Operational Savings from SC2i MTP Project

This report estimates the operational savings that the U.S. military could reap from the more efficient use of blood products that the deployment of SC2i's Massive Transfusion Protocol tool could create in combat environments

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Executive Summary

The Surgical Critical Care Initiative's (SC2i) Massive Transfusion Protocol (MTP) project uses predictive analytics to create a tool that not only produces successful outcomes for patients with wounds associated with trauma, but also more efficiently uses the blood products needed to treat them. It does so by better determining which patients would benefit from a massive transfusion of blood products.

The project is expected to yield meaningful operational benefits for U.S. military forces in the field. Those benefits would be particularly pronounced in high-intensity warfare environments, where the rate and volume of trauma casualties may be high and the resources needed to treat them are likely to be constrained. To quantify these benefits, we used a scenario that simulates a NATO ground campaign to eject Russian and Belarus forces from an Eastern European country. Applying a series of combat and casualty models, we calculate that NATO would require 24 days to achieve battlefield victory and suffer 9,206 killed and 36,255 wounded in action in the process of doing so.

Our study uses these casualty projections to determine the benefits that SC2i's MTP tool could provide to not only Level III military hospitals and the Armed Services Blood Program, but also military logistics and combat forces. Using SC2i's MTP tool, we assess that NATO forces would consume 33,294 fewer units of red blood cells, 19,891 fewer units of fresh-frozen plasma, 1,860 fewer units of apheresis platelets, and 14,635 fewer units of cryoprecipitate than they otherwise would have in our envisioned scenario.

Operationally, that eliminates the need for 88 UH-60 blood product resupply missions. That, in turn, represents a savings of 20,592 gallons of aviation fuel. The saved aviation fuel would enable Allied forces to conduct 88 additional MEDEVAC missions—flying 616 more wounded soldiers off the battlefield, without expanding the existing air ambulance resources assigned to each corps. It would also enable Allied forces to carry out 88 additional AH-64 attack helicopter missions.

The reduction in the needed blood products from the use of SC2i's MTP tool would also free up capacity aboard Air Mobility Command fixed-wing transports that would have airlifted those blood products into the theater. We estimate that the weight savings would be sufficient to ferry enough ordinance for 79 AH-64 attack helicopter missions. In essence, operational savings from SC2i's MTP tool could provide not only the fuel needed for close air support missions, but also much of the ordinance with which to conduct those missions.

Background

The treatment of battlefield casualties has never been easy. Not only do such casualties represent difficult medical conditions. Medical facilities may be inadequate, medical supplies may be short, and trained medical personnel may be unavailable. For the United States today, how its armed forces seek to gain advantage on the battlefield makes the management of those uncertainties even more complex.

American ground forces tend to emphasize maneuver and mobility, which means their medical support must be equally flexible and mobile as their combat counterparts. Medical units must be compact enough to move, but that ultimately limits their ability to stock large volumes of critical supplies.

Early treatment with massive transfusion protocols have been demonstrated to meaningfully improve trauma patient outcomes

Among the most important supplies that both ground maneuver units require are blood products. These include red blood cells (RBC), frozen fresh plasma (FFP), platelets, and cryoprecipitate. In recent years, the ready availability of blood products has become even more vital as early treatment with massive transfusion protocols have been demonstrated to meaningfully improve trauma patient outcomes in both civilian and military settings. Already, military medical officers have identified the logistic hurdles that sometimes prevent them from maintaining robust blood banks in deployed settings.[1] "These hurdles include long transport times, limited number of temperature-controlled storage containers and vehicles, and rapid degradation or use of products."[2]

The last two concerns were already reported during the deployment of the 31st Combat Support Hospital (CSH) to Iraq from January to December 2004. To compensate for the long transportation times from the continental United States, a high number of RBC units were stored in-theater. But since combat in Iraq was intermittent, those RBC units often

[1] C.J. Dente, B.H. Shaz, J.M. Nicholas, R.S. Harris RS, A.D. Wyrzykowski, S. Patel, et al., "Improvements in early mortality and coagulopathy are sustained better in patients with blunt trauma after institution of a massive transfusion protocol in a civilian level I trauma center," *Journal of Trauma and Acute Care Surgery* 66 (2009), pp. 1616-24; Philip C. Spinella, Jeremy G. Perkins, Kurt W. Grathwohl, Alec C. Beekley, Sarah E. Niles, Daniel F. McLaughlin, Charles E. Wade, and John B. Holcomb, "Effect of plasma and red blood cell transfusions on survival in patients with combat related traumatic injuries," *Journal of Trauma and Acute Care Surgery* 64:2 (2008), pp. S69-77; M.A. Borgman, P.C. Spinella, J.G. Perkins, et al., "The ration of blood products transfused affects mortality in patients receiving massive transfusions at a combat support hospital," *Journal of Trauma and Acute Care Surgery* 63:4 (2007), pp. 805-813; V.V. Johnson and S.A. Swiatkowski, "Scientific aspects of supplying blood to distant military theaters," *Current Opinion in Hematology* 14:6 (Nov. 2007), pp. 694-699; M. Borgman, P.C. Spinella, J. Perkins, et al., "Blood product replacement affects survival in patients receiving massive transfusions at a combat support hospital," Poster presentation at the 1st International Miltranet Symposium in Koblenz, Germany, May 2006; R.P. Dutton, "Hemorrhage control in U.S. trauma care," Presented at the 1st International Miltranet Symposium in Koblenz, Germany, May 2006; W.N. Erber, "Massive blood transfusion in the elective surgical setting," *Transfusion and Apheresis Science* 27:1 (2002), pp. 83-92.

[2] Alec C. Beekley, Benjamin W. Starnes, James A. Sebesta, "Lessons Learned from Modern Military Surgery," *Surgical Clinics of North America* 87 (2007), pp. 174-178.

sat unused for long periods. As a result, "the mean age of the RBC units on delivery to the CSH was 27 days, and the mean age of the RBC units on transfusion was 33 days. Several studies have suggested a detrimental effect of transfusions of blood greater than 14 to 21 days old."[3]

During the medium-intensity battles to take Fallujah and An Najaf in 2004, 201 patients received massive transfusions

However, when combat did occur, that blood supply was rapidly exhausted. The 31st CSH provided medical support to the 1st Marine Division's assault on Fallujah in April 2004, the 1st Cavalry Division's assault on An Najaf in August 2004, and the combined assault of both divisions on Fallujah in November 2004. Over the course of these month-long, medium-intensity battles, the number of casualties arriving at the CSH rose quickly. "During this time period, 201 patients received massive transfusions [of more than 10 RBC units in 24 hours]. The frequency of these cases meant that the hospital's blood bank would frequently be outstripped of standard blood products. By necessity, the CSH instituted a fresh whole blood program that recruited donors from within the hospital and from other neighboring units in the area."[4]

The use massive transfusions will have to be weighed against the availability of blood products and the rate of expected casualties

Under these sorts of combat conditions, medical support units must wisely use their relatively scarce blood supplies. Naturally, medical professionals will still seek to perform massive transfusions, given their ability to enhance patient survival and outcomes. But the desire to do so will have to be weighed against the amount of available blood products and the rate of expected casualties. From a medical perspective, the most straightforward solution is to more efficiently use the blood products on hand. Only those patients who would benefit from a massive transfusion should receive one. With a better diagnostic tool to more accurately predict which casualties would benefit from a massive transfusion, one can better economize blood supplies at Level III military hospitals in the field. Doing so would not only improve patient outcomes, but also ease the burden on the logistics required for blood products.

DecisionQ Technology

DecisionQ, a company whose roots go back to Stanford Robotics Labs, has worked with such technology to deal with precisely this sort of data for almost 20 years. DecisionQ's proprietary machine-learning algorithm

[3] Alec C. Beekley, Benjamin W. Starnes, James A. Sebesta, "Lessons Learned from Modern Military Surgery," *Surgical Clinics of North America* 87 (2007), pp. 175. See also S. Basran, R.J. Frumento, A. Cohen, et al., "The association between duration of storage of transfused red blood cells and morbidity and mortality after reoperative cardiac surgery," *Anesthesia & Analgesia* 103:1 (2006), pp. 15–20; R.D. Fitzgerald, C.M. Martin, G.E. Dietz, et al., "Transfusing red blood cells stored in citrate phosphate dextrose adenine-1 for 28 days fails to improve tissue oxygenation in rats," *Critical Care Medicine* 25:5 (1997), pp. 726–32; F.R. Purdy, M.G. Tweeddale, P.M. Merrick, "Association of mortality with age of blood transfused in septic ICU patients," *Canadian Journal of Anesthesia* 44:12 (1997), pp. 1256–1261; C.M. Martin, W.J. Sibbald, X. Lu, P. Hebert, et al., "Age of transfused red blood cells is associated with ICU length of stay," *Clinical & Investigative Medicine* 17 (1994), p. 124.

[4] *Ibid*.

uses heuristic techniques to discover information structure and probabilities across very large and extremely complex datasets. That enables its technology to create cost-effective computational solutions for problems that previously could not be solved. It is exceptionally good at turning low sensitivity/low specificity indicators within multivariate datasets into high sensitivity/high specificity insights.

DecisionQ's approach to predictive analytics can turn very large and complex datasets into high-sensitivity, high-specificity insights

To achieve those results, DecisionQ's technology uses Bayesian belief networks. But unlike other technologies that use the same methodology, it does not require any a priori model. No assumptions need to be made about the relationships among the variables, thus removing any human biases. All the relationships among the variables are built entirely from the input data by searching through all possible models to find the best fit. Then, the model can continuously learn from new data that is introduced, improving itself at machine speeds.

Predictive Analytics

Healthcare service providers have gained greater access to an ever increasing amount of digital information, which offer new ways of achieving new insights that can improve the efficiency of healthcare delivery and improve patient outcomes. That information has become collectively known as "big data." The name is merited for not only its sheer volume, but also its complexity, diversity, and timeliness.

Although efforts to leverage "big data" in healthcare remain at an early stage, they are already beginning to help healthcare service providers address problems related to variability in healthcare quality and escalating costs. That data is now used to understand which treatments are most effective for particular medical conditions, identify patterns related to patient outcomes, and gain other important insights that can not only help patients, but also reduce costs. Technology advances have enabled healthcare service providers to work with such data, even though the quantities of data are enormous and they often have different structures and technical characteristics.

What Is the SC2i MTP Project?

The Surgical Critical Care Initiative (SC2i) has pursued its own Massive Transfusion Protocol (MTP) project using this sort of predictive analytics to treat trauma patients, who may require massive transfusions. Emory University's Department of Surgery has deployed SC2i's MTP at Grady Memorial Hospital, a Level I trauma center certified by the Georgia Department of Public Health, to treat patients from the Atlanta metropolitan region. The hospital admits about 3,500 patients every year, and 27 percent of the surgeries that it performs involve the treatment of penetrating trauma.[5] Traditionally, physicians must determine whether or not to initiate a massive transfusion protocol, based only on his or her immediate assessment of the patient's condition and personal intuition about such wounds.

SC2i's MTP decision-support tool is expected to improve the current decision-making process over whether to implement a MTP

What the SC2i's MTP decision-support tool seeks to achieve is to not only deliver the best possible combination of blood products in a massive transfusion to stabilize patients suffering from trauma wounds, but also provide physicians with a decision-support tool that they can use to identify those patients that require massive transfusions and which do not.

Based on insights gained from Grady Memorial Hospital, we currently expect that SC2i's MTP project can reduce the number of trauma patients who receive a massive transfusion by about 15%. That means that a medical facility could save 15% of the blood products—not to mention the resources and time needed to prepare them for use—that it would have otherwise expended. We believe that Grady Memorial Hospital's experience would be relevant in a military setting, given the kinds of penetrating trauma wounds (including gunshot wounds) that the hospital frequently treats. Moreover, MTP use at trauma centers across the United States has already demonstrated modest success in reducing blood product usage without any impact to patient outcomes.[6]

In a combat environment, where resources can be expected to be constrained, the blood products that are saved can generate further benefits to military operations than merely a direct savings for its medical support units. The 15% savings in blood products also reflects opportunity gains in freed-up resources that would have been needed to transport, maintain, and resupply those blood products—by either reducing the overall size of a deployed force's logistical requirements or providing additional bandwidth to support additional combat or medical support missions. In one example of this, it means that U.S. Army MEDEVAC helicopters would have more fuel and time available to ferry more casualties off the battlefield, rather than being tasked to resupply CSHs with blood products.

[5] "Trauma/Surgical Critical Care at Grady," http://www.surgery.emory.edu/specialties-and-programs/surgery-at-Grady/trauma-surgical%20critical%20care-home.html, accessed Jan. 1, 2015.

[6] L.M. Baumann Kreuziger, C.T. Morton, A.T. Subramanian, C.P. Anderson, and D.J. Dries, "Not only in trauma patients: hospital-wide implementation of a massive transfusion protocol," *Transfusion Medicine* 24:3 (2014), pp. 162-168; L.M. McDaniel, E.W. Etchill, J.S. Raval JS, M.D. Neal, "State of the art: massive transfusion," *Transfusion Medicine* 24:3 (2014), pp. 138-144; John B. Holcomb, Deborah J. del Junco, Erin E. Fox, Charles E. Wade, Mitchell J. Cohen, Martin A. Schreiber, Louis H. Alarcon, Yu Bai, Karen J. Brasel, Eileen M. Bulger, Bryan A. Cotton, Nena Matijevic, Peter Muskat, John G. Myers, Herb A. Phelan, Christopher E. White, Jiajie Zhang, and Mohammad H. Rahbar, "The Prospective, Observational, Multicenter, Major Trauma Transfusion (PROMMTT) Study: Comparative Effectiveness of a Time-varying Treatment with Competing Risks," *JAMA Surgery* 148:2 (Feb. 2013), pp. 127–136; Terence O'Keeffe, Majed Refaai, Kathryn Tchorz, John E. Forestner, and Ravi Sarode, "A Massive Transfusion Protocol to Decrease Blood Component Use and Costs," *Archives of Surgery* 143:7 (Jul. 2008), pp. 686-691.

Research Methodology

We sought to "avoid fighting the last war" in our analysis

To understand the sorts of operational benefits that SC2i's MTP project could produce in military settings, we first had to better define what those settings might be. That is because the project's impact may vary across the wide variety of conditions under which military operations can occur. In addition, we sought to heed the cautionary aphorism to "avoid fighting the last war"—preparing for the next conflict as if it will resemble the last one.

Hence, we sought to understand how SC2i's MTP decision-support tool would perform under battle conditions that reflect potential conflicts that the U.S. military could encounter in the coming decades, given contemporary international security concerns. We focused our research on a possible high-intensity warfare campaign in Eastern Europe. This sort of campaign stands in contrast to the kinds of combat that U.S. forces experienced during their counterinsurgency operations and occupation duties in Afghanistan and Iraq.

While certain aspects of recent operations in Afghanistan and Iraq remain important to our analysis—most notably the organization and equipping of Level III military hosptials—we heavily drew on data from other campaigns in U.S. military history to understand the sorts and rates of casualties that U.S. forces could experience and how modern U.S. medical units might cope with such situations. Our analysis uses data that was collected from conflicts that include World War II (1941-1945), the Korean Conflict (1950-1953), the Persian Gulf Conflict (1991), Operation Enduring Freedom, and the first two years of Operation Iraqi Freedom.

We used three integrated models to quantify the operational benefits that SC2i's MTP decision-support tool could generate

We used three integrated models to quantify the sorts of operational benefits that the use of SC2i's MTP decision-support tool at Level III military hospitals could generate. The first is a combat model that projects the volume and rate of casualties that could be generated from a ground campaign in Eastern Europe. The second is a casualty relevance model that estimates the fraction of those casualties that will require MTP implementation. It determines that number by examining the sorts of wounds that NATO forces are likely to experience in a high-intensity combat environment. The third is our operational savings model that puts the estimate of relevant MTP patients into the context of current Armed Services Blood Program (ASBP) doctrine and the modern operation of U.S. medical support and air ambulance units. Doing so enables us to calculate the blood product and logistics savings that SC2i's MTP decision-support tool could produce.

Combat Model

Combat

Naturally, determining the demand for blood products during any military campaign begins with an estimate of the volume and rate of casualties that it would likely produce. To do that, we had to understand the probable course of such a campaign. Fortunately for our analysis, in the early 1990s, the U.S. Department of Defense began to evaluate a number of possible campaign scenarios in its effort to determine the proper mix of forces it would need in its "Base Force"—the collection of combat capabilities the U.S. military sought to maintain after the Cold War ended. Among the campaign scenarios that the U.S. Department of Defense considered in its planning was one in which a resurgent Russia, in collaboration with its ally Belarus, seizes Lithuania and eastern Poland.[7]

We used a U.S. Department of Defense campaign scenario that envisions conflict between NATO and Russia/Belarus over Lithuania and Poland

Since the time when that scenario was created, the Baltic countries (including Lithuania) and Poland joined NATO; and Russia has become increasingly aggressive in Eastern Europe. In August 2008, Russia attacked Georgia. Then, in March 2014, Russia annexed Ukraine's Crimea province and has provided military support to separatists in the Ukranian provinces of Donetsk, Kharkiv, and Luhansk ever since.[8]

Russian assertiveness has also been felt in the Baltic region. NATO and Sweden have monitored increased Russian naval and air force activity. Meanwhile, on the ground in September 2014, Russia's domestic security services captured an Estonian policeman on Estonia's side of the Estonian-Russian border. Today, NATO countries on the alliance's eastern frontier, particularly Poland and the Baltic states, have begun to strengthen their defenses against possible future Russian aggression. Poland and Estonia have even organized paramilitary forces to act as guerrillas behind Russian lines should their countries be overrun.[9]

Given its current relevance, we sought to use the U.S. Department of Defense "Base Force" scenario as a baseline for our analysis. That scenario envisioned a Russian-Belorussian invasion of Lithuania and

[7] Patrick E. Tyler, "Pentagon Imagines New Enemies to Fight in Post-Cold-War Era," *New York Times*, Feb. 17, 1992, pp. A1, A8; Patrick E. Tyler, "7 Hypothetical Conflicts Foreseen by the Pentagon," *New York Times*, Feb. 17, 1992, p. A8; Barton Gellman, "Pentagon War Scenario Spotlights Russia," *Washington Post*, Feb. 20, 1992, pp. A1, A21.

[8] Anton Zverev, "Battle rages for town where Ukraine rebels reject ceasefire," Reuters, Feb. 16, 2015.

[9] Erik Kirschbaum, "Gorbachev warns of major war in Europe over Ukraine," Reuters, Jan. 9 2015; "The Home Army is back," *Economist*, Dec. 29, 2014; Adrian Krajewski and Christian Lowe, "Poland says to beef up military on its eastern border," Reuters, Oct. 28, 2014; Charles Duxbury and Liis Kangsepp, "Alarm Over Russia Draws Volunteers to Defend Estonia," *Wall Street Journal*, Oct. 2, 2014; "Russia 'blocks Estonia' over captive border security man," BBC News, Sep. 8, 2014; "Insatiable," *Economist*, Apr. 19, 2014.

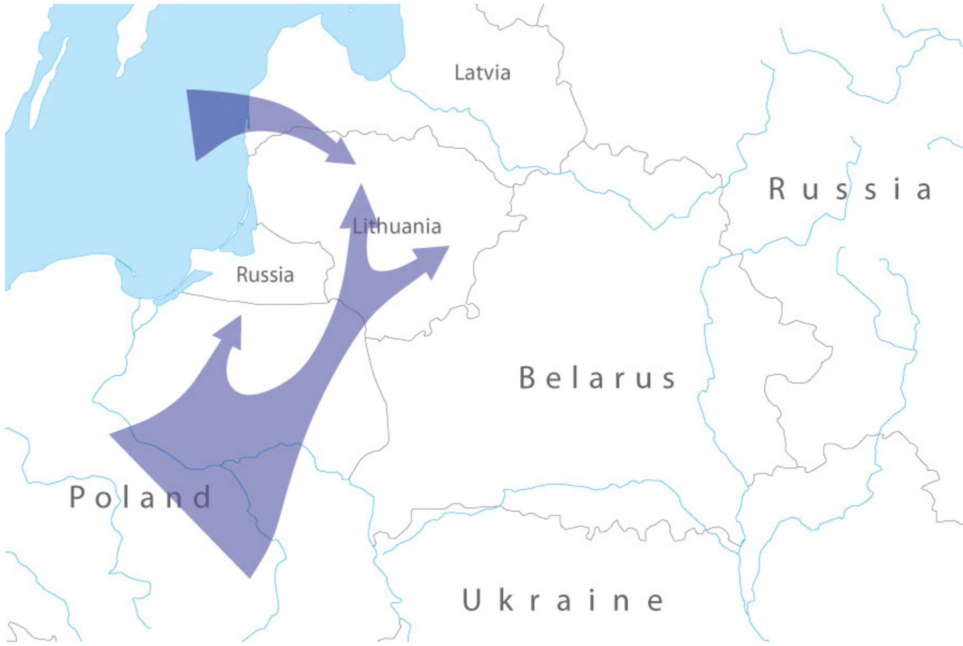
eastern Poland. The invasion force would consist of 24 Russian-Belorussian division equivalents. (See Diagram 1.)

Diagram 1.
Notional Russian-Belorussian Assault on Lithuania and Eastern Poland

The "Base Force" scenario also anticipates that there would be a robust NATO response to that invasion. Twenty-four NATO division equivalents would mount a major counterattack to drive Russian-Belorussian forces out of Lithuania and Poland. (See Diagram 2.) William Kaufmann, the prominent American defense economist at the Brookings Institution, expanded upon the scenario to outline a possible course for that campaign using a variant of Lanchester's iterative force-exchange equations.[10] For the purposes of this analysis, we mirrored Kaufmann's combat simulation methodology, but modified in some meaningful ways.

[10] William W. Kaufmann, *Assessing the Base Force* (Washington, DC: Brookings Institution, 1992), pp. 57-59.

Diagram 2.
Notional NATO Counterattack to Recapture Lithuania and Eastern Poland



First, given that for most NATO militaries—with the exception of France and the United Kingdom—it would take a substantial amount of time for them to mobilize even a single combat-ready division equivalent, we assume that the large preponderance of the 24 NATO division equivalents (or 72 brigade-sized units) envisaged in our scenario would be drawn from the U.S. Army and Marine Corps (and their respective reserve components).

Second, we did not consider the possibility that the NATO counterattack would begin only after a sustained air campaign had fully suppressed the Russian and Belorussian air forces and begun to degrade their ground units. The absence of such a successful air campaign will likely reduce the ability of NATO ground forces to inflict damage on their adversaries.

We assessed that the combat power of NATO units was 20 percent higher than that of Russian-Belorussian forces

Third, we updated Kaufmann's key assumptions regarding the respective strengths of NATO and Russian-Belorussian forces. We reduced the combat power of NATO units to 120% that of Russian-Belorussian units. While NATO combat formations still have superior equipment and training than their Russian-Belorussian counterparts, the conditions under which both forces would fight would mitigate some of these advantages. For example, the dense forests of eastern Poland and Lithuania could to help shield Russian-Belorussian units from NATO attack helicopters. The dense forests could also favor those units, because they would be defending their territorial gains from prepared defensive positions. Meanwhile, NATO forces would have to counterattack to retake the lost territory. Artillery fire could prove to be particularly dangerous to them, as tree bursts could rain shrapnel down upon any exposed infantry below.

We assessed that modern arms would reduce the combat effectiveness by half

the combat effectiveness of NATO and Russian-Belorussian units would to be half

That said, how NATO and Russian-Belorussian units employ their combat power ultimately would determine their respective combat effectiveness in inflicting casualties on their adversaries. We lowered Kaufmann's estimated combat effectiveness scores for NATO and Russian-Belorussian forces from 0.04 and 0.02, respectively, to 0.02 and 0.01, respectively. We did so to account for the lack of aerial superiority and the contemporary emphasis on "network-centric warfare," which enables forces to operate with greater mobility and decentralization, and the heavily forested terrain of eastern Poland and Lithuania. Both these features increase the ability of forces to more effectively elude the detection and targeting of their adversaries.

We expect that NATO will achieve victory after 50% of Russian-Belorussian forces become casualties or are rendered combat ineffective

Fourth, we modified the conditions under which the campaign would end. Kaufmann's model assumes that NATO forces will achieve victory only after all of the Russian and Belorussian divisions are annihilated (i.e., taking 100% casualties). We believe that such an outcome represents an extreme situation. Combat formations are likely to be rendered ineffective long before they are annihilated. Hence, we believe that victory can be achieved after only 50% of Russian-Belorussian forces become casualties or are rendered combat ineffective. While some degraded units, particularly those that remain adequately supplied, may remain cohesive, others will be effectively destroyed with their remaining personnel taken as prisoners.

Casualty Volume and Rate

We estimate that over the course of 24 days of combat NATO forces suffer 38,433 casualties

Our combat model estimates that over the course of 24 days of combat (days in which all forces are actively engaged against one another), NATO forces will achieve victory by degrading Russian-Belorussian forces to half their original strength. In the process of doing so, NATO forces would suffer 45,461 casualties (and Russian-Belorussian forces would incur 126,952 casualties).

Beyond the aggregate number of casualties, the rate at which they occur is equally important for our analysis. That is because the U.S. Military Health System must be ready to resupply the Level III military hospitals with blood products at this rate, if those hospitals are to have the necessary blood product supplies to treat trauma patients with MTPs as they arrive from the battlefield.

However, one should note that to keep our combat model as straightforward as possible we excluded the possibility of a much longer campaign should Russia and Belarus continue to feed fresh reinforcements into the conflict. Such a battle of attrition would require even more forces from the United States and its NATO allies to ensure battlefield success. Nonetheless, we believe the exclusion of this prospect would not fundamentally alter our analysis, because a longer campaign would generate an even higher volume of casualties (and possibly at a faster rate). That would lead to an even higher number of massive transfusions, higher blood product usage, and ultimately higher savings that would be produced from SC2i's MTP project.

Casualty Relevance Model

Killed in Action

While our combat model can give us insight into the volume and rate of casualties, it could not identify which among those casualties would likely need to receive a massive transfusion and, thus, could benefit from the SC2i's MTP project. Hence, we crafted three methods to screen out those casualties who would not be relevant to the project.

Our first task was to discriminate from the total number of casualties those who would die before reaching a medical facility (killed in action or KIA) from those who would be treated at one (wounded in action or WIA). We did not subtract the number of those died of their wounds after receiving medical treatment, because they would still consume medical resources in the course of their treatment.

To do so, we sought out an historic campaign which would mirror the sort of high-intensity combat that one would expect to see in our eastern Poland and Lithuania campaign scenario. Though the Persian Gulf Conflict in 1991 and the Coalition invasion of Iraq in 2003 did reflect some aspects of high-intensity warfare, we judged that they would be poor analogies for our purposes. During those conflicts, Allied forces held complete air superiority from the outset; there was never any interdiction of air or ground ambulance services; and, as military officers later stated, the number of casualties never tested the limits of the deployed medical support units.

We ultimately determined that the experience of the U.S. First and Third Armies in eastern France and Germany during 1944-1945 were best suited as relevant analogies. Both armies conducted mobile offensive operations against a comparably armed and trained, if materially weakened, German Army. The two armies engaged in defensive operations too. During the winter of 1944-1945, the U.S. First Army absorbed the initial blow of the German assault in the Ardennes that led to the Battle of the Bulge and the U.S. Third Army mounted a counterattack that broke up that assault. Both armies then participated in the renewed Allied offensive into Germany in the spring of 1945. Over that period, the two armies suffered 752,396 casualties. Of the casualties, 152,359 were KIA, roughly 20.2% of the total number of casualties.[11]

Returned To Duty

Of the 600,037 soldiers in the U.S. First and Third Armies who were WIA, approximately 150,000 were quickly returned to duty. Presumably, their wounds were clearly not sufficiently traumatic to warrant a massive transfusion. They represented about 25% of the total number of WIA. The remaining 75% (or 450,037 WIA) were treated in field hospitals and constituted those who had wounds that might have been sufficiently severe that they would have warranted a massive transfusion.[12]

Casualty-Producing Agents

We then sought to understand what sorts of wounds the remaining WIA may have suffered, since the type of wound could suggest whether a massive transfusion would be a desired course of treatment. To do that, we sought to determine what would be the likely causes of wounds in our scenario. Casualty-producing agents are influenced by several factors, including not only the weaponry employed, but also the environment in which it is used. For example, artillery shells with proximity fuses that are fired into a forested area could cause not only blast injuries, but also penetrating wounds from the secondary shrapnel of tree bursts. To capture the effect of such agents, we again turned to the histories of the U.S. First and Third Armies in 1944-1945.

The terrain over which the both armies fought was generally similar to that in our scenario—forested and crossed with streams and rivers. While the road network in Eastern Europe today is still not as well developed as that in France and Germany during World War II, that is somewhat mitigated by the fact that modern U.S. forces are equipped with more tracked vehicles than their World War II predecessors. Most importantly, the soldiers of the U.S. First and Third Armies were exposed to the same range of conventional munitions that modern U.S. soldiers would face in eastern Poland and Lithuania. Like the German forces of World War II, Russian and Belorussian forces today can employ large numbers of

[11] By comparison, during there were 58,021 KIA and 303,678 WIA. The ratio of KIA to WIA fell to 1/5.23 from the experience of the First and Third U.S. Armies in 1944-1945, which was 1/3.93. Colonel Kenneth G. Swan, who studied this phenomenon, attributed this to not only better medical care, but also the abundance of medical supplies, including blood products, that were available. Kenneth G. Swan, "Heaton Lecture - Combat Casualty Care," *Journal of the U.S. Army Medical Department*, Sep./Oct. 1992, pp. 4-10.

[12] John B. Holcomb, Lynn G. Stansbury, Howard R. Champion, Charles Wade, and Ronald F. Bellamy, "Understanding Combat Casualty Care Statistics," *Journal of Trauma*, 60:2, pp. 397-401.

armored vehicles armed with high-caliber weapons; use heavy artillery and rocket batteries to deliver high volumes of indirect fire; and utilize anti-aircraft systems to prevent effective Allied close air support.

Thus, we researched the distribution of casualty-producing agents among the 217,070 soldiers wounded in action in the U.S. First and Third Armies during 1944-1945. The classified agents include: small arms, shell fragments, blasts, bombs, burns, and other. Given a breakdown of the number of soldiers who experienced each of these agents, we can begin to estimate the percentage of wounded who have the type of trauma that is most likely to require massive transfusion. That percentage includes those WIA whose wounds were caused by small arms, shell fragments, blasts, and bombs. We applied the same methodology in our casualty model to determine which casualties would likely require massive transfusions, given the likely distribution of casualty-producing agents.[13]

Physical Location of Wounds

Finally, we sought to examine the physical location of patient wounds, since casualty-producing agents alone cannot provide a complete understanding of whether a massive transfusion is needed. For example, a soldier who is struck in the arm by small-arms fire is less likely to require a massive transfusion than one who is struck in the chest by the same small-arms fire. That said, we also considered that the physical distribution of wounds changed during the Korean Conflict with the introduction of body armor. Since the Korean Conflict was the last one in which U.S. forces were both equipped with body armor and engaged against conventional enemies with relatively similar combat power, we sought to use the physical distribution of wounds from American soldiers in that conflict. Our research uncovered a study that collected such data from 552 casualties who were wearing body armor from the U.S. Eighth Army.[14] (While the effectiveness of body armor has improved since the Korean Conflict so too has the lethality of munitions.)

To understand how the physical distribution of wounds would impact the number of relevant MTP patients, we sought the input from physicians associated with Walter Reed National Medical Center and the Uniformed Services University. They assessed the likelihood, on a three tier scale, that wounds on a certain part of the human anatomy would warrant the implementation of a massive transfusion. The three tiers used to modify

[13] James C. Beyer, James K. Arima, and Doris W. Johnson, “Enemy Ordnance Materiel,” in *Wound Ballistics*, ed. James C. Beyer (Washington, DC: Office of the Surgeon General, Department of the Army, 1962), p. 77.
[14] Carl M. Herget, George B. Coe, and James C. Beyer, “Wound Ballistics and Body Armor in Korea,” in *Wound Ballistics*, ed. James C. Beyer (Washington, DC: Office of the Surgeon General, Department of the Army, 1962), p. 733.

the wound location criteria were high (75%), medium (50%), or low (25%).

Subtracting those who are KIA, returned to duty, or have wounds that do not warrant a MTP, we estimate that 13,477 casualties will require massive transfusions

Applying these iterative methods in our casualty relevance model, we eventually found that the fraction of WIA that physicians would likely treat with a massive transfusion to be about one-third of the total daily WIA population. We believe that is a reasonable estimate, given that a report by the U.S. Army's Office of the Surgeon General estimated about 16% of the WIA population during the Vietnam Conflict and 8% of the WIA population during Operation Iraqi Freedom—the former being a medium-intensity conflict and the latter being a low-intensity one—required massive transfusions.[15] Our casualty relevance model estimates that 13,477 of those WIA would require massive transfusions after the 24 days of combat needed to achieve battlefield victory.

Finally, we should note that our casualty model makes no provision for the number of Russian and Belorussian casualties that may require medical treatment at U.S. CSHs or other Allied field hospitals. Given that it is uncertain how rapidly the campaign would proceed, we chose not to assume that large numbers of Russian and Belorussian wounded would fall into NATO hands.

Operational Savings Model

Medical Support Capacity

We envision that eight CSHs will be deployed with combat forces in the field

Given that the scenario we chose envisages a NATO counterattack with 24 division equivalents, we assume these units would be organized into eight corps. Hence, we foresee that eight NATO corps would participate in the counterattack. Since we earlier assumed that the vast majority of NATO combat units would be American, we further assume that the corps would be organized along American lines. As such, traditionally, each corps would receive a CSH as a corps-level asset. Thus, we estimate that there will be eight CSHs in the theater during the campaign.

The use of U.S. medical units to support international combat forces is not unusual. During the Persian Gulf Conflict in 1991 and the Coalition assault on Iraq in 2003, Allied forces relied on American corps-level assets, including CSHs, to support them. Indeed, over the course of Operations Desert Shield and Desert Storm, about 24,000 U.S. military medical personnel deployed to Saudi Arabia and Kuwait—about 5% of the

[15] Alec C. Beekley, Harold Bohman, and Danielle Schindler, "Modern Warfare," in *Combat Casualty Care: Lessons Learned from OEF and OIF*, eds. Eric Savitsky and Brian Eastridge (Washington, DC: Office of the Surgeon General, U.S. Department of the Army: 2012), p. 25.

total number of U.S. forces sent into the theater.[16] Many of these staffed host-country medical facilities or served on two Navy hospital ships, three Navy Fleet hospitals, and 16 Air Force hospitals. Apart from the other types of hospitals that it fielded, the Army mobilized and deployed five CSHs to support the advance of Coalition forces, which were roughly organized into five corps.[17]

Since the active component of the U.S. Army currently maintains a total of ten CSHs and the United States has other substantial military obligations elsewhere in the world, the actual medical support units that would be deployed to Lithuania and Poland are likely to be not only the U.S. Army's CSHs, but also the U.S. Air Force's smaller Air Transportable Hospitals. For the purposes of our analysis, we assume that one medical support unit with the equivalent capacity as a U.S. Army CSH would be attached to each corps.[18]

Blood Product Capacity

After blood shortages during the Korean Conflict, the United States established the ASBP to maintain a ready reserve of blood products in case of a national crisis or in support of expeditionary operations. Normally, the ASBP maintains approximately 65,000 units of frozen RBC and 5,000 units of liquid RBC.[19]

These resources were called upon when Operation Desert Shield began in the early fall of 1990. The responsibility for their distribution fell to supply units within the theater commands. U.S. European Command (EUCOM) deployed the 655th Blood Storage Detachment to expand the Southwest Asia Theater Blood Storage Unit already in Saudi Arabia. As planning for Operation Desert Storm progressed, the 379th Blood Bank Company—reinforced by the 448th Blood Processing Detachment—was dispatched from the continental United States to U.S. Central Command (CENTCOM) to operate its theater blood program. Smaller blood

[16] Robert H. Scales, Jr., *Certain Victory: The U.S. Army in the Gulf War* (Washington, DC: Office of the Chief of Staff, U.S. Army,1993), p. 80.

[17] The corps components were the VII Corps (5 1/3 divisions), XVIII Corps (4 divisions), Marine Central Command (2 1/3 divisions), Joint Forces Command North (2 1/3 divisions), and Joint Forces Command East (about 1 division). William R. Smith, Jr. and Philip Lisagor, "Experience of the 31st Combat Support Hospital in Operation Desert Shield and Desert Storm: A Commander's Story," *Journal of the U.S. Army Medical Department*, Nov./Dec. 1992, pp. 4-10; Angel E. Cintron and George D. Magee, "Medical Logistics Support to Desert Storm," *Journal of the U.S. Army Medical Department*, Sep./Oct. 1992, pp. 35-39; U.S. Department of Defense, *Conduct of the Persian Gulf War: Final Report to Congress*, Appendix G: Medical Support (Washington, DC: U.S. Department of Defense, Apr. 1992), p. 460.

[18] Matthew W. Lewis, Aimee Bower, Mishaw T. Cuyler, Rick Eden, Ronald E. Harper, Kristy Gonzalez Morganti, Adam C. Resnick, Elizabeth D. Steiner, Rupa S. Valdez, *New Equipping Strategies for Combat Support Hospitals* (Santa Monica, CA: RAND, 2010), p. xi.

[19] Armed Services Blood Program, "Armed Forces Blood Program Facts" accessed from http://www.med.navy.mil/sites/NMCP2/Affiliates/BloodProgram/Pages/Default.aspx on Apr. 24, 2015.

distribution detachments were assigned to each of the American-led corps and the U.S. Army Medical Materiel Center in Saudi Arabia.[20]

By the time Operation Desert Storm's ground offensive began in February 1991, a large reserve of RBC had been built up within CENTCOM and EUCOM to meet potential casualty needs. Altogether, 47,478 units of liquid and frozen blood were deployed with medical units in the theater, delivered to hospital and amphibious assault ships in the Persian Gulf, and made ready at U.S. military hospitals across Western Europe.[21] (See Table 1.)

Table 1.
Units of RBC Amassed for Persian Gulf Conflict

	9/15/90	10/15/90	11/15/90	12/15/90	1/15/90	2/15/90
CENTCOM						
Liquid	2,387	3,025	2,457	2,988	12,752	28,944
Frozen	3,966	5,988	6,378	6,372	7,627	7,552
	6,353	9,013	8,835	9,360	20,379	36,496
EUCOM						
Liquid	1,411	1,902	1,366	748	1,168	6,543
Frozen	255	298	599	924	1,363	4,439
	1,666	2,200	1,965	1,672	2,531	10,982

While this may epitomize the ability of the ASBP to mobilize and amass large quantities of blood products in theater to support a military campaign, it does not reflect the ready-use blood product capacity available to a CSH in the field where early treatment with massive transfusions are most likely to take place. While CSHs can draw upon these larger supplies over the course of a campaign, their actual blood products capacity is relatively limited.

Each 248-bed CSH is designed to be relatively compact. That is because it must also be sufficient mobile to relocate as the combat units that it supports move. During the 1980s, the U.S. Army began to equip its CSHs with modularized Deployable Medical Systems (DEPMEDS). The DEPMEDS included all the necessary medical equipment needed to stabilize and perform surgery on battle casualties. Included among the modules is "one isoshelter which serves as a blood bank with two plasma freezers, a blood refrigerator, and blood unit centrifuge for making blood components in emergencies. [Another] serves as the main laboratory,

[20] John R. Brinkerhoff, Ted Silva, and John Seitz, *United States Army Reserve in Operation Desert Storm: Reservists of the Army Medical Department* (Washington, DC: U.S. Army Reserve, Sep. 23, 1993), p. 60.
[21] U.S. Department of Defense, *Conduct of the Persian Gulf War: Final Report to Congress*, Appendix G: Medical Support (Washington, DC: U.S. Department of Defense, Apr. 1992), p. 456.

equipped with Istats and Piccolos for chemistries and blood gases, MLA and RapidPoint coagulation analyzers, and Coulter ACT 10 Hematology Analyzers."[22]

When fully supplied, each CSH is capable of ABO/Rh typing, cross-matching, storage of up to 480-500 units of PRBC (type specific), FFP, platelets, and cryoprecipitate. Given the general medical acceptance of the need for massive transfusions, more FFP, platelets, and cryoprecipitate are likely to be included in a future deployment than were deployed in the past. Since in-theater blood donors can help replenish their RBC supplies, CSHs might seek to have more of the latter three blood product categories on hand when they deploy. The average blood products inventory of the 31st CSH when it deployed to Iraq in 2010 was 180 RBC units, 160 FFP units, and 90 cryoprecipitate units.[23]

Thus, we assess that an initially-deployed CSH would have on hand 300 RBC units, 100 FFP units, 24 platelet units, and 100 cryoprecipitate units, which is as much as can be contained within a DEPMEDS D404 ISO, shelter. These figures are consistent with the blood products supply that the U.S. Army's 2013 textbook, *Emergency War Surgery*, expects that a CSH will deploy with.[24]

Of course, when the supply of blood products runs low, CSH personnel may become "a walking blood bank," which is what occurred in the case of the 10th CSH during its 2006 deployment to Iraq. When the 31st CSH deployed to Iraq in 1990, its nominal strength was 302 personnel. That was quickly expanded to 488 personnel with the augmentation from elements of the National Guard 115th Mobile Army Surgical Hospital from Washington, DC and the U.S. Army Reserve 345th CSH from Jacksonville, Florida. Similarly, when the 10th CSH deployed to Iraq in 2006, its strength stood at 480 personnel. A RAND study in 2010 found that a CSH can be expected to deploy with personnel strength of between 442 and 478.[25]

[22] Carren Bersch and Dottie Dunham, "Where the heroes are: A tribute to military MLTs," Medical Laboratory Observer, December 2003, http://www.mlo-online.com/articles/200312/where-the-heroes-are-a-tribute-to-military-mlts.php.

[23] Amanda Luschinski, "Laboratory Services in Austere Environment: Camp Dwyer, Afghanistan," *Society Scope*, 14:2 (Summer 2011), pp. 1, 5-10.

[24] Office of the Surgeon General, U.S. Department of the Army and Borden Institute, "Battlefield Transfusions," in *Emergency War Surgery*, 4th ed. (Washington, DC: U.S. Department of Defense, 2013), p. 469; U.S. Department of the Army, *Armed Services Blood Program Joint Blood Program Handbook, Technical Manual 8-227-12* (Washington, DC: U.S. Department of the Army, Dec. 1, 2011), p. 43; U.S. Department of the Army, *Operational Procedures for the Armed Services Blood Program Elements, Technical Manual 8-227-11* (Washington, DC: U.S. Department of the Army, Sep. 1, 2007), p. 34.

[25] Matthew W. Lewis, Aimee Bower, Mishaw T. Cuyler, Rick Eden, Ronald E. Harper, Kristy Gonzalez Morganti, Adam C. Resnick, Elizabeth D. Steiner, Rupa S. Valdez, *New Equipping Strategies for Combat Support Hospitals* (Santa Monica, CA: RAND, 2010), p. 3; Karen Linne, "10th CSH boasts 94% survivability rate in war zone," *Mountaineer* 64:36 (Sep. 8, 2006), p. 5; William R. Smith, Jr. and Philip Lisagor, "Experience of the 31st Combat Support Hospital in Operation Desert Shield and Desert Storm: A Commander's Story," *Journal of the U.S. Army Medical Department*, Nov./Dec. 1992, pp. 4-10.

We envision that CSHs will be unable to generate more than 200 units of RBC per day from its own personnel or those of nearby units

Given that people are unable to donate more than a unit of blood in a two-month period, we can reasonably assume that even if all the personnel of a CSH were to provide blood, it could provide no more than about 450 RBC units during the course of our campaign scenario. Of course, there may be nearby units that a CSH can draw on for other blood donors, but these too would eventually be exhausted. Hence, in our blood supply model, we assume that each CSH could receive no more than 200 units of RBC per combat day from local donors.

Blood Product Usage

We assume that the U.S. military medical service would adopt SC2i's MTP, as its standard massive transfusion protocol. Developed at Grady Memorial Hospital, SC2i's MTP prescribes that each relevant trauma patient should receive 16.5 RBC units, 9.8 FFP units, 0.9 apheresis platelet units, and 7.2 cryoprecipitate units. One should note that SC2i's MTP use of blood products differs from that described in the ASBP's 2011 programming guidance. However, we believe that the blood product requirements of SC2i's MTP are largely consistent with mainstream practices, as demonstrated from a brief survey of MTP studies since 2010.[26]

Table 2.
Comparative MTP Blood Products Usage Per Expected WIA

Blood Product	2011 ASBP Programming Guidance	SC2i MTP Blood Product Requirements
RBC	6.0	16.5
FFP	6.0	9.8
Platelets	1.0	0.9
Cryoprecipitate	-	7.2

However, apart from those relevant trauma patients who would receive a massive transfusion protocol, there are many other WIA who will have experienced some sort of wound that would require some blood. To account for their blood products usage, we assumed that these patients

[26] L.M. Baumann Kreuziger, C.T. Morton, A.T. Subramanian, C.P. Anderson, and D.J. Dries, "Not only in trauma patients: hospital-wide implementation of a massive transfusion protocol," *Transfusion Medicine* 24 (2014), pp. 162–168; M. Neal, A. Marsh, R. Marino, B. Kautza, J. Raval, R. Forsythe, G. Marshall, and J. Sperry, "Massive transfusion: an evidence-based review of recent developments," *Archives of Surgery* 147 (2012), pp. 563–571; J. Holcomb, D. Del Junco, E. Fox, et al., "The Prospective, Observational, Multicenter, Major Trauma Transfusion (PROMMTT) Study: comparative effectiveness of a time-varying treatment with competing risks," *Archives of Surgery* (2012), pp. 1–10; H.H. Phan and D.H. Wisner, "Should we increase the ratio of plasma/platelets to red blood cells in massive transfusion: what is the evidence?" *Vox Sanguinis* 98 (2010), pp. 395–402; M. Borgman, P. Spinella, J. Perkins, et al., "The ratio of blood products transfused affects mortality in patients receiving massive transfusions at a combat support hospital," *The Journal of Trauma* 63 (2007), pp. 805–813.

would receive, on average, 3.0 RBC units. That is consistent with the ASBP's 2011 programming guidance per expected WIA patient.[27]

We should note that after reflecting on the past decade of during Operations Enduring Freedom and Iraqi Freedom, the ASBP proposed decreasing the planning factors for most blood products in December 2009. The ASBP proposed the reduction based on the lower rates of both WIA and non-battle injuries that were experienced in both these campaigns.[28]

Blood Product Resupply

Since the casualty rate in our high-intensity combat model would exhaust the fielded stock of blood products in the deployed CSHs after only one combat day, it is important to understand how they will be resupplied with blood products. As envisioned by the ASBP, blood products are packed in standard shipping containers that are 18 inches x 19 inches x 16 inches. The number of blood product units that a shipping container can accommodate depends on the type of blood product. For example, only 12 frozen RBC units fit into a standard shipping container, whereas 30 liquid RBC units can fit into the same container. That is largely because of the added space needed for dry or wet ice that must be included alongside the blood products. The varying number of blood products that each shipping container can hold ultimately determines how much blood can be transported into the theater on a single 463 L pallet. Each 463 L pallet weighs approximately 5,394 pounds.

We assume that the ASBP's ready reserve of frozen RBC would be shipped first into the theater

Given that our scenario envisions a rapid NATO response to a Russian-Belorussian invasion, we assume that the ASBP would not have time to build up a large supply of blood products before U.S. combat units are deployed into the field. Thus, we assume that the ASBP would meet the initial deployment needs of the eight CSHs with its ready reserve of 65,000 units of frozen RBC. We expect that its reserve of 5,000 units of liquid RBC would be allocated across the smaller battalion aid stations and forward surgical teams. Finally, we assume that during the period when these reserves of blood products are being shipped into the theater, the ASBP will have successfully created a new pipeline of fresh blood products that can supply theater demands.

[27] U.S. Department of the Army, *Armed Services Blood Program Joint Blood Program Handbook, Technical Manual 8-227-12* (Washington, DC: U.S. Department of the Army, Dec. 1, 2011), p. 43; U.S. Department of the Army, *Casualty Care, ATP 4-02.5* (Washington, DC: U.S. Department of the Army, May 2013), p. A-7; U.S. Department of the Army, *Theater Hospitalization, FM 4-02.10* (Washington, DC: U.S. Department of the Army, Jan. 2005), p. H-7.
[28] Ronny Fryar, ed., *A History of the Army Blood Program: Shaping the Way Soldiers Receive Lifesaving Blood* (Falls Church, VA: Armed Services Blood Program, 2012), p. 26.

Given that blood products are highly perishable resources, they are often classified as high-priority supplies and are transported into the theater by Air Mobility Command (AMC). However, many other military supplies are also categorized as high priority. Hence, a backlog of military supplies awaiting transport from the continental United States to combat theaters can quickly form.

That was certainly the case during Operations Desert Shield and Desert Storm. Since the services—and not the AMC—were responsible for identifying which supplies were high priorities, many supplies were indiscriminately labeled as such. The "services' failure to properly prioritize" high-priority supplies "contributed to the backlogs at aerial ports of embarkation and caused some legitimate high-priority cargo to be delayed." Many medical supplies and critical spare parts had to compete with other supplies for space aboard the "Desert Express," a Transportation Command initiative, which flew a daily route from the continental United States to the two major Allied airheads in Saudi Arabia.[29]

Airlift shortages appeared again during Operation Iraqi Freedom. When the 226th Medical Logistics Battalion, 30th Medical Brigade was deployed to Balad, Iraq in 2004, it could not fulfill its mission to supply blood products to units operating in the area, because "their blood was delivered from Qatar by medical evacuation aircraft; however, the medical evacuation unit could not sustain their own mission in addition to shipping the blood." Eventually, "Ninety percent of their [blood] shipments were sent as routine shipments using opportune airlift."[30]

The competition for scarce airlift resources is unlikely to disappear, especially during high-tempo military operations when resources of all types will be in short supply. Fortunately, during Operation Iraqi Freedom, "the distribution of blood in theater was adequate. The [larger] problem was its short shelf life, which was approximately a week and a half. The storage dates of blood and blood products were expiring constantly, which increased the use of medical evacuation helicopters to maintain blood supplies.[31]

[29] U.S. General Accounting Office, *Desert Shield/Storm Air Mobility Command's Achievements and Lessons for the Future* (GAO/NSIAD-93-40, Jan. 25, 1993), p. 20, 26.

[30] Jessica L. Buck, "Class VIIIA Materiel: What Problems Were Encountered Transiting OIF Air Transshipment Nodes?" thesis, Air Force Institute of Technology, Mar. 2007, p. 12; Maria F. Johnson, "Combat Blood Operations in Iraq: Providing Blood for Injured Soldiers during Combat Operations Is a Complex Task," *Army Logistician* 37:6 (Nov.-Dec. 2005), p. 26.

[31] A number of resupply problems have dogged U.S. military medical support units. During Operation Iraqi Freedom, some of these were documented as: delay in the shipment of medical cargo despite its high-priority status; lack of care given to medical cargo (Class VIIIA materiel being left in the heat, even if the materiel was heat sensitive); and exclusion of medical military planners from the operational planning process (hence they would not know where and under what conditions combat would occur). Paula DeJohn, "Iraq War poses challenge for medical supply chain," *Hospital Materials Management* 29:10 (Oct. 2004), pp. 1, 4.Edwin H. Rodriguez, "Medical Logistics During Operation Iraqi Freedom," *Army Logistician* 36:3 (May-Jun. 2004), p. 7.

We assume any reduction in the blood products that need to be shipped into the theater would enable the AMC to transport an equivalent weight of other high-priority military supplies

Given the intense competition for airlift resources, our model assumes that AMC transport aircraft would always operate near maximum capacity, especially during a high-intensity military campaign. Thus, any reduction in the amount of blood products that need to be shipped into the theater would not reduce the number of AMC flights. But it would enable the AMC to transport an equivalent weight of other high-priority military supplies into the theater, including munitions, fuel, and critical repair parts and components.

Generally, the AMC would use C-17 heavy military transport aircraft to fly these supplies from the continental United States into theater airheads. From there, C-23B light military transport aircraft would fly them to corps-level airfields. "More than 98 percent of medical supplies were distributed by [fixed-wing] aircraft."[32]

At corps-level airfields, blood products have been primarily transported to CSHs by Army UH-60 MEDEVAC helicopters during military campaigns since the Persian Gulf Conflict.[33] That has been the case even though, in most of these campaigns, CSHs—despite their design for mobility—have been relatively static once they are in the field. During Operation Iraqi Freedom, for example, after the defeat of the Iraqi Army, U.S. medical support units occupied former Iraqi hospitals and remained fixed in the years that followed.

But we believe the availability of UH-60 MEDEVAC helicopters will be even more critical during the maneuver phases of future campaigns, especially those that resemble our campaign scenario. That is because the casualty rate will require U.S. medical support units to advance with the ground forces that they support. During the initial phase of Operation Iraqi Freedom, when the Marine Expeditionary Force advanced on Baghdad, its supporting Army medical units were initially located in Kuwait. Despite the low number of casualties, the capacity of the 498th Medical Company (Air Ambulance) was strained, as its UH-60s were required to fly ever longer missions as U.S. forces pushed deeper into Iraq.

The UH-60s were "flying people all the way back to Kuwait and were running out of fuel." As one account put it, "we [could not] make it because we have to go all the way back and then go all the way back up [to the front]… It required a lot of fuel, and they were starting to move the

[32] C. Brandon Cholek and Matthew A. Anderson, Sr., "Distribution-Based Logistics in Operation Iraqi Freedom," *Army Logistician* 39:2 (Mar.-Apr. 2007), http://www.alu.army.mil/alog/issues/Mar-Apr07/distrib_log_oif.html.

[33] Besides, during the Persian Gulf Conflict, truck capacity was so limited that CSHs required senior-level intervention to enable them to deploy to their attack positions before the ground campaign started in February 1991. U.S. Department of Defense, *Conduct of the Persian Gulf War: Final Report to Congress*, Appendix G: Medical Support (Washington, DC: U.S. Department of Defense, Apr. 1992), p. 463.

fuel points further north to keep up with the movement going north. So, we were telling them, 'Hey, you need to move a hospital or some of these medical support units closer to the front, because pretty soon we are going to be up here in the middle of Iraq, almost to Baghdad, and there's going to be nowhere to fly these guys.' It's nice to have critical care and air ambulance stuff, but if you don't have anything close, it defeats the purpose if I've got to fly the guy two hours to the rear."[34]

We assume that UH-60 MEDEVAC helicopters will bear the responsibility for ferrying blood products to CSHs, as they have in past campaigns

Therefore, we assume in our campaign scenario that both CSHs and UH-60 MEDEVAC helicopters would follow behind the advancing combat forces that they support. However, until CSHs could relocate forward, UH-60s would have to fly longer missions, as they did during the opening phases of Operation Iraqi Freedom in 2003. Thus, it is reasonable to assume that UH-60s would be flying longer blood product resupply missions to the rear, especially if it is impractical to relocate EUCOM's centralized blood bank.

We estimate that UH-60 MEDEVAC helicopters would consume 65% of their internal fuel load on a resupply mission

A UH-60 MEDEVAC helicopter can carry a maximum internal fuel load of 360 gallons. When fully armored for combat situations, a UH-60 has a maximum flight time of about 2 hours and 20 minutes, depending on the altitude at and atmospheric conditions in which it would operate. M oreover, UH-60 pilots are generally required to hold a 20-minute reserve of fuel when flying under visual flight conditions and a 30-minute reserve when flying under instrument-only flight conditions. Hence, for practical planning purposes a UH-60 operating at its maximum range would consume about 85% of its internal fuel load. Since not all blood product resupply missions will require a UH-60 to operate at its maximum range, we estimate that average blood product resupply missions will consume about 65% of its internal fuel load in our scenario.[35]

According to ASBP's planning factors, each UH-60 can carry a full load of 50 standard shipping containers. Although that may be true for UH-60s that are completely empty, during combat operations UH-60 MEDEVAC helicopters will have been configured with armor, racks, and medical equipment to evacuate wounded from battle. Given the numbers of wounded that will need emergency care in a high-intensity war, those helicopters are likely to be in high demand. Thus, those helicopters are unlikely to have their armor, racks, and medical equipment removed to fulfill the needs of periodic blood product resupply missions. Their full-load capacity is likely to be smaller than that of empty UH-60 MEDEVAC helicopters.

[34] Richard V. N. Ginn, Annita Ferencz, and Dr. Sanders Marble, eds., *In Their Own Words: The 498th in Iraq, 2003* (San Antonio, TX: Office of Medical History, U.S. Army Medical Command, Feb. 2008), pp. 141-142.
[35] Michael Crivello, Electronic mail to the author, May 7, 2015; Michael Crivello, Electronic mail to the author, Jan. 5, 2015; Michael Crivello, Electronic mail to the author, Dec. 26, 2014; "Sikorsky S-70 (H-60) - US Army UH-60Q DUSTOFF Medevac Conversion," *Jane's Aircraft Upgrades*, Jun. 11, 2008.

We estimate that UH-60 MEDEVAC helicopters could transport up to 30 shipping containers of blood products on a resupply mission

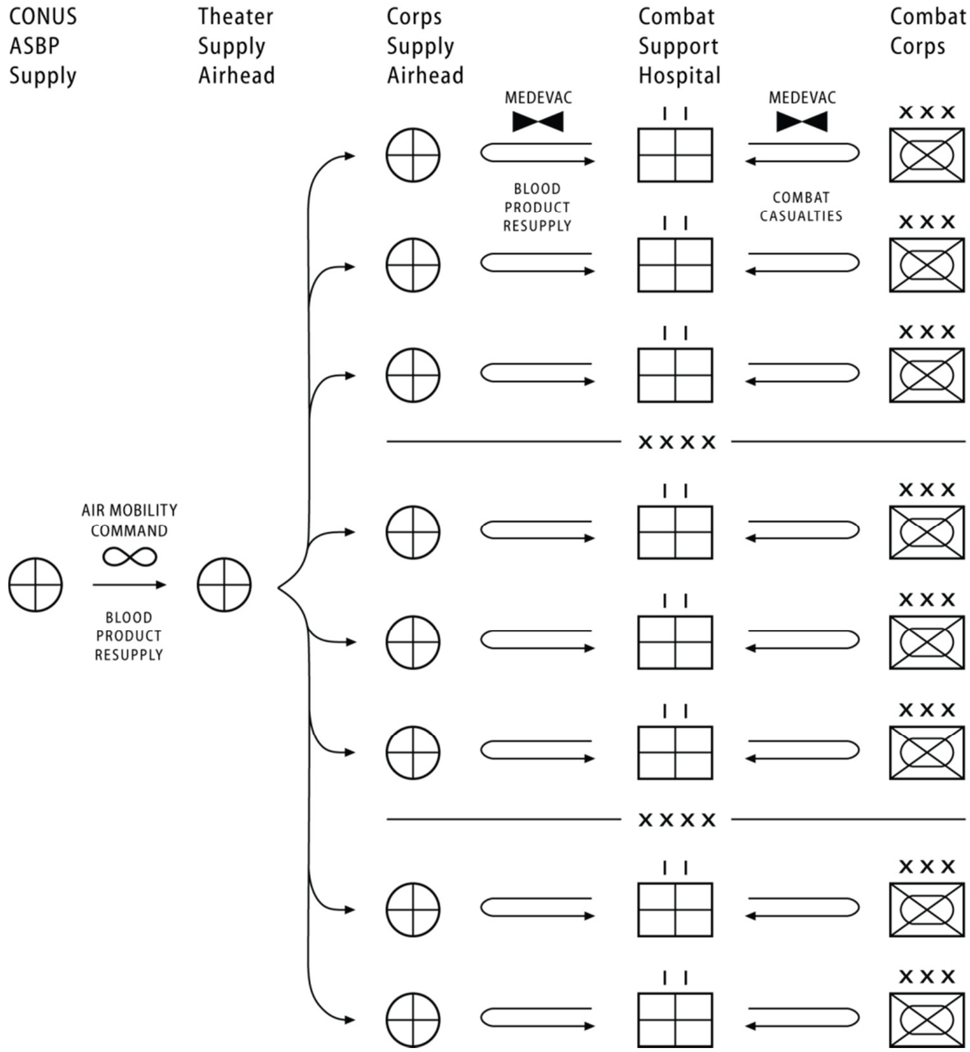
An interview with a former UH-60 MEDEVAC helicopter pilot revealed that the capacity of a UH-60 that has been configured for combat to be only 25-30 shipping containers of blood products.[36] For our scenario, we assumed that each UH-60 could transport 30 shipping containers of blood products. The total amount of blood products within those shipping containers would vary according to the types of blood products that they hold.[37]

Diagram 1 portrays the notional end-to-end logistics which are needed to deliver blood products to CSHs that support frontline combat corps. The logistics diagram traces the resupply of blood products from ASBP resources in the United States to theater and corps-level blood supply depots and then to Level III military hospitals. (See Diagram 1.)

During Operations Iraqi Freedom and Enduring Freedom it was not unusual to see UH-60 MEDEVAC helicopters ferry two or three blood shipment containers at a time.[38] In our scenario, however, they would be required to ferry many more, given the expected usage rate of blood products. With a capacity for 30 shipping containers, each UH-60 blood product resupply mission could delivery as many as 900 units of blood products to CSHs on a single resupply mission.

[36] Michael Crivello, Electronic mail to the author, May 7, 2015.
[37] U.S. Department of the Army, *Armed Services Blood Program Joint Blood Program Handbook, Technical Manual 8-227-12* (Washington, DC: U.S. Department of the Army, Dec. 1, 2011), pp. 45-46; U.S. Department of the Army, *Operational Procedures for the Armed Services Blood Program Elements, Technical Manual 8-227-11* (Washington, DC: U.S. Department of the Army, Sep. 1, 2007), p. 34, 41.
[38] Amanda Luschinski, "Laboratory Services in Austere Environment: Camp Dwyer, Afghanistan," *Society Scope*, 14:2 (Summer 2011), p 10.

Diagram 1.
Notional Logistics Related to Blood Product Resupply



Finally, we must note that there is the real possibility that during a high-intensity conflict AMC fixed-wing transport aircraft or UH-60 MEDEVAC helicopters could be lost due to either hostile action or mechanical failure, while conducting a blood product resupply mission. That might result in the loss of not only the aircraft and its crew, but also all the blood products aboard it. That, in turn, would require additional blood product supplies to replace those that were lost. Since the prospect of the loss of such AMC fixed-wing transport aircraft or UH-60 MEDEVAC helicopters is very difficult to assess, we assume that no aircraft or helicopters transporting blood products would be lost in our envisioned scenario.

Results

Based on the campaign scenario we presented and the 15% savings in blood products that we anticipate will be achieved through SC2i's MTP, we can project the blood product savings that would be produced over the course of our campaign scenario. (See Table 3.)

Table 3.
Blood Product Savings (in units)

Blood Product	MTP Usage Before SC2i	MTP Usage After SC2i	Savings from SC2i
RBC	216,510	183,216	33,294
FFP	150,662	130,771	19,891
Platelets	13,974	12,114	1,860
Cryoprecipitate	96,769	82,134	14,635

However, there are operational savings that such a reduction in blood products can produce. The clearest of which is the corresponding savings in the number of UH-60 blood product resupply missions that would need to be flown to deliver those blood products. We estimate that in our campaign scenario, the implementation of SC2i's MTP would eliminate the need for 88 UH-60 blood product resupply missions. That, in turn, saves about 20,592 gallons of Jet-A fuel, which equates to the need for over eight HEMTT M978A4 Fuel Servicing Trucks.[39]

Given the rate at which casualties are created in the course of our campaign scenario, the demand for UH-60 MEDEVAC helicopters to ferry casualties back from the frontlines is likely to be high. Every blood product resupply mission that a UH-60 does not have to fly means that it can fly a medical evacuation mission in which it can retrieve up to seven casualties from the battlefield. SC2i's MTP savings of 88 resupply missions means that existing UH-60 air ambulance resources can evacuate up to an additional 616 wounded off the battlefield and to earlier medical treatment.

SC2i's MTP tool reduces the need for enough fuel to enable the Army to mount 88 more AH-64 attack helicopter missions

Alternatively, the conserved Jet-A fuel could also be used by Army and Marine combat helicopter units, since they are likely use the same airhead refueling services as the UH-60 MEDEVAC helicopters. While that the mission fuel payload of the AH-64 attack helicopter (357 gallons) is slightly smaller than that of the UH-60 (360 gallons), 20,592 gallons of Jet-A fuel means that Army and Marine aviation units could mount 88

[39] Oshkosh Defense website, "HEMTT A4 M978A4 Fuel Servicing Truck (Tanker)," http://oshkoshdefense.com/variants/m978a4-fuel-servicing-truck-tanker, accessed on Jan. 11, 2015.

more close air support missions along the same flight parameters as outlined for the MEDEVAC helicopters above.[40]

Moreover, a reduction in the amount of blood products that CSHs need to treat battle casualties would also reduce the space and weight of those blood products aboard AMC fixed-wing aircraft that would be needed to transport such high-priority medical supplies from the continental United States to corps-level airfields near the frontline. Given that the capacity of those aircraft would be scarce during a high-intensity conflict; other high-priority military supplies are likely to immediately replace any blood products that were not transported. While AMC transport flights would likely continue—much like the "Desert Express" during Operations Desert Shield and Desert Storm—the space and weight that those blood products would have occupied could be used for munitions, fuel, and critical repair parts and components.

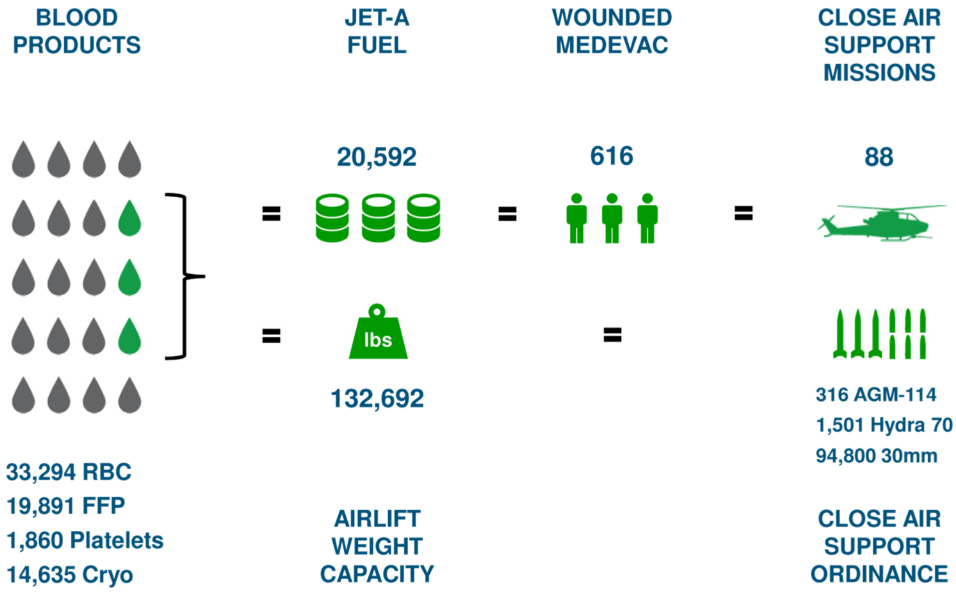
SC2i's MTP tool releases enough weight capacity to enable the AMC to transport ordinance for 79 AH-64 attack helicopter missions

Given our assessment that the implementation of SC2i's MTP tool will reduce the need for 69,680 units of blood products, the AMC would have to transport 2,952 fewer standard shipping containers into the theater. We estimate that those shipping containers would have a combined weight of 132,692 pounds. That means the AMC could transport a similar weight of other high-priority military supplies from the continental United States. In fact, the weight savings would be sufficient to airlift 79 complete sets of multipurpose ordinance load outs for the AH-64 attack helicopter—316 AGM-114 Hellfire missiles, 1,501 Hydra 70 rockets, and 94,800 30mm rounds.

Taken together, the operational savings from SC2i's MTP tool could provide not only the fuel needed for Army AH-64 attack helicopters to mount close air support missions against enemy ground forces, but also the ordinance with which to mount those missions. Those savings are summarized in Diagram 2.

[40] Specifications are for the AH-64D model and conversion of Jet-A fuel of gallons per pound is 6.7. "McDonnell Douglas AH-64A and D," in *Jane's All the World's Aircraft, 1995-96*, eds. Paul Jackson, Kenneth Munson, and John W.R. Taylor (Surrey, England: Jane's Information Group Limited, 1995), pp. 589-593.

Diagram 2.
Summary of SC2i MTP Project's Estimated Operational Savings



Conclusion

The SC2i's MTP project demonstrates how clinical decision-support tools can deliver benefits beyond the improvement of patient outcomes. By using predictive analytics to more accurately determine when a massive transfusion protocol needs to be initiated, SC2i's MTP tool can reduce the unneeded use of blood products. In a high-intensity combat environment, the savings in blood products can yield meaningful operational benefits for not only the ASBP and Level III military hospitals, but also military logistics and even maneuver units.