Comparing the appropriateness of blood use, traceability, and availability of blood products in selected health facilities in central Uganda: The Blood Alarm System versus standard practices

Final Report

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Compiled by Dr. Philip Lugoloobi

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ABBREVIATIONS

BAS:	Blood Alarm System
UBTS:	Uganda Blood Transfusion Services
HMIS:	Health Information Management System
WHO:	World Health Organization
KCCA:	Kampala capital city authority
FFP:	Fresh Frozen Plasma
MHREC:	Mulago Hospital Research and Ethics Committee
UNCST:	Uganda National Council of Science and Technology
HCIV:	Health Centre IV
GH:	General hospital
BPs:	Blood products

EXECUTIVE SUMMARY

Blood transfusion is a critical service that saves lives, especially for people with severe anaemia, mothers experiencing heavy bleeding during childbirth, and patients with serious injuries. In Uganda, many health facilities continue to experience delays and shortages in accessing blood, even though blood donation has improved. These shortages are often caused by poor tracking of blood supplies within hospitals and the misuse of blood due to limited tools to guide healthcare workers on when and how to give blood safely.

To help address these problems, we developed a simple, low-cost digital tool called the Blood Alarm System (BAS). This system works through a mobile and web application and helps hospitals monitor blood supplies in real time. It also supports healthcare workers with guidance to ensure blood is used only when truly needed.

We tested this system in two health facilities in central Uganda (Kisenyi Health Centre IV and Mukono General Hospital) by comparing how blood was managed before and after introducing BAS. First, we observed normal paper-based practices. Then we introduced BAS and collected the same information digitally. We also asked healthcare workers to share their experiences using the system.

The results showed that the Blood Alarm System led to clear improvements. Hospitals were much better at tracking each blood unit from delivery to patient, which increased from 44% under the usual system to 72% with BAS. More importantly, the use of blood followed medical guidelines more consistently, rising from 68% to nearly 72%. While the overall amount of blood in stock did not change, the system helped hospitals maintain better availability of critical blood types needed in emergencies. Healthcare workers responded very positively to BAS. Most said it was easy to use, helped them make better decisions, and fit well into their day-to-day work. The average satisfaction rating was 3.9 out of 5. However, some challenges were reported, including access to internet, reliability of the app, integration into existing systems and staff resistance.

In summary, the Blood Alarm System made it easier and safer for hospitals to manage and use blood. It showed great potential to improve patient care, and healthcare workers supported its continued use. To roll it out more widely, it will be important to improve internet access, integrate the system with existing electronic systems used by UBTS and staff training. If these issues are addressed, BAS could be scaled up to improve blood access and save lives across Uganda and in other similar settings.

ABSTRACT

Introduction: Blood transfusion is a critical intervention in sub-Saharan Africa for managing malaria-related anaemia, obstetric haemorrhage, and trauma. In Uganda, timely access to blood remains a challenge, largely due to inadequate inventory monitoring and inappropriate use of blood products. To address these gaps, we developed the Blood Alarm System (BAS), a low-cost mobile and web-based platform for real-time monitoring of blood products.

Methods: We conducted a pre-post study in two health facilities, Kisenyi Health Centre IV and Mukono General Hospital, comprising two phases. Phase I (13 weeks) assessed baseline practices using standard paper-based systems. In Phase II, the same indicators were captured using BAS in real-time. Key outcomes included blood stock status, traceability, and appropriateness of blood use. A post-intervention survey assessed staff perceptions of BAS. Descriptive and inferential statistics were used to compare outcomes before and after BAS introduction.

Results: A total of 1,401 unique blood units were recorded. Packed RBCs were the most used product (64.0%), and O+ was the most common blood group (45.8%). The median overall stock balance at the time of order did not differ significantly between phases (28.0 vs 30.0 units, $p=0.481$), but availability of critical components (O+/O− packed RBCs and whole blood) significantly increased (median 1.0 vs 3.0 units, $p=0.018$). Blood receipt correlated strongly with units requested ($r=0.70$, $p<0.001$), but weakly with reported stock balance. Traceability improved with BAS (71.7% vs 44.3%, $p<0.001$), while impact on appropriateness of blood use was not statistically significant (71.8% vs 67.5%, $p=0.156$).

Among 34 healthcare workers surveyed, 94.1% found BAS easy to navigate, 69.2% said it integrated well with workflows, and 82.3% felt it improved transfusion decision-making. Most (73.5%) would recommend BAS, which received an average satisfaction score of 3.9 (SD 1.0). Reported barriers included access to internet, reliability of the app, integration into existing systems and staff resistance.

Conclusion: The BAS improved traceability, promoted appropriate use of blood products, and enhanced availability of critical blood components. Healthcare workers reported high acceptability and perceived utility. Addressing challenges such as internet access, staff capacity building, and system integration will be key for scaling BAS to additional facilities and informing the national rollout.

INTRODUCTION

1.0 Background

Blood transfusion is a lifesaving therapy included on the World Health Organisation (WHO) list of essential medicines (1). In sub-Saharan Africa, it's critical to the treatment of diverse pathologies, including malaria-associated anaemia, obstetric haemorrhage, and trauma, which cause significant mortality and morbidity in the region (2).

Despite notable progress in blood donation rates over the years, ensuring the timely availability of safe blood to patients is still a challenge in sub-Saharan Africa (3,4). In Uganda, significant delays in blood transfusions are prevalent, mainly resulting from frequent but avoidable blood stockouts in health facilities(4). Factors contributing to these frequent stockouts include: 1) unreliable hospital blood inventory monitoring approaches leading to delays in order placements, often after receiving emergencies requiring transfusions, and 2) a high rate of inappropriate blood use by clinicians resulting from a significant knowledge gap about transfusion guidelines (5,6). Available literature indicates that up to 55.5% of transfusions among children, who receive 50% of the blood supply in Uganda, are inappropriate (5).

Uganda has a centralised blood bank system under the Uganda Blood Transfusion Services (UBTS), with eight regional blood banks that serve over 300 health facilities. This inherently leaves a significant proportion of facilities located far from the regional blood banks. This system, by design, contributes to persistent delays in blood delivery to the majority of health facilities. Several approaches have been devised to improve the appropriate use, traceability, and timely availability of blood products in health facilities. These include blood transfusion daily activity register books, blood order/usage forms, continuous medical education sessions, and pocket-sized blood transfusion guidelines (7). However, many of these approaches are resource-intensive and are very hard to implement in high-volume facilities. Additionally, while existing electronic solutions offer potential improvements, they are often costly and poorly tailored to local contexts. To address these challenges, we developed an innovative electronic system, the Blood Alarm System (BAS), in close consultation with the UBTS, senior clinicians and digital health experts to streamline these processes efficiently and affordably. The BAS provides a seamless platform for monitoring blood stock, tracking blood products from the bank to the patient and providing updated transfusion guidelines for promoting appropriate use among clinicians.

In this study, we evaluated the platform's effectiveness in ensuring appropriate blood use, traceability, and availability of blood products in health facilities by comparing it with current practices. Additionally, the study assessed the feasibility of the platform and explored the attitudes, perceptions, and acceptability of healthcare workers towards the system in selected health facilities.

1.2 Project description

1.2.1 Current standard practices

There are a number of approaches and tools currently available to ensure uninterrupted availability of blood products in health facilities, their traceability and appropriate use in Ugandan health facilities. These include:

Approach 1: A combination of the Health facility blood products order/usage form and the hospital blood transfusion laboratory technicians

The health facility blood products order/usage form (Health Management Information System (HMIS) UBTS 004), is used by hospital blood transfusion laboratory technicians to place blood orders to the regional blood bank when stock levels become critically low. The form captures a summary of key data, including the number of units used, units previously received, current stock balance, and units returned or expired. It also specifies the number of units requested in the new order, along with details such as blood product type, blood group, and the urgency of the request. This system promotes the timely availability of blood products at health facilities and enhances accountability for this scarce and costly resource.

Approach 2: Blood delivery note

These notes are issued to hospital laboratory technicians by the blood issuing personnel at the regional blood bank at the time of dispatching blood products to a health facility. They contain detailed information about each blood product, including unit numbers, product type, expiry dates, and donation dates. These forms are essential tools for ensuring the traceability of blood products.

Approach 3: Form for requesting blood by the clinicians

When a clinician determines that a patient in the ward or outpatient department requires a blood transfusion, they complete a blood request form addressed to the hospital blood transfusion laboratory (7). This form provides essential information about the patient and the requesting clinician, including details required for tracking and accountability. It also includes a section for the laboratory technician to record compatibility test results and their name. The information from this form is then entered into the daily activity register, as described under Approach 5 below.

Approach 4: Bedside transfusion record (HMIS form 091B)

These are usually filled by a clinician who monitors the blood transfusion. Other than further improving the accountability and traceability of blood products, the tool is also used to report any transfusion reactions. This information is also entered in the daily activity register described under Approach 5 below.

Approach 5: The blood transfusion daily activity register (HMIS UBTS 003)

This register is where all data related to blood transfusions in the health facility is recorded. The information can be categorised into four main sections:

- Blood product information, including the blood unit number (linked to a unique barcode), blood group, type of blood product, donation date, and expiry date.
- Patient information, such as patient name, identification number, ward, age, sex, diagnosis, reason for transfusion, pre-transfusion haemoglobin (Hb) level, and compatibility test results.
- Clinician information, including the name of the clinician who requested the blood product.
- Laboratory technician information, such as the name of the technician who performed the compatibility test and issued the blood product.

When accurately captured, this information is crucial for ensuring the traceability of blood products within health facilities and for enabling audits of blood usage.

Approach 6: Clinical guidelines for blood transfusion pocket books

These portable tools provide guidance on the various medical indications for blood transfusion across different conditions. Ideally, each ward in a health facility should have one to assist clinicians in making informed transfusion decisions.

Approach 7: Continuous medical education sessions (CMEs) and accountability meetings

Since 2024, the UBTS has implemented weekly online meetings featuring presentations on appropriate blood use. During these sessions, randomly selected health facilities are invited to present reports on their blood use practices and discuss the challenges they face. This initiative was informed by previous studies that revealed significant knowledge gaps among clinicians regarding blood transfusion guidelines (6), as well as evidence that CME and in-service training are effective in addressing these gaps (8).

Approach 8: Hospital transfusion committees

Ideally, hospital transfusion committees are responsible for ensuring compliance to transfusion guidelines through in-service training, including providing clinical guidelines for blood transfusion pocket books. They are also responsible for developing blood-ordering schedules to ensure the availability of blood products in the health facility (9).

Although these approaches may have a substantial impact on appropriate use and accountability of blood products, they must all be implemented in conjunction to supplement each other. This makes implementation resource-intensive and impractical in resource-limited settings.

1.2.2 Description of the Blood Alarm System

The BAS is a low-cost, resilient digital platform developed in close collaboration with the UBTS, senior clinicians, and digital health experts. Its primary goal is to eliminate avoidable blood stock-outs in hospitals by:

1. Providing real-time data on hospital blood stock levels and sending notifications to relevant stakeholders about impending stock-outs.

2. Promoting appropriate and efficient blood use by offering clinical guidelines to clinicians at the point of prescribing blood products.

The system consists of both web-based and mobile applications, and all users must have registered accounts to access the platform. The mobile app is designed for clinicians and laboratory technicians, while hospital administrators and blood bank staff access the system via the desktop web app (figure 1).

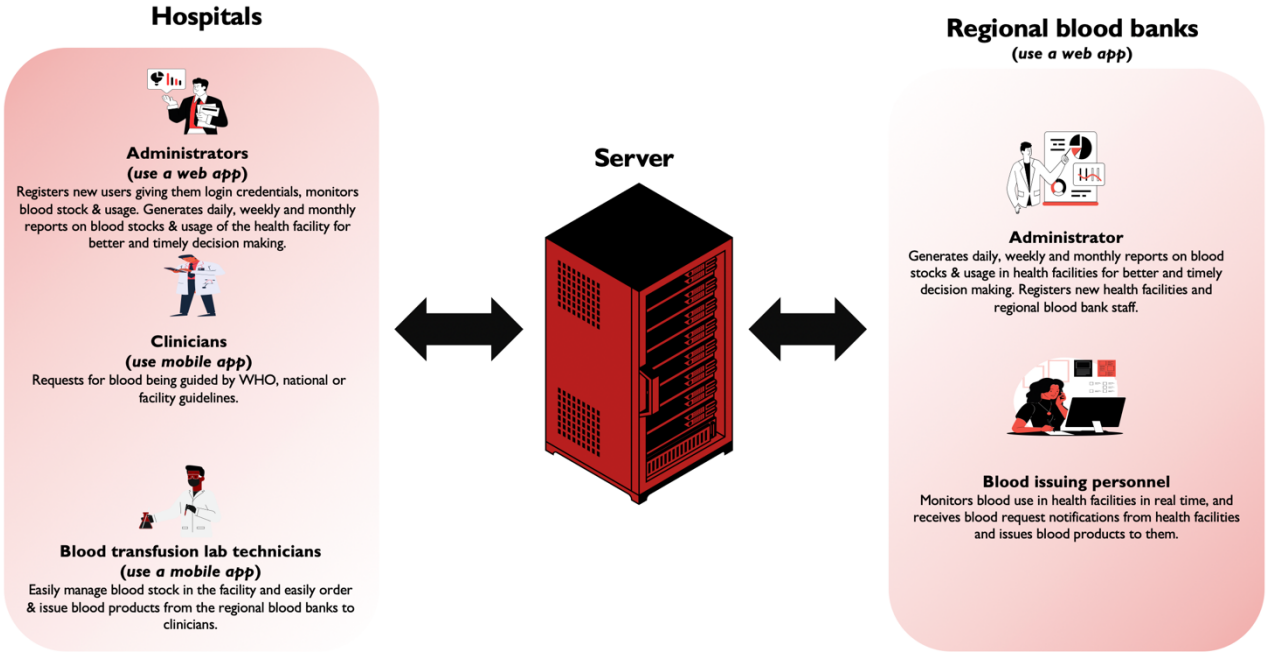


Figure 1: Schematic overview of the blood alarm system

The mobile app version provides the following functions:

For clinicians:

- Access to well-structured blood transfusion guidelines, including patient eligibility criteria and transfusion goals. These guidelines are adapted from national transfusion policies to ensure appropriate clinical use.
- Submit blood product requests directly through the app.
- Report common barriers to appropriate blood use, such as the unavailability of essential investigations (e.g., haemoglobin testing).
- Report transfusion anomalies for documentation and follow-up.

For facility blood transfusion laboratory technicians:

- Monitor real-time blood inventory at the facility.
- Receive notifications about impending stock-outs to facilitate timely blood orders.
- Scan blood units to confirm receipt of products at the facility.

The desktop web app provides the following functions:

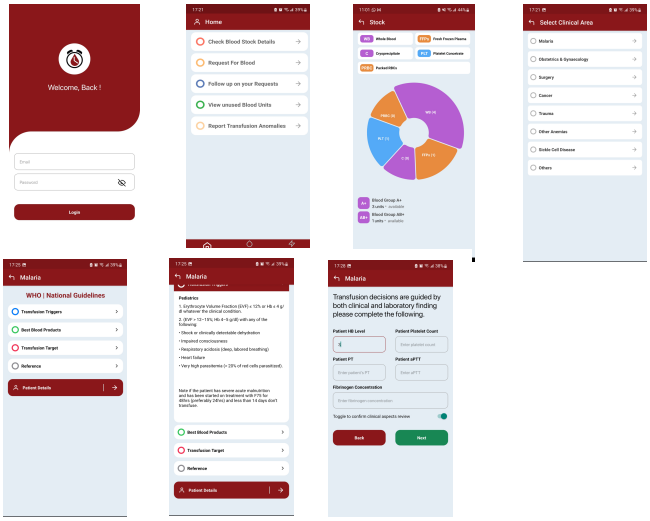
For blood bank staff:

- Monitor hospital blood stock levels in real time to support traceability and efficient order management.
- Access structured statistical reports to inform institutional policy and decision-making.
- Add or update national transfusion guidelines on the platform.
- Register new hospitals and designate their institutional heads.

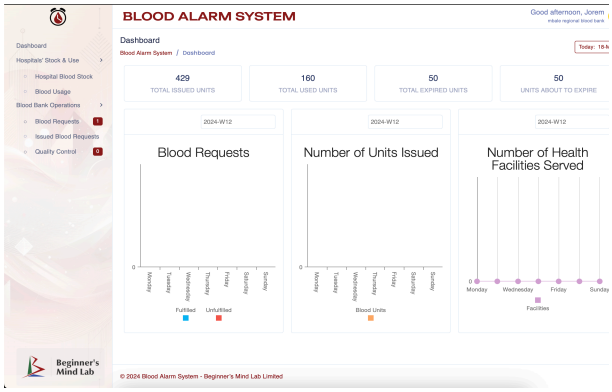
For hospital transfusion committees (Administrators):

- Register clinicians and laboratory technicians affiliated with the health facility.
- Monitor blood use in real time and receive alerts on obstacles affecting appropriate usage.
- Add or update facility-specific transfusion guidelines.
- Receive weekly facility-level reports on blood use patterns and trends.

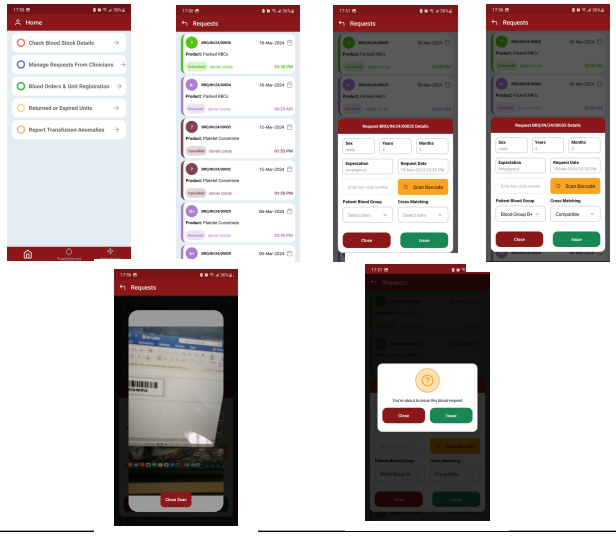
Some screen grabs from Clinician module



Some screen grabs from the regional blood bank module



Some screen grabs from the lab technician module



Some screen grabs from the hospital admin module

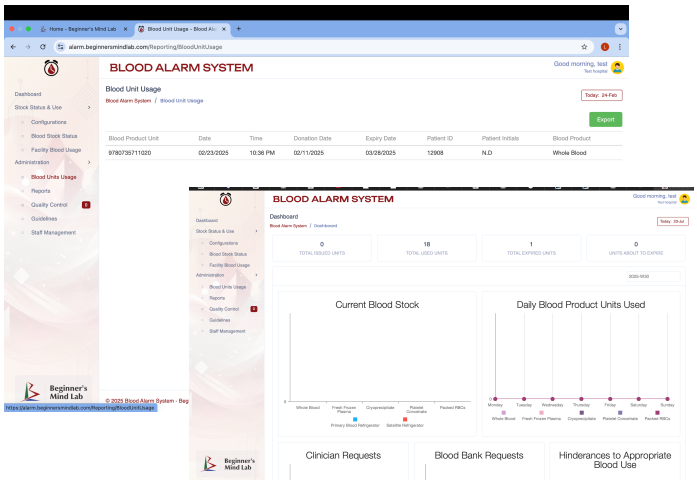


Figure 2: screen shots of the blood alarm system.

METHODS

2.0 Study design

Between November 2024 and May 2025, we conducted a before-and-after study to evaluate the impact of the Blood Alarm System (BAS) on the traceability, appropriate use, and availability of blood products in two selected health facilities in Uganda: Kisenyi Health Centre IV and Mukono General Hospital. In addition, a post-intervention survey was conducted to assess healthcare workers' perceptions and the acceptability of BAS in clinical settings. The study was implemented in three distinct phases:

In brief, Phase I (pre-intervention) involved data collection under standard (paper-based) practices and lasted 13 weeks. During this phase, data was manually collected on traceability, appropriate use, and availability of blood products. This included information on blood stock levels, completeness of patient details supporting appropriate blood prescriptions, and records of blood products received from the regional blood bank. Data were extracted from two main sources: 1) the blood delivery note, and 2) the facility blood transfusion daily activity register HMIS UBTS 003.

In Phase II (intervention phase), the same indicators were collected in real time using the BAS, also over a 13-week period. In this phase, Laboratory technicians scanned the barcodes on blood product units upon receipt, capturing details such as blood product type and expiry date. Then, clinicians entered patient information and submitted requests to the laboratory immediately after prescribing a transfusion.

In the final two weeks, Phase III (post-intervention evaluation), a healthcare worker survey was conducted to assess perceptions, acceptability, and barriers related to the use of BAS in clinical settings.

2.1 Study sites

Two health facilities were purposively selected in consultation with stakeholders, based on a set criterion: 1) One facility from a moderate blood consumption category (defined as an average of at least 50 transfusions in a month) and another from a low blood consumption category, 2) facilities with low healthcare worker turnover, and 3) easily accessible with limited resources. Based on these criteria, Mukono General Hospital (a moderate blood consumption facility) and Kisenyi Health Centre IV (a low blood consumption facility) were selected.

Mukono General Hospital is a public health facility located in Mukono district, about 20km away from Kampala city. The facility is the main referral centre in the district of a population of about 900,000 (10). The facility sources its blood products from Nakasero blood bank, which is estimated to be 23km away and Mengo blood bank, estimated at 29km.

Kisenyi Health Centre IV is located in Kampala district. Kampala is the largest and the Capital City of Uganda with an estimated population size of 1.8 million people (10). This is a public health facility, and one of the eight facilities managed by the Kampala capital city authority (KCCA), which serve a combined estimated population of over 1,200 persons per day. It offers both outpatient and inpatient services, including blood transfusion. It is located about 3.9 km away from the Nakasero blood bank, the main regional blood bank for the UBTS and 2.2km from Mengo blood bank.

2.2 Study participants

Only clinicians, laboratory technicians and administrators involved in blood ordering and consumption activities at the selected facilities were given access to the BAS. These were eligible to participate in the post-intervention evaluation survey if they were willing to provide informed consent.

2.3 Data collection tools and procedures

Data collection was conducted by a team of four trained research assistants. After completing training, they were divided into two groups, with each group assigned to one of the two study facilities. The data collection process was structured according to the study phases. The data sources are summarized in Table 1 below.

In the first phase, research assistants collected data weekly from the delivery notes and facility registers (HMIS UBTS 003). All data in this phase were manually extracted from paper-based registers and entered into a pre-designed paper-based data collection tools.

Following this initial phase, we conducted an initiation training for all healthcare workers at each facility. The training introduced the BAS, outlining its purpose, key objectives, and operational workflow. The training incorporated simulation exercises and role-plays to ensure that healthcare workers grasp the concept.

After the training, healthcare workers involved in blood ordering and the transfusion process were identified, and individual accounts were created for them on the BAS platform. These users were responsible for entering data at various stages of the blood consumption process using the BAS app during the second phase of the study. At each facility, we identified two additional contact persons who were trained prior to the study launch to provide ongoing support to facility staff during data collection to minimise the errors. The contact persons also acted as liaisons between the facility and the regional blood banks and helped retrieve delivery notes in phase II. The contact persons worked directly with the study investigators to ensure adherence to the study standard operating procedures.

In the final two weeks of data collection, research assistants approached eligible facility staff to conduct post-evaluation surveys. These surveys were administered using a pre-designed Google Form questionnaire, after obtaining informed consent from the participants.

Table 1: Different sources from which the data were obtained in this study

#	Phase	Data source	Indicators collected
1	Pre-intervention	Blood delivery note	Blood products unit numbers, amount (units) in stock at the time of order, units requested, units received, date of delivery
		Blood transfusion daily activity register	Blood products unit numbers, blood group, blood product, donation date and expiry date, patient initials, patient identification number, ward, age, sex, diagnosis, reason for transfusion, pre-transfusion tests e.g. Hb, compatibility test results, name of clinician and laboratory technician.
		Form for requesting blood by the clinicians	Clinician name, patient diagnosis, pre-transfusion results, e.g. Hb, compatibility results
		Health facility blood products order/usage form	Stock balance and amount requested for each blood product and type.
2	Intervention	Blood delivery note	Same as above.
		Blood Alarm System	Blood unit numbers, blood group, blood product, donation date and expiry date patient initials, patient identification number, ward, age, sex, diagnosis, reason for transfusion, pre-transfusion tests e.g. Hb, compatibility test results, name of clinician and laboratory technician, time of transfusion, outcome of the transfusion, date and time the blood product was taken.
		Health facility blood products order/usage form	Same as above
3	Post-intervention evaluation	Clinicians, laboratory technicians, and administrators	Demographics of participants, attitude, perceptions towards BAS, and challenges which may limit its implementation in the clinical setting.

2.4 Data management and analysis

Upon completion of data collection in phase I, data entry was done using a predesigned Microsoft Excel database. Double data entry was performed to allow for the identification and correction of any discrepancies. After completion of phase II, datasets were extracted from the BAS, while responses from the post-evaluation survey were downloaded as *.xls* files from Google Forms.

Data from the two study phases were organised into two separate Excel files: the *delivery dataset* (containing entries from the blood delivery notes) and the *consumption dataset* (containing entries from the Blood transfusion daily activity registers). These two datasets were then merged using the blood product unit number as the unique identifier to link records across both sources. The proportion of successfully matched unit numbers was used to assess traceability of blood products across the system.

A transfusions was deemed appropriate based on the following criteria as stated in the Uganda Clinical Guidelines: An Hb of 6 or less among children (0-12 years) or Hb<8 in adults. If Hb was not recorded, this transfusion was deemed inappropriate. Appropriate blood use estimation was considered only if age and the

type of blood products were recorded in the consumption dataset. FFPs and Plateletes were excluded from this estimation.

Descriptive analysis was performed to summarise the proportions of different blood product types used, while exploratory analysis was used to evaluate the completeness of key indicators across registers, disaggregated by study phase. Means and standard deviations were used to summarise metrics such as blood stock balances, units requested and units received, parameters used in the estimation of blood availability. Pearson correlation coefficients were calculated to assess relationships between these variables.

To assess the impact of the BAS on traceability and appropriate blood use, we used chi-square tests to compare proportions between study phases and facility levels. A $p<0.05$ was considered statistically significant. Additionally, descriptive statistics were used to summarise post-evaluation outcomes, stratified by facility level. All analyses were conducted using STATA version 14 (StataCorp, College Station, TX, USA).

2.5 Ethical consideration

The study was approved by the Mulago National Referral Hospital Research and Ethics Committee (MHREC) and the Uganda National Council of Science and Technology (UNCST) for regulatory oversight. Additional administrative clearances were sought from the Kampala Capital City Authority, Kisenyi HCIV and Mukono General Hospital before commencement of the study. Written informed consent was obtained from study participants before data collection.

RESULTS

3.0 Characteristics of blood products and completeness of patient records

Across the two phases, most blood products received were packed red blood cells (687, 64.0%), followed by whole blood (252, 23.5%), fresh frozen plasma (FFP) (103, 9.6%), and platelets (31, 2.9%). This pattern remained consistent between the two phases (Table 1). Likewise, as expected from the distribution of blood groups in the general population (11), blood group O+ was the most used (491, 45.8%) followed by A+(272, 25.3%) and B+ (250, 23.3%), and this was consistent across both phases.

Regarding documentation of patient details, the completeness of records significantly improved during Phase II (Table 1). For instance, patient initials were documented for nearly all transfusions (516, 99.0%) in Phase II, compared to none in Phase I. Similarly, clinician name (521, 100%), IP number (507, 97.3%), patient blood group (521, 100%), and laboratory technician name (521, 100%) were better documented in Phase II, compared to markedly lower rates in Phase I (Table 1). Additionally, the parameters used to determine appropriateness of blood transfusion, including the patient's age, pre-transfusion test, diagnosis, and reason for transfusion, were also recorded more often from 412 (68.7%) in Phase I to 466 (89.4%) in Phase II (Table 2).

Table 2: Characteristics of blood products and completeness of patient details in the health facility register

Variable	Overall	Phase	
		I (Standard)	II (With BAS)
Characteristics of Blood Products (BPs)			
Blood products received			
FFP	103(9.6)	41(8)	62(11.1)
Packed Cells	687(64)	308(59.9)	379(67.8)
Plateletes	31(2.9)	19(3.7)	12(2.1)
Whole Blood	252(23.5)	146(28.4)	106(19)
Blood groups received			
A+	272(25.3)	127(24.7)	145(25.9)
A-	8(0.7)	6(1.2)	2(0.4)
AB+	34(3.2)	21(4.1)	13(2.3)
B+	250(23.3)	132(25.7)	118(21.1)
B-	5(0.5)	3(0.6)	2(0.4)
O+	491(45.8)	215(41.8)	276(49.4)
O-	13(1.2)	10(1.9)	3(0.5)
Completeness of patient details in the facility laboratory register			
Patient initials			
Yes	516(46)	0(0)	516(99)
No	605(54)	600(100)	5(1)
IP Number			
Yes	517(46.1)	10(1.7)	507(97.3)
No	604(53.9)	590(98.3)	14(2.7)
Patient sex			
Yes	919(82)	588(98)	331(63.5)
No	202(18)	12(2)	190(36.5)
Patient age			
Yes	1074(95.8)	553(92.2)	521(100)
No	47(4.2)	47(7.8)	0(0)
Ward			
Yes	1103(98.4)	587(97.8)	516(99)
No	18(1.6)	13(2.2)	5(1)
Blood product taken from the lab			
Yes	1103(98.4)	582(97)	521(100)
No	18(1.6)	18(3)	0(0)
Blood group taken from the lab			
Yes	1115(99.5)	594(99)	521(100)
No	6(0.5)	6(1)	0(0)
Patient blood group			
Yes	1106(98.7)	585(97.5)	521(100)
No	15(1.3)	15(2.5)	0(0)
Indicators of appropriate prescription*			
Yes	878(78.3)	412(68.7)	466(89.4)
No	243(21.7)	188(31.3)	55(10.6)

Treatment outcome			
Yes	468(41.7)	0(0)	468(89.8)
No	653(58.3)	600(100)	53(10.2)
Prescribing clinician			
Yes	1086(96.9)	565(94.2)	521(100)
No	35(3.1)	35(5.8)	0(0)
Issuing laboratory technician			
Yes	976(87.1)	455(75.8)	521(100)
No	145(12.9)	145(24.2)	0(0)

**Indicators included appropriate pre-transfusion test, patient's age, diagnosis and reason for transfusion*

3.1 Traceability of blood products

Across the two phases, a total of 1,401 blood product units were recorded, slightly more in phase I (772, 55.1%). Of those recorded in phase I, up to 55.7% (n=430) were untraceable, while only 28.3% (n=178) of those registered in phase II were untraceable (Figure 3).

With the standard practice (Phase I), the majority (258, 60.0%) of untraceable blood products were identified in the blood transfusion daily activity register. In contrast, most (108, 60.7%) of the untraceable products were found in the delivery notes after introduction of BAS (Phase II).

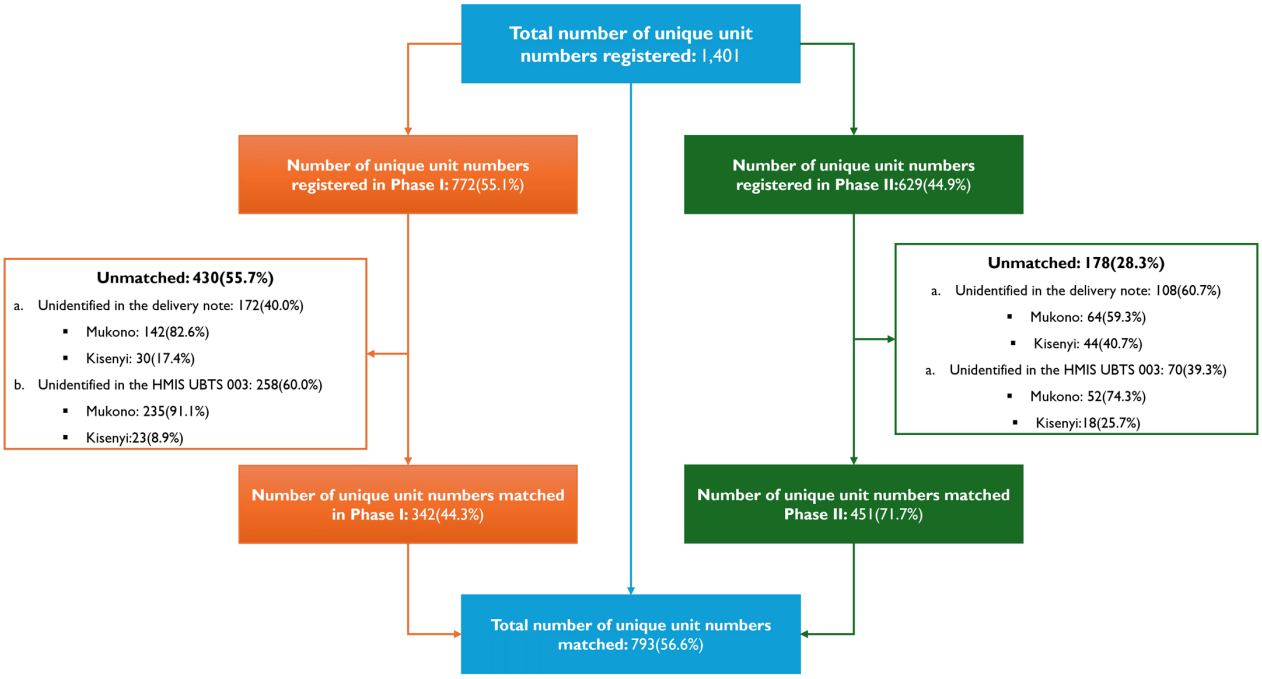


Figure 3: Traceability of blood products between the delivery note and the blood transfusion daily activity register (HMIS UBTS 003) before and after introduction of Blood Alarm System

After introduction of BAS, traceability of blood products significantly improved from 44.3%(n=342) in Phase I to 71.7%(n=451) in Phase II (p<0.001). Traceability was particularly better at Mukono GH compared to Kisenyi HCIV (58.4% vs 47.0%, respectively, p=0.002) (Table 3).

Table 3: Comparing traceability and appropriate use of blood products across phase and study sites

Variable	Overall	Phase			Facility Level		
		I(Standard)	II(BAS)	p	HCIV	GH	p
Traceability				<0.001			0.002
Traceable	793(56.6)	342(44.3)	451(71.7)		102(47)	691(58.4)	
Not traceable	608(43.4)	430(55.7)	178(28.3)		115(53)	493(41.6)	
Appropriateness of blood use				0.156			<0.001
Appropriate	638(69.6)	314(67.5)	324(71.8)		29(21.6)	609(77.9)	
Not appropriate	278(30.4)	151(32.5)	127(28.2)		105(78.4)	173(22.1)	

3.2 Appropriateness of blood use

A total of 1,118 transfusions were registered across both phases. Of these, slightly more transfusions (600, 53.7%) occurred in phase I (Figure 4). Compared to phase I, a smaller number of transfusions were excluded from the estimation of appropriate blood use in phase II (24.2% vs 12.9%, respectively). There was no transfusion excluded due to missing information in phase II (Figure 4).

Of the 916 transfusions included in this analysis, 638 (69.6%) were classified as appropriate (Table 3). After the introduction of BAS, appropriate use of blood products improved from 67.5% to 71.8% although this was not statistically significant (p=0.156). Compared to Kisenyi HCIV, Mukono GH had significantly more appropriate blood transfusions (p<0.001) (Table 3).

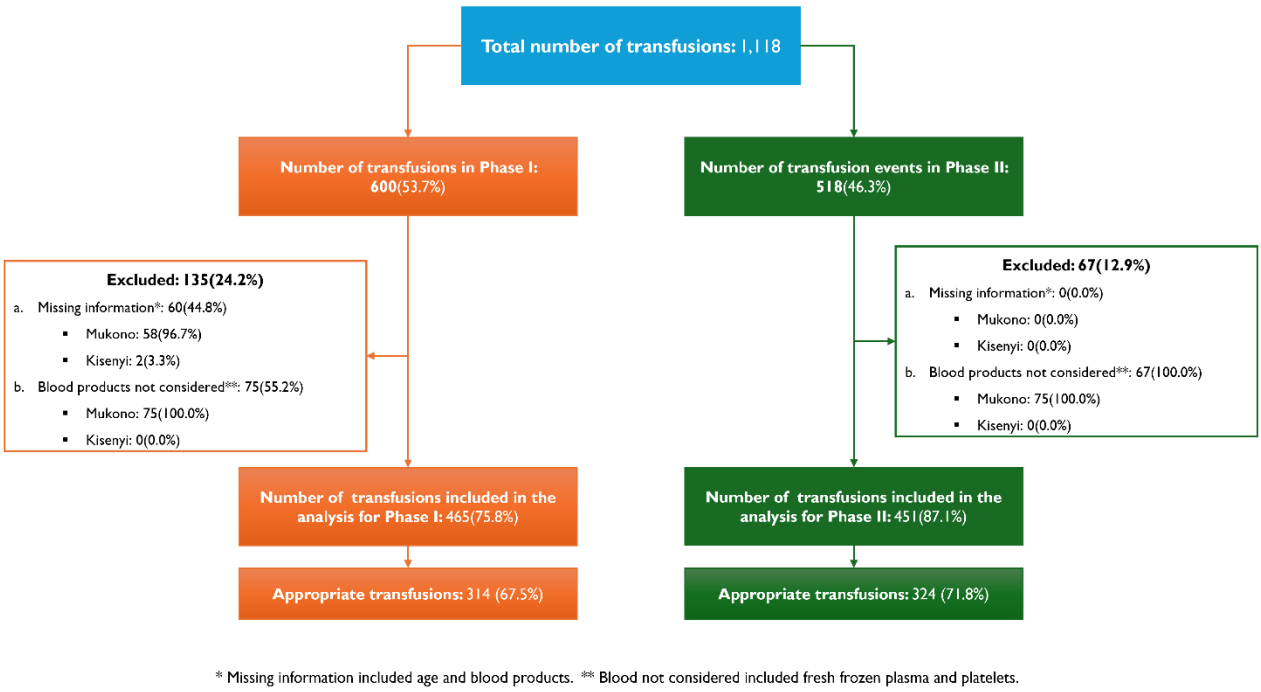


Figure 4: Comparing appropriateness of blood use between study phases

3.3 Availability of blood products in health facilities

Median balance of overall stock at the time of blood order remained unchanged between phases (28.0 vs 30.0 units, p=0.4812). However, there was a notable increase in the stock of critical components (O+ and O-) during Phase II, with a median of 3.0 units (IQR: 1.0–5.0) compared to 1.0 unit (IQR: 0.0–3.5) in Phase I (p=0.0175) (Table 4). Units requested and received did not differ significantly between phases.

Table 4: Availability of blood products at the time of ordering aggregated by phase

Variable	Overall	Phase		
		I (Traditional)	II (With BAS)	p-value
Availability of blood products				
Balance (overall) in stock at order, Median (IQR)	28.0(9.0,39.0)	28.0(9.5,39.0)	30(9.0,40.0)	0.481
Balance of critical components in stock at order, Median (IQR)	2.0(1.0,4.0)	1.0(0.0,3.5)	3.0(1.0,5.0)	0.018
Units requested, Median (IQR)	20.0(7.0,50.0)	24.0(6.0,58.0)	17.0(7.0,46.0)	0.657
Units received, Median (IQR)	7.0(3.0,13.5)	7.0(3.0,12.0)	7.0(3.0,18.0)	0.395

There was a strong positive correlation between units received and units requested (r: 0.70, p<0.001), but this correlation was weak with stock balance (Figure 5).

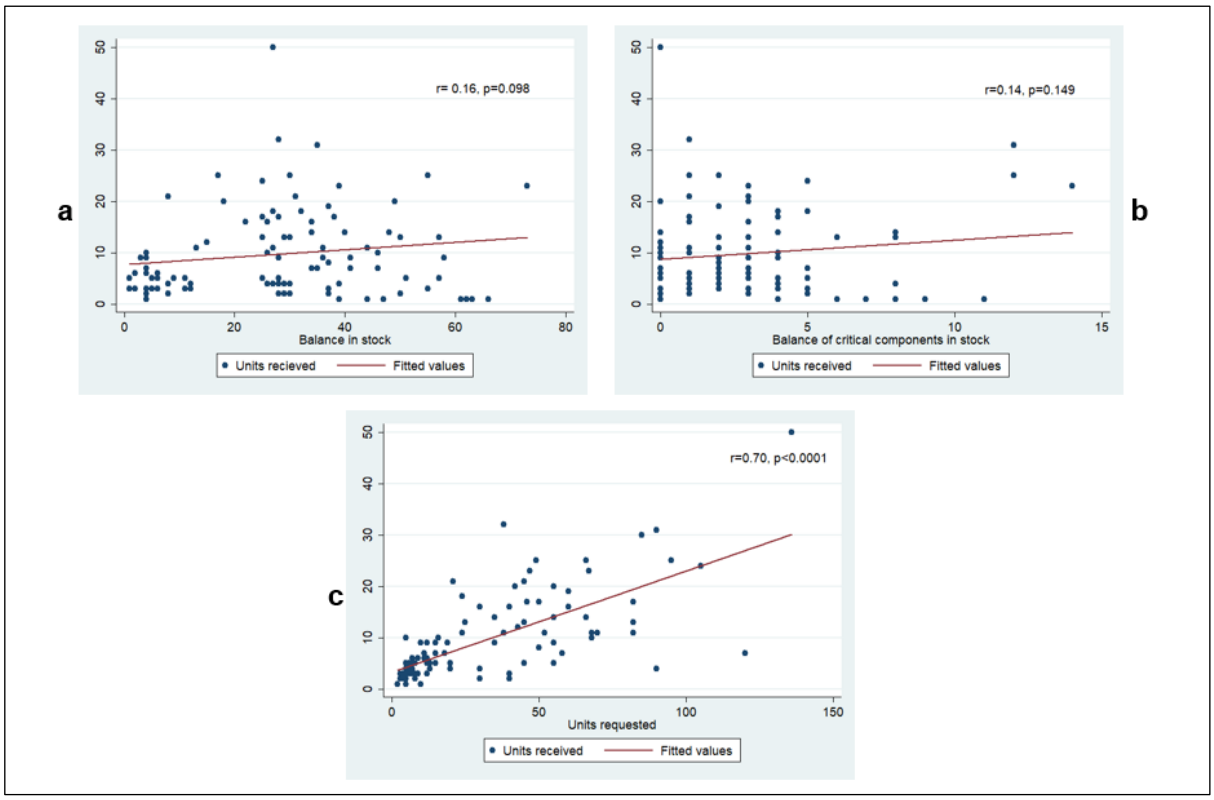


Figure 5: Correlation between the amount (units) of blood products received and a) overall balance in stock, b) balance of critical components (including O+ or O-) and c) units requested from the blood bank

3.6 Staff Characteristics

Of these, most (22, 64.7%) were male, with a mean age of 33.3 (standard deviation (SD): 7.9) years. Clinicians formed the majority (25, 73.5%), followed by laboratory technicians (6, 17.6%) and administrators (3, 8.8%). Overall, staff had an average of 7.7 (SD:7.2) years of experience. Staff at the general hospital were more likely to handle transfusions frequently (18, 69.2%) compared to those at the health centre IV (2, 25.0%) (Table 5).

Table 5: Characteristics of staff who participated in the BAS evaluation survey, N=34

Variable	Overall	Facility level		
		HCIV, N=8	GH, N=26	p-value
Sex				0.098
Female	12(35.3)	5(62.5)	7(26.9)	
Male	22(64.7)	3(37.5)	19(73.1)	
Age, mean (SD)	33.3(7.9)	33.8(6.6)	33.2(8.3)	0.853
Facility level				
General Hospital				
Health Centre IV				
Primary role in the facility				0.519
Administrator	3(8.8)	1(12.5)	2(7.7)	
Clinician	25(73.5)	5(62.5)	20(76.9)	
Laboratory technician	6(17.6)	2(25)	4(15.4)	
Cadre				0.087
Clinical Officer	9(26.5)	0(0)	9(34.6)	
Laboratory technician	6(17.6)	2(25)	4(15.4)	
Lab technologist	1(2.9)	0(0)	1(3.8)	
Medical Officer (GP)	15(44.1)	4(50)	11(42.3)	
Midwife	1(2.9)	1(12.5)	0(0)	
Obstetrics and Gynaecology specialist	1(2.9)	1(12.5)	0(0)	
Pre-intern Dr	1(2.9)	0(0)	1(3.8)	
Years of experience, mean (SD)	7.7(7.2)	9.0(7.6)	7.3(7.2)	0.569
Frequency of handling blood transfusion				0.029
Frequently	20(58.8)	2(25)	18(69.2)	
Occasionally	13(38.2)	5(62.5)	8(30.8)	
Rarely	1(2.9)	1(12.5)	0(0)	

3.7 Perceptions and Acceptability of BAS

Most staff (32, 94.1%) reported being somewhat or very familiar with digital platforms. BAS was perceived as easy or very easy to navigate by most users (32, 94.1%). Staff at the general hospital were more likely to find BAS well integrated into existing workflows (18, 69.2%) compared to those at the health centre IV (0, 0%) (Table 6).

More than half (28, 82.3%) of the staff felt that BAS improved or significantly improved their ability to make transfusion decisions. A similar proportion (25, 73.5%) believed it decreased or significantly decreased the time required to make such decisions. The majority felt that BAS improved awareness of blood availability (29, 85.3%) and traceability (34, 100%).

Most staff (25, 73.5%) would definitely recommend BAS for use in other facilities, and 34 (100%) rated BAS as either effective or very effective in improving accountability. Overall user satisfaction with BAS was high, with a mean rating of 3.9 out of 5 (SD: 1.0) (Table 6).

Most common barriers raised included access to internet (30, 88%), reliability of the app (19, 56%), integration into the existing systems (17, 50%) and resistance from staff (12,35%) (Figure 6).

Table 6: Perceptions, acceptability, and user satisfaction towards BAS among the facility staff

Variable	Overall	Facility level		
		HCIV, N=8	GH, N=26	p-value
Familiarity with the digital platforms in clinical practice				0.002
Not familiar	2(5.9)	2(25)	0(0)	
Somewhat familiar	12(35.3)	5(62.5)	7(26.9)	
Very familiar	20(58.8)	1(12.5)	19(73.1)	
Ease of navigating the BAS app				0.055
Easy	24(70.6)	4(50)	20(76.9)	
Neutral	2(5.9)	2(25)	0(0)	
Very Easy	8(23.5)	2(25)	6(23.1)	
Intuitiveness of BAS' user interface				1.000
Intuitive	20(58.8)	5(62.5)	15(57.7)	
Neutral	5(14.7)	1(12.5)	4(15.4)	
Very intuitive	9(26.5)	2(25)	7(26.9)	
Integrating BAS with your facility's existing workflows				<0.001
Neutral	6(17.6)	5(62.5)	1(3.8)	
Poorly	1(2.9)	1(12.5)	0(0)	
Very well	9(26.5)	2(25)	7(26.9)	
Well	18(52.9)	0(0)	18(69.2)	
BAS provides clear guidelines for making clinical decisions about BT				0.017
Always	13(38.2)	2(25)	11(42.3)	
Most of the time	16(47.1)	2(25)	14(53.8)	
Never	1(2.9)	1(12.5)	0(0)	
Not applicable	2(5.9)	2(25)	0(0)	
Sometimes	2(5.9)	1(12.5)	1(3.8)	
BAS's impact on ability to make BT decisions				0.001
Improved	18(52.9)	1(12.5)	17(65.4)	
Not applicable	2(5.9)	2(25)	0(0)	
Not improved	1(2.9)	1(12.5)	0(0)	
Significantly improved	10(29.4)	2(25)	8(30.8)	
Slightly improved	3(8.8)	2(25)	1(3.8)	
BAS's impact on the time to make BT decisions				0.051
Decreased	19(55.9)	3(37.5)	16(61.5)	
Increased	3(8.8)	0(0)	3(11.5)	
Not applicable	1(2.9)	1(12.5)	0(0)	
Not change	4(11.8)	3(37.5)	1(3.8)	
Significantly decrease	6(17.6)	1(12.5)	5(19.2)	
Significantly increase	1(2.9)	0(0)	1(3.8)	
Effectiveness of BAS on awareness of blood availability				0.153
Effective	14(41.2)	2(25)	12(46.2)	
Neutral	5(14.7)	3(37.5)	2(7.7)	
Very effective	15(44.1)	3(37.5)	12(46.2)	
Effectiveness of BAS on improving traceability of BPs				1.000
Effective	17(50)	4(50)	13(50)	
Very effective	17(50)	4(50)	13(50)	
Effectiveness of BAS on improving accountability of BPs				1.000

Effective	18(52.9)	4(50)	14(53.8)	
Very effective	16(47.1)	4(50)	12(46.2)	
Would you recommend BAS for adoption in other facilities?				0.403
Definitely	25(73.5)	7(87.5)	18(69.2)	
Probably	9(26.5)	1(12.5)	8(30.8)	
Long-term impact of BAS on patient outcomes				0.689
Improve outcomes	20(58.8)	4(50)	16(61.5)	
Significantly improve outcomes	14 (41.2)	4(50)	10(38.5)	
Overall satisfaction rating (max 5), mean (SD)	3.9(1.0)	3.9(0.6)	3.9(1.1)	0.9816

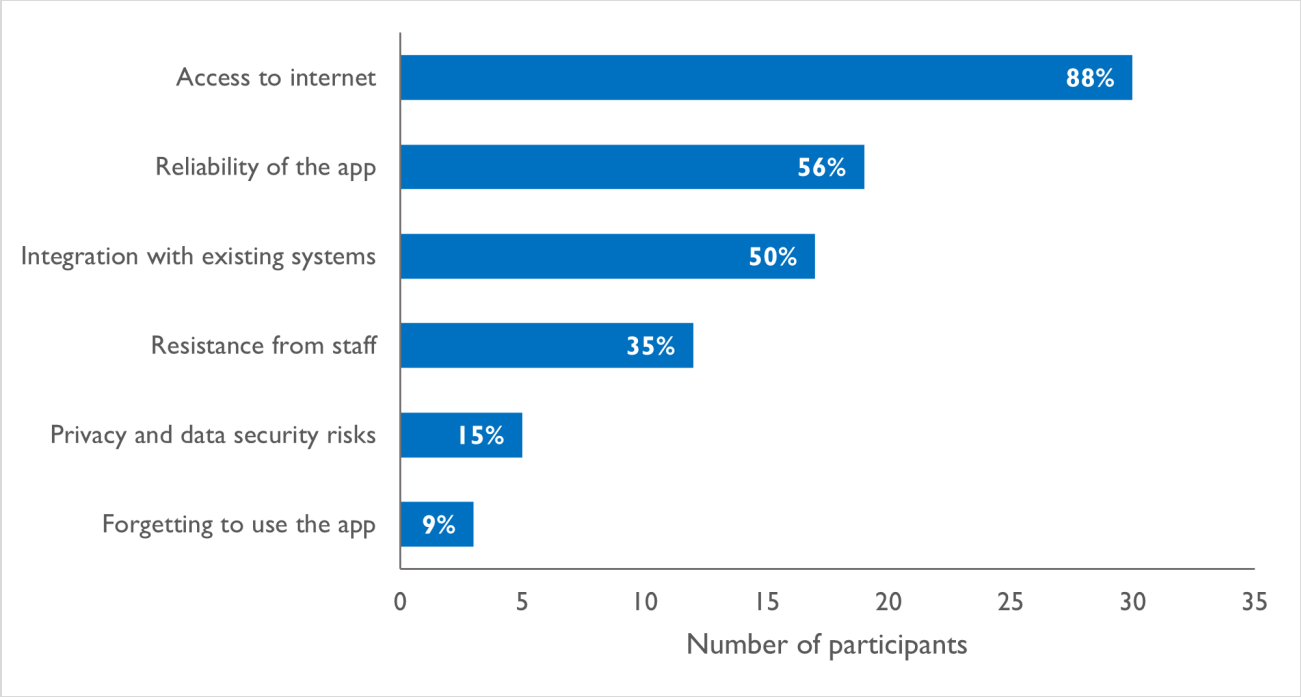


Figure 6: Most common barriers identified by facility staff towards adoption of BAS in clinical settings

DISCUSSION

This study assessed the feasibility and impact of a digital innovation, the BAS, on the traceability, appropriate blood use and availability of blood products in two Ugandan health facilities. Our findings revealed that the use of BAS significantly improved blood product traceability, rising from 44.3% under current standard practice to 71.7% with BAS. This improvement is due to two main features: (1) barcode scanning, which eliminates errors associated with manual entry, and (2) automated, end-to-end electronic documentation, from receipt to patient transfusion. Together, these elements close the loop in the transfusion chain and significantly enhance traceability. Beyond traceability, these features promote accountability, as each transfusion is now tied to specific facility staff. The consistent completion of key data fields in Phase II (compared to missing data in Phase I) also enables robust transfusion audits, which are essential for quality improvement but often difficult with traditional methods or low-resource settings (12,13). Therefore, integrating the BAS into the national blood monitoring frameworks by UBTS could help improve traceability and accountability of blood products.

The study observed a slight improvement in the appropriate use of blood products after introduction of BAS, though this was not statistically significant. Appropriate use of blood products increased from 67.5% to 71.8%. This was higher compared to findings reported by previous studies in Uganda, which cited that only 44.5% blood transfusions among children below five years were appropriate (5). The high proportion of appropriate blood use in our study could be explained by the fact that we included patients of all age groups, including adults who may have varying transfusion thresholds. The BAS system has an in-built function, which provides the clinicians with the updated blood transfusion guidelines and guides them on which product is appropriate in a given clinical scenario. However, given that the difference in phase 2 was not statistically significant, it raises concerns as to why this function did not improve transfusion decision-making among clinicians. A few possible explanations can be elucidated: First, there was limited time for the change in transfusion practices to cause a significant shift in the statistics. This is supported by feedback from post-evaluation, where participants believed the BAS provided helpful guidelines which improved their blood transfusion decision-making. Previous literature has shown that healthcare workers often face a delay in the adoption of digital technologies depending on their familiarity with the technology as well as other associated attributes (14,15). Second, there exist contextual factors hindering the adherence to blood transfusion guidelines among healthcare workers at study sites, which could not be addressed by BAS alone for example, unavailability of laboratory investigations key in informing prescription of blood products. Indeed, similar studies in Uganda have reported poor adherence to clinical guidelines among healthcare workers, recommending in-service training and ongoing support to improve patient outcomes. Therefore, future studies should seek to investigate factors which may influence adherence to blood transfusion guidelines in this setting to guide appropriate interventions to address this gap. Additionally, we observed that appropriate blood use was significantly better at Mukono GH compared to Kisenyi HCIV. Being an HCIV, Kisenyi HCIV may lack essential logistical supplies to conduct pre-transfusion tests, which could have impacted our estimations for the appropriate blood use in this facility. This aligns with prior reports from other low-resource settings,

where inadequate screening, limited access to up-to-date training, and lack of reference guidelines have contributed to inappropriate blood use (16). However, it is important to investigate why Kisenyi HCIV has significantly different blood transfusion practices.

While BAS had no significant impact on overall blood stock levels, it significantly improved the availability of critical components like O+ and O− packed red blood cells and whole blood. This improvement may be attributed to BAS's in-built functionality that prompts users to flag critical component availability during order placement, an option absent in standard registers. This likely raised awareness among facility laboratory staff, motivating them to plan better and place blood orders earlier, thus avoiding last-minute panic requests. This aligns with our finding that most staff reported that BAS enhanced their awareness of blood stock availability, consistent with previous research showing that digital dashboards improve inventory visibility and decision-making in hospital supply chains (17,18). Importantly, early ordering based on stock visibility of critical components can enhance preparedness and reduce avoidable stockouts, ultimately improving patient outcomes. The inclusion of real-time stock indicators also has implications for broader supply chain coordination. For instance, regional or national blood supply coordinators could use this data to redistribute critical components across facilities during shortages. However, our analysis found that the quantity of blood received by facilities correlated strongly with units requested, but not with stock balance at the time of ordering. This suggests a possible misalignment between actual need and supply, which could perpetuate stockouts. This observation is not unique; other studies have noted the lack of standardized demand-based blood allocation models in Uganda and other resource-limited settings (19). To improve efficiency, the UBTS should consider implementing issuance criteria based on real-time consumption rates and stock levels; a function easily enabled by BAS's analytics dashboard, which allows transparent, data-driven decisions.

The BAS was generally well received, achieving a satisfaction score of 3.9 out of 5, which is relatively high for a newly introduced clinical system. Similar or lower ratings have been observed for first-time deployments of electronic medical records in sub-Saharan Africa (20). Factors that could have contributed to this high rating for the BAS include ease of navigation, improved traceability, and the ability to guide appropriate transfusion decisions, all cited by participants as major benefits and supported by previous studies (20,21). However, participants identified some barriers that could hinder the effective integration of the intervention. The most prominent was access to internet, essential for operating the BAS platform. Since BAS requires online connectivity for full functionality, addressing this issue is critical for scale-up. Low-cost strategies such as facility-subsidised routers, offline functionality with periodic syncing, or zero-rated access via telecom partnerships could ensure uninterrupted system use. The second barrier was the reliability of the app. This was a significant issue, particularly during the first two weeks of Phase II, which were characterised by system errors that limited usability. Currently, the BAS runs on a single server, which requires extreme caution when implementing major updates. During the initial 1–2 weeks of phase II, we received several user requests for new features, some of which required major updates. However, due to a lack of a second server that could facilitate thorough testing of system stability before deploying updates to the main server, pre-release testing was limited. As a result, some rushed updates led to occasional system errors. These issues likely raised

concerns among facility staff, who cited reliability as a major barrier. To address this, it is essential to acquire a second server where internal tests and trials can be conducted prior to releasing updates. This will improve system reliability, enhance overall performance, and increase acceptance among end-users. The third barrier was concern about the integration of BAS into the existing frameworks. Particularly, users were concerned about how the system will be integrated with the electronic blood bank management system (e-Delphyn) which primary is used by UBTS to manage stock within the regional blood banks and issuance of blood products to facilities. It is important to note that BAS is not a replacement of e-Delphyn at regional blood bank, but a complementary system which allows for real-time monitoring of blood products utilization in facilities. Additionally, administrators at UBTS were primary stakeholders consulted during the development of BAS to ensure easy adoption. Therefore, the two systems benefit from co-existence which enhances the possibility of integration in the existing frameworks.

Lastly, staff resistance was also listed as a potential barrier. This was especially encountered at Kisenyi HCIV. Resistance to new approaches, especially digital technologies in clinical settings, has been widely reported in the literature (21). In this study, the difference in adoption levels between the two facilities was notable. At Mukono General Hospital, where an electronic medical records system is already operational (used in outpatient department and triage), staff appeared more receptive to the BAS. In contrast, Kisenyi HCIV still relies entirely on paper-based records, which may explain the higher resistance observed. Moreover, hospital leadership at Mukono GH actively supported the integration of BAS, contributing to smoother implementation and a higher number of transfusions recorded during Phase II. Some staff at Kisenyi HCIV reverted to traditional practices, limiting full uptake.

Study limitations

This study had several limitations that should be considered when interpreting the findings. First, both study facilities were located within the same geographic region and near the national blood bank. This may limit the generalizability of our findings to other regions of Uganda, particularly rural or remote areas where blood delivery logistics and infrastructure challenges may differ significantly.

Second, we were unable to systematically account for blood units that were already present in the facility laboratories at the time of study initiation but used during the study period, as well as those received during the study but not transfused by the end of data collection. These unaccounted-for units may have influenced traceability estimates, potentially leading to slight under- or over-estimations. However, considering the large number of transfusions observed and the fact that this issue applied equally across both phases, we believe the impact on our results is likely minimal.

Third, the definition we used for appropriate blood use was ambiguous. This was due to a lack of enough information i.e., detailed patient clinical notes to sufficiently classify transfusion events as well as a diverse population, unlike other studies, which often target a specific age-group with defined cut-offs. While this pragmatic approach was necessary in our setting, it may have introduced misclassification and thus limited the precision of our appropriateness estimates. As a result, caution is warranted when comparing our findings with studies that used stricter clinical criteria or more complete datasets.

Lastly, despite efforts to select study sites with relatively stable staffing, we encountered a significant number of temporary healthcare workers involved in the blood supply chain, including pre-interns, students, and volunteers. Many of these individuals were trained but left during the course of the study, resulting in the loss of valuable user feedback on the platform.

Next steps

1) Establish a dedicated test environment for the BAS platform to ensure thorough testing of new platform versions prior to real-world deployment. This would involve acquiring a secondary server specifically for testing and quality assurance purposes. All testing processes should be conducted in full compliance with local data protection and privacy regulations.
2) Integrate BAS with the UBTS electronic Blood Bank Management System (e-Delphyn) to allow seamless placement, issuance and tracking of blood orders to and from regional blood banks for efficiency and enhanced operations. This recommendation aligns with discussions held with the UBTS Head of IT and their team during the course of the study.
3) Scale to high-volume facilities to provide compelling evidence for national wide adoption. i.e., facilities with the highest blood consumption in the country such as Mulago National Referral Hospital or Kawempe National Referral Hospital. Demonstrating the system's performance in these settings will support advocacy efforts with the UBTS and Ministry of health for broader rollout and nationwide implementation.

Conclusion

The Blood Alarm System demonstrated measurable benefits in improving traceability, availability critical blood components, and a slight improvement in appropriate blood use, while gaining strong user support across different facility levels. However, some barriers were identified by facility staff, including access to internet, reliability of the app, integration into existing systems and staff resistance, though these are solvable. With strategic investments, particularly in internet access, staff capacity-building, and health system integration, BAS holds promise as a scalable, data-driven intervention to strengthen blood transfusion practices in Uganda and similar settings.

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