Technological Innovation for Tuberculosis Contact Control and Monitoring: Pre–Post Evaluation of a Web-Based Application in a Peruvian Hospital

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Abstract*– Contact control and monitoring for a person affected by tuberculosis require coordinated management of the index case, because timely identification and follow-up of exposed persons are necessary to interrupt the chain of transmission. This process includes contact assessment, administration of preventive treatment, and periodic follow-up. This study designed, implemented, and conducted an initial user-centered evaluation of a web-based application in a Peruvian hospital. A one-group preexperimental pretest–posttest design was applied to the complete population of ten professionals responsible for the process. A nine-item Likert-scale questionnaire was administered before and after use of the application. Paired differences were examined using the Shapiro–Wilk test and paired-samples t tests. Perceived efficiency increased from 2.20 to 4.67, usability from 2.88 to 4.70, and satisfaction from 2.13 to 4.90 ($p < 0.001$). The application integrated index cases, contacts, assessments, follow-up visits, alerts, indicators, and auditing. The main contribution is the proposal and initial user-centered evaluation of a functional architecture for digital tuberculosis contact monitoring, grounded in design principles that can be examined and adapted in other hospital settings. Because the study was conducted at a single institution and involved ten professionals, the findings should be interpreted as preliminary contextual evidence rather than statistically generalizable results. The results characterize acceptance and perceived usefulness in the setting studied.

Keywords*– tuberculosis, contact monitoring, digital health, technological innovation, web-based application.

I. Introduction

Tuberculosis (TB) remains a public health problem, with a burden concentrated in low- and middle-income countries. Its control requires coordination of detection, diagnosis, treatment, and surveillance of exposed persons. A scoping review identified mobile applications, data-management platforms, and integrated systems that support the TB care cascade. Their implementation depended on interoperability, digital infrastructure, and user experience [1].

Evidence on digital technologies for TB has focused on treatment adherence. A meta-analysis of 76 studies involving 86,586 participants found modest associations with treatment success and increased reporting of adverse events, together with heterogeneity across interventions and varying levels of certainty [2].

In a multicenter trial conducted in Shanghai, an application integrated with WeChat included reminders, health education, and communication with healthcare personnel. Under the conditions defined by the study, the intervention reduced unfavorable outcomes and adherence problems compared with usual care [3].

Implementation of a platform does not independently ensure improved surveillance. An evaluation of the Indonesian Tuberculosis Information System identified difficulties in data entry, response time, error prevention, and alignment of forms with fieldwork. Users reported the need to improve server capacity, user manuals, and integration with clinical systems to prevent duplicate records [4].

Digital transformation also requires workforce readiness. A systematic review concluded that performance expectancy and ease of use support acceptance, whereas complexity, multiple logins, insufficient infrastructure, and inadequate training restrict use. Training, technical support, and institutional backing were identified as facilitating conditions [5].

The Technology Acceptance Model remains useful for analyzing mobile health applications. Perceived usefulness, ease of use, and behavioral intention are complemented by digital literacy, trust, design, personalization, and social context [6].

In healthcare services, adoption barriers include limited trust, technology anxiety, inadequate training, and insufficient organizational support. Joint analysis of TAM and UTAUT indicates that these frameworks should be adapted to the setting and incorporate facilitating conditions and institutional readiness [7].

Usability is a condition for adoption and transfer. The V3+ framework incorporates usability validation alongside verification and analytical and clinical validation to assess whether a technology can be used clearly and reliably by diverse users before its use is expanded [8].

In TB care, the iterative evaluation of the TB Treatment Support Tools application combined questionnaires with think-aloud interviews. The procedure identified navigation and interaction problems and informed design adjustments, although scores did not change significantly across all cycles [9].

Web-based platforms have also been proposed to integrate surveillance and clinical data. The CROSSWORD protocol presents an interoperable infrastructure to support surveillance of latent TB infection among healthcare workers and students [10].

In Peru, a mobile prototype was developed for monitoring patients with TB, including real-time consultations, display of clinical information, and reminders. The evaluation focused on

the prototype and patients receiving treatment and did not address comprehensive management of the contacts linked to each index case [11].

The literature includes fewer evaluations of web-based applications designed specifically for hospital control and monitoring of contacts of a person affected by tuberculosis (PAT). Studies that assess perceived efficiency, usability, and staff satisfaction within the same intervention before and after implementation are also limited.

To address this gap, a web-based application was developed to centralize index cases, contacts, assessments, preventive treatment, follow-up visits, alerts, indicators, and auditing. The objective was to design, implement, and conduct an initial evaluation of the solution by analyzing changes in perceived efficiency, usability, and healthcare staff satisfaction, based on NTS No. 200-MINSA/DGIESP-2023. The study was structured around two questions: RQ1, what functional and information components are required in a web-based application to support hospital control and monitoring of contacts of a PAT?; and RQ2, what changes are observed in staff assessments after implementation?

The scientific contribution is organized at four levels: a technological artifact that translates the healthcare process into a functional architecture; contextual empirical evidence from the complete population of service users; a paired evaluation before and after implementation; and functional principles and organizational conditions that can be evaluated in other institutions. The scope concerns analytical transferability of the design and implementation rather than statistical generalization of the results.

II. Related Work and Technological Gap

A. Digital technologies applied to tuberculosis care

A review of 21 randomized clinical trials classified interventions as reminder tools or remote-monitoring solutions. The studies reported improvements in treatment adherence, continuity of care, clinical outcomes, and satisfaction, with variation according to the intervention and healthcare setting [12].

Technology-integrated nursing interventions use two-way messaging, video-observed treatment, mobile applications, and remote follow-up. Healthcare personnel participate in needs assessment, training, and support during treatment [13].

The V-SMART protocol proposes a process evaluation for an application designed to manage adverse events in multidrug-resistant TB. The analysis considers the care context, reach, intensity of use, and the perspectives of patients and healthcare workers before scale-up is considered [14].

B. Sustainability, performance, and technology acceptance

A review of 29 studies found that some technologies may reduce costs relative to in-person modalities, particularly video-observed treatment. The economic evidence was heterogeneous and was drawn mainly from high-income countries [15].

The accuracy of technologies used to measure adherence varied across telephone-based systems, digital pillboxes, ingestible sensors, and applications. Methodological diversity and limited programmatic evaluation constrained comparison of results [16].

In low- and middle-income countries, adoption requires connectivity, access to devices, digital literacy, data protection, support, and financial sustainability. Scale-up involves adapting both the technology and the organization to each institution's capabilities [17].

A review of health technology acceptance identified perceived usefulness, ease of use, social influence, and digital literacy as facilitators. Technical problems, usability issues, and privacy concerns were recurring barriers [18].

A UTAUT-based protocol combined interviews, instructional design, expert validation, usability testing, and experimental evaluation. This sequence illustrates the value of incorporating user needs and sociocultural conditions during development [19].

The GEMS questionnaire distinguishes usability from overall satisfaction with a digital solution. This distinction supports analysis of functional interaction and evaluation of the experience as separate outcomes [20].

C. Synthesis of the gap

The reviewed studies focus primarily on treatment adherence, reminders, video-observed treatment, and remote monitoring. Less evidence is available on web-based systems that centralize the relationship between index cases and contacts, organize assessments and follow-up visits, generate alerts, and document process traceability. This study addresses that area through the design of a functional artifact and an initial evaluation with the complete population of service users. The contribution derives transferable knowledge about components and implementation conditions.

TABLE I
SUMMARY OF DIGITAL TECHNOLOGIES AND OUTSTANDING ISSUES

Approach	Users and outcomes	Outstanding issue
Digital adherence	Patients; adherence and outcomes	Integration with contact monitoring
TB information systems	Personnel; quality and satisfaction	Workflow alignment and interoperability
Mobile applications	Patients and professionals; usability	Sustained programmatic evaluation
Present study	Personnel; efficiency, usability, and satisfaction	Multicenter validation and objective metrics

III. Design of the Technological Innovation

A. Operational problem and value proposition

The existing process only recorded the contact on the PAT assessment form and did not provide control or monitoring functions. This fragmentation made it difficult to consolidate evidence on contacts, completed assessments, and pending follow-up visits. The application was designed as a technological artifact to centralize these relationships, provide alerts and indicators, and preserve traceability of operations.

The modules were linked to the identification, registration, assessment, and follow-up procedures established by Health Technical Standard No. 221-MINSA/DGIESP-2024 [21] and to the comprehensive care approach for the affected person,

family, and community established by Technical Standard No. 200-MINSA/DGIESP-2023 [22]. The application organizes information and does not replace clinical decision-making.

B. Functional scope and architecture

The solution was implemented as a browser-accessible application. It includes authentication, index-case management, contacts, assessments, follow-up visits, preventive treatment, alerts, indicators, reports, and auditing. The functional architecture shown in Fig. 1 addresses RQ1 and organizes users, access mechanisms, management modules, and the centralized repository.

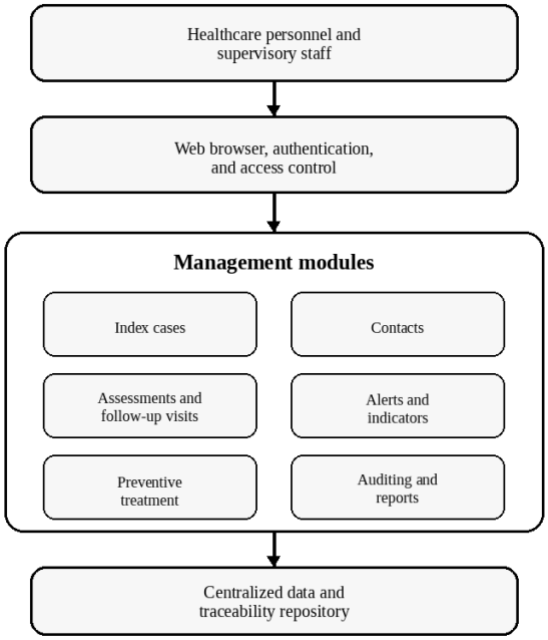


Fig. 1. Functional architecture of the technological artifact.

The index case is the entry point of the workflow. Contacts are linked to this record and may receive assessments, follow-up visits, and preventive actions. The alerts module identifies pending activities, the dashboard summarizes process status, and the audit module records the user, date, and operation. Fig. 2 presents the overall workflow. Design principles were derived from the artifact to describe knowledge that can be examined in other monitoring processes.

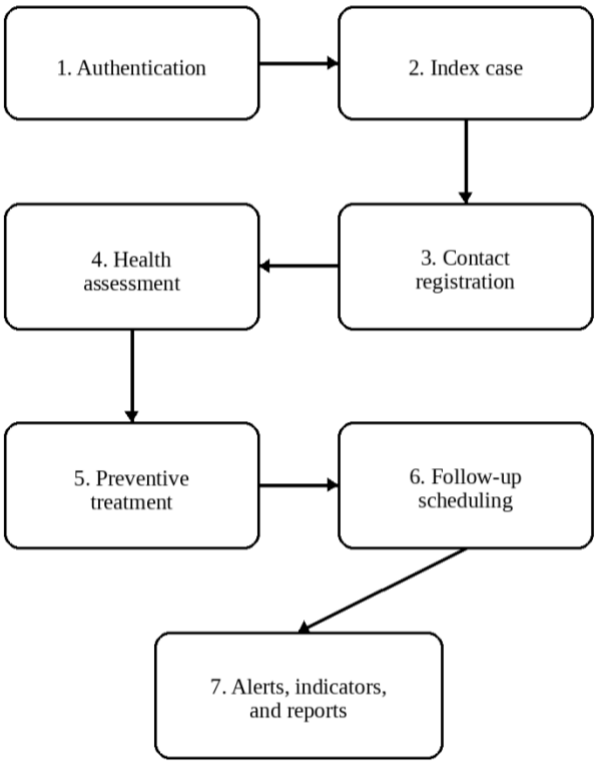


Fig. 2. Digital workflow for contact monitoring.

TABLE II
DESIGN PRINCIPLES AND TRANSFERABLE KNOWLEDGE

Principle	Implementation in the application	Transferable knowledge
Centralization	Cases, contacts, and follow-up visits in a shared repository	Reduce fragmentation in monitoring processes
Linkage	Each contact is linked to an index case	Preserve epidemiological traceability
Pending-activity orientation	Alerts and follow-up status	Prioritize incomplete activities
Operational visibility	Dashboard and indicators	Support supervision and monitoring
Accountability and access	Auditing, users, and roles	Protect data and document changes
Contextual alignment	Modules aligned with the service workflow	Adapt the technology before transfer

C. Interface, security, and development

The interface was designed according to principles of operational simplicity and continuity of the healthcare staff workflow. The application reorganizes information through interrelated modules that provide access from the index case to contact follow-up, integrating indicators, alerts, and traceability within a single platform.

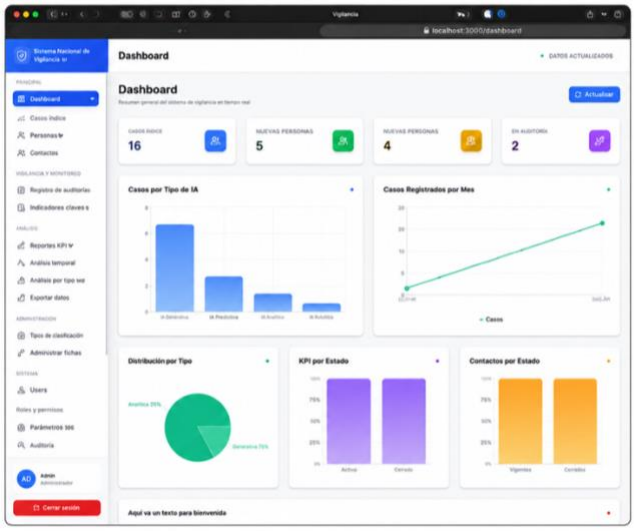


Fig. 3. Monitoring dashboard.

The main dashboard is the entry point for operational supervision of the process. Its design consolidates indicators and pending activities in a single view, reducing the need to consult multiple independent records. This organization supports identification of contacts awaiting assessment and improves visibility of the overall process status.

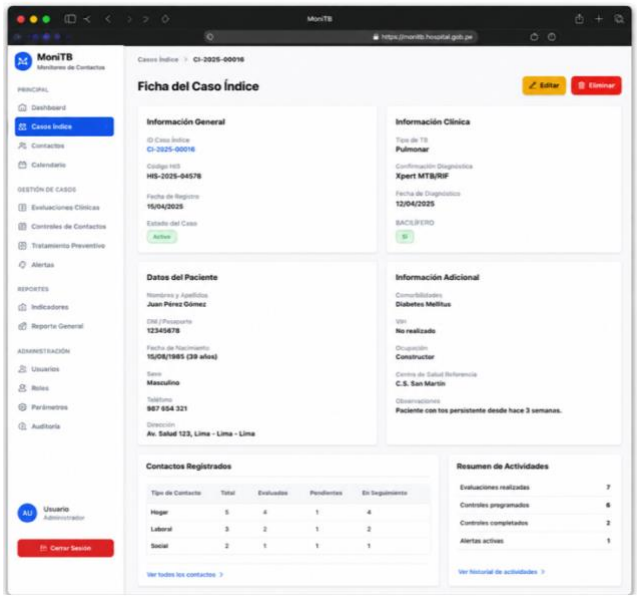


Fig. 4. Index case record.

The index case record implements the epidemiological linkage principle defined in the functional architecture. Each contact remains linked to the case that initiated follow-up, preserving traceability across assessments, follow-up visits, and preventive treatment. This structure prevents information fragmentation and supports longitudinal monitoring of the process.

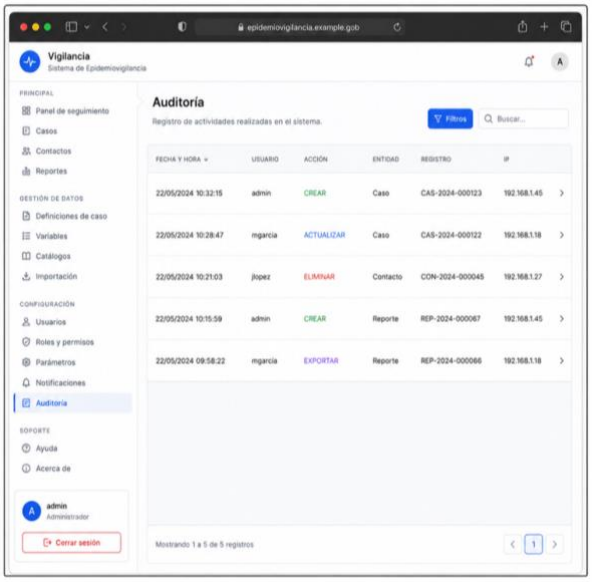


Fig. 5. Audit log.

The audit module implements data accountability through systematic recording of all operations performed by users. This functionality supports information governance by enabling event reconstruction, tracking of modifications, and access control within the system.

Development was organized through Scrum and iterative deliveries that covered data persistence, business logic, and the user interface. The main output extends beyond software implementation to the definition of a functional architecture aligned with the hospital contact-monitoring workflow. This architecture provides a reusable model for surveillance processes that require traceability, longitudinal follow-up, and integration of clinical and operational information.

IV. Methodology

A. Design and participants

A quantitative study was conducted using a one-group preexperimental pretest–posttest design, represented as $O_1 \rightarrow X \rightarrow O_2$.

O_1 corresponded to the initial measurement, X to implementation and use of the application, and O_2 to the post-implementation measurement. The design was used as an initial user evaluation and describes changes between measurement points without establishing the intervention as the only possible explanation.

The study was conducted in the unit responsible for the Tuberculosis Health Strategy within the Department of Pulmonology at a hospital in Lima. The population comprised ten professionals involved in contact registration and follow-up: physicians, nursing staff, and technicians. A census sample was used; all ten members of the service participated and completed both measurements. The results therefore characterize the users in this implementation setting and do not represent professionals from other institutions.

B. Variables and instrument

The intervention was the web-based application. Outcomes were organized into perceived efficiency, usability, and

satisfaction. The term perceived efficiency is used because the study did not measure time, errors, or productivity. Data were collected using a nine-item questionnaire with a five-point Likert scale ranging from strongly disagree to strongly agree.

TABLE III
DIMENSIONS AND MEASUREMENT APPROACH

Dimension	Operational definition	Measurement
Perceived efficiency	Speed, organization, and access to information	Five-point Likert questionnaire
Usability	Learning, navigation, and interaction	Five-point Likert questionnaire
Satisfaction	Overall assessment of the experience	Five-point Likert questionnaire

The questionnaire was reviewed through expert judgment by a systems engineer and a pulmonologist, who assessed relevance, clarity, and coherence.

C. Procedure and analysis

Before implementation, participants completed the pretest questionnaire with reference to the conventional contact-monitoring procedure. They then received training and access to the web-based application, which was used during the evaluation period to manage index cases, contacts, assessments, follow-up visits, and monitoring activities. At the end of the use period, the same questionnaire was administered again as the posttest, allowing comparison of participant perceptions under a repeated-measures design.

Data were processed in Jamovi. Means, standard deviations, minimum values, and maximum values were calculated. Normality of the posttest–pretest differences was assessed using the Shapiro–Wilk test. Because p values exceeded 0.05, paired-samples t tests were applied with a two-sided significance level of 0.05. Mean differences, 95% confidence intervals, and Cohen's dz effect size were reported, calculated as follows:

$$dz = \frac{t}{\sqrt{n}}$$

D. Implementation and data considerations

The same participants were evaluated at both measurement points, preserving the pairing of observations. The statistical dataset consisted of staff responses rather than identifiable clinical information about patients or contacts. The interfaces are presented for functional description and do not display readable information that identifies individuals.

Effective exposure to the application depends on the duration of use, the training provided, and the number of cases processed. These elements were not included in the analysis and represent implementation variables that should be recorded in future evaluations to interpret the stability of perceptions and integration of the tool into routine activities.

V. RESULTS

A. Normality and pretest–posttest comparison

All ten participants completed the pretest and posttest assessments, and no data were missing. Normality of the differences was not rejected for perceived efficiency ($p = 0.4977$), usability ($p = 0.5071$), or satisfaction ($p = 0.3098$). In all three dimensions, the posttest mean exceeded the pretest mean.

TABLE IV
DESCRIPTIVE AND INFERENTIAL RESULTS

Dimension	Pretest M ± SD	Posttest M ± SD	Difference	p
Efficiency	2.20 ± 0.79	4.67 ± 0.32	2.47	<0.001
Usability	2.88 ± 0.68	4.70 ± 0.25	1.82	<0.001
Satisfaction	2.13 ± 0.67	4.90 ± 0.16	2.77	<0.001

The Shapiro–Wilk test indicated that differences between the two measurements were compatible with a normal distribution for all three dimensions ($p > 0.05$). Paired-samples t tests were therefore applied.

B. Perceived efficiency

Perceived efficiency increased by 2.47 points relative to the pretest, from a mean of 2.20 to 4.67. The difference was statistically significant, $t(9) = 7.20$, $p < 0.001$, with a very large effect size ($dz = 2.28$), indicating a consistent increase in perceived operational performance after system implementation.

C. Usability

The score increased from 2.88 to 4.70. The difference was 1.82 points, $t(9) = 6.61$, $p < 0.001$, 95% CI [1.20, 2.45], with $dz = 2.09$. The standard deviation decreased from 0.68 to 0.25.

D. Satisfaction

The mean increased from 2.13 to 4.90 points. The 2.77-point difference was statistically significant, $t(9) = 12.76$, $p < 0.001$, 95% CI [2.28, 3.26], with $dz = 4.03$. The concentration of responses near the upper end of the scale should be considered when interpreting the effect magnitude.

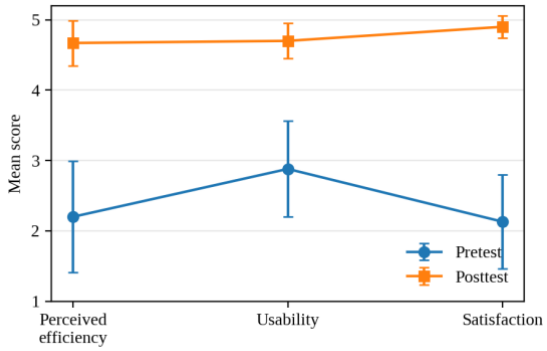


Fig. 6. Pretest and posttest scores; bars represent one standard deviation.

Overall, the results provide an affirmative answer to RQ2, with statistically significant increases in all three dimensions after implementation of the application. These findings concern user perceptions and do not establish improvements in operational or clinical indicators. Such indicators should be incorporated into future studies to validate the effect of the proposed model.

VI. Discussion

After implementation, perceived efficiency, usability, and satisfaction increased, together with lower dispersion. The reduced dispersion indicates a consistent assessment across professionals with different profiles and may reflect a short learning curve and a coherent interface. Data centralization, linkage between cases and contacts, and availability of alerts and indicators provide an operational explanation consistent with the observed assessments. Because all service professionals participated, the results describe the experience of this setting.

A. Perceived efficiency and process organization

The increase in perceived efficiency is consistent with the emphasis in the literature on timely data, workflow alignment, and reduction of duplicate records. In the Indonesian system, data-entry, server, and integration problems affected user experience [4]. The review of technologies for the TB care cascade also identified interoperability, infrastructure, and user experience as implementation domains [1]. Efficiency in the present study was self-reported; subsequent evaluation should include time per record, completeness, duplicate entries, and completed follow-up activities.

B. Usability and satisfaction

The observed usability is associated with the modular organization and access through a single interface. Evaluation of the TB Treatment Support Tools showed that questionnaires and interviews can identify navigation problems and inform iterative development [9]. The V3+ framework states that usability should be validated before scale-up [8]. The present measurement provides initial evidence without task observation or error logging.

Satisfaction showed the largest difference. This outcome is distinct from ease of use because a usable platform may not meet service expectations. GEMS treats the two dimensions separately [20]. The score may also be influenced by training, support, participation, and novelty. Longitudinal measurement would permit assessment of its stability.

Effect sizes were large in all three dimensions. Their magnitude should be interpreted together with the sample size, paired nature of the data, and concentration of posttest scores near the upper limit. With ten participants, consistent changes produce high dz values; confidence intervals and individual distributions should therefore accompany statistical significance in the interpretation.

C. Implementation and technological contribution

Evidence on digital adherence and mobile applications supports the potential of digital health in TB care [2], [3], although those outcomes are not equivalent to contact monitoring. The contribution of this study is operational: integrating index cases, contacts, follow-up visits, alerts, and action history within a hospital environment.

V-SMART emphasizes the need to analyze context, reach, and intensity of use before scale-up [14]. In low- and middle-income countries, connectivity, devices, training, privacy, and sustainability shape implementation [17]. CROSSWORD demonstrates the relevance of integrating surveillance with institutional systems [10]. The evaluated application centralizes internal data and did not demonstrate external interoperability.

The contribution of this research comprises four components. First, it presents a functional artifact that integrates index cases, contacts, follow-up visits, alerts, and action history. Second, it provides contextual evidence from the complete population of service users. Third, it documents changes through an initial paired evaluation. Fourth, it derives design principles and implementation conditions that can be examined in other institutions.

VII. Research Contributions

This research contributes to digital health through the design, implementation, and evaluation of a web-based application specifically intended for hospital monitoring of contacts of patients with tuberculosis. The contribution is structured into eight complementary dimensions: development of a specialized technological artifact, innovation in the care process, information integration, generation of contextual empirical evidence, user-centered design, formulation of transferable principles, strengthening of institutional capabilities, and contribution to regional development through technology applied to a public health problem.

A. Development of a specialized technological artifact

The primary technological contribution is the integration of functional components—cases, contacts, assessments, follow-up visits, and alerts—that previously operated in a fragmented manner, demonstrating the feasibility of a centralized system for contact monitoring in a hospital setting. The solution includes modules for recording index cases, contacts, health assessments, scheduled follow-up visits, preventive treatments, alerts, indicators, reports, and audit activities.

This integration translates the requirements of contact surveillance into a functional architecture that can be understood, used, and evaluated by the responsible personnel. The application organizes the relationships among the index case, exposed persons, completed assessments, and pending activities. The technological artifact therefore represents the workflow followed by the hospital service in digital form.

The developed structure provides a reference for future solutions addressing healthcare processes that require longitudinal follow-up, linkage among records, and control of activities. The defined modules identify the minimum components needed to organize a contact control and monitoring system: case identification, contact linkage, assessment recording, scheduling of follow-up visits, alerts, indicator visualization, and traceability of operations.

B. Innovation in the hospital monitoring process

The second contribution concerns transformation of the information flow used by healthcare staff. The application

consolidates the activities that comprise control and monitoring within a digital environment, establishing a sequence that includes authentication, index-case registration, contact registration, health assessment, preventive treatment, scheduling of follow-up visits, and generation of alerts, indicators, and reports.

This organization provides an explicit representation of the process and supports continuity across its stages. Each contact remains linked to the corresponding index case, while assessments and follow-up visits are recorded as events associated with that contact's monitoring. The solution thus provides an information structure aligned with the epidemiological logic of the process.

The innovation also incorporates mechanisms for operational visibility. The monitoring dashboard displays indicators on cases, contacts, and pending activities, providing staff with an overview of process status. Alerts direct attention to records requiring action, and reports support consultation of accumulated information. Together, these functions support the service's daily management activities.

C. Information integration and traceability

The third contribution is the integration of clinical, epidemiological, and operational data in a centralized repository. The application links index-case information to registered contacts and preserves the sequence of activities completed during follow-up.

The audit module strengthens this contribution by recording the user, date, time, type of action, and affected item. This functionality supports reconstruction of system operations and supervision of information use. Traceability is relevant in healthcare settings because it identifies the origin of records and preserves evidence of modifications.

The combination of centralization and auditing provides a basis for data governance within the monitoring process. In addition to storing information, the solution identifies responsible users, organizes events, and maintains continuity among recorded activities. This approach can inform development of other institutional systems that require action tracking and change control.

D. Empirical evidence from a real-world setting

The fourth contribution is empirical evidence on implementation of a technological innovation in an operational hospital service. The evaluation included all professionals directly involved in contact control and monitoring; therefore, the sample represented a census of the unit studied.

The pretest–posttest design compared assessments from the same participants before and after application use. Scores increased across all three dimensions. Perceived efficiency increased from 2.20 to 4.67 points, usability from 2.88 to 4.70 points, and satisfaction from 2.13 to 4.90 points. The differences were accompanied by lower response dispersion, indicating a more consistent post-implementation assessment among users.

These results provide information on the experience of professionals who interacted directly with the solution in its intended setting. The evidence links the functional characteristics of the application with the perceptions of staff responsible for monitoring. The study thereby incorporates the user perspective into evaluation of the innovation.

E. Incorporation of a user-centered approach

The fifth contribution concerns evaluation of the application across three dimensions of staff experience: perceived efficiency, usability, and satisfaction. This selection enables examination of the solution as both a software product and a tool integrated into professional activities.

Usability assesses how easily participants interact with the platform, locate information, and use its functions. Satisfaction reflects an overall assessment of the experience, while perceived efficiency captures staff views on the organization and availability of information during monitoring.

These dimensions are consistent with current approaches to evaluating digital health technologies, which recognize user-centeredness as a condition for adoption and sustained use. The V3+ framework incorporates usability validation into the evaluation of digital health technologies and emphasizes the need to design tools that can be used consistently in their intended settings [8].

Reviews of technology acceptance in healthcare also identify perceived usefulness, ease of use, training, and facilitating conditions as factors relevant to incorporation of technologies into professional activities [5], [7]. This research provides contextual evidence on these dimensions within a tuberculosis surveillance process.

F. Formulation of transferable design principles

The sixth contribution is the derivation of functional principles that can inform future digital solutions for healthcare monitoring. These principles are grounded in the application's structure and the implementation experience.

The first principle is information centralization, which establishes the need to consolidate monitoring data in a shared repository. The second is epidemiological linkage, through which each contact remains associated with the corresponding index case. The third is orientation toward pending activities, implemented through alerts and monitoring status indicators.

The fourth principle is operational visibility, represented by indicators and dashboards that summarize process status. The fifth is traceability, which records actions performed within the system. The sixth is access control, which structures information use according to authorized profiles. The seventh is alignment with the institutional workflow, whereby system functions represent the activities performed by healthcare staff.

These principles are transferable because they describe design decisions that can be examined and adapted in other digital health projects. They convert an implementation experience into explicit knowledge about the functional organization of monitoring systems.

G. Contribution to technological and organizational capabilities

The seventh contribution is the identification of capabilities required to incorporate a web-based application into a hospital process. Software development must be accompanied by authentication, user administration, support, training, data

protection, maintenance, and alignment with institutional procedures.

These capabilities connect the technical and organizational dimensions. Infrastructure maintains system availability, training supports effective use of functions, assigned responsibilities sustain administration, and auditing contributes to information control. Together, these elements provide a reference for planning adoption of digital solutions in other services.

Research on implementation of TB technologies has identified infrastructure, interoperability, and user experience as central components of adoption [1]. Technical support, staff training, and adaptation to care workflows also influence use within services [5], [14]. This study translates these general components into requirements applicable to hospital contact monitoring.

H. Contextual contribution to digital health in Peru

The eighth contribution is the generation of technological knowledge situated in the Peruvian healthcare context. The application was designed with reference to the identification, assessment, and follow-up activities established by NTS No. 200-MINSA/DGIESP-2023 for tuberculosis prevention and control [21], [22].

The alignment between regulatory requirements and functional design provides a solution adapted to the procedures of its implementation setting. The study thus documents a digital transformation experience applied to contact surveillance in a Peruvian hospital.

International literature on digital technologies for TB focuses on adherence applications, reminders, video-observed treatment, and remote monitoring. This research extends that scope by addressing contact management from the perspective of personnel responsible for the hospital process.

VIII. IMPLICATIONS, SCALABILITY, AND LIMITATIONS

A. Implications and conditions for transfer

In practice, the application can support information retrieval, identification of pending activities, indicator-based supervision, and traceability of operations. The principles of centralization, epidemiological linkage, orientation toward pending activities, operational visibility, accountability, and contextual alignment provide a basis for adapting and evaluating the solution in other services. Transfer requires infrastructure, training, leadership, support, security, and evaluation mechanisms.

TABLE V
Capabilities Required for Adoption and Transfer

Dimension	Required capability	Associated risk
Technology	Server, connectivity, backup, and maintenance	Interruptions or loss of availability
Human resources	Training and support	Incomplete use or operational errors
Organization	Assigned staff, leadership, and procedures	Low adoption or discontinuation
Security and data	Access controls, auditing, privacy, and governance	Exposure or inappropriate use of information
Evaluation	Indicators of use, quality, and performance	Insufficient evidence for scale-up decisions

Scale-up should proceed progressively. First, the institution's infrastructure, workflows, and needs should be assessed. Modules should then be adapted, user profiles defined, and personnel trained. Implementation should begin with a pilot supported by indicators of use, data quality, and performance. Expansion to other services should follow verification of technical stability, user acceptance, and alignment with institutional procedures.

B. Security, privacy, and sustainability

Contact monitoring involves sensitive health data; information protection is therefore a condition for application adoption. The evaluated version included authentication, user management, and audit logging. The study did not examine data encryption, incident recovery, automated backups, vulnerability testing, or compliance with institutional security policies. These capabilities require evaluation before use is expanded or the application is integrated with other systems.

Sustainability requires resources for hosting, connectivity, corrective and adaptive maintenance, technical support, training of new users, and updates in response to regulatory changes. A future economic evaluation should compare resources used in the previous process with implementation and operating costs, considering staff time, record volume, duplicate entries, technical incidents, and service continuity.

C. Limitations

The study is limited by the small number of participants, evaluation at a single institution, absence of a comparison group, and use of self-reported measures. All professionals responsible for monitoring in the unit participated, which provides complete coverage of the local setting but does not establish transferability of the results to other institutions.

Post-implementation assessments may also reflect novelty effects, social desirability, and expectations generated by implementation. Exposure time, frequency of use, and the number of cases processed by each participant were not systematically recorded. Concentration of posttest scores near the upper end of the scale suggests a possible ceiling effect. The results should therefore be interpreted as initial evidence of acceptance, usability, and perceived usefulness, not as evidence of operational, clinical, or epidemiological improvement.

Future studies should include multiple institutions, comparison groups, longitudinal follow-up, time and data-quality metrics, standardized usability tests, interviews, security assessment, interoperability, and costs. Triangulation of system logs, task observation, and user assessments would determine whether the design principles remain applicable as workload increases or institutional conditions change.

D. Evaluation agenda for validation and scale-up

The next evaluation stage should address the identified limitations directly. Objective performance metrics and usage logs are required to complement self-reported measures. Multicenter studies are needed to extend evaluation beyond a single institution. The absence of a comparison group can be addressed through comparative designs or interrupted time-series studies.

User-experience evaluation can combine standardized questionnaires, task observation, interviews, and incident analysis. This triangulation would determine whether favorable scores are maintained as workload increases, new user profiles participate, or functional changes are introduced. It would also help distinguish design difficulties from barriers associated with training, connectivity, or service organization.

TABLE VI
Proposed Domains for the Next Evaluation Stage

Domain	Suggested indicators	Method
Operational	Time per record, completeness, duplicate entries, and alerts addressed	System logs and observation
User experience	Usability, satisfaction, task errors, and perceived workload	Questionnaires, tests, and interviews
Technical and security	Availability, response time, incidents, backups, and access	Technical monitoring and security testing
Healthcare	Contacts assessed, timeliness of follow-up visits, and preventive treatment	Program data and longitudinal follow-up
Economic	Implementation and operating costs and staff time	Cost and process evaluation

A multicenter design would permit examination of the influence of infrastructure, service size, and institutional organization. Inclusion of a comparison group or interrupted time-series design would strengthen attribution of changes. Analysis of scale-up requires documentation of adaptations at each institution and verification that data quality is maintained as the number of users and records increases.

IX. Conclusions

This study enabled the design, implementation, and initial evaluation of a web-based application for the control and monitoring of contacts of people affected by tuberculosis in a Peruvian hospital. The application integrated, within a single environment, the management of index cases and contacts, health assessments, preventive treatment, follow-up, alerts, indicators, reports, and auditing, facilitating the centralization and organization of information associated with this process.

The results should be interpreted in light of the study characteristics. The evaluation was conducted at a single institution and included all professionals responsible for tuberculosis contact control and follow-up. Their participation captured the experience of all users involved in the evaluated setting. The small number of participants, the preexperimental design, the absence of a comparison group, and the use of self-reported measures limit the generalizability of the findings and preclude causal inference.

Accordingly, the primary contribution of the study lies in the implementation experience of a technological solution designed to digitize contact follow-up, which can serve as a basis for future evaluations with larger samples and in different healthcare settings.

The next stage of research should evaluate the solution in multiple institutions, incorporate objective indicators of performance and use, analyze security and interoperability, and assess the stability of the results through longitudinal follow-up or comparative designs. This would allow determination of whether favorable results are maintained across diverse institutional contexts and the extent to which the proposed functional principles translate into sustainable and verifiable improvements in tuberculosis contact monitoring.

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