

Healthcare workers' acceptance of drone-based vaccine delivery and associated factors at rural health posts in Rwanda: a cross-sectional study using a census approach

Etienne Numviyumukiza

numviyumukizaetienne@gmail.com

University of Rwanda

Gislain Ineza

University of Rwanda

Olivier Niyonkuru

University of Rwanda

Florence Haruna

Zipline International Inc

Pedro Kremer

Zipline International Inc

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Abstract

Background

Drone-supported medical logistics can shorten delivery times and extend access to health products for remote health facilities, but sustained integration depends on frontline healthcare workers' acceptance. Evidence on acceptance among workers directly involved in routine drone-supported vaccine delivery in sub-Saharan Africa remains limited.

Methods

We conducted a cross-sectional study using a census approach within the program-provided sampling frame among vaccination focal persons at rural health posts in Rwanda from 15 January to 15 February 2026. Of 124 program-listed health posts screened, 104 were eligible and contributed one participant each from 24 districts across four provinces. Seventy participants self-administered a bilingual KoboToolbox questionnaire, and 34 completed it through telephone-assisted administration. An adapted 46-item instrument measured acceptance, perceived benefits, usability, perceived operational effectiveness, leadership support, and risks. Internal consistency, descriptive statistics, rank correlations, and multiple linear regression with HC3 robust standard errors were used.

Results

The mean acceptance score was 4.64/5 (SD 0.43; 95% CI 4.56–4.72); using a study-defined, descriptive, non-validated cutoff of ≥ 4.5 on the five-point scale, 71.2% were classified as having high acceptance. Agreement was universal that drone delivery was a wise and desirable idea, although only 48.1% trusted drone-delivered vaccines as much as vaccines delivered by health workers. The adjusted model explained 67.9% of the variance in acceptance. Perceived speed benefit ($B = 0.400$, 95% CI 0.204–0.596; $p < 0.001$) and ease of use/compatibility ($B = 0.375$, 95% CI 0.125–0.625; $p = 0.004$) showed independent positive associations with acceptance. The adjusted privacy-risk estimate was imprecise and its 95% robust confidence interval included the null ($B = -0.095$, 95% robust CI: -0.194 to 0.005 ; $p = 0.062$). The most frequently endorsed concerns were malfunction causing property damage or injury (55.8%), malfunction damaging vaccines (45.2%), and delivery to the wrong address (39.4%).

Conclusions

Vaccination focal persons reported high acceptance of drone-based vaccine delivery, with higher acceptance associated with greater perceived speed benefit and ease of use/compatibility. Implementation should preserve simple workflows and timely service while strengthening visible safeguards for vaccine integrity, operational safety, and trust. Because the study was cross-sectional

and relied on perceptions, causal effects and objective supply-chain performance require prospective evaluation.

Background

Equitable immunization depends not only on vaccine availability but also on reliable delivery to the point of care. The Immunization Agenda 2030 places equity and strong primary healthcare systems at the center of efforts to ensure that everyone benefits from vaccination (1). In rural and geographically difficult settings, the last leg of the supply chain can be constrained by distance, road conditions, transport availability, cold-chain limitations, and the cost of repeated small deliveries (2, 3).

Uncrewed aerial vehicles, commonly called drones, can bypass some surface-transport constraints and provide rapid, on-demand transport of temperature-sensitive products. Modelling work has suggested that drones can improve vaccine availability and reduce logistics costs when utilization is sufficient (3). Operational evidence is also emerging. In Rwanda, drone delivery of blood products was faster than estimated road transport and was associated with fewer expirations (4). In Ghana, aerial logistics was associated with fewer vaccine shortages and missed vaccination sessions, as well as greater vaccination activity (5), while a later assessment reported perceived improvements in access to maternal and emergency medicines (6). Rwanda has also tested drone delivery of veterinary vaccines, with stakeholders identifying both logistical value and the need for coordination, training, and reliable operations (7).

Technical feasibility alone does not ensure routine adoption. Healthcare workers receive, store, and use delivered products and must integrate new ordering and receipt procedures into existing services. Reviews of medical-drone applications identify user acceptance, safety, regulation, human resources, and sustainable operating models as central implementation challenges (3). Qualitative research in Nepal similarly found that trust and perceived accessibility supported drone use, while weather, skilled staffing, and financing were concerns (8).

The Technology Acceptance Model proposes that perceived usefulness and ease of use shape intention to adopt a technology (9). The Diffusion of Innovation theory includes relative advantage, compatibility, complexity, observability, and user characteristics (10). Drawing on these traditions, Yoo and colleagues developed a drone-delivery acceptance questionnaire that included speed, environmental benefit, complexity, performance risk, privacy risk, and personal innovativeness (11). Sham and colleagues adapted it for medicine and vaccine delivery among rural healthcare workers in Malaysia, where slightly more than half endorsed drone delivery, and perceived delivery risk and leadership innovativeness were among the associated factors (12). Other studies have reported generally favorable attitudes toward medical drones, while highlighting the roles of knowledge, usability, skepticism, and perceived competence (13–15).

Evidence from healthcare workers with direct responsibility for vaccination at rural health posts in an operational African drone-delivery program remains limited. This study, therefore, aimed to (1) assess

healthcare workers' acceptance of drone-based vaccine delivery, (2) identify perceived factors associated with acceptance, and (3) describe patterns of operational and privacy concerns among vaccination focal persons in Rwanda.

Methods

Study design and setting

We conducted an analytical cross-sectional study using a census approach within the program-provided sampling frame and reported it in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidance (16). Data were collected from 15 January to 15 February 2026 at health posts participating in Rwanda's drone-supported vaccine-delivery program. Research was conducted across 24 districts in four provinces: Eastern, Northern, Southern, and Western.

Health posts are community-level service points within Rwanda's primary healthcare system. For this program, vaccines were transported through a drone-supported last-mile model, and the vaccination focal person at each participating health post was responsible for receiving and managing vaccine supplies. The Rwanda Biomedical Center facilitated administrative access and engagement with health facilities and immunization authorities. Zipline provided financial support for study activities through a Zipline–University of Rwanda research grant, excluding publication costs, as well as technical and logistical assistance to identify programme health posts and facilitate contact with eligible focal persons. The research team retained responsibility for recruitment, consent, data collection, analysis, and reporting; neither partner participated in consent or interviews. Participants were informed that participation or refusal would not affect their employment, professional relationships, or access to drone-delivery services, and that individual responses would not be shared with Zipline, the Rwanda Biomedical Center, employers, or supervisors.

Participants and census approach

Zipline supplied an operational programme list of 124 health posts. According to programme records, this list was intended to cover all health posts enrolled in the initial drone-based vaccine-delivery phase and considered active at the start of fieldwork; it was not an independently verified national enumeration. We sought one healthcare worker responsible for vaccination services at each health post. Eligibility required participants to be aged at least 18 years, serve as the current vaccination focal person or an equivalent responsible staff member at a listed health post, and provide informed consent. The research team independently contacted and screened every listed health post; 14 were no longer functioning and six lacked an eligible vaccination focal person. The remaining 104 eligible focal persons (83.9% of the operational list) were approached, and all completed the survey; there were no refusals, non-responses, or incomplete questionnaires. Because the study used a census of all eligible health posts in the programme-provided sampling frame, no a priori sample-size calculation was performed.

Questionnaire adaptation and translation

The immediate source was the healthcare worker questionnaire used by Sham et al. for drone-delivered medicine and vaccines (12). Its 30 core items were adapted from the Drone Acceptance Questionnaire developed by Yoo et al. (11), and two leadership innovation items were adapted through Sham et al. from Comtet and Johannessen (13). The Rwanda instrument retained or contextually adapted 31 of these items and added 15 literature-informed items addressing trust, accessibility, delay reduction, outreach reliability, healthcare-system compatibility, and perceived operational effects relevant to vaccine management at health posts. The final questionnaire comprised 46 Likert items scored from 1 (strongly disagree) to 5 (strongly agree). The source authors were consulted, and the instrument was used with permission.

Three experts with experience in immunization, implementation science, data analysis, and academic health research reviewed the instrument qualitatively for relevance, clarity, and contextual appropriateness. The research team completed English-to-Kinyarwanda forward translation and back-translation; an independent translator reviewed both versions, followed by a harmonization meeting of research team members. Participants could select the English or Kinyarwanda questionnaire.

Measurement and scoring

The primary outcome was the mean of eight acceptance/attitude items (Q1–Q4, Q6, Q7, Q9, and Q10), preserving the 1–5 response scale. Seven candidate predictor scores were computed as item means: speed benefit (Q11–Q15), environmental benefit (Q16–Q19), ease of use/compatibility (Q21–Q23 and Q26–Q28), leadership support (Q24–Q25), perceived operational effectiveness (Q29–Q35), performance risk (Q36–Q41), and privacy risk (Q44–Q46). The ease of use/compatibility composite combined usability, system compatibility, and local adaptability and was interpreted as a study-specific combined construct rather than as perceived ease of use alone. Higher scores indicated more of the named construct. The perceived operational-effectiveness items captured health workers' perceptions of reductions in vaccine wastage, missed vaccination opportunities, vaccine degradation, and zero-dose children; these responses were not verified against programme, facility, cold-chain, or vaccination-coverage records. Q5, Q8, and Q20 were retained as standalone descriptive items. Personal innovativeness (Q42–Q43) was not used in explanatory models because its internal consistency was inadequate (Cronbach's $\alpha=0.557$). For descriptive presentation only, an acceptance mean of ≥ 4.5 on the five-point scale was labelled high acceptance. This was a study-defined, non-validated cutoff and was not used as the outcome in the regression analysis, which retained the continuous acceptance score.

Principal-axis factoring with Promax rotation was used as a preliminary assessment of the adapted item set. Sampling adequacy was evaluated with the Kaiser–Meyer–Olkin statistic and Bartlett's test. Parallel analysis informed the number of factors (17). Because the sample was modest for 46 items and the exploratory structure did not fully reproduce all theory-defined domains, composite construction jointly

considered the source framework, loading patterns, conceptual coherence, and internal consistency; the results were not treated as full psychometric validation. Cronbach's alpha summarized internal consistency (18). The full scoring framework is provided in Supplementary Material 1.

Data collection and data quality

The bilingual questionnaire was programmed in KoboToolbox. Seventy participants (67.3%) self-administered the questionnaire using an electronic link. Thirty-four (32.7%) received telephone assistance from trained data collectors, who read the questions and entered responses in KoboToolbox. Data collectors were trained on study procedures, consent, neutral administration, and completeness checks. Participants were assigned coded identifiers; names and direct personal identifiers were not included in the analytical dataset. All 46 Likert items were complete. One response to the drone-delivery experience item was missing and was excluded only from the corresponding descriptive percentage.

Statistical analysis

Categorical variables were summarized using frequencies and percentages. Composite scores were summarized using means, standard deviations, and 95% confidence intervals. Item-level agreement combined responses of agree and strongly agree. Spearman's rank correlation was used to describe monotonic associations between acceptance and candidate predictors, as several composites showed marked ceiling effects.

All seven theory-informed candidate predictor domains were entered simultaneously into an ordinary least squares model with acceptance as the continuous outcome. The primary model was associational and theory-focused rather than a causal confounder-adjustment model. Education was examined in a targeted sensitivity model because formal training may influence how healthcare workers appraise technology-related benefits and risks; bachelor's and master's degrees were combined as 'bachelor's degree or higher' because only two participants held a master's degree. Age, sex, professional experience, province, and drone-delivery experience were not added as a comprehensive covariate set because the sample size was 104 and several categories were sparse. Administration mode could not be evaluated because it was not retained as a participant-level variable linkable to the de-identified dataset. Linearity and residual patterns were inspected, multicollinearity was assessed using variance inflation factors (VIFs), and leverage and Cook's distance were examined. Residuals were non-normal because acceptance was concentrated near the upper boundary; therefore, HC3 heteroskedasticity-consistent standard errors, confidence intervals, p values, and a joint HC3 robust Wald F test were used for inference (19). A second sensitivity analysis excluded observations with Cook's distance greater than $4/n$; no observation was excluded from the primary analysis. A two-sided p value <0.05 was considered statistically significant. Analyses were independently reproduced in SPSS version 27.

Ethical considerations

Ethical approval was obtained from the University of Rwanda, College of Medicine and Health Sciences Institutional Review Board (Ref: CMHS/IRB/714/2025; 4 September 2025). All participants received information on the study purpose, procedures, voluntary participation, confidentiality, and the right to decline. Participants who self-administered the questionnaire provided electronic informed consent in KoboToolbox. For telephone-assisted administration, the study information was read aloud, verbal informed consent was obtained, and the data collector documented consent electronically before proceeding. All 104 participants consented.

Results

Participant flow and characteristics

Of 124 program-listed health posts screened, 104 were eligible, and all contributed one vaccination focal person (83.9% of the original operational list; 100% completion among eligible participants). Participants represented 24 districts across four provinces. Most participants were aged 36–45 years (46.2%), were male (58.7%), had a diploma-level education (50.0%), and were nurses (81.7%). Community health worker supervisors comprised 54.8% of participants, and nurses in charge comprised 45.2%. Among 103 participants with non-missing experience data, 42 (40.8%) reported 1–2 years of experience with drone vaccine delivery (Table 1).

Table 1
Participant characteristics (N = 104)

Characteristic	Category	n (%)
Age, years	18–25	3 (2.9)
	26–35	21 (20.2)
	36–45	48 (46.2)
	46–55	23 (22.1)
	≥ 56	9 (8.7)
Sex	Female	43 (41.3)
	Male	61 (58.7)
Education	Secondary	19 (18.3)
	Diploma	52 (50.0)
	Bachelor's degree	31 (29.8)
	Master's degree	2 (1.9)
Profession	Nursing	85 (81.7)
	Midwifery	9 (8.7)
	Public health	7 (6.7)
	Medicine	3 (2.9)
Role	Community health worker supervisor	57 (54.8)
	Nurse in charge	47 (45.2)
Years in current role	0–2	12 (11.5)
	3–5	11 (10.6)
	6–10	23 (22.1)
	11–15	15 (14.4)
	≥ 16	43 (41.3)
Province	Eastern	24 (23.1)
	Northern	25 (24.0)
	Southern	33 (31.7)
	Western	22 (21.2)
Drone-delivery experience†	Never used	9 (8.7)

Characteristic	Category	n (%)
	< 6 months	21 (20.4)
	6–12 months	24 (23.3)
	1–2 years	42 (40.8)
	> 2 years	7 (6.8)

Percentages use $N = 104$ except for drone-delivery experience ($\dagger$), for which one response was missing; valid percentages use $n = 103$.

Preliminary measurement assessment

The Kaiser–Meyer–Olkin statistic was 0.811, and Bartlett’s test was significant ($\chi^2=3954.10$, $p < 0.001$), indicating that the correlation matrix was suitable for exploratory factor analysis. Parallel analysis suggested four factors; a seven-factor Promax solution was examined for conceptual interpretability and explained 60.4% of the variance. Given this divergence and the participant-to-item ratio, the factor findings were treated as preliminary. The eight theory-informed scores used in the analysis had Cronbach’s alpha values from 0.816 to 0.939 (Table 2).

Table 2
Composite-score descriptives and internal consistency

Domain	Items	k	Mean	SD	Cronbach’s α
Acceptance/attitude	Q1–Q4, Q6, Q7, Q9, Q10	8	4.64	0.43	0.917
Speed benefit	Q11–Q15	5	4.70	0.51	0.939
Environmental benefit	Q16–Q19	4	4.50	0.62	0.901
Ease of use/compatibility	Q21–Q23, Q26–Q28	6	4.48	0.47	0.868
Leadership support	Q24–Q25	2	4.57	0.52	0.816
Perceived operational effectiveness	Q29–Q35	7	4.32	0.62	0.842
Performance risk	Q36–Q41	6	2.77	0.81	0.817
Privacy risk	Q44–Q46	3	1.99	0.74	0.930

Scores range from 1 to 5. Higher risk scores indicate greater concern. k , number of items. The perceived operational-effectiveness score reflects health-worker reports rather than objectively verified programme outcomes.

Acceptance of drone-based vaccine delivery

The mean acceptance score was 4.64 (SD 0.43; 95% CI 4.56–4.72), and using the study-defined, non-validated descriptive cutoff of ≥ 4.5 , 74 participants (71.2%) were classified as having high acceptance.

All participants agreed or strongly agreed that drone delivery was a wise and a desirable idea. Agreement was also high for willingness to use the service (99.0%) and to continue using it (99.0%). However, the standalone trust item showed a more divided response: 50 participants (48.1%) agreed that they trusted drone-delivered vaccines as much as vaccines delivered by health workers, 47 (45.2%) disagreed, and seven (6.7%) were neutral. Seventy-eight participants (75.0%) agreed that drone vaccine delivery could be reliable during outreach activities.

Factors associated with acceptance

In unadjusted rank correlations, acceptance was positively associated with speed benefit (Spearman's $\rho = 0.770$), ease of use/compatibility ($\rho = 0.732$), environmental benefit ($\rho = 0.598$), perceived operational effectiveness ($\rho = 0.533$), and leadership support ($\rho = 0.519$), and negatively associated with privacy risk ($\rho = -0.438$) and performance risk ($\rho = -0.314$); all $p \leq 0.001$. The perceived operational-effectiveness score represented participants' reports, not independently verified programme outcomes.

The seven-predictor model accounted for 67.9% of the observed variance in acceptance in this sample (adjusted $R^2 = 0.656$; conventional omnibus $F[7,96] = 29.06$, $p < 0.001$). VIFs ranged from 1.43 to 3.04. Residuals were non-normal (Shapiro–Wilk $p < 0.001$), and seven observations exceeded the Cook's distance screening threshold of $4/n$; therefore, the HC3 results in Table 3 were used for inference. Speed benefit ($B = 0.400$, 95% CI 0.204–0.596; $p < 0.001$) and ease of use/compatibility ($B = 0.375$, 95% CI 0.125–0.625; $p = 0.004$) showed independent positive associations with acceptance. The adjusted privacy-risk estimate was imprecise and its 95% robust confidence interval included the null ($B = -0.095$, 95% robust CI: -0.194 to 0.005 ; $p = 0.062$). Other domain scores were not independently associated with acceptance. Performance risk, although inversely correlated with acceptance in unadjusted analysis, had a small positive, non-significant coefficient in the adjusted model; this reversal may reflect shared variance with other predictors or instability around a null association.

In the education-adjusted sensitivity model, speed benefit ($B = 0.383$, 95% robust CI 0.178 to 0.589; $p < 0.001$) and ease of use/compatibility ($B = 0.397$, 95% robust CI 0.144 to 0.650; $p = 0.002$) remained positively associated with acceptance. Privacy risk was not statistically significant ($B = -0.081$, 95% robust CI -0.188 to 0.025 ; $p = 0.132$). After excluding the seven observations with Cook's distance greater than $4/n$, speed benefit and ease of use/compatibility remained positively associated with acceptance, whereas the privacy-risk estimate was stronger and statistically significant ($B = -0.078$, 95% robust CI -0.118 to -0.037 ; $p < 0.001$). This change indicates sensitivity of the privacy-risk estimate to influential observations and warrants cautious interpretation. Full HC3 estimates for both sensitivity models are reported in **Supplementary Table S6**.

Table 3
Multiple linear regression of factors associated with acceptance (N = 104)

Term	B	HC3 SE	Standardized β	95% robust CI	p value
Constant	1.355	0.515	—	0.334 to 2.377	0.010
Speed benefit	0.400	0.099	0.481	0.204 to 0.596	< 0.001
Environmental benefit	0.003	0.065	0.004	-0.126 to 0.131	0.965
Ease of use/compatibility	0.375	0.126	0.409	0.125 to 0.625	0.004
Perceived operational effectiveness	-0.027	0.043	-0.039	-0.113 to 0.059	0.539
Performance risk	0.011	0.025	0.020	-0.038 to 0.060	0.665
Privacy risk	-0.095	0.050	-0.165	-0.194 to 0.005	0.062
Leadership support	-0.003	0.086	-0.004	-0.174 to 0.168	0.973

Outcome: mean acceptance score (1–5). $R^2=0.679$; adjusted $R^2=0.656$. B, unstandardized coefficient; CI, confidence interval; HC3, heteroskedasticity-consistent covariance estimator. The perceived operational-effectiveness predictor reflects health-worker reports rather than objectively verified programme outcomes.

Perceived risks and concerns

The mean performance-risk score was 2.77 (SD 0.81), compared with 1.99 (SD 0.74) for privacy risk. The most frequently endorsed performance concern was that a malfunction could damage property or injure someone (55.8%), followed by concerns that a malfunction could damage the vaccines carried (45.2%) and that delivery could occur to a different address (39.4%). Concern that vaccines could be stolen was least frequently endorsed (16.3%). Agreement with the three privacy-risk statements ranged from 6.7% to 10.6% (Table 4).

Table 4
Item-level performance and privacy concerns (N = 104)

Domain	Questionnaire concern	Mean (SD)	Agree/strongly agree, n (%)
Performance risk	Malfunction could damage vaccines	3.17 (1.04)	47 (45.2)
	Malfunction could damage property or injure someone	3.31 (1.12)	58 (55.8)
	Delivery to a different address	2.96 (1.25)	41 (39.4)
	Vaccines could be stolen	2.33 (1.00)	17 (16.3)
	Vaccines could be damaged by others	2.44 (1.10)	26 (25.0)
	Delivery could take too long or remain incomplete	2.41 (1.17)	27 (26.0)
Privacy risk	Could lose control over privacy	1.93 (0.74)	7 (6.7)
	Could lead to a loss of privacy	1.99 (0.77)	8 (7.7)
	Might not respect privacy	2.06 (0.87)	11 (10.6)

Responses ranged from 1 (strongly disagree) to 5 (strongly agree). Labels are concise but preserve the meaning of the administered items.

Discussion

Principal findings

Vaccination focal persons at rural health posts in 24 Rwandan districts reported very high attitudinal acceptance of drone-based vaccine delivery. Perceived speed benefit and ease of use/compatibility were assessed in robustness and sensitivity analyses. Although privacy concerns were low descriptively and inversely correlated with acceptance, their adjusted association was sensitive to influential observations. Operational safety concerns were more salient than privacy concerns, particularly the possibility of a malfunction causing injury or property damage, damaging vaccines, or resulting in delivery to the wrong address. A notable qualification to the high acceptance score was that fewer than half of participants trusted drone-delivered vaccines as much as vaccines delivered by health workers.

Comparison with previous research

The acceptance observed here was higher than in the Malaysian rural healthcare-worker study from which the questionnaire was adapted, where approximately 53–55% endorsed drone delivery as a good, wise, or desirable idea (12). The difference may reflect context and exposure: the Malaysian study involved a broad range of staff considering a prospective service, whereas our participants were vaccination focal persons drawn from health posts within an operating delivery programme. A Malaysian study involving public and healthcare respondents similarly reported generally positive medical-drone acceptance, but emphasized the roles of knowledge, attitudes, and perceptions rather than demographic characteristics (14).

The independent associations of speed benefit and the combined ease of use/compatibility construct are broadly consistent with the Technology Acceptance Model and Diffusion of Innovation theory (9, 10); however, the combined construct should not be interpreted as the isolated effect of perceived ease of use. Yoo et al. identified speed advantage and complexity as central to drone-delivery adoption (11), and participatory work on drone-based medication delivery found perceived usability and usefulness closely related to intention to use (15). These perceptions are consistent with evidence that drone-enabled logistics can improve delivery timeliness and access to critical products, including blood-delivery evidence from Rwanda and broader aerial-logistics evaluations in Ghana (4–6). However, the Ghanaian programmes differed in commodities, service pathways, outcomes, and operational models from routine last-mile vaccine delivery at Rwandan health posts; their findings should therefore be considered contextual rather than directly comparable. The present study does not directly measure delivery time or stock outcomes, but it suggests that frontline workers recognize these service attributes and that these perceptions are linked to acceptance. Accordingly, the operational-effectiveness findings should not be interpreted as objective evidence that the programme reduced vaccine wastage, missed vaccination opportunities, vaccine degradation, or zero-dose prevalence.

Environmental benefit had a high mean score and a positive bivariate association with acceptance, but it was not independently associated after accounting for speed benefit, ease of use/compatibility, and other constructs. This distinction matters: participants reported perceived environmental advantage, not measured emissions. Claims about climate benefits should therefore be tested using life-cycle or route-specific comparisons rather than inferred from acceptance data.

Leadership support also received high ratings and correlated with acceptance, consistent with prior healthcare drone research (12, 13). Its adjusted coefficient was near zero, likely because leadership support shared substantial variance with ease of use/compatibility. Leadership may still be important for implementation through training, workflow design, and problem-solving, even if it does not explain unique statistical variance in this modest sample.

Implications for health-service implementation

The results point to three practical priorities. First, the service should protect the features most closely associated with acceptance: rapid response, clear ordering procedures, predictable receipt, and minimal additional workload. Second, program communication should make vaccine-quality safeguards visible.

Temperature control, handling procedures, chain-of-custody documentation, and contingency plans for delayed, incomplete, or misdirected deliveries should be explained to frontline staff and audited using objective indicators. This may help address the gap between high willingness to use drones and lower trust that drone-delivered vaccines are equivalent to vaccines delivered by health workers.

Third, safety assurance should be continuous rather than limited to initial rollout. Staff should know how incidents are reported, how damaged packages are quarantined, how alternative transport is activated, and how communities are protected at delivery points. Privacy concerns were uncommon, but transparent information about what data are collected, who can access it, and how location and order information are protected remains appropriate. These measures address implementation readiness without treating acceptance as proof of effectiveness.

Strengths and limitations

A strength of the study is its census approach among all 104 confirmed eligible vaccination focal persons within the programme-provided sampling frame, with complete Likert responses and representation across 24 districts and four provinces. Participants were directly connected to vaccine management at health posts, making the findings more operationally relevant than surveys of hypothetical public acceptance. The bilingual instrument, expert review, and transparent reporting of mixed modes of administration also strengthen interpretability.

Several limitations should be considered. The cross-sectional design precludes causal interpretation: perceived speed benefit and ease of use/compatibility may increase acceptance, but highly accepting workers may also evaluate the service more favorably. Because all predictors and acceptance were measured in the same questionnaire session using similarly framed Likert-scale items, common method variance and acquiescence bias may have contributed to the relatively high adjusted R^2 . The ease-of-use/compatibility composite combined related but theoretically distinct aspects of usability, system compatibility, and local adaptability; larger studies should validate these dimensions separately. The operational-effectiveness items were self-reported perceptions rather than objectively verified programme outcomes; no facility or programme records were used to confirm changes in vaccine wastage, missed vaccination opportunities, vaccine degradation, or zero-dose children. Recruitment-channel bias cannot be excluded because Zipline facilitated facility identification and initial contact, potentially making the study appear connected to the programme operator despite independent recruitment and confidentiality safeguards. Separately, telephone-assisted administration may have increased social desirability bias; the administration mode was not stored at the participant level for adjustment. Responses showed a strong ceiling effect, residual non-normality, and influential observations; HC3 inference reduced but did not eliminate uncertainty, particularly for privacy risk.

The sample was limited to one focal person per eligible health post and did not include other staff, community members, or decision-makers. Findings should not be generalized to unrepresented districts, urban facilities, or all Rwandan healthcare workers. Fourteen program-listed health posts were no longer functioning, and six lacked an eligible vaccination focal person; their experiences may differ. Because

the sampling frame originated from programme records rather than an independent enumeration, completeness beyond the initial programme phase cannot be assumed. Finally, the ≥ 4.5 threshold used to define high acceptance was study-defined for descriptive reporting and was not a validated cutoff.

Conclusions

Vaccination focal persons at rural health posts in Rwanda reported high acceptance of drone-based vaccine delivery. Perceived speed benefit and ease of use/compatibility were the factors most consistently associated with acceptance across the reported analyses. Implementation should preserve rapid, uncomplicated workflows while strengthening visible safeguards for vaccine integrity, operational safety, and trustworthy data practices. The contrast between strong willingness to use the service and less consistent trust in drone-delivered vaccines deserves focused communication and objective quality monitoring. Prospective studies linking worker experience to verified logistics, cold-chain, stockout, cost, and immunization outcomes are needed before concluding system effectiveness or environmental impact.

Abbreviations

- CI: Confidence interval
- HC3: Heteroskedasticity-consistent covariance estimator, type 3
- IRB: Institutional Review Board
- KMO: Kaiser–Meyer–Olkin
- RBC: Rwanda Biomedical Center
- SD: Standard deviation
- STROBE: Strengthening the Reporting of Observational Studies in Epidemiology
- VIF: Variance inflation factor

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from the University of Rwanda, College of Medicine and Health Sciences Institutional Review Board (Ref: CMHS/IRB/714/2025; 4 September 2025). All participants provided informed consent. Electronic consent was used for self-administered questionnaires; verbal consent for telephone-assisted participants was documented electronically by the data collector before questionnaire administration.

Consent for publication

Not applicable. The manuscript contains no identifiable individual information, images, or personal details.

Availability of data and materials

The de-identified dataset used and analysed during the current study is available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests. For transparency, Zipline provided non-financial technical and logistical assistance limited to identifying program health posts and facilitating initial contact, and the Rwanda Biomedical Center facilitated administrative access. Neither organization participated in consent, data collection, analysis, interpretation, manuscript preparation, or the decision to publish.

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Authors' contributions

EN led the conceptualization, methodology, investigation, project administration, data collection, formal analysis, and drafting of the manuscript. GI and ON contributed to the study design, implementation, field coordination, validation, and revision of the manuscript. FH and PK reviewed the research process and approved the final manuscript.

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Use of generative artificial intelligence

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