Blood

The Liquid Will to Fight

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Introduction

Mortality risk increases by 5% for every minute blood is delayed for an exsanguinated trauma patient.[1] Blood is type-specific, temperature-sensitive, and quick to expire, (42 days shelf life when stored appropriately), making it difficult to plan for and use without appropriate training and equipment. The Joint Staff Surgeon has recommended the following planning factors: 20% of wounded in action (WIA) will require blood; each WIA requiring blood will need 8 units.[2]

Universal whole blood transfusion for U.S. Forces was first performed in 1917 by U.S. Army Captain Oswald Robertson in World War I. His first blood bank consisted of 22 bottles of universal whole blood, which helped resuscitate 20 Soldiers.[3] By World War II, the U.S. Military was able to provision over 340,000 pints of whole blood, which played a vital role in treating the wounded in the European theater of operations.[4]

The Vietnam War presented the first opportunity for the U.S. Military's blood program to use type-specific blood groups on a large scale; of the 100,419 universal donor transfusions, there were zero reported deaths from transfusion incompatibility. However, there were 9 reported deaths attributed to hemolytic transfusion reactions, even after extensive cross-matched blood compatibility testing.[5]

These historical records are provided to show that blood transfusion and banking are not new concepts, and although risk is present, this commodity is vital for sustaining combat power and preventing death.

The aim of this article is to create shared understanding to help future practitioners quickly become familiar with today's current information, and empower them with tactical, operational, and strategic planning considerations so that they can formulate blood supply into their sustainment plan with confidence in tomorrow's fight.

Blood Support Standard Operating Procedures

Whole blood and blood products, or CL VIII(B), are managed by a joint effort through the Armed Services Blood Program. Due to Title 10 of the United States Code, any blood products collected and stored must meet the FDA-approved standard for collection.

Blood product collection typically takes place in an Armed Services Blood Donor Center (BDC). Collected blood product is then sent to a central repository center called the Armed Services Whole Blood Processing Laboratory (ASWBPL). The ASWBPL maintains both blood and blood products for contingencies/wartime. CL VIII(B) required in theater is sent to a central shipment point within that theater.

This central point is known as the Expeditionary Blood Transshipment Center (EBTC) and is responsible for issuing blood to Blood Supply Units (BSUs).

Current doctrine states that the BSU is responsible for the logistical movement of blood from the EBTC to the Blood Product Depot (BPD). BSUs can go as far forward as the Role 2, depending on what is designated in the operation plan based on their capabilities.

The BSU role is normally assigned to a fixed Military Treatment Facility (MTF), a casualty receiving ship, or a Role 3.[6]

The EBTCs, BSUs, and BPDs are all managed by the Joint Blood Program Officer (JBPO). The JBPO is typically a Laboratory Officer and, if assigned to a Joint Task Force, should be appointed to serve as the single integrated medical logistics manager for joint blood operations. The JBPO advises the Geographic Combatant Command Surgeon on all matters concerning theater blood operations and exercises responsibility for managing the Geographic Combatant Commander's (GCC) blood program. Figure 1 outlines the flow of this process.

For GCCs without an assigned JBPO, the Command Surgeon must designate a blood program officer that can provide support for theater blood operations.[6]

Depending on geographic size of the military operation, or based on mission requirements, the GCC may designate one or more Area Joint Blood Program Officers (AJBPO) who can plan, coordinate, and communicate the same way as the JBPO does, but within a more defined geographical area.

These officers need to be knowledgeable enough to coordinate deliveries of blood products to area facilities and then report to the JBPO as well as their respective command element. The AJBPO is responsible for making sure the blood distribution program for their assigned geographic area's operation is working.[6]

Medical providers requesting or holding CL VIII(B) are required to use two standardized message formats set by the

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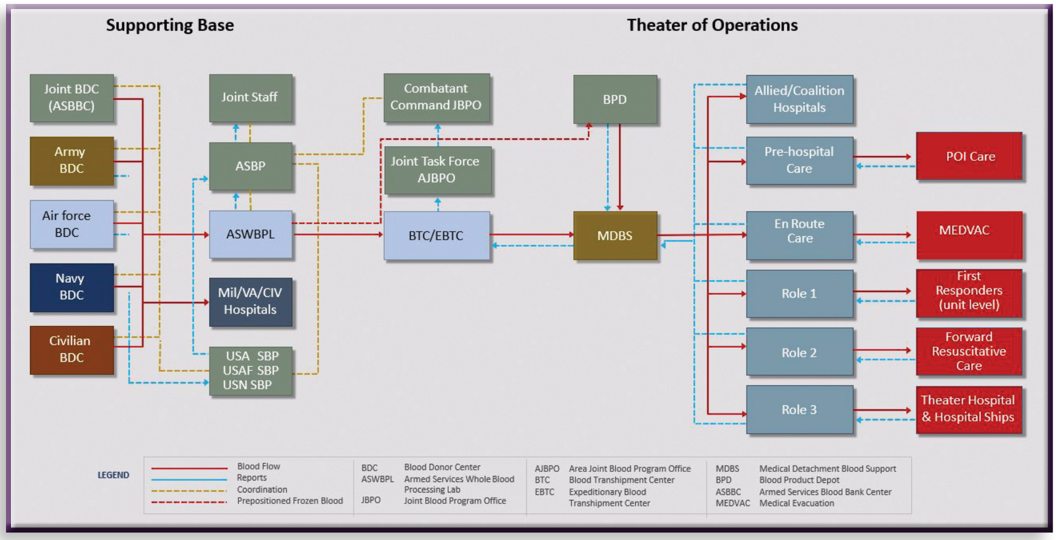


FIGURE 1 *Armed Services Blood Program blood product flow chart.*

Department of Defense (DoD) that allow for interoperability between all Services. The two standardized message formats are called the Blood Report (BLDREP) and the Blood Shipment Report (BLDSHIPREP). All medical assets are required to submit a daily BLDREP to their blood product supplier. The exact report format and reporting period will be provided by the AJBPO/JBPO according to theater policy.[6]

Blood Support in LSCOs

The future practitioners of tomorrow's war need to assume that there will be high casualty rates in large-scale combat operations (LSCOs), and that there will be surges of superiority throughout the various domains.[7] Regardless of the conditions, our planners need to be able to capture the capacity required to meet the supply demand. This challenge is what we refer to as the *Warfighter Supply Chain Management Effort* (WSCME), and we argue that each of its four fundamental pillars requires redundant solutions with omnidirectional consideration. These four pillars are: materiel sourcing, materiel package, delivery ownership, and delivery system.

To begin, the first way to increase capacity is within the materiel sourcing process. FDA-approved blood products are not the only solution. We know this because blood support efforts have leaned into solutions, such as FDA-like approved blood from seven countries of origin and the development efforts for blood substitutes (i.e., freeze-dried plasma). However, many leaders continue to list "walking blood bank" as their alternative source for blood in combat during simulation and training exercises. The walking blood bank is an option, but it needs to be considered as the emergent solution within the Primary, Alternate, Contingency, and Emergency (PACE) plan to preserve the performance and survivability of the fighting force as much as possible. Future practitioners should look at where blood can be sourced before and during conflict. The best solution would be for our forces to have BPDs fully stocked, partner nation support, and blood substitutes created that have a long shelf life and require no temperature management. However, even the best planned materiel sourcing can change within conflict. Our BPDs may become targeted, our partners may run out of supplies to support, and industry may fail to meet the demand for blood substitutes. Logisticians in the future must consider other ongoing solutions for materiel sourcing, and that may require sourcing from the indigenous population or from host nation hospitals.

Next, future practitioners need to consider end-user requirements. Bulk shipment of blood may be needed at the Role 2, but medical personnel at the Role 1 to point of injury (POI) may require a more modular package because of their reduced carrying capacity. Package requirements need to be conditioned prior to conflict, as this will maximize the effect of blood reaching every end user and reduce wastage. Push packages, or "speedballs," should be standardized as a menu of options for all requesters to select from within theater; these must support both the owner of delivery and delivery system. For example, if the option to resupply blood via partner force air assets is available, our practitioners need to ensure that the bundle meets the requirements of said partner force and their platform. If they are unfamiliar with the requirements needed to sustain the package, (i.e., refilling ice within package every 4 hours), or their platform cannot support the current package, it will only aid our adversaries.

Within a combined joint fight, logisticians may need sustainment support from external entities. Current doctrine conceptualizes linear delivery for each Service, but as shown in World War II, LSCO requires omnidirectional consideration. Sustainment will require a combined joint effort, and this needs to be considered prior to armed conflict. The use of blood or blood collection from host nations may not be feasible prior to conflict due to Title 10 of the U.S. Code, but the coordination for support can still be productive since it raises capacity levels through other means, such as potential locations for blood storage or management support.

Lastly, future practitioners need to consider the delivery means through which blood will be delivered. Many current leaders are looking into "smart" delivery systems, like aerial drones. Drones are an option, but we must also consider the potential of our adversaries to contest these systems and the costs associated with drone capability. We argue that logisticians need to also consider other economical options, and looking into the past, there are multiple solutions ranging from the possibility of mule resupply to artillery-fired resupply. Additionally, logisticians must also consider the feasibility of other domain avenues and their potential solutions, like torpedo-fired resupply or submersible drone delivery.

Planning Factors

Before diving into blood planning support for an LSCO fight, we must consider three factors: blood needed per patient, blood capacity starting from the ASWBPL and working down to the maneuvering medics, and blood package considerations. To remedy this, the Joint Staff Surgeon's Office hosted an Operational Planning Team in March 2022 to find a standard planning factor needed for WIA casualties.

The OPT concluded with the recommendation to future GCCs to plan for 8 units of whole blood or whole blood equivalent (WBE) per WIA casualty and that historically only 20% of casualties will require blood.[2] The assumption is that 2 units will be required at the POI, and the remaining 6 units will be required at follow-on roles of care.

Therefore, hypothetically, if a GCC estimates that 1,000 warfighters will be wounded within 24 hours, 200 of them will require 8 units of whole blood or WBE each. This totals to 1,600 units needed within that 24-hr time span.

Next, we will explore the capacity of our known blood support capabilities. The ASWBPL can store and process up to 1,000 packed red blood cells (PRBC), 1,000 fresh frozen plasma (FFP/PF24), 500 cryoprecipitate (CRYO), and 500 frozen red blood cells (FRBC) per week. BPDs can store frozen blood products, as well as thaw and deglycerolize frozen RBC, prior to being issued to BSUs. It should be noted that the BPD focuses on storing frozen group O and A RBCs for use during the initial stages of a contingency operation before liquid blood can be shipped from the CONUS donor centers and the ASWBPL or as an emergency supplement to theater blood supplies.[6]

There is no doctrinal quantity provided for the BPD's carrying capacity, as these are often stood up just prior to conflict. Practitioners need to keep this in mind because the ability to prepare prior to engagement may be more challenging than estimated. EBTCs can process and store 3,000 units of blood per week.[6]

BSUs are typically the Army's MDBS, which are doctrinally composed of 30 personnel, can perform emergency collection of 3,900 units of fresh whole blood and 900 units of apheresis platelets, and can also store 300 units.[8] Field Hospitals (Role 3) can hold up to 480 units of whole blood/WBE. Roles 1 and 2 are currently ongoing materiel solution fielding.

What we can say so far is that the Role 1 requires capacity to hold enough blood to support maneuvering medics (who, individually, can carry 2 units each) within their battalion, while the Brigade Support Medical Company (BSMC) will require enough blood to support their Medical Treatment Platoon and the Brigade Medical Supply Office (BMSO) team, so that they can meet the resupply demands of each supported unit within the Brigade (BDE). If assigned, the Forward Resuscitative Surgical Detachment (FRSD) also has a 200-unit capacity and may be positioned far forward in the fight. Although doctrine states BSUs can distribute blood to Role 2 assets like the FRSD, it may be worth advising against based on probability of survivability to conduct the blood resupply mission. Combatant commanders at each echelon will need to consider how far external support can maneuver, and at which point they will need to sustain resupply efforts internally. This will require Sustainers to understand the packaging considerations needed for blood to ensure supplies are not compromised.

These packaging considerations include weight, cubic dimensions, delivery system, temperature control, and time in custody. Blood products, once provided to the Brigade, may only have 10–14 days of shelf life left. To further challenge company-level logisticians, blood products require temperature monitoring to ensure that they are safe for use (see figure 2). It is advised that resupply efforts are made as easily as possible. The fastest possible way to do this is conducting one-for-one transfers in which BMSOs maintain the same containers as the end users and provide resupply with pre-filled packaged containers through a Forward Support Company's (FSC) Logistics Train.

The FSC can issue the new, pre-filled container to the end user and collect the old container from the end user, much like what is done with pallet swaps. Regardless of a unit's standard operating procedure for conducting resupply, logisticians will be successful if they apply fundamentals taught within the planning phase of Logistics Captain's Career Course, such as calculating weight and cubic requirements.

FIGURE 2 *The Armed Services Blood Program's blood product storage consideration snapshot.*

Red Blood Cells – Liquid
- Expiration: 35 or 42 days
- Storage temp: at 1–6°C
- Shipment temp: at 1–10°C

Platelets – Liquid
- Expiration: 5 or 7 days
- Store/ship temp: at 20–24°C
- Not available for shipment to theater.
- Performing in-theater platelet apheresis collections (not fully tested).

Liquid Plasma
- Expiration: 26 or 40 days
- Storage temp: at 1–6°C
- Shipment temp: at 1–10°C

Frozen Red Blood Cells
- Expiration: 10 years frozen
- Storage temp: at ≤65°C
- Shipment temp: at ≤40°C
- Thawed/deglycerolized 14 days at 1–6°C (*only on units frozen since 2005 in closed system)
- Prepositioned in some theaters and shipboard

Plasma (Fresh Frozen/Frozen Within 24 hrs.)
- Expiration: 1 year
- Stored/ship temp: at ≤18°C

Cold Stored Platelets
- Expiration: 14 days
- Storage temp: at 1–6°C
- Shipment temp: at 1–10°C

Low Titer Group O Whole Blood
- Expiration: 21 or 35 days
- Storage temp: at 1–6°C
- Shipment temp: at 1–10°C

Cryoprecipitate
- Expiration: 1 year
- Store/ship temp: at ≤18°C
- Infuse within 6 hr of thaw/pool

Convalescent Plasma
- Expiration: 1 year
- Store/ship temp: at ≤18°C

Note: All expiration dates are from date of collection.

A typical package used to deliver blood is a reusable cardboard and styrofoam standard container called a Collins box. Collins boxes require either wet or dry ice based on the products being delivered. The capacity of one of these boxes is 20 units whole blood, 30 units PRBC, 15 units FFP/PF24, or 30 units of CRYO; one unit of whole blood (500mL) weighs approximately 1.42 pounds. These boxes have a cubic dimension of 18 inches (long) × 19 inches (wide) × 16 inches (high) and weigh 9.5 pounds when empty. Necessary wet ice will weigh approximately 14 pounds, whereas necessary dry ice will weigh approximately 20–30 pounds. The total approximate weight of one package will range from 44–54 pounds.[6] We recommend future logisticians plan around the maximum weight number.

Blood Planning Scenario Application

Understanding the various requirements of the supported unit, the commodity, and delivery system, logisticians will need to meet capacity to the BDE's supply demand. Consider the following scenario: a medical logistician in the 82nd Airborne Division receives notification that 2 days of supply (DOS) of blood is required (1 DOS=480 units; 960 units total) and will be delivered between two missions, one DOS via an airborne equipment drop from C-130J aircrafts and one DOS via the ground assault convoy (GAC). Blood will be delivered in the airborne equipment drop mission utilizing container delivery system (CDS) bundles, while the GAC will deliver blood utilizing AcuTemp AX56L mobile refrigeration and freezer system (refrigerator capable of blood storage for 48 hr; empty weight: 145 pounds.) transported by the FSCs via M1078A1 or the light medium tactical vehicle (LMTV).

The medical logistician, understanding the planning factors above, will also need to understand the capacity of each system used to deliver these products as stated earlier. These systems include the CDS bundle, C-130J, AcuTemp, and the LMTV. A CDS bundle is typically delivered using a T-10 Cargo (T-10C) parachute which has a weight minimum of 200 pounds and a weight limit of 500 pounds. If the CDS bundle is being delivered out of paratroop door of a C-130J, the bundle must remain under 72 inches in height and 36 inches in width. Knowing this, the medical logisticians will have to plan to meet these limiting factors. First, they will need to calculate the number of Collins boxes needed, which is a total of 24 (480 units of whole blood total). Next, the logistician needs to calculate the total boxes per bundle. The logistician is constricted to stacking the bundle with one box, as stacking them side-by-side (horizontally) will reach 36 inches in width after two boxes. The vertically stacking capacity is met at four boxes (64 inches). Other factors will further reduce the true height and weight of the bundle, such as the shock absorbers (honeycomb) and the parachute (the maximum dimension of the bundle is recommended not to surpass 48 inches (long) × 30 inches (wide) × 66 inches (high) to include the cargo parachute which is placed on top).[9] The weight of this bundle will be approximately 184–224 pounds (a T-10C parachute weighs 8 pounds). Under these conditions the logistician will require six CDS bundles. This information may have implications on the operation. A combatant commander may consider that the six bundles are not feasible, and thus, find it necessary to issue a fragmentation order (FRAGO) to deliver bundles via ramp rather than paratroop door. This shift will then allow the medical logistician to reconfigure the bundles to be bigger and possibly deliver up to 9–11 boxes per CDS bundle based on weight, which would then require three CDS bundles instead of six.

As for GAC blood support planning, the medical logistician now needs to consider the amount of weight and capacity of each AcuTemp. Each AcuTemp can hold 40 units of whole blood, will weigh 201.8 pounds filled, and has a cubic dimension of 39.2 inches (long) × 23.2 inches (wide) × 22.8 inches (high). One LMTV has the capacity to carry six wooden pallets and a total weight of 5,000 pounds.[10] The dimensions of one wooden pallet are 48 inches (long) × 40 inches (wide). The FSC commander recommends that pallets should not exceed 5 feet in height (with boxes secured using ratchet straps or cellophane packing wrap). Knowing these factors, the medical logistician can pack two AcuTemps horizontally and up to two AcuTemps vertically for a total of four AcuTemps per pallet. To meet the one DOS demand, the medical logistician has calculated that 12 AcuTemps will be needed, and so three pallets would be required—half of the total allotted space on one LMTV, as shown in in Figure 3.

FIGURE 3 *Army medical logistician loads a Light Medium Tactical Vehicle with CL VIII.*

Blood Management at BDE and Below

The capability to manage blood requires standardized communication procedures and appropriate equipment to ensure blood products maintain appropriate temperatures required. Current doctrine states the use of two standardized, formatted reports built by the DoD, but there is no doctrine stating exactly how blood reporting and requests will flow from the BDE to the medic, and from the medic back to the BDE. We suggest that blood resupply and reporting must be actioned like any other commodity. The resupply request is sent from the maneuvering Companies to their respective Battalion S-4. The Battalion S-4s send their requests to the BDE and is consolidated by the BDE S-4 and sent to the appropriate parties based on the BDE's current allotment. If blood products are on-hand with the BMSO, the BDE Surgeon will advise the S-3 to action orders for the BMSO to ready push packages for inbound FSCs or the outbound Sustainment & Distribution Company.

If supplies are exhausted and the request is not urgent the BDE S-4 will deliver the consolidated request to the DIV G-4 for processing resupply. If supplies are exhausted and resupply is urgent the BDE S-4 will correspond with the BDE SPO for external support. To maintain capacity, it is suggested that the BDE S-4 monitors and manages supply requests needed from 0–47 hours. The SPO will monitor and manage the supplies required for 48–96 hours out and provides this information to the BDE S-4 to maintain "push" and "pull" logistical operation efforts.

To maintain these logistical efforts, BDE assets require the equipment necessary to maintain blood products, such as temperature control storage, blood fluid warmers, individual carry systems, and subcomponents for blood administration and hemorrhage treatment.

To understand this requirement, we suggest starting with understanding the capacity limit from the maneuvering medic and working back to the Brigade Support Battalion (BSB). This will set the baseline of what can actually be supported. Using the Light Infantry Brigade Combat Team structure, we determined that one maneuvering (combat) medic can carry 2 units of blood, and each maneuvering company has 15 maneuvering medics. The total carrying capacity for all maneuvering medics alone per single Infantry Battalion is 30 units. Additionally, these medics will be limited to the amount of weight they can carry individually and will require a materiel solution that supports dismounted operations. The most commonly used materiel solution is the "Golden Hour Box," which allows blood to remain at appropriate storage temperature for up to 72 hours all maneuvering medics alone per single Infantry Battalion is 30 units. These medics will be limited to the amount of weight they can carry individually and will require a materiel solution that supports dismounted operations. The most commonly used materiel solution is the "Golden Hour Box," which allows blood to remain at appropriate storage temperature for up to 72 hours.

The Battalion's Role 1 possesses a stronger potential for maneuvering equipment and must be able to resupply their maneuvering medics. For these reasons, it is necessary for the Role 1 to possess up to 2 temperature control storage units that can store a (minimum) total of 30 units of blood and can support Role 1 split operations when needed.

Eventually all six of the BDE's Role 1s will require resupply from the BSB. Additionally, the BSB will need equipment capability to maintain their Role 2 operations. The Role 2 patient capacity within 24 hours is 50 WIA, with an estimated 10 WIA needing blood. The minimum blood required at the Role 2 is estimated to be 60 units. The BMSO will need equipment capability to meet the Role 1 (150 units) and Role 2 (60 units) requirements for resupply, which totals to 240 units. Again, split operation capability is paramount and the materiel solution for storage needs to support this.

The BDE's requirements to match omnidirectional support must be considered so that they can support partner forces, special operation forces, forward resuscitative surgical detachments, etc. BSB commanders need to consider what other options are available to maintain blood products, like the use of the multi-temperature refrigerated containerized systems (MTRCS) found with the field feeding team inside both the BSB and maneuvering FSCs, to match these demands.

To support hemorrhage treatment and blood administration, medics and providers will require blood fluid warmers to prevent hypothermia. The goal of infusing warmed IV fluids/blood is to reduce negative heat balance rather than to actively warm the patient, because every decrease of 1.0°C (1.8°F) in core temperature below 36°C (96.8°F) results in a 10% increase in RBC consumption in the first 24 hours of admission. Furthermore, data emphasizes the need for effective hypothermia prevention at the POI, and continued patient warming during massive transfusion, with warmed 38–42°C (100.4–107.6°F) whole blood . These devices need to be lightweight (~2 pounds), small in dimension, portable, and capable of warming 4 units of whole blood with a flow rate of 150mL/min.[11] BMSOs need to review their Authorized Stockage List with the BDE surgeons to ensure the appropriate medications and subcomponents for blood administration are standardized and listed to facilitate the ordering process. BDE surgeons must take the time to educate BMSOs on the requirements and why they are needed. For example, patients given 4 units of blood that was stored in citrate blood bags will need 30mL of calcium gluconate or 10mL of calcium chloride to prevent hypocalcemia; or, to reduce hemorrhagic shock, medics will use 2g of tranexamic acid. By understanding the "why" behind products, the BMSO can tailor their limited capacity to meet priority requirements.

Global Supply Chain Management

Objective determination of the supply chain's survivability is vital. This must be done through supply chain stress tests, which can help the DoD identify issues in manufacturing nodes, distribution, transportation, and financial solvency.[12] These tests can be conducted virtually; however, the distribution and transportation testing must be conducted in live exercises. To produce the most reliable data for global supply chain management, practitioners need to determine the estimated blood demand and lead time between the manufacturing and distribution nodes (industry, BDC, EBTC, BPD, etc.).

This can be done by first estimating the WIA within each AOR using the Casualty Rate Estimation Tool (CREstT) in the Joint Medical Planner's Tool Kit (MPTK). Once WIA is determined, using the Joint Staff Surgeon's recommendation of 8 units (2 at POI and 6 at follow on roles of care), we can then determine the estimated blood requirement. It is vital that medical operations officers include the Joint effort, and not just their parent Service, while collecting WIA estimations. This estimation is just a baseline; it will not account for ongoing armed conflict, which introduces a random fluctuation element in determining a demand pattern.

Next, global managers need to consolidate the estimated requirements from each AOR and determine if the supply chain can meet or exceed demand. This can be done initially with site visits to industry and BDC locations to observe current operations and investigate limiting factors for manufacturing and current, maximum capacity. A recent CNA study determined that the bottlenecks within the BDCs are donor availability staff limitations and consumable supply shortages.[13]

This discovery allows global managers to determine solutions that increase capacity for materiel sourcing. However, lead time delays are inevitable. Global managers cannot estimate when and how external factors, like our supply chains being targeted, will affect the DoD, but they can identify whether internal factors are further limiting. For example, by running multiple live exercises between the various manufacturing and distribution nodes, global managers will be able to determine the lead time caused by either manufacturing or transportation. By determining both and the standard deviations of each, global managers can help determine the appropriate safety stock and restock levels for all distribution nodes, providing commanders insight on blood resupply timeline to tactical units.[14] (See formula and example in Figure 4).

FIGURE 4 *Safety stock and reorder level formula guide.*

Formula Acronyms

- Demand (D)
- Demand Standard Deviation (DSD)
- Lead Time (LT)
- Mean Lead Time (MLT)
- Lead Time Standard Deviation (LTSD)
- Standard Deviation of LT Demand (SDLTD)
- Service Level Standard Deviation (SLSD)
- Safety Stock (SS)
- Reorder Level (RL)

Safety Stock and Reorder Level Formula

$MLT = LT \times D$

$SDLTD = \sqrt{(LT \times DSD^2) + (D^2 \times LTSD^2)}$

$SS = SLSD \times SDLTD$

$RL = (LT \times D) + SS$

Example Application of SS and RL Formula

A global manager determined that 1x BDC had the following supply flow signals:

(D) = 100 units per week
(DSD) = 20 units
(LT) = 8 weeks
(LTSD) = 0.5 weeks

This means that the MLTD is 800 units and the SDLTD is 75.5 units.

If the BDC must maintain a 95% service level which has been determined to have a 1.64 standard deviation (SLSD) then the global manager will be able to determine that the SS must be set at 124 units and the RL must be set at 924 units to be meet an economically viable solution.

Prior to orders being made, global managers need to determine the necessary quantity that must be ordered each time to reduce cost and waste. This is known as the Economic Order Quantity (EOQ). The EOQ is an estimate that identifies the best order quantity by balancing the conflicting costs of holding stock and placing replenishment orders.[14] (See formula and example in figure 5).

The EOQ is a valid, deterministic model when demand is known with certainty and is applied at a constant rate and paired with reorder and safety stock provisional numbers. Global managers need to consider other additional factors prior to confirmation of final order numbers. For example, lead time, demand, cost, and product production are not constant. It is recommended that weighted moving averages are utilized to determine demand forecasted requirements when met with seasonal or random fluctuations often observed during armed conflict and contingency operations.14 (See formula and example in figure 6).

As stated earlier, the plan must not focus on high inventory levels, which simply circumvent supply chain issues (see figure 7) that must be found and remedied prior to global emergencies through time compression, like identifying and remedying bottlenecks in the manufacturing of blood products.[14]

FIGURE 5 *Economic Order Quantity formula guide.*

Formula Acronyms

- Cost of placing an order (P)
- Annual demand in units (D)
- Cost of a unit of inventory (U)
- Annual stock-holding cost as a fraction of unit cost (F)
- Cost of holding stock per unit per year (UF)

Economic Order Quantity Formula

$EOQ = \sqrt{(2PD) / (UF)}$

Example Application of EOQ Formula

A global manager determined that 1x BDC had the following supply flow signals:

(P) = $75
(D) = 2,400 units
(U) = $50
(F) = 25% (1/4)

This means that the EOQ is 174 units.

FIGURE 6 *Weighted Moving Average formula guide.*

Formula Acronyms

- Forecast demand (F_t)
- Number of periods to be averaged (n)
- Actual demand in the past up to 'n' periods (A_{t-n})
- Weighting factor (w)

Weighted Moving Average (WMA) Formula

$$F_t = \frac{w_1A_{t-1} + w_2A_{t-2} + \ldots + w_nA_{t-n}}{n}$$

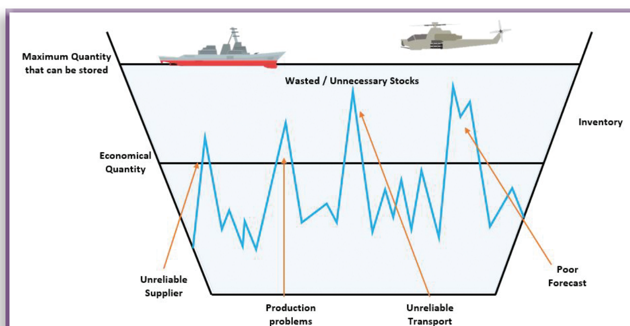
Example Application of WMA Formula

A global manager determined that 1x BDC had the following supply flow signals from 1x year (1 Period = 3 months) based on supply demand across the DoD

A_{t-1} = 2000 units w_1 = 10%
A_{t-2} = 2000 units w_2 = 10%
A_{t-3} = 3500 units w_3 = 30%
A_{t-4} = 4200 units w_4 = 50%

This means that the F_t for the next period will be 1,038 units.

FIGURE 7 *Illustration of potential supply chain issues.*



Going back to the BDC bottleneck example, installation commanders and tactical leaders can help alleviate issues through various avenues, including messaging, by encouraging blood donors to donate at the installation's BDC. Additionally, ASBP can leverage 3rd Party entities (i.e., the Red Cross) via contractual agreements to help increase blood sourcing support when required.

Arctic Considerations

Further discussion is required to identify solutions to known capability gaps in arctic environments. As stated earlier, the goal of infusing warmed IV fluids/blood is to reduce negative heat balance rather than to actively warm the patient, since every decrease of 1.0°C (1.8°F) in core temperature below 36°C (96.8°F) results in a 10% increase in red blood cell (RBC) consumption in the first 24 hours of admission. Additionally, we discussed how data emphasizes the need for effective hypothermia prevention at the POI, along with continued patient warming during massive transfusion, with warmed 38–42°C (100.4–107.6°F) whole blood at a rate of 150mL/min.[11]

Equipment modernization efforts must aim to not only meet the temperature challenges of hot climates, but also frigid climates. The arctic poses a real challenge because current devices and products either become ineffective at maintaining required specifications needed (flow rate, temperature, etc.) or freeze completely (i.e., administrative IV tubing sets become brittle).[15] One potential solution that may be effective is researching the effects of chemical warmers, such as meals ready-to-eat (MRE) heaters. By redesigning these heaters with a thermal insulator for blood products and the needed subcomponents (i.e., IV tubing), the DoD can provide a cost- effective solution to afford blood capability in frigid environments. Additionally, this item may be useful to substitute out the current heaters found in the cold weather MREs, to provide cross-functionality and further aid as emergency stocks for medics since these items will be essentially cross-loaded amongst the fighting force if resupply efforts prove ineffective.

Walking Blood Bank and Revolving Blood Bank

As stated earlier, the walking blood bank must be considered as the emergent plan for blood support. Tactical and operational leaders must be cognizant of the fact that maneuvering Servicemembers who volunteer blood for those WIA will also place themselves at a greater deficit in the event that they are wounded.

Medical leaders also need to accept the fact that whole blood will be difficult to resupply to the forward line of troops, and commanders need options that are as reinforced as possible to prevent loss of life. The future fight will require medics and Combat Life Savers (CLS) that are capable of safely administrating blood to the wounded in need; that emergency plan needs to be exercised in discussion and training to build shared understanding across the force on what must be avoided, but most importantly, what is pragmatically sustainable.

For example, a study conducted by the U.S. Special Operations Command (USSOCOM) that was designed to understand the effects of blood donation on SOF operators after donating one unit of fresh whole blood found that there was degradation in human performance. However, most of these volunteers were able to remain mission capable despite the drop in oxygen-saturated RBCs.[16]

Further studies must be conducted to determine the effects of additional donated units, and the effects of blood donation on the average service member population, so that commanders can understand effects on mission capability prior to decision- making. If emergency resupply is needed, future practitioners need to determine the approach that best supports the mission.

The Naval Medical Center San Diego's Combat Trauma Research Group-West is studying the validation between two emergency low-titer O whole blood (LTOWB) approaches using cold stored whole blood (CSWB) to meet blood demand afloat. Much like ground forces, the Navy is assuming blood products will be scarce and the walking blood bank may not meet the demand for immediate action, as it will be extremely difficult to move personnel during an active combat engagement. Additionally, the FDA states that donors must wait 56 days to donate blood again. These limiting factors have influenced the two revolving blood bank (RBB) concepts: Exchange Transfusion RBB and Rotating Donors RBB.[17]

The Exchange Transfusion RBB concept works by

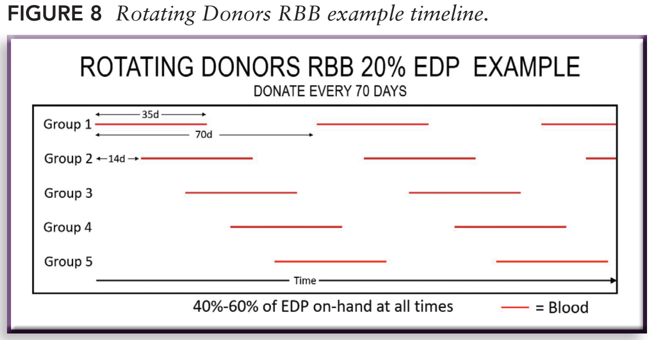
- identifying emergency donor panel (EDP)
- drawing 1 unit, labeling, and storing 100% of the entire EDP blood,
- used if needed or replaced back in same donor if unused prior to expiration
- drawing, labeling, and storing new unit of 100% EDP population and repeating all steps.[17]

The Rotating Donors RBB concept (shown in Figure 8) will allow for 40%–60% of the EDP blood to remain on hand and works by:

- identifying all EDP
- draw 1 unit, labeling and storing only 20% of the entire EDP
- weeks later, draw from the next fraction of EDP, and repeat
- blood unused that expires is discarded repeat all steps.[17]

One concern that must be noted is that the current ASBP Handbook states that fresh whole blood that is pulled must be either: a) used within 8 hours, or b) refrigerated for 24 hours. Any additional time extension beyond the 24 hours in cold storage requires approval from the JBPO.[6]

FIGURE 8 *Rotating Donors RBB example timeline.*



RBB = revolving blood bank EDP = emergency donor panel.

Military Working Dogs

Practitioners need to also consider military working dog (MWD) blood support requirements. Logisticians must understand that at no point can blood from a human go to a MWD or blood from a MWD go to a human. If this were to occur, recipients will have extreme hemolytic reactions.[18] For this reason, canine blood products must be labeled so that prior to their use, the administrator is able to determine the product with ease, preventing accidental administration of incorrect products to recipients as shown in Figure 9.

FIGURE 9 *Properly labeled military working dog blood product.*

Another issue logisticians need to keep in mind is that donor MWDs will require chemical sedation, as blood is typically drawn from the jugular vein, and so the pharmaceutical requirements to meet this demand must be annotated. Whole blood needing to be collected should be administered within 4–6 hours.

If blood cannot be administered, it must be stored at 4–6°C within 4 to 6 hours of collection. whole blood collected in citrate donor bags can last 21 days. If frozen (–20 to –80°C) within 8 hours of collection, it can be stored for up to 1 year and later become frozen plasma. After blood is donated, the MWD donor will require 24 hours off duty to recover (to include no flying).[18]

However, the challenges with MWD blood banking are: the "walking blood bank" concept is inapplicable in most cases due to the limited number of MWDs in the area the DoD does not have a centralized MWD blood donor collection and distribution site, which leaves Veterinary Treatment Facilities to find the solution on their own (usually through commercial procurement or immediate donor collection).[18]

As for whole blood substitutes, blood products such as freeze-dried plasma are currently in development and are much closer to being finalized for use than human blood substitute products. The challenge for these products will be ensuring a supply demand that is adequate enough for industry to continue to support.[18]

We recommend that the DoD policy adjusts so that MWD blood support is possible. This could take place through multiple avenues, such as exploring training opportunities for the Veterinary Services to build familiarity with blood collection, storage, and administration of blood products; closing equipment gaps within veterinarian units and facilities; or, by incorporating MWD blood support into the ASBP.[18]

Training: Delivery and Use

Tactical and operational units need to become familiar with blood collection, storage, transportation, and administration. Current schoolhouses, like the Army's Combat Medic Advanced Individual Training, have introduced autologous blood transfusion into their training. This concept of training is when individuals learn how to draw blood from an individual and provide it back to the same individual in order to understand the individual tasks associated with both blood collection and administration. However, we argue that medics and providers need to continue refresher training at their units to maintain proficiency, and this must be conducted in a "crawl, walk, run, and fly" concept. For example, the BDE nurse can use the Medical Simulation Training Center (MSTC) to achieve the first three steps. The crawl and walk phase can be conducted jointly in a classroom setting through didactic and hands-on (autologous blood transfusion) training as shown in Figure 10 and Figure 11.

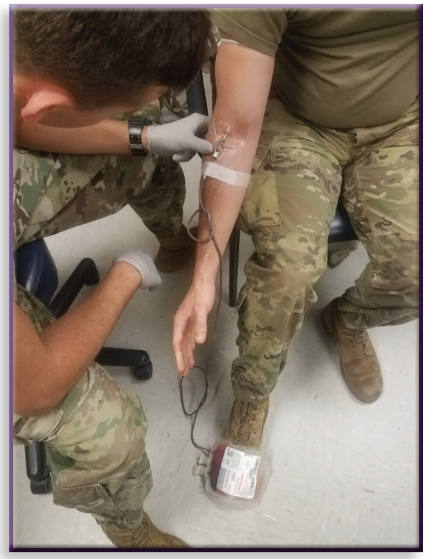


FIGURE 10 *Blood collection training.*

FIGURE 11 **(BELOW)** *In 2019, then 1LT Jesspal Bachhal (SPO MEDLOG) and CPT James Bills (BDE Nurse) conducted the exact training outlined for the "crawl" to "run" phase in 3rd Brigade Combat Team, 82nd Airborne Division at Ft. Liberty's MSTC site.*

The "run" phase can be conducted the following day using a medical lane to verify students' confidence with blood collection and administration individual tasks, using volunteers from the unit to act as role-players and autologous subjects for the students. The "fly" phase must be observed through BDE training events like Combined Training Center rotations. Medical training at these events typically ends at the Role 1 or 2 and have very little avenue for medical personnel to test capacity. We acknowledge the risk with this type of training but believe risk mitigations can make these training events possible, especially if observer, controllers, trainers (OTCs) become familiar with this requirement and incorporate safety precautions within the training event (i.e., internal unit nurse conducts floating observation to help assist OCTs validate each echelon of care training).

We must also consider the potential for CLS to conduct blood transfusion tasks. The LSCO environment challenges may reduce medical personnel capacity. To help commanders maintain a large breadth of administration capacity, we advocate that all service components need to introduce blood transfusion tasks in an "advanced" CLS course setting for mature Service Members that have the potential to be capable of performing these tasks (this can even be considered as an Additional Skill Identifier). The argument against this is that in 2009 fluids were removed from CLS training because personnel wasted time trying to gain venous access.[19] We counterargue that this lesson will not be re-learned the hard way because it can be easily mitigated with appropriate training and reiteration with what is already being taught in CLS, such as the fundamental principle of applying the most important intervention (i.e., tourniquet) immediately.[20] Next, units must incorporate blood support into logistical training events. So far, the training spotlight has been focused on collection and administration, yet the real "valley of death" to execute this treatment strategy is the ability to transport and store CL VIII(B) internationally and within theater. The first exercise to attempt rapid resupply (within 72 hours) from the U.S. to a required theater in recent years was Talisman Sabre 2023. Talisman Sabre is the largest-scale joint defense exercise between Australia and the United States to date, with 13 nations and 35,000 participating personnel conducting 15 major training events in the Indo-Pacific region.[21] During this exercise, medical personnel executed a blood resupply requirement to transfer CL VIII(B) products from the continental U.S. to Darwin, Australia, with final destination being Townsville, Australia. To meet the rapid demand, blood was sourced from both Japan and Hawaii.

U.S. medical personnel had to work with their Australian Army counterparts to overcome regulatory differences, such as units needing to be repackaged into boxes that hold fewer units, which caused delays in shipment of CL VIII(B) from Japan. This took 3 days to remedy and was eventually received by the U.S. Marine Rotational Force-Darwin in Royal Australian Air Force-Darwin, Australia. This exercise not only highlighted the importance of partner force support but also cross-service support, as supplies delivered to Townsville required assistance from the Navy, Marines, and Air Force partners.[22] Out of the 115 blood products shipped, only 10 FFP units were quarantined on receipt due to exceeding the safe temperature range of said product (E Gasaway, email communication, October 30, 2023).[2]

Other Solutions and Considerations

All services suggest LTOWB Type O makes up a total of 45% of the total American population with 7% being type O negative (universal donor). However, type O negative recipients can only receive blood from other type O negative donors. We recommend that A blood training utilization is considered because type A makes up a total of 40% of the American population; that is a total combined population of 85% between type O and A donors. This will help reduce the unnecessary use of low-titer O blood products on type A recipients. Practitioners can develop training now to help mitigate risk of wrongful administration.[2] We also believe that the risk of blood shortage is higher than the risk of wrongful administration in the future LSCO environment as noted earlier in the Vietnam statistics.[5]

Additionally, tactical units need to incorporate dispersion of blood types within their formations. The Ranger O Low Titer Whole Blood (ROLO) Program has restructured all Platoons to have dispersed low-titer O personnel within their formation to help support their walking blood bank protocol become more sustainable in the event of its needed activation.

Forces without a distributed EDP will fail to provide commanders an emergency blood support option.[24]

As pointed out earlier, the current ASBP states that fresh, warm blood that is pulled from a donor must be administered within 8 hours or refrigerated for 24 hours. Any additional time extension beyond the 24 hours in cold storage requires approval from the JBPO.[6] Due to the nature of SOF operations, USSOCOM has developed a policy to authorize donor blood to be returned to donor if unused known as the Special Operations Low-Titer O Whole Blood (SOLO) Program. However, for the rest of the force, this is not outlined specifically as a potential solution for unused blood in the ASBP and must be further explored for safety efficacy for the larger DoD force to reduce waste and support the RBB concept.[25]

Freezing products is the best capacity building approach for blood support, especially for contingency planning as mentioned earlier owing to the long shelf life of frozen products. However, the equipment needed to thaw and deglycerolize blood products only exist with echelons above BDE and require large amounts of time to make products ready for distribution. For example, the ASBP states that one technician, using a three-cell washing machine, can deglycerolize 12 units in 12 hours.[6] In LSCO, the requirement for blood may become bottlenecked due to this limiting factor. It may become necessary to field and train this equipment at echelons below BDE to reduce capacity limiters for frozen CL VIII(B). Additionally, with further research, it may be determined that current CL VIII(B) must be frozen during delivery as high kinetic delivery (drone, artillery, etc.) increases probability of blood cells rupturing (hemolysis) due to vibrations or burst of speed.

Conclusion

As the DoD transitions towards LSCO, blood will continue to be an increased topic of concern for all GCCs. Blood supply has always been a critical commodity because of its ability to ensure both combat power sustainment and reduced preventable deaths since 1917. In the last two decades, blood has been almost exclusively managed by the ASBP and medical departments across the service components; however, LSCOs may not allow such a luxury for GCC planners. Future conflict planners need to consider that one of more components to blood support may require their attention. Planners need to understand the current flow of blood sourcing from the ASBP, the various storage requirements, transportation needs, and the current administration policies and procedures in effect to ensure warfighters receive adequate and safe blood products and supplies. Lastly, leaders across the DoD need to continue discussion now to address solutions for capacity, artic considerations, MWDs, and training.

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Author Contributions

JSB was the lead for figure creation, collection of data, and drafting of the manuscript. Both APD and FYB co-conceived the study, participated in designing the study, data collection, and the data interpretation. All authors participated in contributing to text and the content of the manuscript, including revisions and edits. All authors approve of the content of the manuscript and agree to be held accountable for the work.

Disclosures

None declared.

Disclaimer

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