Original Paper

Digital Health Platform for Interinstitutional Perinatal Blood Dispatch in Rural Taiwan: 4-Year Implementation Study Using the RE-AIM Framework

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Abstract

Background: Postpartum hemorrhage is the leading direct cause of maternal mortality worldwide. In rural regions where obstetric clinics lack on-site transfusion capability, distance to the tertiary blood bank is a modifiable determinant of outcome. Existing electronic blood-ordering systems are confined to single-site hospital deployments; no peer-reviewed report describes an interinstitutional perinatal blood dispatch platform coordinating a tertiary blood bank with primary obstetric clinics.

Objective: This study aims to describe the design, implementation, and RE-AIM (Reach, Effectiveness, Adoption, Implementation, and Maintenance) evaluation of a digital platform linking a tertiary blood bank with 4 community obstetric clinics in rural Taiwan over 4 years.

Methods: We conducted an observational implementation evaluation at a tertiary referral center. Launched on November 1, 2021, the platform is a stand-alone web application coordinating ordering, identity and blood-type verification, and cold-chain dispatch across the blood bank and 4 affiliated clinics; it is not electronically integrated with the hospital blood-bank information system. Effectiveness was assessed against 2 prespecified service-level agreement (SLA) targets set by consensus before launch: routine dispatch ≥90% within 90 minutes and emergency dispatch ≥90% within 30 minutes. Reach, adoption, implementation, and maintenance were extracted from platform audit logs. Stakeholder satisfaction was measured using a 28-item service quality (SERVQUAL) instrument at 3 and 15 months postimplementation (clinic physicians, nurses, and allied staff). A continuous-improvement unmanned aerial vehicle (UAV) delivery feasibility substudy (initiated in year 3) evaluated whole-blood stability across 4 red-cell storage time points over a 4-km corridor.

Results: The platform supported 252 dispatch episodes (38 emergency and 214 routine) from November 1, 2021, through August 31, 2026, and delivered 554 blood product units. Adoption reached 100% (4/4) of eligible clinics and all obstetric clinicians. The emergency SLA was met in 84.2% (32/38) of episodes and 100% in both 2025 and 2026 to date; median emergency turnaround was 28 (IQR 23-29) minutes. The routine SLA was met in 97.7% (209/214) of episodes; median routine turnaround was 72 (IQR 62-79) minutes. Zero serious transfusion-related adverse events were documented across all 252 episodes. SERVQUAL composite satisfaction rose from 4.65 (SD 0.53; n=32; Cronbach α=0.985) at 3 months to 5.00 (SD 0.01; n=38; α uninformative owing to

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ceiling effect) at 15 months. In the UAV substudy, preflight and postflight whole-blood parameters remained within similar ranges across all 4 storage days.

Conclusions: An interinstitutional perinatal blood dispatch platform achieved universal clinic adoption, sustained prespecified SLA targets for emergency and routine dispatch, and was compatible with 0 serious transfusion-related adverse events across nearly 5 years of rural operation. Organizational-level digital health interventions in resource-constrained perinatal networks need not depend on full hospital-information-system integration while supporting sustained service quality; prespecified SLA frameworks plus audit-log analytics offer a transparent evaluation mechanism where randomized comparator designs are infeasible. UAV-delivery feasibility findings are preliminary.

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KEYWORDS

blood bank; digital health; health informatics; implementation science; perinatal care; postpartum hemorrhage; PPH; Reach, Effectiveness, Adoption, Implementation, and Maintenance (RE-AIM); rural health; transfusion safety; UAV; unmanned aerial vehicle

Introduction

Background

Digital health technologies—defined as electronic health records, web-based clinical ordering systems, mobile health apps, and connected diagnostic and decision-support tools—are reshaping how time-critical clinical decisions are made and how resources are allocated across geographically distributed health systems. Their value is particularly evident in rural and resource-constrained settings, where the geographic and informational distance between front-line care providers and centralized clinical services is itself a determinant of clinical outcome.

Despite rapid uptake of intrahospital electronic blood-ordering and computerized cross-matching systems, which have reduced wrong-blood-in-tube events and ABO blood group (ABO)–incompatible transfusions in single-site deployments [1], the digital exchange of clinical orders and safety-critical patient identifiers between institutions located at separate sites—for example, between a primary obstetric clinic and a distant hospital blood bank—remains one of the weakest links in transfusion safety. Root-cause analyses of preventable transfusion errors recorded by the UK Serious Hazards of Transfusion (SHOT) scheme repeatedly identify paper-based ordering, fragmented identity verification, and absence of cross-institutional information exchange as recurring proximal causes [1,2]. To our knowledge, no peer-reviewed report describes a digital interinstitutional perinatal blood dispatch platform that coordinates clinic-initiated electronic ordering, automated 3-way blood-type concordance interception, and end-to-end cold-chain dispatch in routine practice across institutional boundaries.

Clinical Setting and Unmet Need

Postpartum hemorrhage (PPH) is the leading direct cause of maternal mortality globally and accounts for approximately one-quarter of all maternal deaths [3,4]. A World Health Organization (WHO) individual participant data meta-analysis of more than 312,000 women confirmed that measured blood loss combined with abnormal hemodynamic signs is an accurate predictor of death or life-threatening morbidity, and that diagnostic-treatment delay is a principal modifiable determinant of outcome [5]. The clinical imperative for rapid access to compatible blood products in obstetric hemorrhage is well established. The first hour after onset of major PPH is associated with the highest preventable mortality risk. Prevention bundles, uterotonics, tranexamic acid, and early transfusion together form the cornerstone of care [3,5-7]. Active management of the third stage of labor reduces severe primary PPH and the need for transfusion, but does not eliminate the risk of catastrophic bleeding once it occurs [8]. In primary obstetric clinics without an on-site transfusion service, the rate-limiting step in resuscitation is therefore the logistic distance—and, critically, the information distance—to the nearest blood bank.

Maternal mortality in Taiwan has not decreased in parallel with comparable high-income economies. The national maternal mortality ratio of approximately 13 per 100,000 live births in 2020 ranked Taiwan 30th of 36 reporting Organisation for Economic Co-Operation and Development (OECD) members, approximately 3 times the OECD median. Yunlin County, on the western alluvial plain of central Taiwan, is one of the country's most demographically vulnerable regions. The crude birth rate is the fifth-lowest nationally; the proportion of residents who are illiterate is the highest; and standardized mortality rates for diabetes, cardiovascular disease (excluding hypertensive disease), and cancer rank first, second, and third nationally, respectively.

Fourteen of the county's 20 townships are formally designated as National Health Insurance medical-resource-shortage areas. Obstetric specialists in Yunlin represent approximately 2% of the national obstetric workforce, and National Taiwan University Hospital, Yunlin Branch (NTUH-YL) is the county's only tertiary-level emergency-response hospital. Among Taiwanese obstetric clinics that historically performed deliveries, fewer than 40% still provide intrapartum care; the remainder have ceased deliveries because of declining birth rates, an aging obstetric workforce, and the disproportionate medicolegal and infrastructural burden of unanticipated obstetric emergencies—a pattern paralleling rural maternity-unit closures documented in North America and other high-income settings [9]. Establishment of a perinatal blood dispatch platform for this catchment was formally designated as a deliverable within the Ministry of Health and Welfare (MOHW) Perinatal Care Network Project. The 4 community obstetric clinics that remain

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active in Yunlin County conduct approximately 800 to 1000 deliveries per year between them, yet have no on-site blood bank. Routine and emergency blood products have historically been supplied by the Taichung Blood Center, located 70 km away, with a round-trip ground-transport time of approximately 2 to 3 hours.

Prior Digital Health and Dispatch Innovations

Prior digital-health innovations addressing the geographic distance between obstetric front-line care and hospital blood banks fall into 2 broad categories. The first is electronic blood ordering and computerized cross-matching within single-hospital information systems. Centralized hospital information systems with barcoded patient identification, computerized cross-matching, and automated alerts have reduced wrong-blood-in-tube events and ABO-incompatible transfusions in intrahospital deployments [1]. To our knowledge, however, equivalent electronic interinstitutional ordering systems linking a hospital blood bank with off-site primary obstetric clinics have not been described in the peer-reviewed literature for the obstetric-emergency context.

The second category is unmanned aerial vehicle (UAV) delivery of blood products. The Rwandan national drone blood-delivery program—operating across 20 health facilities—has demonstrated, in a time-series analysis of nearly 13,000 deliveries, that UAV delivery is, on average, 79 to 98 minutes faster than equivalent road delivery and has reduced blood-unit expirations by 67% over 12 months [10]. The Montreal Medi-Drone pilot established that simulated red blood cell, platelet, and fresh frozen plasma products can be transported by UAV without exceeding prespecified temperature variability [11]. Subsequent feasibility and economic-evaluation studies from Malaysia have suggested favorable cost-effectiveness for short-distance UAV transport, particularly when the alternative is a long ground route around topographic barriers [12,13]. Vibration studies in military and helicopter emergency medical service contexts have raised concerns about mechanical stress on red cells under certain modes of transport, and a German validated study of helicopter-borne blood depots demonstrated that quality is preserved when temperature and packaging are appropriately controlled [14,15]. A digital ordering infrastructure is a prerequisite for any UAV-based delivery modality: without electronic, time-stamped, identity-verified ordering, a UAV in flight has no validated request to fulfill.

Reach, Effectiveness, Adoption, Implementation, and Maintenance Framework as Applied to an Organizational-Level Digital Health Intervention

The RE-AIM (Reach, Effectiveness, Adoption, Implementation, and Maintenance) framework was originally developed for individual-level behavioral interventions [16] and has been extended to organizational- and system-level implementations [17]. Its application to a digital health platform that operates at the interinstitutional level requires each dimension to be defined against an appropriate unit of analysis. In this study, we operationalize *reach* at the patient level (patients in the target catchment engaged by platform-mediated dispatch), *effectiveness* at the dispatch-episode level (against the prespecified service-level agreement [SLA] targets described in the Methods section and against the safety end point of 0 serious transfusion-related adverse events), *adoption* at the clinic and clinician levels (eligible clinics and clinicians using the platform), *implementation* at the dispatch-episode and staff-usage levels (workflow fidelity and barcode-based interception), and *maintenance* at the time-series level (sustained service volume and stakeholder satisfaction across 4 years). This distinction between reach and adoption—one at the patient level and one at the organizational level—is followed consistently throughout the manuscript.

Study Aims

We hypothesized that a digital, interinstitutional blood dispatch platform could close the geographic and informational distance between rural obstetric clinics and a tertiary blood bank. The platform combines electronic clinic ordering with national-identifier smart-card authentication, synchronous request-form printing at the hospital blood bank, barcode-driven 3-way blood-type concordance interception, and dedicated cold-chain ground transport. We further hypothesized that UAV delivery, supported by prior international experience [10-13], could provide a next-step transport modality once the digital ordering infrastructure is in place.

Within this evaluation, our specific aims were to: (1) characterize platform reach and adoption across the target rural perinatal population and affiliated obstetric clinics; (2) evaluate effectiveness against prespecified SLA targets for clinic-to-bedside blood-supply turnaround and against the safety end point of 0 serious transfusion-related adverse events; (3) assess implementation fidelity, including barcode mismatch interception and workflow adherence; (4) examine maintenance of platform use, performance, and stakeholder satisfaction over 4 years of routine operation; and (5) evaluate, as an internal continuous-improvement substudy initiated in year 3 of platform operation, the feasibility of UAV-based whole-blood transport across a representative short-range corridor as a candidate future modality to reduce the residual courier segment of turnaround time (TAT).

Methods

Study Design

We report an observational implementation evaluation of a digital health platform in routine clinical practice over the full operational period from November 1, 2021, to August 31, 2026 (n=252 dispatch episodes, of which 38 were emergencies and 214 were routine). The evaluation followed the RE-AIM framework [16,17]; SQUIRE 2.0 (Standards for Quality Improvement Reporting Excellence, version 2.0) was used as a complementary reporting guideline [18]. Although no fully preregistered prospective protocol existed, the effectiveness end point was governed by 2 prespecified SLA targets, set by consensus at a meeting between the NTUH-YL blood-bank team and physicians at the affiliated obstetric clinics before platform launch (Measures: Mapping to the RE-AIM Framework section).

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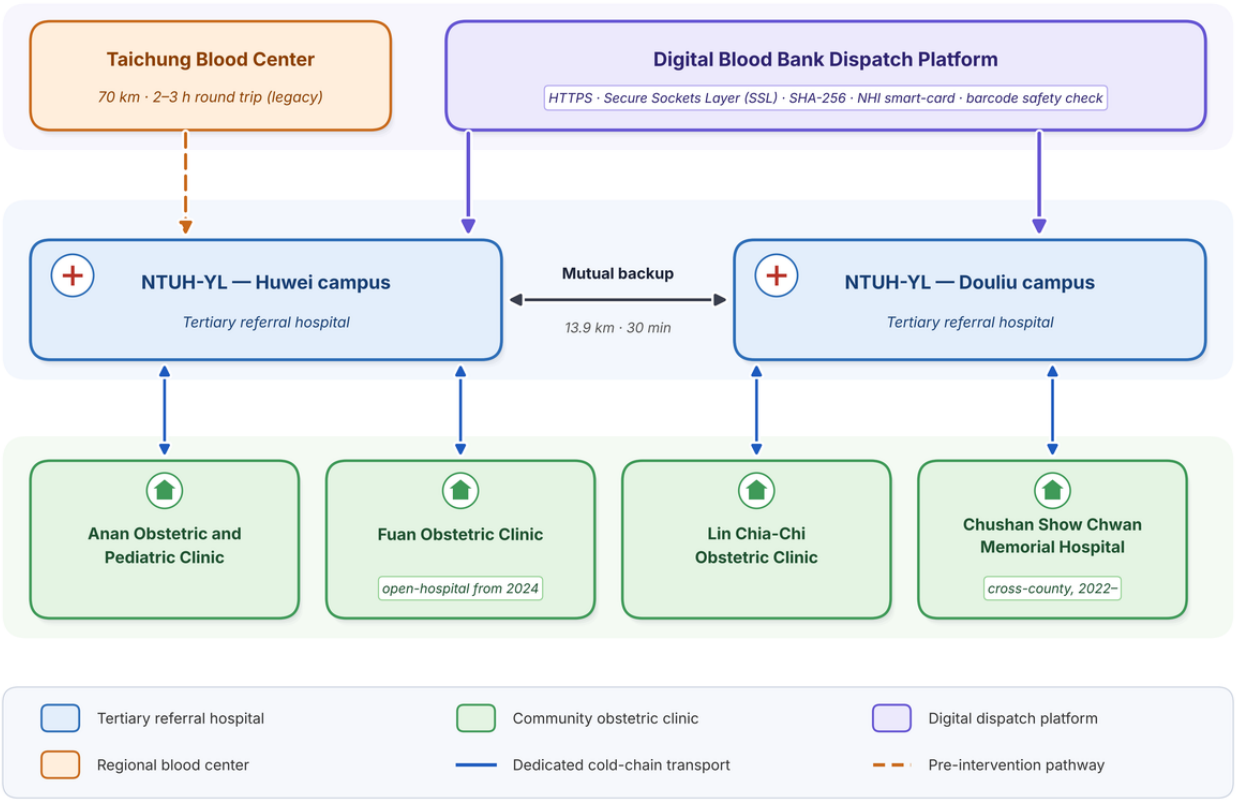
Setting and Population

National Taiwan University Hospital, Yunlin Branch (NTUH-YL) is a 946-bed dual-campus academic medical center (Douliu and Huwei campuses) serving Yunlin County (population approximately 670,000) and adjacent areas of Nantou, Changhua, and Chiayi Counties. NTUH-YL was upgraded to quasi-medical-center status by the Taiwan Joint Commission on Hospital Accreditation in 2025 and is the only tertiary-level perinatal and neonatal referral center in the county. Its Maternal-Child Medicine Center, established in March 2017, houses 12 obstetrician–gynecologists and 14 pediatricians and serves as the regional core hospital under the MOHW Perinatal Care Network Project (Figure 1).

Figure 1. Geographic and workflow schematic of the interinstitutional perinatal blood dispatch network in Yunlin County, Taiwan. The Digital Blood Bank Dispatch Platform (top, lavender) coordinates 2 National Taiwan University Hospital, Yunlin Branch (NTUH-YL) tertiary referral campuses (Huwei and Douliu, light blue), connected by a mutual-backup ground corridor of 13.9 km (approximately 30 minutes by car). Solid blue arrows show the dedicated cold-chain ground-transport links from each hospital campus to its affiliated community obstetric clinics (light green). The dashed orange line indicates the legacy supply pathway from Taichung Blood Center (70 km, 2-3 hours round trip) used before the platform launched in November 2021. h: hours; HTTPS: Hypertext Transfer Protocol Secure; min: minutes; NHI: National Health Insurance; NTUH-YL: National Taiwan University Hospital, Yunlin Branch; SHA-256: Secure Hash Algorithm 256-bit; SSL: Secure Sockets Layer.



The preimplementation transfusion pathway for the 4 affiliated community obstetric clinics—Anan Obstetric and Pediatric Clinic, Fuan Obstetric Clinic, Lin Chia-Chi Obstetric Clinic, and Chushan Show Chwan Memorial Hospital—required a paper-based blood request, transport of a patient blood sample by clinic personnel to a designated laboratory (typically Taichung Blood Center, 70 km away), waiting for blood-type confirmation and crossmatch, and ground transport of the units back to the clinic. Under this legacy pathway, patients requiring urgent transfusion were often transferred directly to a tertiary hospital rather than transfused at the clinic; consequently, preimplementation clinic records do not permit separate analysis of emergency and routine categories. The target population for this implementation was therefore the perinatal care population of Yunlin County served by the 4 affiliated obstetric clinics—approximately 800 to 1000 deliveries per year—together with the obstetric and laboratory-medicine clinicians providing front-line and tertiary care, respectively.

System Architecture and Data Flow

The platform is a stand-alone web-based add-on system serving the 4 affiliated obstetric clinics and the NTUH-YL blood bank. It is not electronically integrated with the hospital's own blood-bank information system; coordination between the platform and the blood bank occurs through a printed dispatch document generated by the platform at order submission and, for exception handling, telephone confirmation. Because there is no electronic data exchange with the blood-bank information system, no Health Level 7 Version 2 (HL7 v2) or Fast Healthcare Interoperability Resources (FHIR) standard applies.

The platform uses a three-tier logical architecture: (1) a browser-based client tier accessed by clinic and blood-bank staff over the public internet on standard Windows workstations running Microsoft Edge or Google Chrome, requiring no clinic-side native software installation; (2) an application tier hosted at the NTUH-YL Hospital Information Management Office data center; and (3) a Microsoft SQL Server database

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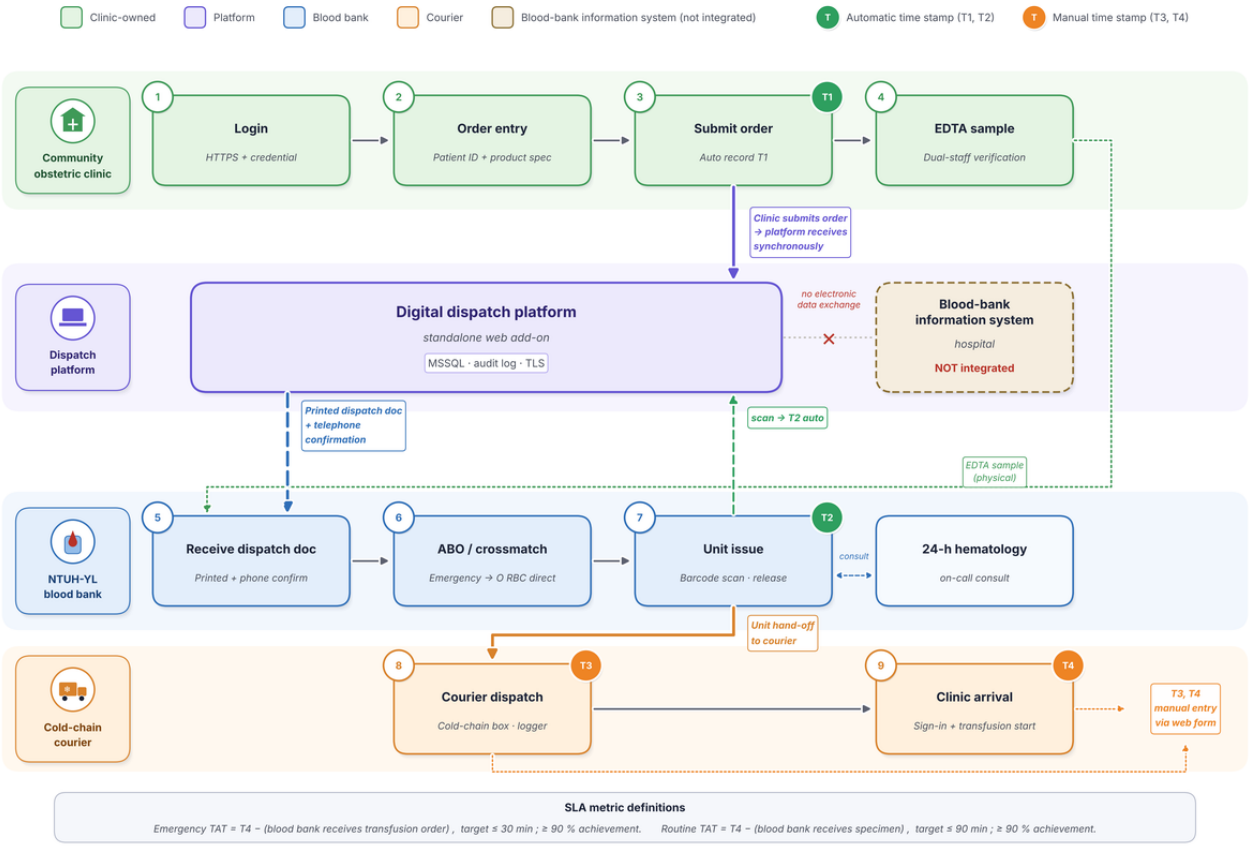
that stores dispatch requests, associated clinical metadata, and platform audit-log events (Table S2 in Multimedia Appendix 1). Inbound and outbound traffic is encrypted in transit using Transport Layer Security (TLS) over HTTPS, backed by a signed digital certificate. Authentication uses institution-issued accounts with passwords stored server-side as Secure Hash Algorithm 256-bit (SHA-256) one-way cryptographic hashes. Patient identification at the point of order uses the contact-based national-identifier microchip on the National Health Insurance smart card, read by a personal computer/smart card–compliant card reader at the clinic workstation; this populates the demographic fields automatically and eliminates manual transcription. Interinstitutional connectivity uses standard public-internet routing without dedicated leased lines.

The platform automatically records 2 workflow time stamps: the order-submission time at the clinic (T1) and the unit-issue time at the blood bank, written when the blood-bank technologist scans the unit for release (T2). Two additional workflow time stamps are entered manually by the operators concerned via the same web interface: courier dispatch time (T3, entered by the courier) and clinic-arrival time (T4, entered by receiving clinic staff). All 4 time stamps are written to the same audited database. The workflow and data flow are shown in Figure 2. Client-side JavaScript performs first-pass field validation; server-side stored procedures perform authoritative validation before commit. On rejection, no dispatch record is written, and the client receives a structured error message with corrective instruction.

Figure 2. Workflow and data flow of the interinstitutional perinatal blood dispatch platform. The platform is a stand-alone web add-on system (lavender box, center); it operates alongside—but is not electronically integrated with—the hospital's blood-bank information system (tan box, right), as indicated by the dotted line with a red ✕. Green solid circles mark the 2 workflow time stamps that are recorded automatically by the platform (T1=clinic order submission; T2=unit issue by blood-bank barcode scan). Orange solid circles mark the 2 workflow time stamps entered manually by the operators concerned (T3=courier dispatch; T4=clinic arrival). Service-level agreement (SLA) metric definitions appear in the footer of the figure and correspond to Table S1 in Multimedia Appendix 1. ABO: ABO blood group; doc: document; EDTA: ethylenediaminetetraacetic acid; h: hours; MSSQL: Microsoft SQL Server; NTUH-YL: National Taiwan University Hospital, Yunlin Branch; RBC: red blood cell; SLA: service-level agreement; TAT: turnaround time.



Intervention

Overview

The intervention was developed iteratively from January to October 2021 by a multidisciplinary Perinatal Care Working Group comprising the Department of Obstetrics and Gynecology, Department of Pediatrics, Department of Laboratory Medicine (which encompasses the regional blood bank), and the Hospital Information Management Office. The platform went live on November 1, 2021. The intervention comprises 4 interlocking components, of which the interinstitutional digital blood dispatch platform (component 1) is the focus of this report.

Component 1: Digital Blood Dispatch Platform (Focus of This Report)

The clinical workflow consists of the following steps, as illustrated in Figure 2 and detailed in Textbox 1.

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Textbox 1. Workflow of the clinic-based obstetric blood ordering, safety verification, and dedicated blood delivery system.

Authentication

The clinic obstetrician logs in using an institution-issued account (with Secure Hash Algorithm 256-bit [SHA-256]–hashed passwords).

Patient identification

The clinician inserts the patient's National Health Insurance smart card into a card reader at the clinic workstation. Demographic fields (name, national identifier, date of birth, and sex) are populated automatically.

Order specification

The clinician selects, from drop-down menus, the patient's self-reported ABO blood group (ABO)/Rhesus D blood group antigen (RhD), the requested blood products (leukocyte-poor red blood cell concentrate, fresh frozen plasma, and prestorage leukocyte-reduced apheresis platelets), the number of units, the required time, the requesting campus (Douliu or Huwei), and whether a blood warmer is required.

Submission

Upon submission, the platform records T1 (automatic time stamp) and generates a printed dispatch document at both the clinic and the blood bank. For declared emergencies ("blood required within 5 minutes"), the platform routes the request for direct issue of O RhD-positive (or O RhD-negative, upon request) red blood cells without awaiting crossmatch results.

Sample handling

A 2-mL ethylenediaminetetraacetic acid (EDTA) tube is collected at the clinic, double-checked, and countersigned by 2 clinic staff members. It is dispatched together with the printed request form to the hospital blood bank.

ABO typing, crossmatching, and safety interception

At the blood bank, the technologist enters the laboratory-determined ABO/RhD type and scans the barcode of each candidate blood unit. The platform performs real-time three-way concordance checking of (1) the patient's self-reported blood type, (2) the laboratory-determined blood type, and (3) the blood unit type. If a discrepancy is detected, a modal warning is triggered, blocking issuance.

Unit issue

T2 (automatic time stamp) is recorded during the same barcode scan, and the unit is released.

Dedicated cold-chain transport

Units are packed in a validated insulated container with continuous temperature logging and transported by a contracted dedicated courier, who enters T3 (manual time stamp) at dispatch. Clinic staff enter T4 (manual time stamp) upon arrival.

On-call hematology consultation

A laboratory medicine specialist physician is available by telephone 24 hours a day to address ABO/RhD typing discrepancies, abnormal antibody screening results, and complex obstetric transfusion guidance.

Components 2-4 (Contemporaneous Parallel Initiatives, Not Evaluated in This Study)

Three additional service-line initiatives were implemented under the same MOHW Perinatal Care Network Project during the same period. They are described here for context only, are not evaluated in this report, and may plausibly have contributed to broader outcomes captured under maintenance. Component 2 involved electronic referral for high-risk pregnancies, whereby affiliated clinics initiate electronic referrals through the National Health Insurance Administration's e-referral platform when high-risk features are identified during antenatal visits. Component 3 involved 24-hour neonatal retrieval with 4G remote vital-sign monitoring, whereby 4 mobile 4G neonatal physiologic monitors were deployed at affiliated clinics to transmit continuous heart rate, respiratory rate, oxygen saturation, and temperature data to a central display at the NTUH-YL neonatal intensive care unit. Component 4 involved an open-hospital obstetric model, whereby patients receive antenatal care at the participating clinic and present to NTUH-YL for delivery, where the clinic-based obstetrician and hospital obstetrician jointly attend the delivery.

UAV-Delivery Feasibility Substudy (Initiated Year 3)

After 3 years of platform operation, service-quality data indicated that, of the workflow segments contributing to composite TAT, the segment least amenable to further reduction under ground transport was the courier segment (T3 to T4). In year 3, the multidisciplinary program working group initiated a UAV feasibility substudy as an internal continuous-improvement activity, aimed at exploring whether an alternative aerial transport modality could reduce this segment while preserving cold-chain integrity and blood-product quality. The substudy was performed in collaboration with the Department of Aeronautical Engineering, National Formosa University (official English name of 國立虎尾科技大學, Huwei, Yunlin, Taiwan). Flights used a DROXO DX5 quadcopter UAV (airframe weight 7 kg; wingspan approximately 1.1 m × 0.5 m; maximum take-off weight 15 kg; payload capacity approximately 3 kg—sufficient to carry 2 units of packed red blood cells together with the cold-chain container and insulation; ingress protection rating IP65, permitting flight under light rain) over a 4-km one-way test corridor with a total mission time of approximately 8 minutes. Whole-blood units (collected with citrate-phosphate-dextrose-adenine-1 anticoagulant preservative solution [CPDA-1]) from 3 healthy adult volunteer donors were stored under standard blood-bank

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conditions and tested on days 1, 8, 15, and 25 of storage—yielding 3 donor units × 4 storage days = 12 unit-day pre/post pairs. For each test day, each unit was loaded into a validated insulated container fitted with a continuous temperature logger, foam-wrapped, sealed, and flown over the test corridor. Sodium, potassium, chloride, red blood cell count, hemoglobin, hematocrit, platelet count, and the laboratory hemolysis index were measured immediately before and immediately after each flight. Container temperature was sampled continuously throughout each flight and required to remain within the regulatory 2 °C to 10 °C window. The current substudy reports initial feasibility on whole-blood units only—the highest-use product in our network; additional flight distances and other blood-product types are under evaluation and will be reported separately.

Measures: Mapping to the RE-AIM Framework

Measures were prespecified for each of the 5 RE-AIM dimensions, plus the UAV feasibility substudy (Table 1). Prespecified operational definitions and data sources for each measure are summarized in Table 2.

Table 1. Mapping of study measures to the RE-AIM[a] framework, with the unit of analysis specified per dimension.

RE-AIM dimension	What it captures	Unit of analysis	Operational measures used in this study
Reach	Target population engaged	Patients	Patients receiving platform-mediated dispatched transfusions in the target Yunlin catchment area during the study period; a comprehensive patient-level denominator could not be captured (Limitations section).
Effectiveness	Effect on primary clinical and safety outcomes	Dispatch episodes	Achievement of prespecified SLA[b] targets: routine dispatch ≥90% within 90 minutes; emergency dispatch ≥90% within 30 minutes; and freedom from serious transfusion-related adverse events.
Adoption	Uptake by clinics and clinicians	Clinics; clinicians	Number of activated clinics (numerator) divided by the total number of eligible obstetric clinics in the catchment area (denominator); proportion of orders submitted through the platform rather than legacy pathways.
Implementation	Fidelity and intermediate process quality	Dispatch episodes; staff usage	Workflow adherence, including the barcode-based 3-way blood-type concordance interception rate, protocol deviation events, and staff use of the on-call hematology consultation channel.
Maintenance	Sustainability over time	Time series	Continued service volume across consecutive calendar years; sustained SERVQUAL[c] composite stakeholder satisfaction between the 3-month and 15-month postimplementation assessments; platform downtime and protocol decay events.
UAV[d] substudy (exploratory)	Feasibility of UAV transport modality	Unit-days	Preflight vs postflight Na, K, and Cl levels; red blood cell count, hemoglobin, hematocrit, platelet count, and laboratory hemolysis index; intracontainer temperature stability within the regulatory range of 2 °C to 10 °C.

[a]RE-AIM: Reach, Effectiveness, Adoption, Implementation, and Maintenance.

[b]SLA: service-level agreement.

[c]SERVQUAL: service quality.

[d]UAV: unmanned aerial vehicle.

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Table 2. Operational definitions of prespecified measures, with RE-AIM[a] domain alignment.

Measure	RE-AIM domain	Operational definition
Emergency SLA[b] achievement rate	Effectiveness (primary)	Proportion of emergency episodes with (T4 − blood bank order-receipt time) ≤30 minutes; target ≥90%.
Routine SLA achievement rate	Effectiveness (primary)	Proportion of routine episodes with (T4 − blood bank specimen-receipt time) ≤90 minutes; target ≥90%.
Emergency turnaround time distribution	Effectiveness (descriptive)	Median (IQR) and range of episode-level emergency turnaround times, by calendar year and overall.
Total dispatch episodes and units	Reach/maintenance	Counts per calendar year and in aggregate.
Transfusion-related serious adverse events	Effectiveness (safety)	Acute hemolytic reactions, febrile nonhemolytic reactions, transfusion-related acute lung injury, transfusion-associated circulatory overload, anaphylaxis, and septic reactions, ascertained through per-episode clinician assessment of pre-, intra-, and posttransfusion physiological parameters.
Transfusion incidents (process safety events)	Implementation	Wrong-blood-in-tube events; ABO[c] mismatches detected before transfusion; mislabeling; and temperature excursions.
Stakeholder satisfaction	Maintenance	28-item SERVQUAL[d] composite score (5-point Likert scale) at the 3-month and 15-month postimplementation assessments.
UAV[e] substudy end points	Exploratory	Preflight vs postflight Na, K, Cl, red blood cell count, hemoglobin, hematocrit, platelet count, and lipemia, icterus, and hemolysis indices; container temperature stability.

[a]RE-AIM: Reach, Effectiveness, Adoption, Implementation, and Maintenance.

[b]SLA: service-level agreement.

[c]ABO: ABO blood group.

[d]SERVQUAL: service quality.

[e]UAV: unmanned aerial vehicle.

Effectiveness End Point: Prespecified SLA Targets

Before platform launch, a consensus meeting between the NTUH-YL blood bank team and physicians at the affiliated obstetric clinics established 2 explicit SLA targets that would define successful Effectiveness. The routine SLA is defined as the time of clinic arrival (time stamp T4) minus the time the blood bank received the specimen for ABO/RhD typing, antibody screening, and crossmatching, with an allowable interval of no more than 90 minutes; the operational target is that at least 90% of routine episodes meet this 90-minute threshold. The emergency SLA is defined as the time of clinic arrival (time stamp T4) minus the time the blood bank received the transfusion order for direct issue of O-type packed red blood cells, with an allowable interval of no more than 30 minutes; the operational target is that at least 90% of emergency episodes meet this 30-minute threshold. The preimplementation operational reference of approximately 180 minutes was derived from structured prelaunch interviews with clinic physicians and nurses, who reported their typical waiting time for blood under the legacy pathway; it is not a chart-review dataset and does not permit separation of emergency and routine categories (Setting and population section).

Stakeholder Satisfaction: Service Quality Substudy

A 28-item service quality (SERVQUAL) instrument [19] was administered to physicians, nursing staff, and allied clinic staff (including clinic pharmacists) at the 4 affiliated obstetric clinics at 3 and 15 months postimplementation; the instrument was not administered to NTUH-YL blood-bank medical technologists or courier staff. The instrument covers 5 service-quality dimensions (tangibles, 5 items; reliability, 6 items; responsiveness, 7 items; assurance, 5 items; and empathy, 5 items), rated on a 5-point Likert scale with a not-applicable option. The full instrument in traditional Chinese, as administered, is provided in Table S3 in Multimedia Appendix 1.

Administration was anonymous, capturing only professional role (physician, nurse, and other, where “other” includes clinic pharmacists and other allied clinic staff) and sex. The physician cohort at the 4 affiliated clinics is small and stable; the nursing cohort may have experienced turnover between the 2 administrations, and per-individual pairing is not possible under anonymous administration. Comparisons between the 2 administrations are therefore made at the professional-group level, with physicians as an identified stable cohort and nurses as a stable-population aggregate. The published primary comparison used the overall composite score across the 28 items; per-dimension scores were also computed. Internal consistency was assessed with Cronbach α at each administration. The 3-month administration is described as an early postimplementation baseline rather than a preintervention baseline.

Analysis

Counts and medians with IQRs were summarized descriptively by calendar year and over the aggregate period. The primary effectiveness metric is the achievement rate against each prespecified SLA target; formal pre-vs-post statistical testing is not applied because no per-episode preimplementation TAT

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dataset exists (Setting and Population section). Postimplementation TAT distributions are reported as median (IQR) and range by urgency and by calendar year (Table S1 in Multimedia Appendix 1). A Wilcoxon rank-sum test comparing 2022 (year 1) with the most recent full year of emergency TAT is applied to demonstrate within-period stability.

SERVQUAL composite scores were compared between the 3-month and 15-month administrations using 2-tailed paired-samples *t* tests at the professional-group level, with the acknowledged limitation that per-individual pairing is not possible under anonymous administration (Discussion section). For the UAV substudy, per-parameter preflight vs postflight comparisons are reported descriptively (mean difference and 2-tailed paired *t* test *P* value with the small-sample caveat) per storage day; the 4 storage days function as internal replicates of the null hypothesis rather than as independent primary tests, and no family-wise adjustment is applied. All analyses were performed with R (version 4.3) and Microsoft Excel; figures were generated with matplotlib (Python) and BioRender.

Ethical Considerations

The operational activity of the digital dispatch platform is a sanctioned regional clinical service delivered under the MOHW Perinatal Care Network Project. Patient-level activity in the main study (dispatched transfusion for clinical need at the affiliated obstetric clinics; n=252 episodes and 554 blood-product units across the operational period) was routine clinical care delivered through the platform, not a research intervention: patients received blood dispatch only when their attending clinician identified a clinical need through the ordinary care pathway, and no additional research-related interventions, biological sampling, or data collection were introduced beyond routine care. The aggregate service-evaluation data reported here were extracted retrospectively from the platform audit log and are reported in deidentified aggregate form; this activity therefore did not require submission to the Research Ethics Committee as a human-subjects research protocol.

The UAV-delivery feasibility substudy is a separate research protocol involving additional blood collection from healthy adult volunteer donors for laboratory quality-control testing. This substudy was reviewed and approved by the National Taiwan University Hospital Research Ethics Committee (approval number 202505058RIN; protocol title “Evaluation and verification of drone optimization of blood product dispatch center delivery efficiency”; principal investigator YCH) in collaboration with the Department of Aeronautical Engineering, National Formosa University. All volunteer donors provided written informed consent and were required to meet the standard blood-donation eligibility criteria of the Taiwan Blood Services Foundation (aged 18-65 years, body weight ≥50 kg; normal vital signs, and hemoglobin concentration ≥13 g/dL for men and ≥12 g/dL for women). Pregnant women, individuals with recent surgery or transfusion, and those meeting other exclusions specified in national blood-donation standards were not enrolled. A single blood collection of up to 250 mL per donor was drawn for the substudy.

Transfusion-related adverse events (in the main-study clinical activity) were ascertained on a per-episode basis by the attending clinician at the requesting clinic. For each transfusion, the clinician documented the patient’s pretransfusion, intratransfusion, and posttransfusion physiological parameters (vital signs, oxygen saturation, subjective symptoms, and any acute clinical events such as chills, rash, dyspnea, hypotension, or fever) and made an attribution judgment as to whether any observed change was attributable to the transfusion. Any suspected reaction was to be escalated to the on-call hematology consultation channel and, if confirmed, reported to the hospital’s transfusion committee under standard institutional procedure.

Results

Service Volume

Over the full operational period from November 1, 2021, through August 31, 2026, the platform supported 252 dispatch episodes for 252 individual patients, of which 38 (15.1%) were declared emergencies and 214 (84.9%) were routine. A total of 554 blood-product units were issued across the 4 affiliated obstetric clinics. Annual service volume is shown in Figure S1 in Multimedia Appendix 1. A modest decrease in dispatch episodes in 2025 is attributable to 2 operational events outside platform control: 1 of the 4 affiliated obstetric clinics (Fuan Obstetric Clinic) ceased intrapartum services in September 2024 because of clinician retirement, transitioning to an antenatal-only open-hospital model; and the contracted ground courier service withdrew transport of blood products in December 2025.

Reach and Adoption

Adoption reached 100% (4/4) of eligible clinics and of obstetric clinicians in each clinic; all clinical blood orders during the operational period were submitted through the platform rather than through legacy pathways. Patient-level reach is characterized by the 252 dispatch episodes across the study period; a true patient-level reach proportion cannot be computed because the denominator—all obstetric transfusion-eligible events in the Yunlin catchment—is not comprehensively captured in either clinic or hospital records, and, under the legacy pathway, many such patients were transferred directly to tertiary hospitals rather than treated locally (Setting and Population section).

Effectiveness: SLA Achievement and TAT

The prespecified emergency SLA of at least 90% within 30 minutes was met in 84.2% (32/38; 95% CI approximately 69.6%-92.6%) of emergency episodes across the pooled series. Achievement varied by year: 0% (0/1) in 2021 (single launch-phase episode), 87.5% (7/8) in 2022, 83.3% (10/12) in 2023, 71.4% (5/7) in 2024 (during a period of courier-service disruption affecting the first half of that year), 100% (2/2) in 2025, and 100% (8/8) in 2026 through August. The median emergency TAT across the series was 28 minutes (IQR 23-29; range 13-54; 95% CI approximately 25-29). Full year-by-year distributions are presented in Table S1 in Multimedia Appendix 1.

For routine dispatches (n=214), the prespecified SLA of at least 90% within 90 minutes was met in 97.7% (209/214; 95% CI approximately 94.6%-99%) of episodes. Achievement by year was consistently high: 100% (3/3) in 2021, 96.1% (49/51) in

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2022, 98.3% (57/58) in 2023, 96.2% (51/53) in 2024, 100% (31/31) in 2025, and 100% (18/18) in 2026 through August. The median routine TAT was 72 minutes (IQR 62-79; range 23-118; 95% CI approximately 69-74). Unlike the emergency series, routine achievement did not show a dip in 2024, consistent with the interpretation that the temporary courier disruption in the first half of 2024 primarily affected time-critical dispatches. The preimplementation TAT reference (approximately 180 minutes, derived from clinician-recall prelaunch interviews and not separated by category) is not directly comparable and was not tested.

Safety and Implementation Fidelity

Across 252 dispatch episodes and 554 blood-product units, per-episode clinician judgment identified 0 transfusion-related acute hemolytic reactions, 0 febrile nonhemolytic transfusion reactions, 0 cases of transfusion-related acute lung injury, 0 cases of transfusion-associated circulatory overload, 0 anaphylactic transfusion reactions, and 0 septic transfusion reactions. Zero ABO-mismatch transfusions were completed, 0 wrong-blood-in-tube events propagated to transfusion, and 0 documented temperature-excursion incidents occurred during transport. The automated 3-way blood-type concordance check generated visible interception warnings on at least 1 documented occasion during the observation period (a clinic-reported type-B RhD-positive patient determined to be type A on laboratory testing); the unit was halted, retyped, and reissued correctly with no harm.

Stakeholder Satisfaction

The 28-item SERVQUAL instrument was administered at 2 postimplementation time points: 3 months (n=32 clinic respondents; 4 physicians, 19 nurses, and 9 allied clinic staff) and 15 months (n=38; 6 physicians, 30 nurses, and 2 allied clinic staff). The 3-month composite mean was 4.65 (SD 0.53) across the 28 items, with excellent internal consistency (Cronbach α=0.985 overall; per-dimension α from 0.907 for assurance to 0.961 for responsiveness). The 15-month composite mean rose to 5.00 (SD 0.01), essentially at the 5-point scale ceiling; internal consistency at 15 months cannot be meaningfully estimated because virtually all respondents scored 5 on all items, producing near-zero item variance (Cronbach α approaches its lower boundary under such conditions [19]). Mean improvement between the 2 administrations was consistent across dimensions: tangibles +0.34 (4.66 → 5.00), reliability +0.31 (4.69 → 5.00), responsiveness +0.41 (4.59 → 5.00), assurance +0.38 (4.61 → 4.99), and empathy +0.27 (4.72 → 4.99). Selected item-level scores from the 2 administrations are shown in Table 3; a full item-level listing is provided in Table S3 in Multimedia Appendix 1.

Table 3. Selected SERVQUAL[a] items at 3-month and 15-month postimplementation administrations (physicians and nursing staff at 4 affiliated obstetric clinics; n=32 respondents per administration). The full 28-item instrument is provided in Table S3 in Multimedia Appendix 1. Comparisons are at the professional-group level; per-individual pairing is not possible under anonymous administration (Discussion section).

SERVQUAL item[b]	3-month, mean (SD)	15-month, mean (SD)	*P* value (paired *t* test)
Tangibles: platform information system meets clinical needs	4.66 (0.55)	5.00 (0.00)	.001
Tangibles: hospital blood inventory meets clinic demand	4.72 (0.52)	5.00 (0.00)	.005
Reliability: blood-product quality and accuracy	4.81 (0.40)	5.00 (0.00)	.01
Reliability: timeliness of blood supply	4.75 (0.51)	5.00 (0.00)	.009
Responsiveness: immediate assistance when platform problems arise	4.63 (0.61)	5.00 (0.00)	.002
Responsiveness: will continue using the platform	4.75 (0.44)	5.00 (0.00)	.003
Assurance: hospital provides transfusion-consultation service	4.66 (0.60)	5.00 (0.00)	.003
Empathy: special blood-type identification ensures patient safety	4.72 (0.52)	5.00 (0.00)	.005
Empathy: blood warmer provision improves transfusion safety	4.72 (0.58)	4.97 (0.16)	.02
Composite (all 28 items)	4.65 (0.53)	5.00 (0.01)	<.001

[a]SERVQUAL: service quality.

[b]5-dimension mapping is provided in Table S3 in Multimedia Appendix 1.

UAV-Delivery Feasibility Substudy

Twelve unit-day paired flights were conducted (3 donor whole-blood units × 4 storage days: days 1, 8, 15, and 25), each over a 4-km corridor with an 8-minute single-trip mission time. Container temperature was maintained between 2 °C and 10 °C throughout each flight (Figure S2 in Multimedia Appendix 1). Preflight and postflight biochemical and hematologic values lay within similar ranges on each storage day tested; no consistent direction of change was apparent across the 4 storage days examined. Per-parameter pre-vs-post 2-tailed paired *t* test *P* values are reported in Table S4 in Multimedia Appendix 1 alongside the raw preflight and postflight values for reference. Where individual comparisons reached *P* values of less than .05 (day 15 chloride, *P*<.001; day 25 chloride, *P*=.04), the corresponding absolute mean difference was no greater than 1.7 mmol/L—a magnitude within analytical measurement variability for the chloride assay and not clinically meaningful. On day 25, hemoglobin, hematocrit, and platelet count showed trends toward differences that did not reach statistical significance (*P*=.06, .09, and .07, respectively), with absolute mean differences of no greater than 0.13 g/dL, 0.4%, and 4 × 10^3/μL—also within analytical measurement variability and not

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clinically meaningful. Figure 3 shows the integrated paired-value visualization for all 7 measured biochemical parameters across the 4 storage days.

The much larger K+ signal in the dataset is the storage-day trajectory (mean preflight K+: 3.27 mmol/L on day 1, 11.49 on day 8, 15.90 on day 15, and 21.33 on day 25), which reflects the classical time-dependent leakage of intracellular potassium from red blood cells stored in CPDA-1 and is independent of flight condition. The pre-vs-post K+ mean difference on day 1 (+0.09 mmol/L; 2-tailed paired *t* test *P*=.10) is neither statistically significant on a 2-tailed test nor clinically meaningful.

Figure 3. Preflight vs postflight comparison of whole-blood biochemical and hematologic parameters for the unmanned aerial vehicle (UAV)–delivery feasibility substudy. Seven parameters are shown across 4 storage days (days 1, 8, 15, and 25): sodium (mmol/L), potassium (mmol/L), chloride (mmol/L), red blood cell count (× 10^6/μL), hemoglobin (g/dL), hematocrit (%), and platelet count (× 10^3/μL). Each panel shows paired preflight (open circle) and postflight (filled circle) values for the 3 donor units on each of the 4 storage days. The laboratory hemolysis index was 0 in all measurements and is not plotted. Numeric values and per-comparison 2-tailed paired t test P values are provided in Table S4 in Multimedia Appendix 1.



Service-Line Co-Benefits Within the Wider Perinatal Network

Although not the primary focus of this report, parallel improvements were observed across the 3 companion components of the perinatal network. Annual high-risk pregnancy antenatal referrals from affiliated clinics to NTUH-YL rose from a 2021 baseline of 8 to a 4-year mean of 27.5 per year; neonatal retrievals rose from a 2021 baseline of 8 to a 4-year mean of 21.4 per year; and 70 successful deliveries occurred under the shared-care open-hospital model between November 2021 and December 2024, with 9 additional pregnancies enrolled and awaiting delivery at the time of writing. Because these initiatives ran in parallel and could plausibly contribute to broader outcomes, they are noted here as contextual co-observations rather than as outcomes attributable to the dispatch platform.

Discussion

Principal Findings

We report an observational implementation evaluation of a digital, interinstitutional perinatal blood dispatch platform operating between a tertiary hospital blood bank and 4 primary obstetric clinics serving a rural Taiwanese county over 4 years and 10 months (252 dispatch episodes, 554 units). Evaluated against the RE-AIM framework, adoption reached 100% of eligible clinics and their obstetric clinicians; effectiveness was assessed against 2 prespecified SLA targets set by consensus before launch, with the pooled emergency series achieving the target of no more than 30 minutes in 84.2% (32/38) of episodes and the 2 most recent operational years (2025 and 2026) reaching 100%, and the routine series achieving the target of no more than 90 minutes in 97.7% (209/214) of episodes; 0 serious transfusion-related adverse events were documented on

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per-episode clinician ascertainment; SERVQUAL composite stakeholder satisfaction rose from a 3-month postimplementation baseline of 4.65 (SD 0.53; n=32; Cronbach α=0.985) to a 15-month composite of 5.00 (SD 0.01; n=38), close to the scale ceiling; and implementation fidelity was sustained without documented protocol-deviation events resulting in serious adverse outcomes. A continuous-improvement UAV-delivery feasibility substudy, initiated in year 3, found no consistent direction of change in whole-blood biochemical or hematologic parameters across the 4 storage-day flights tested.

Interpretation Within the RE-AIM Framework

Reach and Adoption

Full activation of all 4 (100%) eligible affiliated obstetric clinics reflects strong organizational adoption in a low-resource rural setting. Two features supported this: the platform leverages digital health infrastructure already present in routine Taiwanese clinical practice (the National Health Insurance smart card and personal computer/smart card–compliant readers), eliminating the need to install proprietary identification hardware at the clinic; and the platform operates through standard public internet routing rather than dedicated leased lines, lowering the cost and reproducibility barrier for additional sites. Patient-level reach in the target catchment cannot be reported as a proportion because the preimplementation denominator is not comprehensively captured in either clinic or hospital records, and the legacy pathway routinely transferred urgent cases directly to tertiary hospitals rather than treating them at the clinic (Limitations section).

Effectiveness Against Prespecified SLA Targets

Framing effectiveness against 2 SLA targets set in advance by consensus between blood bank and clinic clinicians provides prespecified outcome measures without requiring a formal prospective protocol. The emergency target (≥90% within 30 minutes) was achieved in the pooled series (32/38, 84.2%) and consistently in the most recent operational years (100% in 2025 and 2026 to date); the routine target (≥90% within 90 minutes) was met in 97.7% (209/214) of episodes over the entire operational period, and every calendar year individually reached at least 96%. The 2024 dip in emergency achievement (5/7, 71.4%) coincides with a period of courier-service disruption in the first half of that year and is discussed further in the Limitations section; notably, routine achievement in 2024 was 96.2%, suggesting the courier disruption primarily affected time-critical dispatch rather than the overall service capacity. The 2024 dip is instructive: it illustrates that effectiveness under this framework tracks operational reality directly, without requiring assumptions of causal attribution to the platform. Comparisons with the Rwandan national drone blood-delivery program (mean UAV delivery time 49.6 minutes; 79-98 minutes faster than estimated ground delivery [10]) and North American UAV pilot studies reporting flight times of 17 to 28 minutes for short-range urban delivery [11] span our observed emergency TATs, although transport modality, distance, population, and TAT definition differ substantially and preclude formal comparison.

Implementation and Maintenance

Sustained implementation fidelity over 4 years is itself a result. Real-world digital health interventions commonly show protocol drift or selective abandonment within 12 to 18 months of go-live. In our setting, the 3-way blood-type concordance interception, dedicated cold-chain transport, and on-call hematology consultation channel remained in active use at the end of the observation period. Sustained fidelity may reflect one or more of the following, which our data cannot separate: (1) the platform's automation of the barcode-based safety check, (2) the training and audit program that accompanied deployment, (3) the small, stable clinician group with strong preexisting professional relationships across the network, and (4) a Hawthorne effect associated with participation in an evaluated service. Four-year maintenance is further supported by sustained service volume across consecutive calendar years, ceiling-level SERVQUAL stakeholder satisfaction, and 0 serious transfusion adverse events at the end of the observation period.

The 15-month SERVQUAL composite mean of 5.00 lies close to the ceiling of the 5-point Likert scale, indicating that the SERVQUAL instrument as administered lacks dynamic range to detect further improvement or subtle deterioration beyond the 15-month time point. Sustained satisfaction should therefore be interpreted as absence of decay rather than as evidence of continuing improvement.

Exploratory UAV Feasibility Findings

The UAV substudy reports initial feasibility on whole-blood units only—the highest-use product in our—over a 4-km, 8-minute route with 3 donor units per storage day (12 total unit-day observations). Preflight and postflight parameters lay within similar ranges on each storage day tested. This is a preliminary feasibility observation. It cannot establish that UAV transport does not affect blood-product quality: the sample is too small to detect small effects, the transport distance is short relative to potential operational routes, and only whole-blood units were tested. Additional flight distances and additional blood-product types are under evaluation and will be reported separately. The findings are consistent with the Montreal Medi-Drone results for simulated red blood cells (temperature variability ≤5% [11]) and with the validated helicopter blood-depot program reported from Selleng et al [15]. Concerns raised by vibration studies in military settings about red-cell injury under extreme mechanical stress [14] are unlikely to apply to short-range civilian quadcopter missions.

An important interpretive point concerns potassium. The dominant K+ signal in the dataset is not flight-related but reflects the well-characterized time-dependent leakage of intracellular potassium from red cells stored ex vivo in CPDA-1, giving mean preflight K+ values that rise from 3.27 mmol/L on day 1 to 21.33 mmol/L on day 25. Within any given storage day, the preflight vs postflight difference is small and, on day 1 (mean difference +0.09 mmol/L, 2-tailed paired *t* test *P*=.10), is neither statistically significant on a 2-tailed test nor clinically meaningful.

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Limitations

Principal strengths of this study are a 4-year, 10-month observation period that captures maintenance dynamics beyond the typical pilot horizon; an a priori multilevel evaluation framework (RE-AIM); a complete denominator of the eligible affiliated clinics in the catchment (4/4); an explicit prespecified SLA target framework governing the Effectiveness end point; and a per-episode clinician-ascertained safety end point through the full 4-year, 10-month period.

Several limitations should be acknowledged. First, there is no concurrent control, and this is a material limitation for 3 independent reasons. The first is ethical. Once the platform was operational and demonstrably faster in the early operational quarter, allocating patients requiring urgent perinatal transfusion to the known-slower legacy pathway solely for research purposes would have been ethically unacceptable; no individual patient could be transfused twice under different protocols to serve as her own control. The second is structural. Under the legacy pathway, urgent patients were transferred directly to a tertiary hospital rather than transfused at the clinic, so no preimplementation in-clinic urgent-transfusion comparator population exists to permit a pre-vs-post comparison in the emergency category. The third concerns downstream outcomes. Individual patient outcomes beyond the transfusion episode (eg, 30-day maternal or neonatal outcomes) cannot be tracked because clinic-based transfusion episodes are followed under separate clinical records that this research protocol does not link, in accordance with patient privacy provisions. Consequently, we present no patient-level clinical outcomes attributable to the platform.

Second, the observational design leaves several alternative explanations for observed improvements over time that our data cannot exclude: secular trends in Taiwan's national blood bank service infrastructure; coincident MOHW investment in the Perinatal Care Network Project (components 2-4); COVID-19 pandemic effects on obstetric service patterns during part of our study period; Hawthorne effects associated with participation in an evaluated service; and improved availability of the on-call hematology channel driven by MOHW workforce policy. Third, the preimplementation TAT reference (approximately 180 minutes) is a clinician-recall interview value from prelaunch structured interviews, not a chart-review dataset, and does not permit a formal comparison. Fourth, the SERVQUAL substudy measured composite satisfaction at 3 months (n=32) and 15 months (n=38) and is subject to a marked ceiling effect at the 15-month administration that renders Cronbach α uninformative and eliminates the instrument's dynamic range for detecting further improvement; per-individual pairing is not verifiable under anonymous administration. Fifth, the reported rate of 0 serious adverse transfusion events, while reassuring, reflects a denominator of 554 units and does not establish that the platform improved transfusion safety in an absolute sense—both because the low base rate of serious transfusion reactions and the small denominator preclude such inference, and because no concurrent comparator was available. Sixth, the UAV feasibility substudy evaluated only whole-blood units and only over a 4-km corridor; UAV transport of platelets and plasma, and longer-range missions, require separate evaluation.

Implications for Practice and Policy

The platform is technically modest. It relies on standard HTTPS web technology, SHA-256 password hashing, a national smart-card identifier, and barcode scanners that are already present in most hospital blood banks. The principal investments were institutional and informational, not technological: a sustained multidisciplinary working group, a MOHW reimbursement framework recognizing interinstitutional dispatch as a billable activity, and a regional clinical culture in which the tertiary hospital regards the primary obstetric clinic as a partner rather than a competitor. The platform has attracted several visits from other Taiwanese health care institutions for study and learning; no full replication has yet been completed elsewhere. Within Taiwan, our team estimates that another rural network could replicate the platform in 12 to 18 months, given uniform availability of the enabling infrastructure—the National Health Insurance smart card as a universal patient identifier, the MOHW Perinatal Care Network reimbursement framework, and regional tertiary blood-bank capacity.

International transferability is more limited. The specific implementation depends on 4 Taiwan-specific enabling conditions: the National Health Insurance smart card as a universal patient identifier; the MOHW Perinatal Care Network reimbursement framework; a regional tertiary hospital with existing blood-bank capacity and 24-hour hematology cover; and an established professional network of obstetric clinicians willing to formalize interinstitutional workflows. In settings that lack one or more of these conditions, the design principles—electronic identity verification at order entry, server-side 3-way blood-type interception, audit-logged interinstitutional workflow, and dedicated cold-chain transport—may translate, but the specific implementation cannot be assumed to.

Future Directions

Two extensions are planned. First, AI-driven inventory prediction: we will pilot a machine learning model trained on multiyear dispatch records to forecast 48-hour clinic-level red blood cell and platelet demand, aimed at reducing the small residual fraction of orders for which the requested unit is not in inventory at the time of request. Second, scaled UAV delivery: building on the feasibility data reported here, we plan a real-world implementation study with participating clinics, a regulatory framework agreement with the Taiwan Civil Aeronautics Administration, and clinical end points including emergency TAT and a composite of severe maternal morbidity. Drawing on the Rwandan program's principal lessons [10] that UAV networks deliver their largest absolute benefit when integrated with rigorous demand prediction and robust ground-based contingency, we will pair UAV delivery with retained ground-based redundancy.

Conclusions

This observational implementation evaluation shows that a modest, standards-based digital dispatch platform—operated as a stand-alone web add-on without electronic integration into the hospital blood-bank information system—can achieve universal clinic adoption, sustain prespecified service-level

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targets for both emergency and routine perinatal blood dispatch over nearly 5 years, and be compatible with 0 serious transfusion-related adverse events in a rural tertiary-to-primary-clinic network. More broadly, the findings suggest that organizational-level digital health interventions in resource-constrained perinatal networks need not depend on full hospital information system integration to generate measurable, durable improvements in service quality: prespecified SLA frameworks established through local clinician consensus, together with routine audit-log analytics, provide a transparent and reproducible mechanism for evaluating effectiveness in settings where randomized comparator designs are neither feasible nor ethical. For other rural regions, the underlying design principles—synchronous order submission, interinstitutional cold-chain coordination, and SLA-anchored performance monitoring—are more likely to transfer than the specific technical implementation, which depends on Taiwan's national health infrastructure, reimbursement mechanisms, and institutional partnerships. The exploratory UAV-delivery feasibility findings support further investigation of aerial transport as a potential complement to ground courier logistics for the irreducible courier segment of the dispatch workflow, particularly where geography, weather, or staffing constrain ground transport.

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Data Availability

The aggregated, deidentified data supporting the findings of this study are not publicly archived because they form part of the routine operational records of a sanctioned regional clinical service. Reasonable requests for further aggregated, deidentified data may be directed to the corresponding author and will be reviewed in accordance with applicable data-governance and patient-confidentiality requirements at NTUH-YL.

Generative AI Use

During the preparation of this work, the authors used large-language-model assistance (Claude, Anthropic) for language polishing, drafting of standard boilerplate sections, and formatting of reference metadata to Vancouver style. All scientific content, study design, data collection, statistical analyses, results interpretation, and conclusions are the sole intellectual work of the authors. No generative AI was used to fabricate, alter, or interpret data. The authors have reviewed and take full responsibility for the entire content of the manuscript.

Authors' Contributions

Conceptualization: YCH, MKS, MHMM, FJY
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Investigation: CLY, ALH, HCS, CWH, YHY
Methodology: YCH, FJY
Project administration: YCH
Resources: CLY, ALH, HCS, CWH, YHY, MKS, MHMM
Supervision: YCH, MKS, MHMM, FJY
Writing – original draft: YCH, FJY
Writing – review & editing: CLY, ALH, HCS, CWH, YHY, MKS, MHMM, FJY

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Conflicts of Interest

None declared.

Multimedia Appendix 1

Additional data.
[DOCX File , 539 KB-Multimedia Appendix 1]

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Abbreviations

ABO: ABO blood group
FHIR: Fast Healthcare Interoperability Resources
HL7 v2: Health Level 7 Version 2
MOHW: Ministry of Health and Welfare
NTUH-YL: National Taiwan University Hospital, Yunlin Branch
OECD: Organisation for Economic Co-Operation and Development
RE-AIM: Reach, Effectiveness, Adoption, Implementation, and Maintenance
RhD: Rhesus D blood group antigen
SERVQUAL: service quality
SHA-256: Secure Hash Algorithm 256-bit
SHOT: Serious Hazards of Transfusion
SLA: service-level agreement
SQUIRE 2.0: Standards for Quality Improvement Reporting Excellence, version 2.0
TAT: turnaround time
TLS: Transport Layer Security
UAV: unmanned aerial vehicle
WHO: World Health Organization

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