

# Using Interactive Visual Analytics to Optimize Blood Products Inventory at a Blood Bank

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**Abstract**—Blood products and their derivatives are perishable commodities that require an efficient inventory management to ensure both a low wastage rate and a high product availability rate. To optimize blood product inventory, blood transfusion services need to reduce wastage by avoiding outdates and improve availability of different blood products. We used advanced visualization techniques to design and develop a highly interactive web-based dashboard to (1) monitor the blood product inventory and the on-going blood unit transactions in near-real-time, and (2) audit retrospective data to identify and learn from procedural inefficiencies based on analysis of transactional data. We present pertinent scenarios to show how the blood transfusion staff can use the dashboard to locate units with specific characteristics, investigate the lifecycle of the units, efficiently transfer units between facilities to minimize outdates, and probe blood product lifecycle patterns that led to discard to discover inefficiencies in the Blood Transfusion Services (BTS).

**Keywords**—Interactive Visual Analytics, Data Visualization, Blood Transfusion Services, Dashboard, Inventory Management.

## I. INTRODUCTION AND BACKGROUND

Blood product inventory management is a highly complex operation that relies on interpretation of multi-dimensional data including lifecycle-dependent variables such as real-time transaction states of the units, age of the units, discard reasons and lifecycle-independent variables such as blood types, special attributes (e.g., irradiation and phenotyping) and the suppliers [1]. Currently, hospitals and blood suppliers employ a mixture of non-standardized methodologies including paper reporting, spreadsheets, ad-hoc laboratory information system queries, and often the data is used for month-end reporting rather than near-real-time decision-making. This month-end reporting consists only of the summarized data and therefore it cannot be used for auditing the causes of procedural inefficiencies that lead to wastage. Although the raw blood transfusion data gives a high resolution of the blood product inventory, the interpretive richness and timeliness of the raw data is lost, and quality improvement, such as waste reduction and efficient utilization, is not possible given current methods.

Given the rapid transactions taking place in a blood bank, Blood Transfusion Services (BTS) need an up-to-date account of blood products within their inventory to (a) ensure there is adequate supply of different types of blood products to meet

demand; (b) minimize blood unit's wastage due to expiry; and (c) find matching blood units in response to specialized transfusion criteria as per the demand from medical units. Besides, to improve the efficiency of transfusions especially by reducing wastage, BTS need to audit the retrospective data that was recorded by the Laboratory Information System (LIS) to identify the transactional patterns within a blood unit's evolving lifecycle that led to a discard (i.e., wastage due to operational reasons rather than being outdated). This audit is done manually and hence is tedious, not in real-time and prone to missing out underlying inefficiency patterns that are low in frequency and previously unknown. Therefore, new data analytics complemented by interactive data visualization methods are needed to analyze, visualize and interpret blood unit transaction data, in near real-time, to optimize blood unit inventory and to detect underlying wastage patterns.

Operational dashboards are being used in various domains to provide an easy-to-interpret overview of on-going processes, activities, users and inventories for system management, diagnostics and optimization. In the recent years, there have been studies around blood product inventory dashboards [2]–[4]. Sharpe et al. [4] developed a real-time dashboard that displays the Red Blood Cell (RBC) unit inventory in a tabular format which is color-coded based on unit's closeness to expiry. Comparing the pre-implementation and post-implementation situations of the inventory proved that utilizing the dashboard reduced the outdate rates significantly. Gomez et al. [2] implemented a dashboard to manage a large platelet inventory, resulting in reducing outdate rates. Woo et al. [3] introduced a similar real-time dashboard suitable for multiple blood products. On examination of the current dashboard solutions for blood inventory management, we note that the existing blood inventory dashboards are cumbersome with limited interactivity and filtering criterion, whilst lacking the ability to audit retrospective blood transfusion log to identify operational inefficiencies that lead to wastage due to discards.

Interactive Visual Analytics (IVA) provides a suite of data visualizations to interpret and interact with high-volume and high-dimensional data. IVA's significant ability in taking part to solve complex problems in various domains has been proved [5]. Chishtie et al. [6] comprehensively reviewed the application of Visual Analytics methods in healthcare areas, specifically population health and Health Services Research

(HSR). According to their research, there has been a huge demand in implementing and utilizing IVA in the last decade as the promising power of effective data visualization to discover knowledge in data has been understood. Notwithstanding, only 4% of the literature is dedicated to address the problem of health system resource planning using IVA approaches [6].

In this paper, we present the design and workings of an innovative Blood Inventory Dashboard (BID) using advanced IVA methods to (a) help blood transfusion services visualize in real-time the evolving inventory of the blood bank; and (b) visualize the lifecycle patterns of all the blood units to understand both typical and atypical blood unit lifecycles to help improve efficiency and reduce wastage. BID provides the monitoring of three blood products—i.e., Red Blood Cells (RBC), Platelets and Plasma. We have developed and applied interactive data visualizations for (a) real-time management of the blood bank's inventory; and (b) auditing the blood unit distribution process to identify reasons/processes leading to inefficiencies and wastage. BID analyzes streams of blood transaction data, from a LIS, that constitutes the unit's lifecycle, characteristics/product type and location within the hospital. BID has been developed for the Central Zone-BTS (CZ-BTS) servicing Halifax, Canada. Our work advances the optimization of blood bank inventories from various aspects, which has a direct impact on blood inventory optimization which affects the reduction of healthcare costs.

## II. BLOOD UNIT TRANSACTIONAL DATA

The transactional data represents the different states a blood unit went through during its lifecycle. Note that the lifecycle of a blood unit consists of a number of transaction states, from its collection to its transfusion/discard. The list of transaction states is [Received, Unconfirmed, Confirmed, Available, Transferred, Assigned, Issued, Crossmatched, Quarantined, Destroyed, Discarded, Transfused], where a unit can go through cycles of these states till transfused/discarded. The detail of the transaction states is provided in [1].

The raw dataset comprises event logs depicting a series of time-stamped transactions experienced by a blood unit during its lifecycle. Fig. 1 shows a snapshot of the event log in the order of the time that the transactions were recorded in the LIS. The data is integrated from multiple blood transfusion sites.

Unit number	Blood type	Supplier	State	Inventory location	State date-time	Expiry date-time
C057119691252	O Pos	CBS - Dartmouth ISBT	Transfused	VG BTS	2019-11-12 18:08:59	2019-11-24 23:59:00
C057119686134	O Pos	Hospital IWK	Issued	VG BTS	2019-11-12 18:21:59	2019-12-03 23:59:00
C057119684940	O Pos	CBS - Dartmouth ISBT	Issued	DG BTS	2019-11-12 18:31:14	2019-11-27 23:59:00
C057119680292	O Neg	CBS - Dartmouth ISBT	Crossmatched	VG BTS	2019-11-12 19:22:34	2019-11-26 23:59:00
C057119684498	A Pos	Prince Edward Island	Crossmatched	HI BTS (Main)	2019-11-12 19:47:11	2019-11-28 23:59:00
C057119684940	O Pos	CBS - Dartmouth ISBT	Transferred	DG BTS	2019-11-12 19:48:14	2019-11-27 23:59:00
C057119680292	O Neg	CBS - Dartmouth ISBT	Issued	VG BTS	2019-11-12 19:49:02	2019-11-26 23:59:00
C057119692521	A Pos	CBS - Dartmouth ISBT	Crossmatched	HI BTS (Main)	2019-11-12 19:50:11	2019-11-29 23:59:00
C057119680292	O Neg	CBS - Dartmouth ISBT	Discarded	VG BTS	2019-11-12 19:54:02	2019-11-26 23:59:00
C057119680287	O Neg	Aberdeen Hospital	Crossmatched	VG BTS	2019-11-12 20:10:07	2019-11-26 23:59:00
C057119680287	O Neg	Aberdeen Hospital	Issued	VG BTS	2019-11-12 20:10:31	2019-11-26 23:59:00

Fig. 1. A snapshot of the raw dataset showing the log of the transactional events in the Blood Transfusion Services (BTS) in the order of event time. This snapshot only shows Red Blood Cell (RBC) units. The rows are color-coded to distinguish the transaction states for each RBC unit. Not all the attributes are included in this snapshot.

The raw dataset is pre-processed to transform from the event log format to a lifecycle format which will be used to visualize and analyze patterns of blood product lifecycles. As the new format, a *transition sequence* is developed for each blood unit based on the transaction states that the unit went through; Each transition sequence consists of a number of

transitions between subsequent transaction states (i.e., *transition step*).

In this study, we have taken a 5-year timeframe (January 2015 – December 2019) of the RBC transactional dataset from CZ-BTS in Halifax, Canada as proof-of-concept. This gives us access to 723,623 transaction states for 71,065 RBC units.

## III. BID DESIGN AND IMPLEMENTATION

We take an IVA approach to implement BID. Fig. 2 shows the overall architecture of BID in functional terms. We collect real-time transactional data from the LIS, which is a distributed system among all the blood transfusion sites. The BID's backend is developed incorporating Java Spring framework to have a RESTful web service. The REST architecture gives a light-weighted service which increases the responsiveness of the server through the provided APIs. The frontend is a combination of React and D3 which are JavaScript-based libraries, optimized for fast interactive multi-dimensional visualizations. The BID's interface is separated into two different views: (1) BID-Live for visualizing live streams of data; (2) BID-Audit for visualizing the retrospective data. BID-Live is updated every 30 minutes by sending an HTTPS GET request to the REST APIs—the update rate can be adjusted based on the transaction frequency in the blood product supply chain. BID-Audit takes into account the record of the last five years and presents the historical transactions in the transition sequence format. BID-Audit retrieves data from the long-term cache storage which records the processed real-time data for auditing purposes.

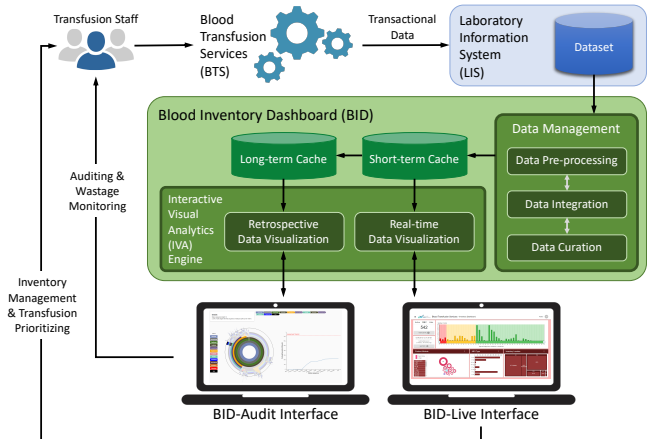


Fig. 2. The functional architecture of Blood Inventory Dashboard (BID)

## IV. BID INTERFACE DESIGN AND FUNCTIONALITY

BID consists of two data visualization interfaces:

(1) *BID-Live interface*, for real-time inventory visualization to know the volume of specific blood units and to prioritize units for transfusion that are either nearing expiry or recognized as being potential to be discarded soon. The staff can build their queries via interacting with the filterable visualization to spot blood units that have certain characteristics—i.e., time to expiry, blood type, product attributes, inventory location. Also, the evolving lifecycle of the blood units is viewable to help in prioritizing blood units for transfusion based on risk assessment of being discarded.

(2) *BID-Audit interface*, for retrospective data visualization to help the staff to identify abnormal patterns of lifecycles which were not readily apparent from the transactional data and to see how much frequent it is in the

system to fall into such patterns. Studying blood unit's lifecycle patterns that lead to discard can contribute to discovering operational inefficiencies in the BTS. Towards this goal, BID-Audit provides a high-level overview of the transition sequences of blood units, highlighting the sequences that led to a discard. Filterability of the visualization allows the staff to dig into even less frequent transition patterns, thus allowing in-depth analysis of the lifecycle patterns at the level of institutional processes and users involved in the transactions leading to wastage.

#### A. BID-Live

The interface (Fig. 3) has a modular design, comprising interconnected information modules such that interactions in one module updates the information presented in others. At the top-level, Module 1 shows the current inventory level of the selected blood product; this number changes to show the inventory of specific units in user queries to find specific blood units. The *view detail* button presents information about all the selected units in terms of unit number, time to expiry, past transactional steps, product type, etc.

To avoid outdates, Module 2 represents the inventory from the shelf-life viewpoint. Since avoiding outdates is central to inventory management, a heat-histogram is used to visualize the time-to-expiry of units which is divided into three color coded zones based on the number of days remaining to expiry—i.e., red for  $\leq 3$  days warning about the units that are about to expire, orange for  $\leq 15$  days and green for  $> 15$  days). Note that for RBC, the shelf-life of a blood unit is 42 days hence the heatmap shows a blood unit life in the range of 1-42 days. We implemented sliders within the heatmap visualization to enable staff to focus on specific expiry subperiods, such as examining only those units that have 10

days to expire. As the slider is used, the interconnected nature of the dashboard will update the information in all the other modules to focus on only the units in the selected subperiod.

To facilitate crossmatching of blood units with the patient-specific transfusion requisition, the dashboard allows the generation of specialized multi-attribute queries by clicking and selecting the required attributes. Module 3 presents the distribution of the product attributes (e.g., units that are washed and have no negative antigen, units that have certain positive antigens and no other attributes, etc.). We used a space-efficient interactive combination of bubble-pie chart and priority list to facilitate query formulation. The priority list shows the attributes in the order of importance and can be adjusted according to the priorities of the staff. A combination of the antigens (positive and/or negative) and special typing can be selected via either the chart or the list to find units having all the selected attributes.

To further facilitate crossmatching, Module 4 includes a histogram showing the number of units available for each blood type. The staff can click on multiple bars to apply the unit filtering based on the blood types.

Module 5 illustrates the distribution of the units across multiple inventory locations/sublocations. This information is essential as most of the operational inefficiencies that lead to discards are caused by unnecessary unit transfers among transfusion sites. We utilized a treemap visualization [7] to give a count of the blood unit volumes in different locations/sublocations in a space-efficient way—the greater the volume of units in a location/sublocation, the larger its representation on the treemap). Multiple inventory locations/sublocations can be selected for getting a cumulative blood unit count via clicking on the treemap elements.

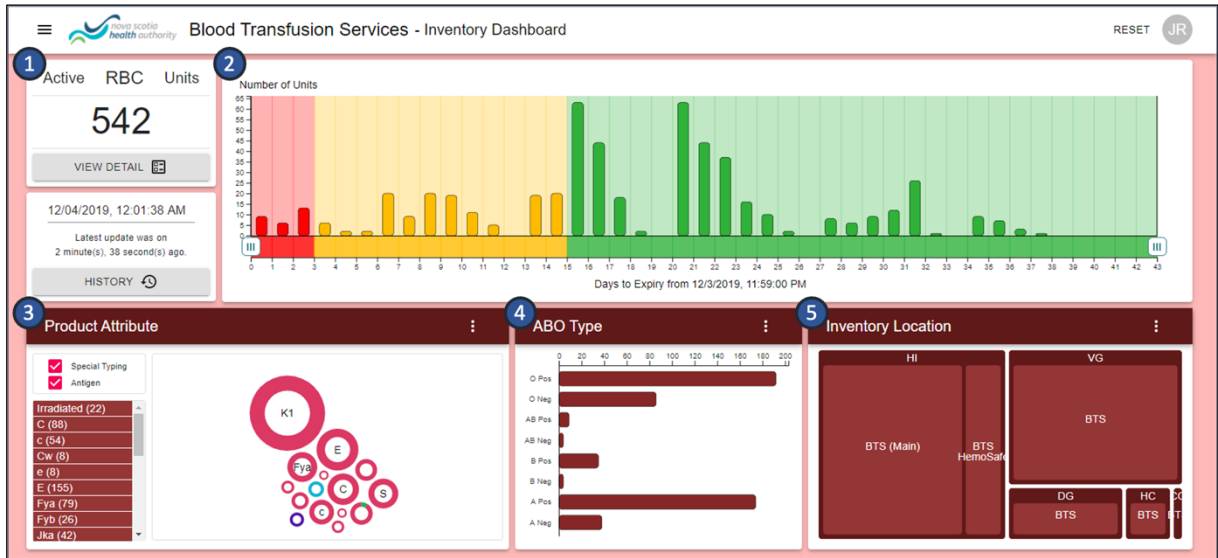


Fig. 3. The modular design of BID-Live (i.e., interface to visualize the blood inventory in real-time), illustrating the key modules. Module 1 shows the current inventory level of the selected blood product. Module 2 represents the inventory from the shelf-life viewpoint. Module 3 presents the distribution of the product attributes (i.e., alternations made to the product and included antigens). Module 4 includes a histogram showing the number of units available for each blood type. Module 5 illustrates the distribution of the units among inventory locations/sublocations.

To illustrate the working of BID-Live, we present a scenario that highlights the staff's interactions to inspect the inventory and find specific blood units. Since the O-negative blood type can be transfused urgently in the cases where crossmatching does not work out, the staff intends to see the O-negative RBC units that will be expired in the next 15 days,

in VG BTS inventory location and they are irradiated. To generate this query, the staff perform a sequence of interactions, each applies to one of the modules to narrow down the filtering. Fig. 4 shows the BID-Live interface as per the staff's interaction to choose the RBC units that will be expired in 15 days via dragging the slider on the heat-

histogram. Then, among the filtered units, the irradiated units are taken via clicking on the corresponding circle in the bubble-pie chart (Fig. 5). The remaining units are filtered to O-negative blood type in the next step via interacting with the bar chart (Fig. 6). Eventually, VG BTS inventory location is clicked on the treemap (Fig. 7). It may be noted that 3 units are returned by the query, following which the staff can explore the units' details via the view detail button (see Fig. 8). On this page, the up-to-date transactional lifecycles of the RBC units can be viewed. This lifecycle information is used by the staff to identify the units that meet specific requirements, such as units that are at high risk of being discarded due to their long transition sequences, units that are not in 'Transferred' state at the time, units that underwent unsuccessful crossmatching at least once before, etc. Mouse

hovering on the transition steps reveals more detail—i.e., date and time that the transition step was entered into the LIS, the hospital where the RBC unit is located at the time of the transition step, ward location if the state is 'Issued', discard reason if the state is 'discarded', etc. In this scenario, unit number 2 (Fig. 8) went through a relatively longer transition sequence, such that it experienced three times crossmatching and being transferred to different inventory locations three times which can put the RBC unit into high risk of being discarded due to the potentially unusual sequence of transitions. Thus, as a proactive measure to reduce discards, the staff may prioritize this unit for transfusion. This optimization decision was supported by BID-Live which facilitated exploring the available blood products in the BTS inventory in real-time.

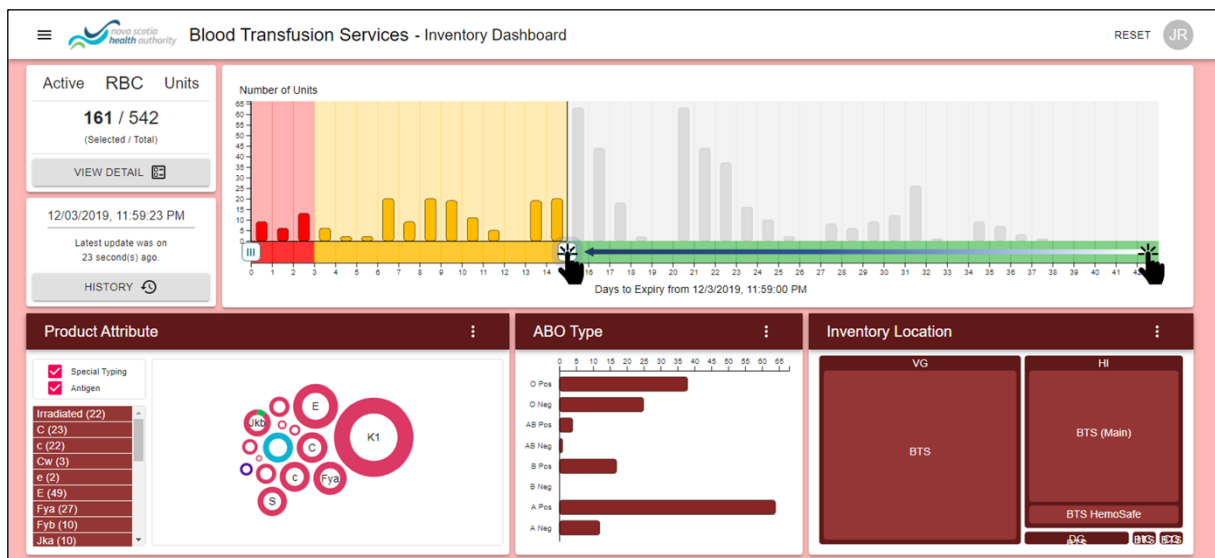


Fig. 4. The BID-Live interface showing the interaction with the heat-histogram to filter the RBC units to those that will be expired in 15 days. The other modules are updated accordingly.

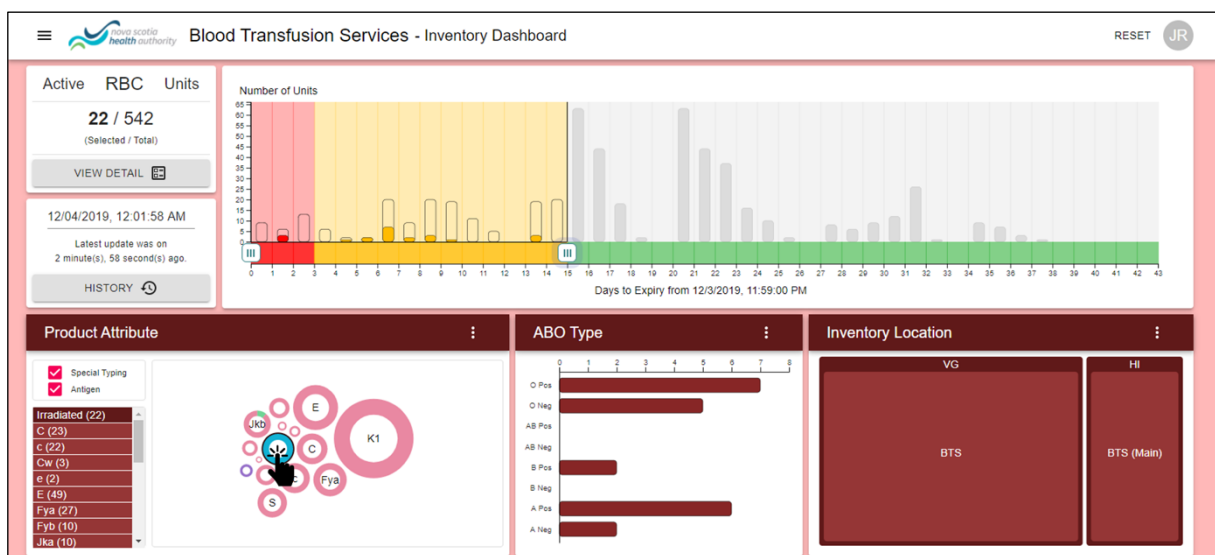


Fig. 5. The BID-Live interface showing the interaction with the bubble-pie chart to narrow down the filtering that was applied in Fig. 4 to the units that are irradiated.

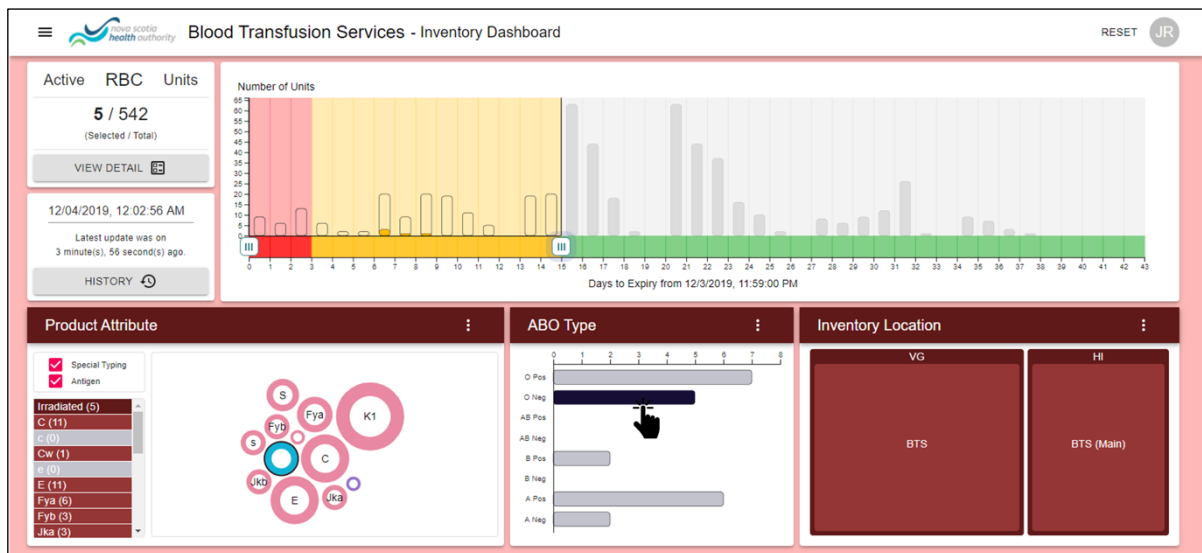


Fig. 6. The BID-Live interface showing the interaction with the bar chart to select O-negative RBC units from among the units that were filtered in Fig. 5.

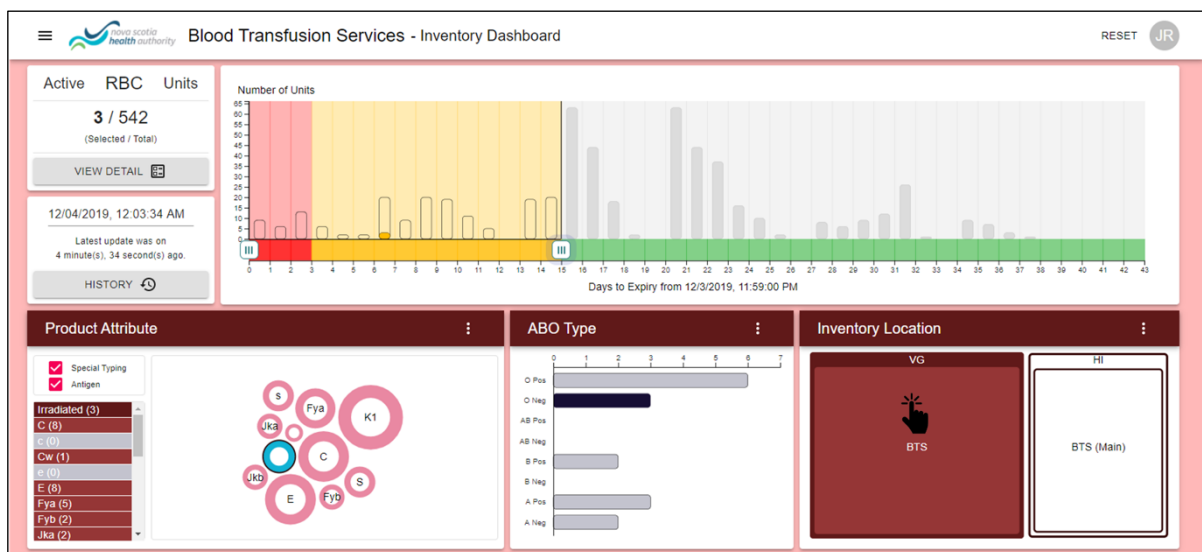


Fig. 7. The BID-Live interface showing the interaction with the treemap to filter the RBC units that were selected in Fig. 6 to those that are located in VG BTS inventory.

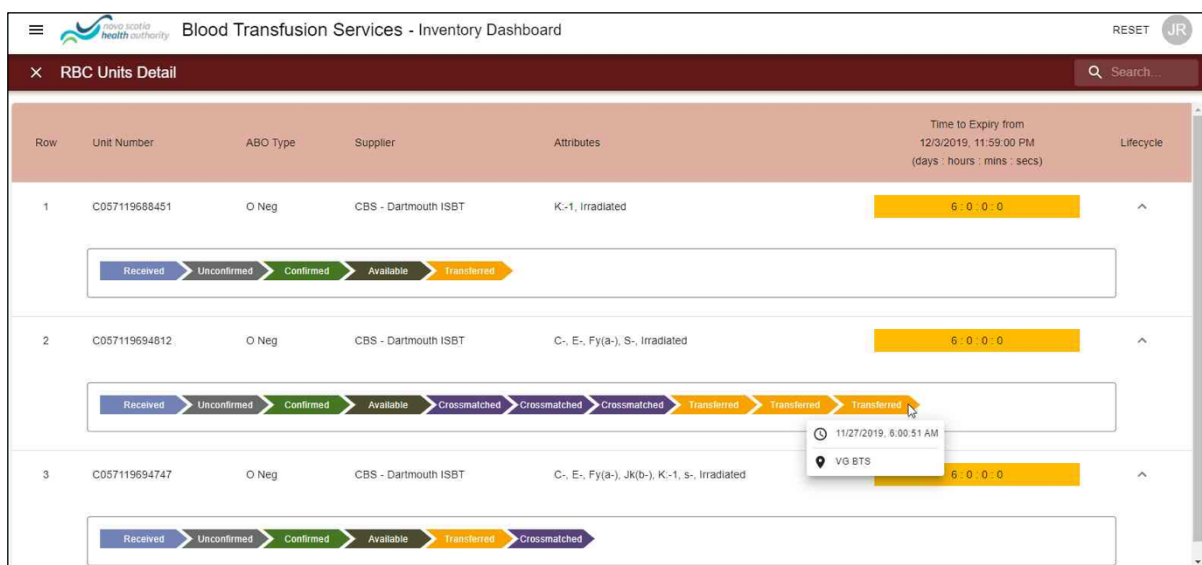


Fig. 8. The list of the queried units that would be presented after clicking on the view detail button on Fig. 7. For each of the units, the transactional lifecycles are depicted. Mouse hovering on the transition sequence shows more detail about the corresponding lifecycle step. The RBC unit in row 2 has gone through a relatively longer lifecycle which puts it into a higher risk of being discarded due to operational inefficiencies in the BTS. This unit can be prioritized for transfusion as a proactive measure to reduce discards.

## B. BID-Audit

We have designed and developed BID-Audit as a separate interface to study the retrospective transactional data. For this research, we considered a five-year timeframe as the targeted period of our audit study as this gives an extensive history of the transactions to probe the lifecycle patterns of the blood products to identify the sequence patterns that lead to discards. Investigating the lifecycle patterns not only facilitates performance assessment of the BTS in long term but also helps to learn how likely it is that a blood unit will be discarded from its evolving lifecycle. Some of the potential questions that are intended to be answered utilizing BID-Audit are as following:

- What are the typical sequence patterns that lead to a successful transfused state?
- What is the distribution of the different transfused patterns?
- What is the distribution of the different discard patterns?
- What sequence patterns did lead to an outdate of a blood unit?
- What are critical markers of the sequence patterns that points to a potential discard?
- Which sequence patterns did lead to discard more frequently over the last 5 years?
- After a certain sub-sequence of transaction state, what were the most prevalent patterns to be followed?
- What were the rare wastage patterns (e.g., frequency less than 0.05%), and what did mainly cause the wastages for the longest patterns?

To study how the BTS performed in the last five years especially to identify procedural inefficiencies, we are relying on lifecycle patterns that the blood products went through. Hence, BID-Audit is designed to effectively visualize patterns of transition sequences that were developed for each blood unit during the pre-processing phase. Due to the way the human brain processes information, there should be a solid relevance between the concept of transition sequence pattern and the way the data is visualized [8].

There is a selection of visualization techniques that can visualize transition sequences effectively. This category of visualization techniques falls into two general sub-categories [9]: (i) Node-Link diagrams such as trees and dendrograms. They consist of nodes and connections which define parent-child relationships among the nodes, and (ii) Space-Filling diagrams where the focus is on the relative sizes of the nodes within the hierarchy. The size of each node reveals its relative quantity, and its location in the diagram stands for its position in the hierarchy. The visualization techniques in this sub-category use either containment or adjacency to represent hierarchy; The former are called Enclosure diagrams which are plotted as treemap commonly, and the latter are called Adjacency Diagrams which have various layouts such as sunburst, and circle packing.

While Node-Link diagrams are focused on the structure of the hierarchy, they fail to effectively show valuable information about the relative quantity of a node among all the other nodes on the same level in the hierarchy. Additionally,

these diagrams are not space-efficient as the size of the diagram has a positive polynomial relationship with the number of the nodes. For these reasons, we chose Space-Filling Diagrams since we need a compact easy-to-understand diagram which not only shows the sequence of transaction states from the time a blood unit is provided until it is either transfused or discarded but also brings into attention the magnitude of the transition patterns.

Among the mentioned visualization techniques in the Space-Filling sub-category, we chose Adjacency diagrams because it is closer to human comprehension of hierarchy than Enclosure diagrams which are cumbersome to interpret precisely [10]. Also, among Adjacency diagrams, sunburst layout tends to use space more economically than circle packing layout where there is a lot of empty space within the circles. Therefore, an interactive sunburst diagram is considered to visualize the lifecycle patterns within the dataset via aggregating all the transition sequences.

Lifecycle Pattern Sunburst (LPS) (Fig. 9) consists of rings as transition steps. The first step is the innermost ring, and as we move outward from the center, we approach to the final transaction state which can be either “Transfused” or “Discarded”. The angle of each segment shows how much frequent the occurrence of the corresponding state is, and in each level of the hierarchy, states are sorted in descending order clockwise by transaction state frequency.

LPS, as the core of BID-Audit interface (Fig. 10) is interactive (i.e., mouse hovering on the diagram reveals more detail about the highlighted sub-sequence). In this view of the data, sequences with less than 0.05% pattern frequency are excluded which gives us an overview of the BTS over the last five years. For BID-Audit, we applied the same modular design as BID-Live, incorporating interconnected modules that would be updated upon interactions with LPS (module 1).

Statistical values related to the highlighted sub-sequence are shown in module 2—i.e., length of the transition sub-sequence, frequency ratio of the highlighted sub-sequence pattern.

To clearly demonstrate to the staff the lifecycle trend that is highlighted in LPS via mouse hovering, a breadcrumb trail of the sub-sequence is shown in module 3.

Since time duration between the transaction states give complementary information about the highlighted sequence pattern, average amount of time it takes to transit from a transaction state to its subsequent states is shown as a line chart in module 4; it is noteworthy that there is no direct correlation between lifecycle duration and length of lifecycle in terms of number of transaction states—i.e., a long transition sequence can happen in a relatively short time. This module also compares the trend to the average expiry time which is essential to study the wastage reason—i.e., not reaching the expiry threshold means there is a high risk of wastage due to operational inefficiencies for the blood units that follow the sequence pattern.

Besides the big picture of the prevalent lifecycle patterns that LPS shows, it is important to explore infrequent patterns since a wide variety of uncommon sequence patterns exist that led to discard. To this intend, module 5 filters LPS based on the outcome of lifecycle patterns (i.e., discarded/transfused) and sequence pattern frequencies.

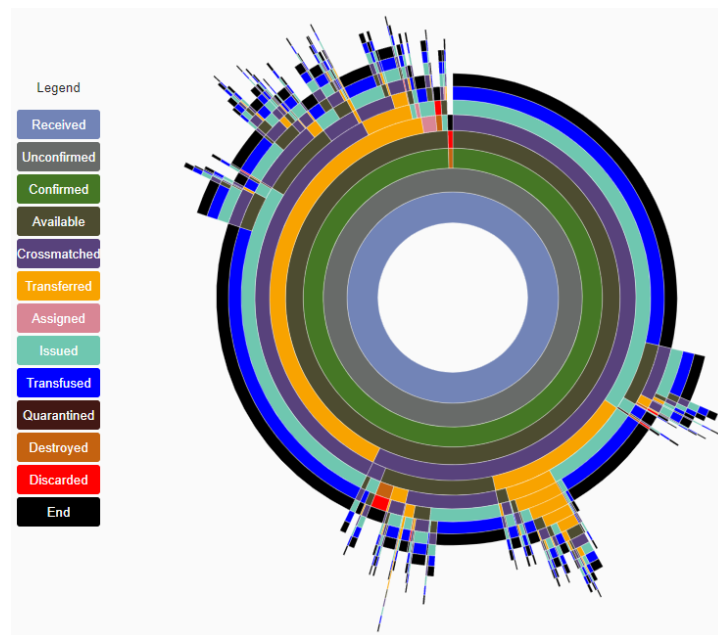


Fig. 9. Lifecycle Pattern Sunburst (LPS) giving an overview of the transactions by excluding the patterns that have frequencies less than 0.05%. Starting from the innermost ring, each ring represents a transition step towards the final transaction state of a lifecycle (the outermost segments) that can be either Transfused or Discarded. The frequency of a transition step is displayed by the angle of the corresponding segment. In each level of the hierarchy, transition steps are sorted clockwise from most to less frequent.

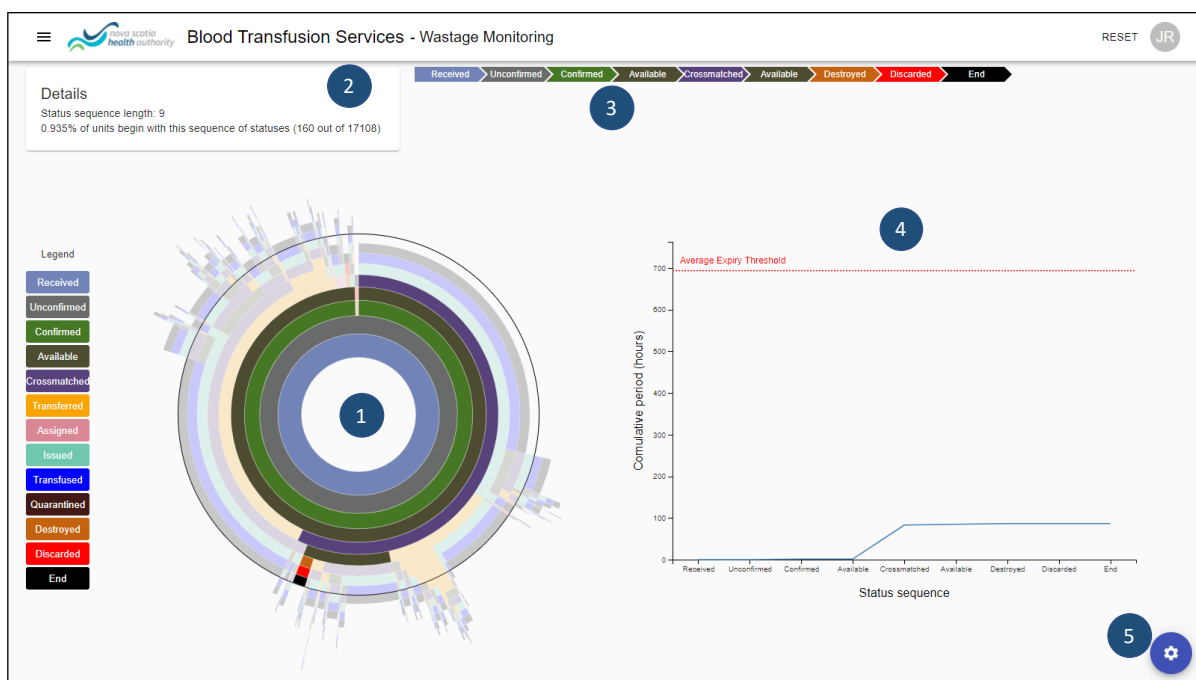


Fig. 10. BID-Audit showing a highlighted transition sequence by hovering the mouse on LPS. The other modules on the screen are updated upon the interaction with LPS. Module 2 shows the statistical detail about the highlighted sub-sequence. Module 3 shows the corresponding sequence breadcrumb. Module 4 shows time durations for each transition step in a cumulative format and compares the trend with the average expiry time. Module 5 opens filtering on LPS based on the outcome and frequency of lifecycle patterns.

To answer to the potentially pertinent questions, we present scenarios to highlight the staff's interactions for auditing the RBC data accordingly.

- The staff want to identify the most prevalent discard patterns over the last five years. A quick look at LPS where uncommon patterns are filtered out (Fig. 9) reveals three frequent discard patterns ('Discarded' states are shown in red). Mouse hovering on the most frequent discard pattern among the three identified patterns (Fig. 10) shows that 0.94% of the RBC units

(160 out of 17108) were discarded right after going through the following sequence of transaction states.

*Received → Unconfirmed → Confirmed → Available → Crossmatched → Available.*

The line chart shows that there were not significant delays in processing these units compared to their average expiry time. Considering that the units were discarded after being crossmatched for once, it can be inferred that there was a potential inefficiency in the collection and screening process—i.e., Received, Unconfirmed and Confirmed states.

- The staff need to know what the frequent patterns were if an RBC unit was transferred right after being crossmatched for the first time. Towards this goal, they look for the following transition sequence in LPS where uncommon patterns are filtered out (Fig. 9).

*Received → Unconfirmed → Confirmed → Available → Crossmatched → Transferred.*

Mouse hovering on the adjacent outer segments (i.e., possible subsequent transition steps) shows that 61.68% was the chance to be issued and 31.37% was the chance to be transferred again. Also, interacting with more outer segments (i.e., farther transition sequences) reveals that 4.5% of these units were transfused in around eleven days on average after being transferred for six times consecutively to various hospitals.

- The staff want to investigate the rare wastage patterns and see which relatively long sequences emerged potentially from operational inefficiencies in the BTS. Fig. 11 shows a screenshot of the LPS as the staff has filtered out the common sequences (i.e., sequences with greater than 0.05% pattern frequency) that led to transfusion. Mouse hovering on the patterns reveals the potential inefficiencies in the transfusion process for that particular pattern. For example, one blood unit followed the highlighted pattern in the screenshot in Fig. 12 and was expired as the unit went through several transitions to the “Transferred” state. Fig. 13 shows an example of a unit that had a quite long transition sequence yet was wasted due to a reason other than expiry. LPS reveals that among the patterns longer than 20 steps, 67.74% of the units (21 out of 31) were discarded due to an operational reason.

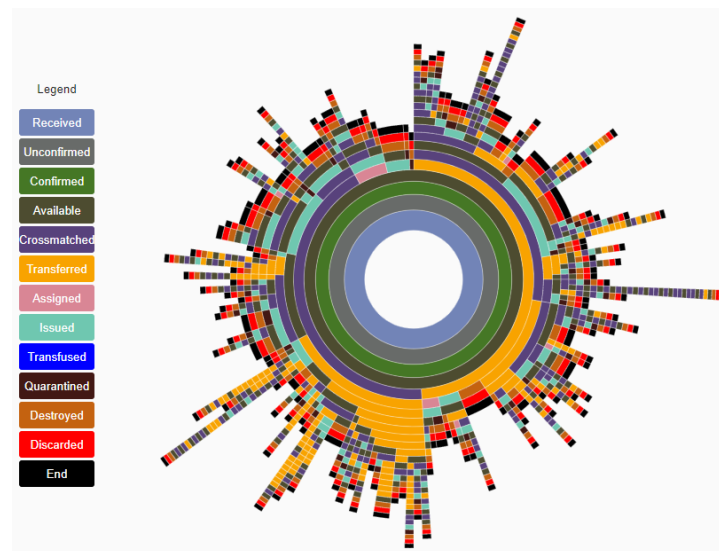


Fig. 11. In this view of LPS, transfused RBC units with greater than 0.05% sequence pattern frequency are filtered out which gives an overview of the discarded units that experienced uncommon lifecycle patterns.

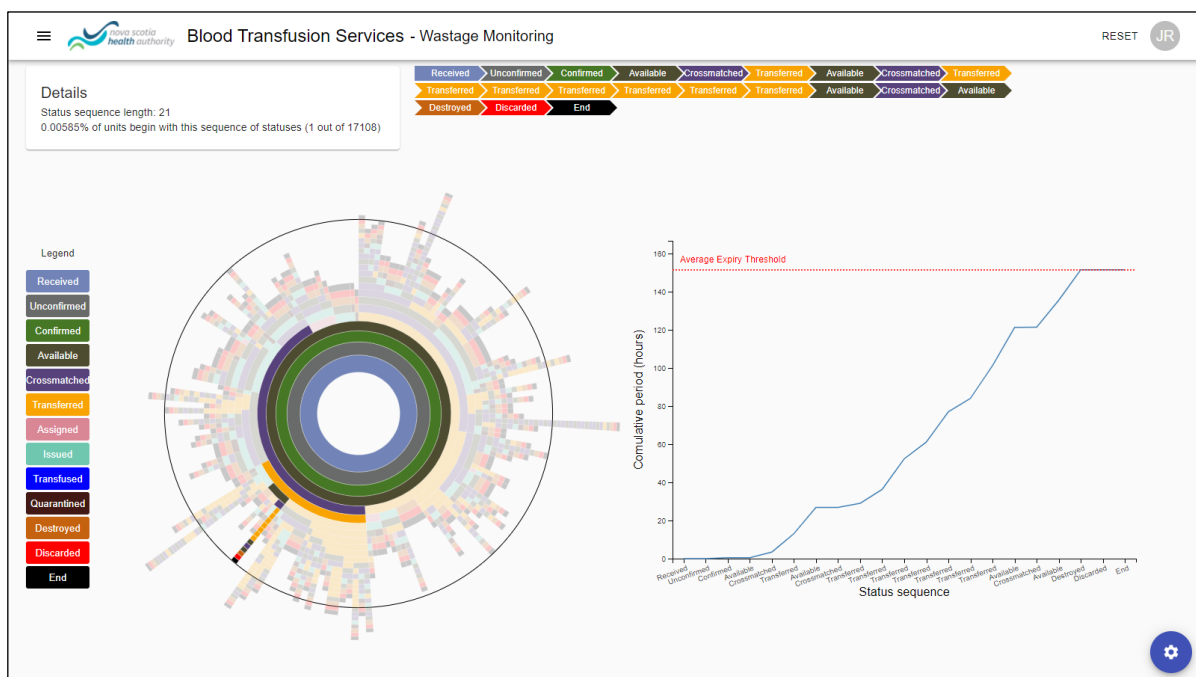


Fig. 12. BID-Audit interface showing the uncommon sequence patterns of discarded RBC units. Mouse hovering on LPS has highlighted a sequence transition pattern that happened to one RBC unit and led to being outdated.



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