frontline medical providers can receive accurate delivery estimates. At the same time, logisticians can increase delivery frequency and maximize the shelf life of supplies at forward locations. Small UAVs, as well as unmanned surface vehicles (USVs) or autonomous surface vehicles (ASVs), may also be able to penetrate complex air defense systems, giving them access to locations otherwise cut off from traditional mobility platforms from air and sea. Efficient unmanned vehicle management will be even more critical during LSCO, when traditional resupply routes may be more limited.

Finally, integrating AI into military supply chain management can optimize route planning and resource allocation by factoring in troop movements, casualty risks, and available infrastructure. This real-time adaptability reduces logistic bottlenecks and delays, ensuring that blood and other medical supplies reach the units with the greatest need.[14] By combining RFID, unmanned vehicles, and AI, the military can develop a fully optimized, data-driven blood logistics system that maximizes blood viability, minimizes waste, and delivers life-saving supplies precisely where and when they are needed most.

3. Improving Blood Storage Logistics

Blood storage logistics in dynamic environments, such as combat zones, require constant monitoring of inventory levels, expiration dates, and storage conditions. Manually managing these variables is inefficient and prone to error, often resulting in blood wastage and unmet demand. AI can improve the efficiency of blood storage logistics by tracking real-time inventory and predicting when supplies need replenishment. Logisticians and blood producers can then use AI-driven decision support to optimize production and delivery, maximizing blood utilization in expeditionary settings.

The pharmaceutical industry has successfully implemented AI-driven logistics systems to track the expiration of sensitive products and optimize distribution channels. AI and automation in pharmaceutical logistics have proven essential in delivering medications before expiration, reducing waste, and improving overall reliability.[15] These same principles can be applied to military blood management. AI can monitor inventory in real time, minimizing wastage by ensuring blood products are distributed to areas of high demand before expiration.

Blockchain technology and RFID can be integrated with AI systems to enhance transparency and traceability in blood supply chains, though they serve different roles. As an Internet of Things (IoT) device, RFID tracks each blood unit's real-time physical movement and status, while blockchain provides a secure, decentralized system for recording and verifying this data. By analyzing RFID data with AI, every unit of blood can be monitored from donor to end use, reducing the risk of mismanagement or loss. Blockchain and AI have already improved traceability in industries such as food and pharmaceuticals, enhancing transparency and operational efficiency.[16] In military operations, integrating AI with real-time storage data and blockchain ensures complete visibility over blood inventory, preventing losses due to miscommunication or logistic errors.

Real-time tracking and AI-based predictive algorithms can forecast blood demand and align production accordingly. By integrating data from various locations, considering historical trends, and factoring in logistic constraints, AI can recommend optimal production targets for blood producers. AI's role in predictive analytics has already been proven in other sectors, such as organ transplantation, where it has improved the forecasting of organ demand based on patient data and environmental factors. Applying this approach to military blood logistics could ensure the right amount of blood is available at the right time and place, reducing shortages and excess inventory.

4. Expanding the Donor Pool and Optimizing Donations

AI has significant potential to optimize donor recruitment and expand the pool of eligible donors, thereby maximizing blood production. Blood donation is typically managed by local leadership teams at donor centers, with limited incentives offered to encourage participation. AI can revolutionize this process by analyzing donor data to identify patterns in donation behavior, optimizing donation windows, and personalizing incentives to boost turnout. By predicting the best times and locations for blood drives, AI can ensure that donation rates align more closely with demand, leading to more efficient blood production.

AI can help maximize donations of the most in-demand blood types. In organ donation systems, AI has successfully optimized donor recruitment by analyzing medical histories, geographic locations, and behavioral data to match donors with recipients.[17] Similar applications can be adapted to blood donation systems. For example, AI could identify populations most likely to donate low-titer type O whole blood (LTOWB), the preferred blood type for military trauma resuscitation, and offer personalized incentives based on demographic and behavioral data. By leveraging predictive models and real-time data, AI can anticipate when and where eligible donors will be available, further optimizing donation campaigns.[18]

AI can improve the blood donor experience and encourage repeat donations by personalizing engagement strategies.

Sailors assigned to Naval Health Clinic Oak Harbor and tenant commands aboard Naval Air Station Whidbey Island participate in the culminating practical exercise of Tactical Combat Casualty Care (TCCC) training. (Defense Health Agency photo by Matthew D. Williams/Released)

Currently, incentives such as T-shirts, snacks, and patches are common but often follow a one-size-fits-all approach. AI can analyze past interactions and tailor incentives to specific populations, boosting donor engagement by offering rewards that align with individual motivations.[19] For example, younger donors might respond better to social media recognition, while older donors may prefer health-related rewards like fitness trackers. Additionally, AI can analyze traffic patterns, donor wait times, and geographic factors to recommend optimal locations and times for blood drives, minimizing disruptions to donors' schedules. This technology has already proven successful in other sectors, such as organ donation and health care supply chains.[20]

AI's ability to track and predict donor behavior over time enables the anticipation of fluctuations in blood donation rates and the adjustment of recruitment efforts accordingly. By leveraging big-data analytics to predict seasonal donation patterns, holidays, and other events that affect donor availability, AI can help military blood centers maintain a stable supply year-round.[21] This reduces the risk of shortages during critical periods, ensuring that military units are always equipped with necessary blood supplies.

Limitations of AI

Despite AI's many potential benefits in logistics and supply chain management, its application in tactical decisionmaking within expeditionary environments remains limited. These environments are often chaotic, unpredictable, and marked by a wide range of injuries, making it difficult for AI to provide reliable clinical inputs in real time. In such settings, AI systems may struggle to match human medics' adaptability and nuanced judgment. Human intuition, adaptability, and experience often outperform AI in chaotic, resource-limited environments, particularly when quick and flexible responses are required.

Combat scenarios often involve complex wounds and medical conditions that require immediate, context-sensitive decisionmaking. While AI excels at analyzing large datasets and predicting trends, it may struggle to process the wide range of unpredictable factors encountered in real-world combat. For example, AI's response to trauma and battlefield injuries may be limited because it cannot fully account for the environmental, emotional, and situational variables a human medic can assess. This limitation in clinical decisionmaking is further compounded by the extreme time pressures combat medics face, where the ability to assess and adapt quickly is critical to survival.

The lack of reliable infrastructure, such as internet connectivity and computational resources, may limit AI's effectiveness in these environments. Combat operations often occur in remote areas where medics and personnel may not have access to the technology or connectivity required to efficiently operate AI systems.[22] While IoT and AI-driven health care systems have made significant strides in more stable settings, their dependence on connectivity and real-time data streams becomes challenging in combat zones, where such infrastructure cannot be guaranteed. AI programs may also be susceptible to cyber attacks either by disabling the capability or by corrupting data.

In resource-limited environments where conditions change rapidly, AI systems may struggle to provide the nuanced judgment and real-time adaptability required. This is particularly true in expeditionary settings, where medical conditions can deteriorate quickly, and preprogrammed AI responses may fall short. For example, AI systems trained on historical data might be unable to adjust to unforeseen combat injuries, environmental hazards, or shifting supply conditions in real time. In such situations, the human ability to make quick, informed decisions will likely remain superior to AI, mainly when rapid changes occur on the battlefield.

Finally, privacy and security concerns must also be addressed. While integrating blockchain and AI can enhance security and traceability in logistics systems, operational security in combat zones may still limit the deployment of these technologies. In military environments, the need for secure and protected data is paramount, and the risk of AI systems being compromised in these settings is an ongoing challenge that must be carefully considered.

Conclusion

AI offers significant potential to enhance blood production and distribution as a decision-support tool for human decisionmakers. Its proven success in health care and pharmaceutical supply chains demonstrates its ability to improve resource allocation and reduce inefficiencies. In the expeditionary environment, AI can help maximize blood product availability, optimize distribution, and extend shelf life. However, the limitations of AI in chaotic and unpredictable settings mean that human adaptability will remain crucial. Integrating AI into the blood production and distribution supply chain will better prepare the expeditionary force for future large-scale conflicts. **JFQ**

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