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Better management of blood supply-chain with GIS-based analytics

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Abstract This paper presents a novel application of operations research, data mining and geographic information-systems-based analytics to support decision making in blood supply chain management. This, blood reserve availability assessment, tracking, and management system (BRAMS), research project has been funded by the Office of the Secretary of Defense. (This DoD funded SBIR project is performed by the researchers at Knowledge Based Systems, Inc. (KBSI).) The rapidly increasing demand, criticality of the product, strict storage and handling requirements, and the vastness of the theater of operations, make blood supply-chain management a complex, yet vital problem for the department of defense. In order to address this problem a variety of contemporary analytic techniques are used to analyze inventory and consumption patterns, evaluate supply chain status, monitor performance metrics at different levels of granularity, and detect potential problems and opportunities for improvement. The current implementation of the system is being actively used by 130 mangers at different levels in the supply chain including facilities at Osan Air Force Base in South Korea and Incirlik Air Force Base in Turkey.

Keywords Blood inventory management · Data mining · Data validation · Geographic Information System (GIS) · Analysis at multiple levels of abstraction

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1 Introduction

The increasing demand for healthcare services coupled with the higher cost of medical care makes it necessary to better utilize the medical resources. This phenomenon is even more prominent in military healthcare systems, where the budget allocation has stayed relatively the same while the demand has increased exponentially in recent years. With the aging population in the US, advances in medical treatments that require blood transfusions, and increased military engagements throughout the world, the demand for blood and blood products continues to increase.

Blood is composed of many components (red cells, white cells of various kinds, platelets, plasma), several of which are extracted from whole blood. Each blood component serves for a separate function in the human organism and has a different use in medical treatment. As a critical medical resource, blood is often required for trauma victims, battlefield injuries, various types of surgeries, organ transplantations, child delivery, and for patients receiving treatment for cancer, leukemia, and anemia. Every unit of blood is precious: a single pint of blood can sustain a premature infant's life for two weeks while 40 or more units of blood may be needed for the survival of a single trauma victim and 8 units of platelets may be required daily by a leukemia patient undergoing treatment.

Ever since the first volunteer blood donor service opened in 1921, the search for blood donors has been constant. Among the reasons for the dire need for this medical resource are that (1) there is no *exact* substitute for human blood; (2) every day brings advances in life-saving techniques, many of which require blood or products made from blood, and (3) blood products cannot be stored indefinitely (red blood cells must be used within 35–42 days of collection for the safety of the recipient; platelets have an even shorter shelf life—they must be used within five days of collection) (Chapman 2007). Because blood can be needed at any time, it must be collected regularly. Nobody expects to need blood, but if it is not available when the need arises, the consequences can be deadly. Although those who donate can tell you there is no better feeling than saving a life, about only five percent of eligible donors actually donate.

There are also significant risks associated with blood transfusion, the mitigation of which complicates the process and increases its cost. The most widely publicized area of risk in blood transfusion is the transmission of infection from a donor to a recipient. Although other areas of risk exist (e.g., transfusion of incorrect blood due to misidentification of a patient's blood type), the most important risk factors related to the blood supply-chain are infection related, and hence certain costly mechanisms are usually put in place to control this risk. The risk of transmission of infection by blood transfusion is relatively well established (Sullivan 2005). Risks of infection by hepatitis B virus (HBV), human immunodeficiency virus (HIV), and hepatitis C virus (HCV) are well documented. New infectious risks continue to emerge, with the more recent identification of Mad Cow disease, West Nile virus and Creutzfeldt-Jakob disease (vCJD). The greatest risks arise in the period before the identification of a particular agent as a potential risk, the development of a means to test donations for that risk and the introduction of such tests into organization's repertoire of screening tests. These infection-related issues and risk alleviation procedures of blood transfusion further complicate the management of the blood supply-chain.

The remainder of the paper is organized as follows. The background of the research effort including the description of the military health system and the blood supply-chain management is presented in the next section; which is followed by a detailed description of the information system developed. The concluding remarks along with further research directions are discussed in the last section.

1.1 Military Blood Program

The Military Blood Program, established in 1952 by Presidential Order as part of the National Blood Program and today commonly called the Armed Services Blood Program (ASBP), comprises approximately 81 blood banks and blood donor centers worldwide, including 22 Food and Drug Administration licensed blood donor centers (ASBP 2008). The administrative branch, the Armed Services Blood Program Office (ASBPO), is a joint health agency chartered to monitor the implementation of blood program policies established by the Assistant Secretary of Defense (Health Affairs) and to coordinate the blood programs of the military services—Army, Navy, and Air Force—and the unified commands. All of the ASBP components are expected to function together to successfully operate the military blood program.

The mission of the armed services blood program is to provide quality blood products and services for all worldwide customers in peace and war (ASBP 2008). The criticality of the product, storage and handling requirements, and the vastness of the theater of operations (practically the entire world), make blood supply chain management a complex problem. The goal of this research project—blood reserve availability assessment, tracking, and management system (BRAMS)—is to facilitate timely collection and detailed analyses of data on blood availability and consumption from Department of Defense (DoD) medical facilities using an integrated Web-based decision support system (BRAMS 2007). In order to achieve this goal BRAMS designed and developed a variety of analytical capabilities to support better decision making in blood supply chain management.

The ASBP supplies blood and blood products for more than 4 million active service members, retirees and their families across the nation and around the world. This means blood must be available for routine military medical treatment facility operations as well as contingency operations. Since the Korean War, the military blood program has provided over 3 million units of blood to treat battlefield illnesses and injuries alone. In addition to providing blood in combat situations, the ASBP also supports the peacetime needs of military personnel and their families. Blood must be available to military hospitals for both scheduled and emergency procedures. Every year military hospitals transfuse more than 54,000 units of red blood cells, 20,000 units of plasma, and 5,000 units of platelets (ASBP 2008).

The Armed Services Blood Distribution System is made up of units and facilities at supporting bases and in the theater of operations. A pictorial representation of this complex system is shown in Fig. 1. As can be seen in Fig. 1, blood is collected and processed at supporting bases (represented by the large rectangle on the left side of the figure). Joint Services blood donor centers known as Armed Services Blood Bank Centers, US Army Blood Donor Centers, US Air Force Blood Donor Centers, and US Navy Blood Donor Centers send blood collected at their sites to the Armed Services Whole Blood Processing Laboratories. When necessary, blood from civilian blood donor centers is also sent to these laboratories.

The Armed Services Whole Blood Processing Laboratories send blood into the theater of operations by two methods: (1) pre-positioning some frozen blood at Blood Product Depots and (2) sending blood and blood components to Expeditionary Blood Transshipment Systems, which then forward the blood products to the Blood Supply Units. The Expeditionary Blood Transshipment Systems, Blood Product Depots and Blood Supply Units send blood to a number of groups (e.g., forward surgery, theatre hospitals, en-route care, US Navy ships, force service support groups, coalition hospitals) that transfuse blood to those injured in theater. Forward surgery units and theater hospitals provide blood to be transfused by first

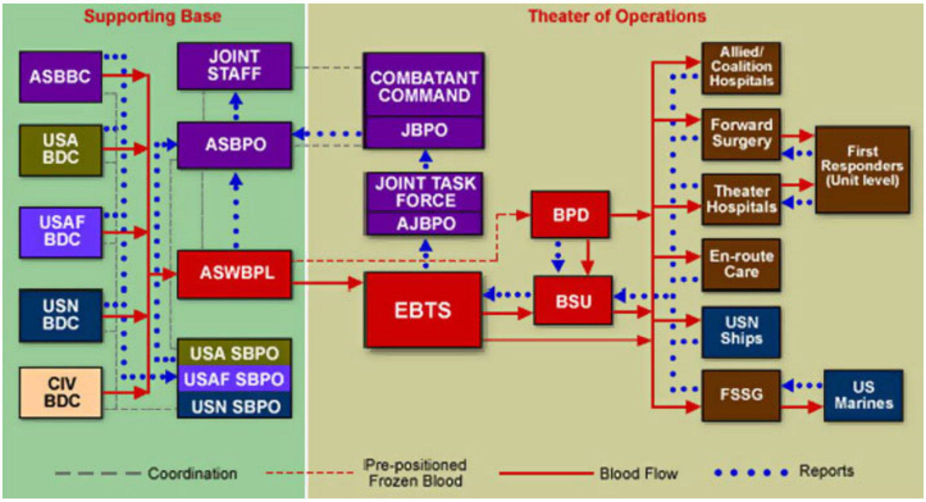


Fig. 1 Armed services blood distribution system.[1] *Abbreviations:* AJBPO: Area Joint Blood Program Office; ASBBC: Armed Services Blood Bank Center–Joint Service Blood Donor Center; ASBPO: Armed Services Blood Program Office; ASWBPL: Armed Services Whole Blood Processing Laboratory; BDC: Blood Donor Centers; BPD: Blood Product Depots; BSU: Blood Supply Units; CIV: Civilian; EBTS: Expeditionary Blood Transshipment System; FSSG: Force Service Support Groups; JBPO: Joint Blood Program Office; SBPO: Service Blood Program Office; USA: United States Army; USAF: United States Air Force; USN: United States Navy

responders (unit level). Armed Forces service support groups provide blood to be transfused to US Marine Corps units.

1.2 Blood supply chain management

A simplified depiction of the blood supply chain system is presented in Fig. 2. In the context of ASBP, on the supply side, the activities start with advertising and educational campaigns to recruit potential blood donors from both military and civilian populations. The blood is collected in one of many nationwide blood collection centers and then sent to the hospitals and/or blood banks for testing and further processing. After a series of tests to eliminate the possibility of infectious diseases in the blood sample, the blood moves to the processing stage where it is separated into its components (red cells, white cells of various kinds, platelets, plasma), packaged and stored. As demand arises, the correct blood products are transported to medical facilities for consumption.

Some of the earliest studies related to blood supply chains date back to the 1970s and early 1980s (Pierskalla and Roach 1972; Brodheim and Prastacos 1979; Prastacos 1984; Sapountzis 1984). Some of the key parameters and high-level modeling concepts proposed in these early studies paved the way for most of the more recent studies that are more granular in their modeling approaches to the ever-more-complex system of blood supply chains. The majority of the recently published research, where more focused models of the blood supply have been proposed, have used simulation modeling in the context of developing policies for

[1] Source: Armed Services Blood Program website, accessed on August 12, 2008, at http://www.militaryblood.dod.mil/About/activities/distrib/distribChart.cfm.

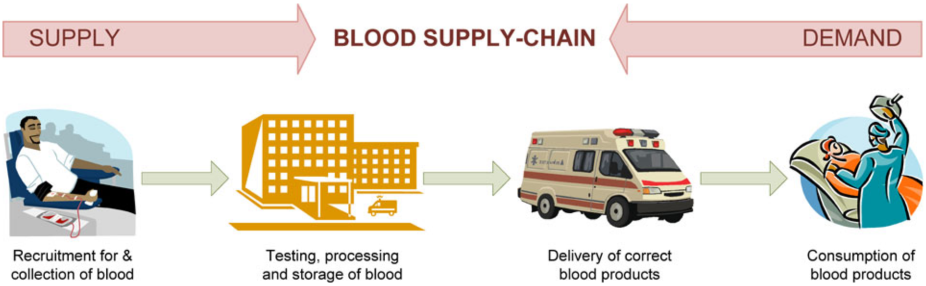


Fig. 2 A simplified illustration of the blood supply-chain system

managing the blood inventory systems in a hospital environment (Rytila and Spens 2006; Sime 2005).

In another closely related study, Katsaliaki and Brailsford (2007) analyzed policies for managing the blood inventory system in a typical UK hospital where the supplier was a regional blood center. The objective of the project was to improve procedures and outcomes by modeling the entire supply chain for that hospital, from donor to recipient. The supply chain of blood products is broken down into material flows and information flows. A discrete-event simulation model was used to determine ordering policies leading to reductions in shortages and wastage, increased service levels, improved safety procedures, and reduced costs. According to the findings of this study, such a model can be used by hospital managers as a decision support tool to investigate different procedures and policies.

Our research differs from these efforts in two ways; (1) the underlying system is larger in scope and hence is much more complex, and (2) it uses a variety of tools (as opposed to just simulation) including data mining, optimization, GIS-based analytics and enhanced visualization to help manage the blood supply chain system.

Using data collected as a normal part of the business process for retrospective analysis to improve operational effectiveness (and efficiency) is a formidable task for most organizations. The data must be transformed into actionable insights—capable of generating actionable results and measurable improvements in performance. The transformation of data to knowledge requires deep understanding of the relationships among variables as well as the underlying processes so that the resulting model can recognize a given situation and trigger an appropriate responding action. Taken to its logical conclusion, such a process will ultimately allow for forecasting changes and proactively initiating solutions. Therefore, effective utilization of data mining techniques can radically improve one's impact on the supply chain management and can generate an ongoing process of innovation and improvements.

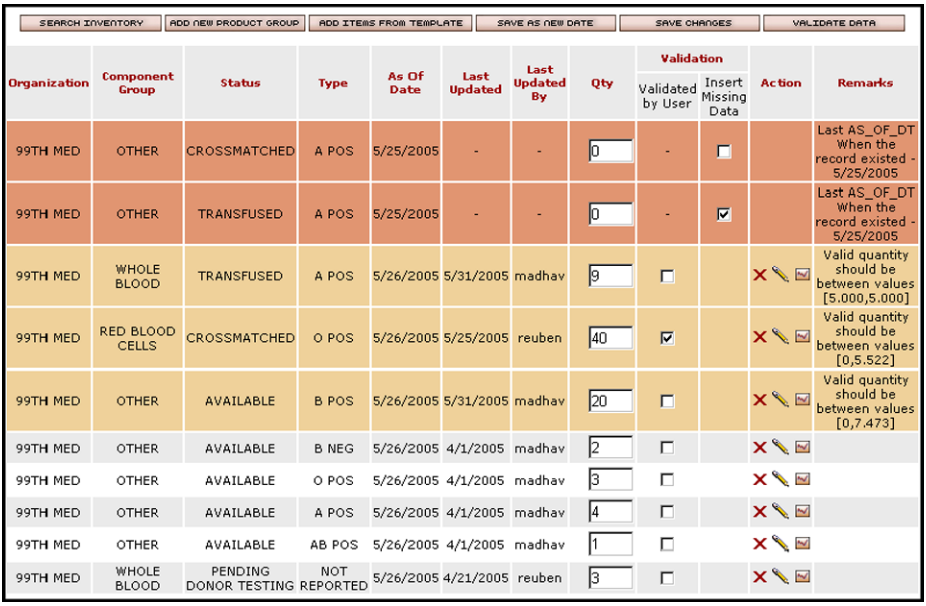
In this study, a variety of data mining techniques are utilized. A typical classification-type data mining problem in medicine (as well as in a number of other areas) can be formulated simply in the following way. A structured dataset consisting of two disjoint sets $\{P\}$ and $\{N\}$ of n-dimensional real vectors is given. Each of the vectors in the dataset corresponds to a patient, the vectors in $\{P\}$ corresponding to patients having a specific medical condition (e.g. pneumonia), while those in $\{N\}$ (the *controls* in medical language) do not have that condition. The components of the vectors, called *attributes* (or *features* or sometimes *variables*) can represent the patient characteristics such as demographics, results of certain tests, the expression levels of genes or proteins in the blood and the presence or absence of certain symptoms (in which case they are usually expressed as binary variables with the values of zero or one). Diagnosis and prognosis, two special cases of what is called classification in data mining, are considered the chief medical problems that lend themselves very well to data-driven analyses (Hammer and Bonates 2006). The basic idea of classification is to *learn* (i.e., discover patterns and/or extract information) from the dataset to be able to recognize the positive or negative nature of a new sample. Simply put, diagnosis refers to extracting information from a given dataset in order to recognize whether a *new* patient (one not contained in the learning dataset) does or does not have the specific condition under analysis. Prognosis is a somewhat similar problem with a time constraint imposed upon the formulation. In this case it is assumed that the vectors in the dataset are known to have or not to have developed a particular medical condition (e.g., a cardiac event, cancerous metastases, etc.) within a well-defined time period (typically 5 or 10 years). In this case, again the problem is to learn enough from the given data to predict whether a new patient is prone to develop the condition under analysis within that time period. Despite the level of success demonstrated in various data-mining-driven medicine data analyses, the identification of individualized therapies—on the basis of data analysis and mathematical/computational diagnostic and prognostic systems—is still a major challenge due largely to the high level of analytic expertise required and the lack of user-friendly information dissemination media.

Access to sophisticated models of data mining has been limited to a few experts due to the complex nature of these systems. Organizations must build bridges that allow all knowledge workers (including non-data-mining experts) to gain mission-critical insights from vast warehouses of data and information. Therefore, ASBP aims to develop and deploy an analytics and knowledge discovery-driven solution portfolio to be readily used by the supply chain logisticians. This paper presents the efforts to develop such a solution for the blood supply-chain.

2 Blood reserve availability assessment, tracking, and management system

One of most important motivations behind any integrated supply chain management (as is the case in this research effort) is to eliminate the barriers by enabling the synchronization and sharing of valuable information among the stakeholders (Delen et al. 2007). The success of a supply chain system depends on the level (and the timeliness) of the visibility of the resources (i.e., blood in this research) from suppliers (i.e., donors) to the customers (i.e., the recipient patient). The improved visibility of such information coupled with predictive analytics would yield significant benefits in inventory management, resource utilization, and product distribution.

Useful information can be produced by aggregating and summarizing large amounts of data coming from disparate sources. The accurate collection, consolidation, and preparation of data are vital to proper analyses. A large portion of time (more than 80% in most cases) spent on developing medical applications is accounted for by these data pre-processing stages (Cios and Moore 2002). In order to better facilitate the collection while minimizing data-related errors, BRAMS gathers daily blood status data from MTF through automatic data feeds as well as manual data entry through a Web interface. Manual data entry is primarily targeted for deployed facilities that do not have systems set up for automatic uploads. Since some of the data is entered manually, despite various on-the-spot data validation mechanisms embedded into the system, there is a chance that the data is entered incorrectly. Even in the automatic entry mode, the accuracy and validity of the data is influenced by the systems used to receive, track, and maintain shipments based on their specific data maintenance procedures. Recognizing the value of valid data, BRAMS employed a number of rule-based techniques to validate the data, where anomalies are detected and corrected (often via the automated communication with the source) using a graphical, color coded Web-interface (see Fig. 3).


SEARCH INVENTORY | ADD NEW PRODUCT GROUP | ADD ITEMS FROM TEMPLATE | SAVE AS NEW DATE | SAVE CHANGES | VALIDATE DATA

Organization	Component Group	Status	Type	As Of Date	Last Updated	Last Updated By	Qty	Validation: Validated by User	Validation: Insert Missing Data	Action	Remarks
99TH MED	OTHER	CROSSMATCHED	A POS	5/25/2005	-	-	0	-	☐		Last AS_OF_DT When the record existed - 5/25/2005
99TH MED	OTHER	TRANSFUSED	A POS	5/25/2005	-	-	0	-	☑		Last AS_OF_DT When the record existed - 5/25/2005
99TH MED	WHOLE BLOOD	TRANSFUSED	A POS	5/26/2005	5/31/2005	madhav	9	☐			Valid quantity should be between values [5.000,5.000]
99TH MED	RED BLOOD CELLS	CROSSMATCHED	O POS	5/26/2005	5/25/2005	reuben	40	☑			Valid quantity should be between values [0,5.522]
99TH MED	OTHER	AVAILABLE	B POS	5/26/2005	5/31/2005	madhav	20	☐			Valid quantity should be between values [0,7.473]
99TH MED	OTHER	AVAILABLE	B NEG	5/26/2005	4/1/2005	madhav	2	☐			
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99TH MED	OTHER	AVAILABLE	A POS	5/26/2005	4/1/2005	madhav	4	☐			
99TH MED	OTHER	AVAILABLE	AB POS	5/26/2005	4/1/2005	madhav	1	☐			
99TH MED	WHOLE BLOOD	PENDING DONOR TESTING	NOT REPORTED	5/26/2005	4/21/2005	reuben	3	☐			

Fig. 3 Data validation and data quality assurance in BRAMS

In the following sub-sections, three major modules of BRAMS are summarized. First, the inventory management sub-system is explained. Then, the proactive nature of the blood supply-chain management system is described. Finally, the GIS-based emergency management and information visualization module is discussed.

2.1 Inventory management

Inventory management is a crucial function in the blood supply chain, not only because of the vitality of the product, but also because of the high cost and the perishable nature of the blood. In the military health system, blood inventory managers are very keen on maintaining enough inventories to meet planned (and unplanned) demand, but at the same time to minimize expirations and spoilage. These are two conflicting objectives that make inventory management even more challenging. In order to manage these conflicting objectives, the end users requested instant visibility into shortages and excess inventories at different levels in the supply chain. To facilitate such management, an inventory management dashboard has been designed to summarize blood status and visually contrast excess and critical inventories. This dynamic report continually analyzes the inventories for blood products at each facility based on their historical consumption rates and the adopted inventory policies. The inventory is characterized in terms of number of days of operations it would support. A dashboard type graphical illustration is developed to show the inventory status using color coded graphics to help blood inventory managers to make better decisions.

An innovative feature of BRAMS is that the inventory status analyses can be performed at different levels of abstraction—at MTF, regional, service, command, and entire DoD levels. In addition to generating inventory status analysis reports, BRAMS also forecasts inventory and consumption at different levels of abstraction using traditional statistical forecasting techniques for short-to-medium-term logistic planning purposes.

2.2 Proactive supply chain management

Blood supply managers are often involved in responding to emergencies that require coordination with other blood supply chain and homeland security officials. While they are dealing with these emergency situations, some less significant logistic issues may escape them. That is, smaller issues and gradual deviations may go undetected initially and be noticed only when that deviation causes a significant impact on the supply chain. To avoid such situations, the end users requested an automated means of detecting these problems and bringing them to their attention as early as possible so that the managers will have greater flexibility in the range of options to fix the issue. To address this user request, various alert types and notification mechanisms were designed and implemented as part of the BRAMS project. Table 1 summarizes some of these alert types, metrics, and measurement mechanisms.

Alerts allow supply chain managers to proactively identify problems by using software agents (continuously running autonomous software components) that monitor critical metrics such as inventory levels, not-in-stock items, unusual trends in consumption, and expiration rates of blood and blood products and therefore develop solutions before the problems become critical. Notifications are sent to concerned program and preparedness managers via e-mail or pop-up messages within BRAMS. By automatically monitoring all the relevant metrics—detecting problems before they become critical and notifying the corresponding managers—BRAMS intends to change the blood supply chain from a reactive agency to a proactive agency. BRAMS users have the flexibility to define what metrics to monitor, acceptable levels for those metrics, and even the mode of alert notifications.

The alerts are implemented at different levels of abstraction—MTF, regional, service, command, and DoD levels. A *publish-and-subscribe* architecture was used to implement the alerts. Users can choose to subscribe to different alerts that they are authorized to, based on their roles within the organization.

Early in the design of the system, we entertained the idea of implementing these features as *on-demand* reports as opposed to automated alerts. That type of implementation would have required the user to actively (and periodically) generate the reports for identification of problems. However, with the automated alerts mechanism, as requested by the end users, problem detection has become a continuing exercise where the users are notified as the issues are detected.

Table 1 Main types of alerts supported in BRAMS

Alert Type	Issue Monitored	Algorithm, Heuristic, and/or Metric Used
Current Status	Excess and Shortage Inventories	(1) Number of days the inventories will cover based on historical consumption. (2) Number of days inventory will cover based on forecasted consumption.
Sudden Changes	Inventory, consumption, expiration and destruction spikes and valleys	(1) 2σ or 3σ deviation from respective mean. (2) % Deviation from respective mean. (3) % Deviation from previous spike or valley.
Trend Analyses	Gradual changes in inventory, consumption, expiration and destruction trends	(1) Consecutive X data points that are monotonically increasing (or decreasing). (2) X out of Y data points that are increasing (or decreasing). (3) % Increase (or decrease) of last data point compared to average increase (or decrease) over specified period.

2.3 GIS-based emergency management and information visualization

The military blood supply chain is a complex system with collection, processing, transportation, and transfusion locations distributed across the world. Management of this blood supply chain requires coordination with facilities, labs, and blood centers in specific geographic locations. Responding to emergencies requires visibility into not only the current inventory levels at the specific location, but also the availability, proximity and accessibility of inventory in other locations. In order to facilitate such visibility, various dashboard-type user interfaces are developed where blood supply chain information is overlaid on a geographical map. What follows is a brief explanation and illustration of this visualization environment.

A geographic information system (GIS) is a system for capturing, storing, analyzing and visualizing spatial data referenced to the Earth (Bolstad 2005). In the strictest sense, it is an information system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically-referenced information. In a more generic sense, GIS is a tool that enables users to create interactive queries (user-created searches), analyze the spatial information, edit data and maps, and present the results of all these operations.

In this research project two distinct application platforms are used for GIS display: (i) Google™map—provides 2D GIS visual display, and (ii) Google™Earth—provides 3D GIS visual display. Figure 4 illustrates the high-level GIS interface developed to facilitate inventory and emergency management. The user can select a facility and choose to display the facilities that have the required blood components and types within a specified distance. This geographically-enhanced information allows stakeholders at different levels to better manage inventories and respond to emergencies in a timely manner.

An extended capability of BRAMS is the GIS-based Transportation and Planning (GTP) module where information is generated to better distribute and balance blood products among different facilities. GTP takes the geographical and inventory-related information of different facilities as its input to analyze and plot facilities on a GIS map as nodes. The inventory level at each facility (shortage, normal and excess) is calculated using historic

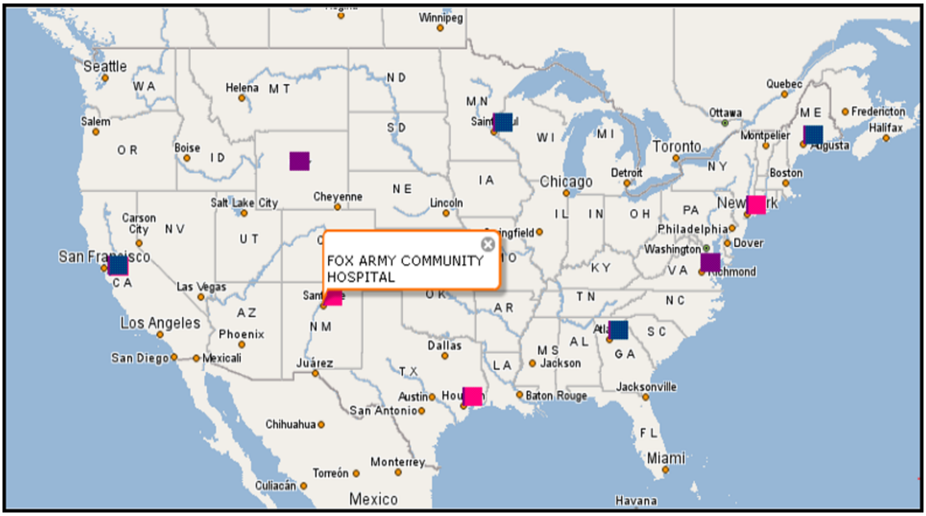

Fig. 4 High-level blood inventory management interface

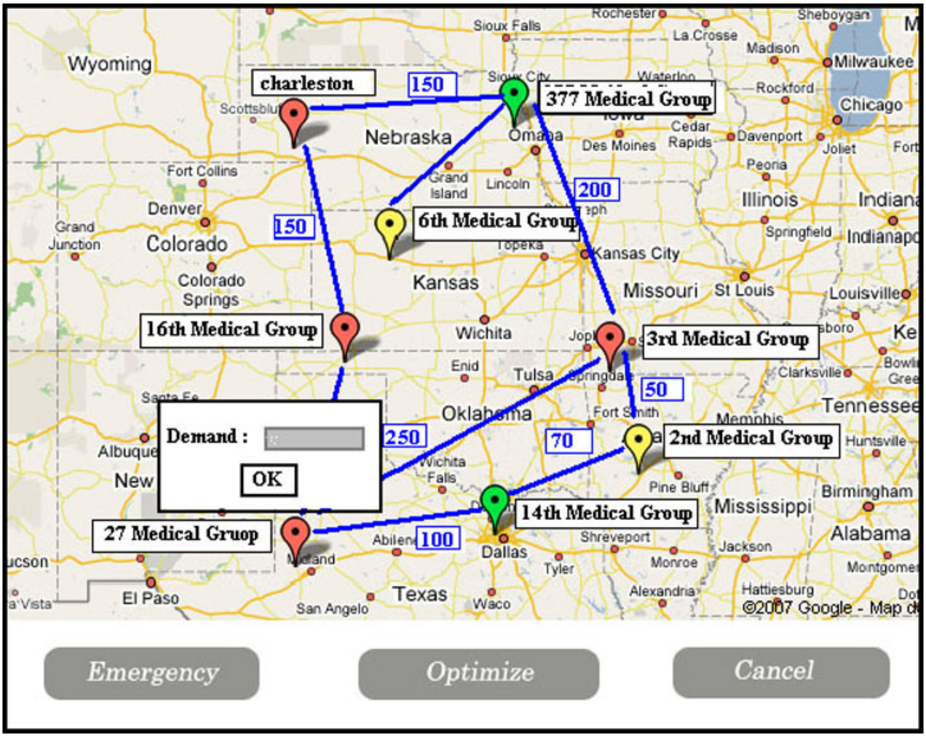

Fig. 5 Balancing inventory network by supply chain optimization

data and is displayed using common coloring schemes on the map (the color red indicates a shortage; green indicates an excess; and yellow indicates a normal inventory) (see Fig. 5). The detailed information regarding a facility and its blood (and blood product) inventory can be retrieved from the map by clicking on the facility node.

In Fig. 5, a line joining the nodes is characterized by distance, transportation constraints, costs, and other constraints. An optimized transportation solution is generated to move the products from ‘excess’ locations to ‘shortage’ locations and is displayed on the map. There are two scenarios where this GIS-based application provides a visual illustration of the optimized transportation plan: (i) in emergencies, where an efficient emergency response algorithm is used to respond to the blood requirement at the location facing an emergency (the application is made more interactive by allowing the user to enter the inventory demand value on the GIS map interface itself), and (ii) for supply chain optimization, the inventory network of facilities is balanced optimally by moving the products around the network to meet the shortages and excess inventories at various locations.

In the three dimensional map (see Fig. 6) the spatial information related to excess inventories, shortages, expirations, and consumptions is presented on a GIS presenter using Google Earth™. The information is encoded into texts, colors, and geometric shapes to reflect both qualitative and quantitative variances. As illustrated in Fig. 6, blood inventory is color-coded green, yellow, and red to illustrate excess, normal, and shortage respectively. The 3D bar charts provide quantitative information about the inventory levels at different geographic locations.

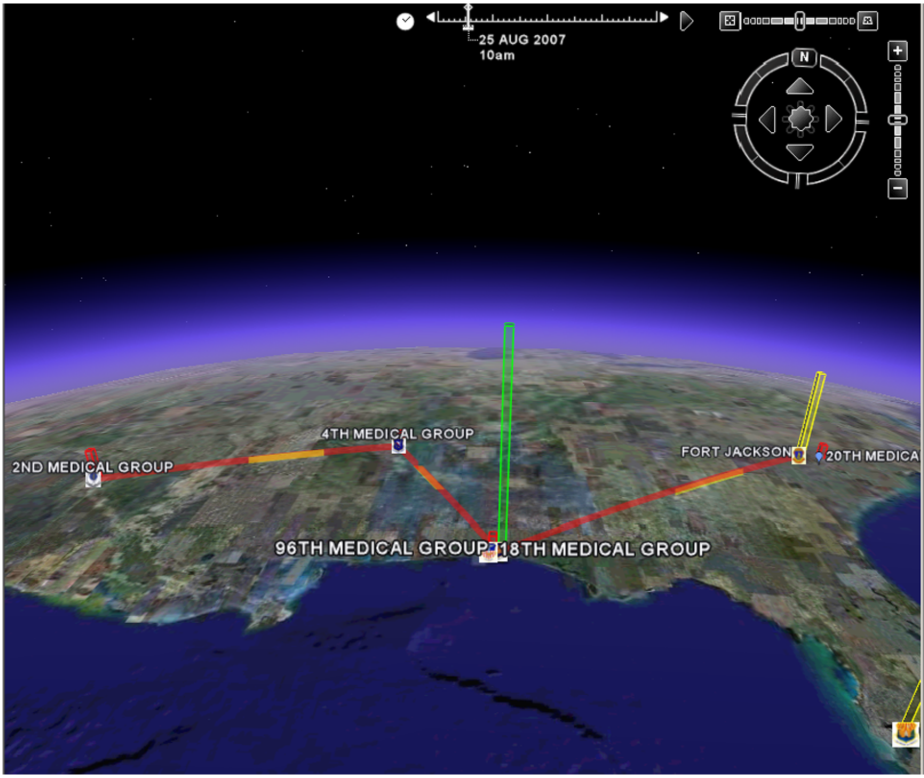

Fig. 6 Facility level inventory and transportation information

These GIS-based analytics driven visualization provides users with an information rich environment capable of accurately reflecting the current system status as well as the status changes over time. Additionally, because of its spatial features, this visualization dashboard can help users determine whether an issue is local to a specific facility or spread across the entire supply chain; or due to a regional causes (e.g., an emerging outbreak of an epidemic in a specific region causes an unexpected increase in the demand for blood transfusions). Furthermore, by incorporating the time-related inventory information into the visualization system (as an additional data input), in addition to the spatial information, the system can also animate the temporal information (inventory changes over time at different locations).

These development efforts provided users with a GIS-based environment that is capable of accurately reflecting the changes over time. Such a rich visualization environment can help users determine whether an issue is local to a specific facility, random across the entire supply chain, or due to any regional causes; for example if an emerging outbreak of an epidemic in a region causes an increase in blood transfusions within that region. Overall, the outcomes of this research effort offer the following advantages:

- *Help users break from confined thinking*. Instead of focusing on a specific facility (and potentially missing important and relevant developments), users now have a greater chance to identify changing trends around them by having to look at a larger area. For example, a certain viral infection may cause donated blood to be unusable (requiring additional tests), with the spread of the virus from the east coast toward the west coast. Having a national (or global) view, plotting all of the detected cases on a map (by using an application like BRAMS), users would have a better chance to identify and mitigate the threat.

- *Help users break the time barrier by providing a sequence of events*. Instead of considering an event at a single point in time, users of this application can view the lifecycle of an event plotted and animated over a spatial map. This rich information content would increase the possibility of capturing and profiling a recurring event or its association with other events.
- *Allow users to analyze spatio-temporal information simultaneously*. Quite often related events should be considered within a certain spatio-temporal domain. Time information embedded in the generated data file enables users to visualize whether certain events occurred in the same region within the same or in a different period of time.
- *Assist users in identifying abnormal consumption patterns.* Having locally focused data specific to certain event distributed overtime makes it hard (if not impossible) to assess the operational effectiveness of the facilities. A facility that consistently requests more than what they needed undermines the overall performance of the system. An integrated analytics system like BRAMS (which is capable of looking at the supply and consumption patterns of the complete system) makes it possible (and rather trivial) for the decision makers to identify such a facility.

3 Summary and conclusions

This paper presented a research effort where operations research, data mining and GIS-based analytics techniques are used to support blood supply chain management. Very often operations research and data mining applications turns out to be academic exercises where researchers try complex algorithms to develop descriptive of predictive models without giving much consideration to its tangible business value and real-world applicability. The focus of this research effort has been to facilitate effective and efficient blood supply chain management by developing practical solutions to pressing issues using advanced data mining techniques and GIS-based analytics.

Taking into account the complexity and hierarchical management structure of the underlying system, BRAMS is designed to support users at different levels in the blood supply chain—from the ASBP level, to the individual services level, to regional and facility level. At ASBP level users can analyze the status of the nation's supply chain, identify critical blood positions, and plan for emergency responses. At the individual services level (Army, Air Force, Navy, and other DoD services) users can evaluate the nation's blood posture readiness either for peace time or war time operations and plan for responding to emergencies. At regional level users can analyze the status of their regions, identify imbalances in the inventory positions of different facilities within their region, and detect changes in trends in inventory, consumptions and expirations. At facility level users can analyze the inventory status of their individual facilities, identify shortages (overages), and develop a plan to coordinate with other facilities to address the shortages or overages. BRAMS employs a role based access control mechanism to provide the necessary functionality and access privileges to different users based on their roles and credentials. Currently around 130 users at different levels in the supply chain are actively using BRAMS, including facility level users from Osan Air Force Base in South Korea and Incirlik Air Force Base in Turkey.

In terms of future work, we are exploring the integration of radio frequency identification (RFID) technology to facilitate better tracking of blood products and more efficient management of the supply chain (Evans 2008). RFID is a generic technology that refers to the use of radio frequency waves to identify objects (in this case blood and/or blood products). Since accurate and timely data collection is the key to the success of any integrated supply-chain system, the emerging technology of RFID can potentially be the enabler of such features. With RFID, the information at different organizational levels and organizational units can be distributed in real time, eliminating delays and data entry errors. Additionally, active RFID tags along with environmental sensors (e.g., temperature, humidity, etc.) can be used to constantly monitor the wellbeing of the blood products as they go through the supply chain, potentially eliminating the incorrect use and accidental expirations.

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