Centralized Monitoring of Biomedical Equipment in Honduran Public Hospitals: Open-Source Dashboard-WebGIS Architecture

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***Abstract*—Biomedical equipment management in low- and middle-income public health systems remains fragmented, undermining the availability of clinical services. This study developed and validated a centralized platform to monitor the operational status of biomedical equipment in Honduran public hospitals. Following a mixed-methods approach and the V-Model, requirements were elicited from biomedical engineers and technicians (n=8), and a national inventory of 8,476 units across 25 hospitals was cleaned, normalized, and migrated to a relational database with 0% record loss. The system integrates a computerized maintenance management system (CMMS)-equivalent inventory, a Chart.js dashboard, and a Leaflet WebGIS behind a role-based REST API built with open-source tools (MySQL, Flask, Docker). Three indicators were defined: the Hospital Operability Index (IOH), the Category Inoperability Rate (TIC), and the Critical Catalog Gap (BCC). The diagnosis revealed that 16.3% of units were in poor condition and 9.2% required accessories, with Monitoring Equipment being the most affected category (28.6%); the Critical Catalog Gap classified 11 of 22 hospitals as red, revealing coverage gaps that operability alone does not show. Usability, evaluated with the System Usability Scale (SUS) among eight biomedical staff, reached a mean of 91.88/100 (excellent). Integrating a CMMS-type inventory, an operational dashboard, and a WebGIS is a viable and replicable solution for resource-limited Latin American public health systems.**

***Index Terms*—biomedical equipment management, computerized maintenance management system (CMMS), key performance indicators, operational dashboard, WebGIS.**

I. Introduction

The World Health Organization (WHO) estimates that between 50% and 80% of biomedical equipment remains non-functional in developing countries [1]. In Honduras, at least 17% of equipment is out of service [2], a situation compounded by the disabling of 28% of operating rooms [3] and public healthcare funding of only 3% of GDP [4]. Locally, the closest precedent is a functional CMMS prototype developed in C# for the health sector in San Pedro Sula, which evidenced low adoption of these systems [5]. The problem is not a Honduran particularity: its electronic immunization and logistics registries were rolled out without a coherent national digital-health strategy [6]; in Homa Bay County, Kenya, all surveyed public hospitals kept manual records, with only 51.2% of inventories updated [7]; and in Uganda over 1,400 donated devices were found unused [8].

CMMS have been documented as isolated implementations: in Benin (Sub-Saharan Africa), a closed-loop CMMS for low-income hospitals optimized device management when designed around real local needs [9]; in Uruguay, a CMMS on Limble managed 851 biomedical units efficiently but depended on a full-time intern, limiting scalability [10]; and a review argued that IoT enables automated asset monitoring [11]. Historical analysis can anticipate failures [12], AI-based predictive models outperform reactive approaches [13], and a replacement model integrated cost, clinical risk, and historical performance to determine optimal substitution [14].

Clinical dashboards support performance management: in Iran, a radiology adverse-event dashboard obtained a usability score of 76.3/100 [15]; in Ethiopia, an obstetric-care readiness dashboard involved end users from early design [16]; reviews show that effectiveness depends on content and design [17] and that only half of documented dashboards involved end users [18]; and EmergInsight, in Italy, transformed daily operational monitoring [19].

Geographic information systems (GIS) support health-service planning: in New South Wales, Australia, an interactive GIS for congenital-heart-disease services showed that three rural clinics would raise rural patients within one hour of care from 44% to 55% [20]; and in Santiago de Veraguas, Panama, the Two-Step Floating Catchment Area method assessed access to public and private facilities, showing GIS methods are reproducible in Latin America [21]. Each body of literature thus covers one dimension: CMMS provide traceable registries without geospatial or dashboard components; dashboards visualize operations but do not take the equipment inventory as their unit of analysis; and GIS-in-health apply geospatial reasoning to patient access, not to equipment location and status.

Security and interoperability frame any centralized health platform, although they were not the focus of this study. A scoping review of 76 studies proposed a sociotechnical framework in which cybersecurity depends jointly on technology, human factors, and organizational processes [22]; HL7 FHIR with role-based access control was validated in Peru through WiraChain, a blockchain-and-FHIR platform tested under load [23]; and a risk-aware RBAC/ABAC model improved authorization accuracy in 43 simulations [24]. These works inform the platform's security and interoperability roadmap, not its validated scope.

No reviewed system integrates the three dimensions (CMMS, dashboard, WebGIS) in a Latin American public-health context (Table I), which constitutes the gap this work

addresses.

TABLE I
COMPARISON WITH RELATED SYSTEMS

Study	CMMS	Dashb.	WebGIS	LatAm
Medenou et al. [9]	✓	-	-	-
Duarte et al. [10]	✓	-	-	✓
Hernández [5]	✓	-	-	✓
Karami et al. [15]	-	✓	-	-
Branda et al. [19]	-	✓	partial	-
Nicholson et al. [20]	-	-	✓	-
Pérez-Fernández and Michel [21]	-	-	✓	✓
This work	✓	✓	✓	✓

II. METHODS

This non-experimental, cross-sectional study with a descriptive-projective scope used a mixed-methods design, combining quantitative analysis of the institutional inventory with qualitative requirement elicitation from biomedical staff, since the problem has an objective dimension (status, location, maintenance history) and a subjective one (staff workflows) [25].

A. Design and Development Methodology

Development followed the V-Model [26] (Fig. 1), in which each construction phase has a matching validation phase, in three moments: (i) functional requirements through semi-structured interviews; (ii) prototype construction; and (iii) evaluation with the same user profile using the SUS.

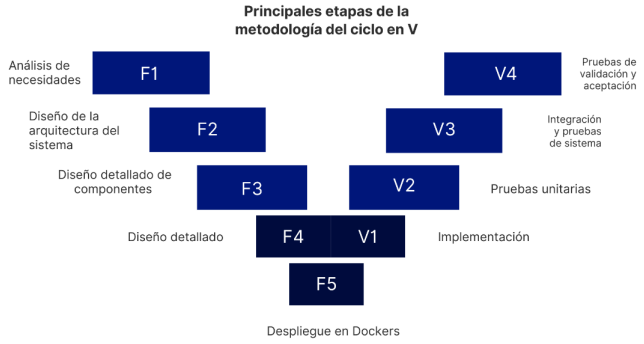


Fig. 1. Stages of the V-cycle methodology used for system development.

B. Data Collection and ETL Pipeline

The primary source was the official inventory of the Honduran Secretariat of Health (SESAL), an Excel workbook. Semi-structured interviews were applied to eight active biomedical engineers and technicians (purposive non-probabilistic sampling; Table II), a size justified by thematic saturation, typically reached with six to twelve experts in usability studies of health information systems [27].

An ETL pipeline (Python 3.12, pandas 2.2) removed duplicates by serial number, normalized hospital and brand names, converted dates to ISO 8601, and verified completeness before migration to MySQL 8.0. Three types of inconsistency were flagged and mitigated with explicit rules rather than deleted (Table III), following standard data-quality dimensions of completeness, accuracy, and consistency [28], [29]. A pilot batch of 1,507 records was traced end-to-end with 0.0% loss, the threshold then applied to the full 8,476-unit migration.

TABLE II
PARTICIPANT PROFILE AND SUS SCORES

Code	Role	Experience	SUS
E-1	Biomedical engineer	<6 months	90.0
E-2	Biomedical engineer	3 years	80.0
E-3	Biomedical engineer	3 years	75.0
E-4	Biomedical engineer	<6 months	100.0
E-5	Biomedical engineer	<6 months	100.0
E-6	Biomedical engineer	2 years	100.0
E-7	Head of biomedical dept.	3 years	100.0
E-8	Biomedical technician	1 year	90.0
Mean SUS			**91.88**

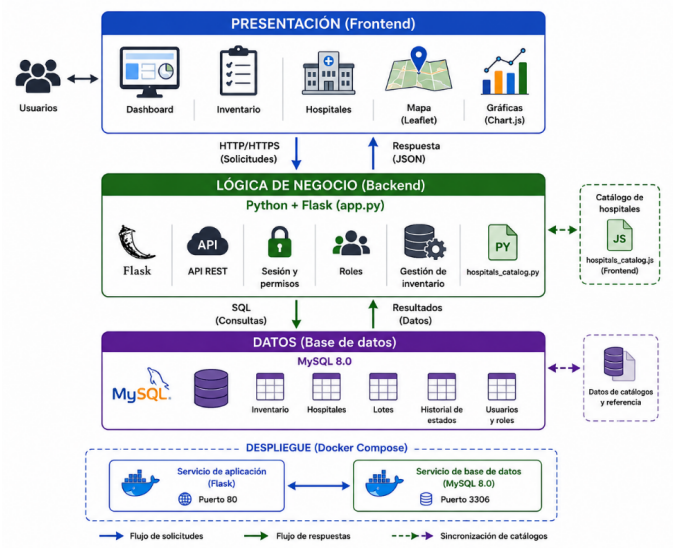


Fig. 2. System architecture: presentation, business logic, data, and deployment layers connected through a role-based REST API.

TABLE III
DATA-QUALITY FINDINGS AND MITIGATION

Finding	Magnitude	Mitigation
Arithmetic mismatch status/total	55 rows (3.6% of pilot)	Boolean flag; rows excluded from operability calculations
Under-reported status at one hospital	109 units	Records preserved as data-completeness indicator
Typographical category/language errors	11 rows	Normalization mapping in the ETL stage

The platform has three layers (Fig. 2): presentation (HTML5, CSS3, JavaScript, Chart.js, Leaflet.js), logic (Python/Flask), and data (MySQL). A REST API centralizes access, so the frontend never queries MySQL directly; the three services run in Docker Compose, and all components are open-source.

C. Key Performance Indicators

Three KPIs were defined, each computed with a verifiable MySQL formula and a three-level color scale (Table IV):

$$IOH = \frac{\text{equipment in good condition}}{\text{total equipment}} \times 100\% \qquad (1)$$

$$TIC = \frac{\text{equipment in poor condition}}{\text{total equipment in category}} \times 100\% \qquad (2)$$

$$BCC = \frac{\text{missing critical equipment}}{\text{size of critical catalog}} \times 100\% \qquad (3)$$

where IOH (Hospital Operability Index) measures clinical availability per hospital, TIC (Category Inoperability Rate) measures poor-condition equipment per category nationally, and BCC (Critical Catalog Gap, n=12 critical descriptions grouped into eight types: defibrillator, ventilators, vital-signs monitors, infusion pumps, electrocardiograph, anesthesia machine, incubators, aspirator) identifies capacity deficits.

The thresholds in Table IV are initial cut-offs defined by the authors, neither taken from a SESAL regulation nor calibrated against outcomes, and are therefore adjustable parameters. Two anchors guided them. For IOH, the green band ($\geq 85\%$) places a hospital at the out-of-service level documented for Honduras (17% [2]) in yellow, not green. For BCC, the bands map onto the discrete 12-item catalog: green tolerates at most one missing critical type (8.3%), yellow two to four (16.7-33.3%), and red five or more ($\geq 41.7\%$). TIC flags as red any category with more than one in five units in poor condition.

TABLE IV
KPI DEFINITIONS AND COLOR THRESHOLDS

KPI	Green	Yellow	Red
IOH	$\geq 85\%$	70-$< 85\%$	$< 70\%$
TIC	$< 10\%$	10-20%	$> 20\%$
BCC	$\leq 15\%$	$>$ 15-40%	$> 40\%$

D. Validation

Validation operated on three levels. The first was technical accuracy, with acceptance thresholds of 0% record loss in extraction, zero absolute difference between dashboard KPIs and independent SQL queries, and 100% traffic-light agreement.

The second was functional usability through the SUS (acceptance threshold 70 points), as in similar studies [15], since end-user involvement increases adoption [18]. The third was feedback from a clinical engineer (M.Sc.), who confirmed that the platform acts as an intermediary between hospital inventories and the health secretariat. Cybersecurity was not an objective, and no formal evaluation (penetration testing, vulnerability scanning, or audit) was performed; development applied baseline measures (credential-based authentication, role-based access over three profiles enforced at each API endpoint, no direct database access from the frontend, and Docker service isolation), which are a baseline, not a validated security posture.

III. RESULTS AND DISCUSSION

Interviews converged on three axes: no centralized digital system (dispersed spreadsheets fragment information and limit traceability), predominance of corrective over preventive maintenance, and equipment status, maintenance history, and spare-part availability as criticality criteria. This supports the proposed indicators and shows that the problem extends

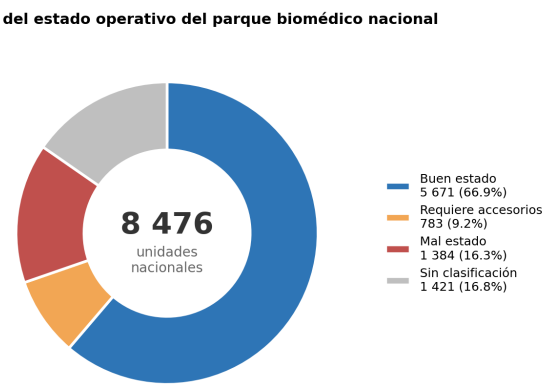


Fig. 3. National characterization of the biomedical equipment stock (8,476 units). Units requiring accessories (783) are a subset of units in good condition (5,671); good, poor, and unclassified units add up to the national total.

beyond digitization to structural weaknesses in traceability and spare-part management.

The consolidated inventory comprised 25 hospitals, 131 equipment types in eight functional categories, and 8,476 units: roughly two-thirds in adequate condition, one in six in poor condition, and a similar share without explicit classification (Fig. 3). Categories differed (Fig. 4a): Basic Equipment (n=2,022) had the lowest poor-condition rate (5.6%) and Monitoring Equipment (n=900) the highest (28.6%), followed by Operating-Room (n=473, 20.7%), Therapy (n=1,788, 19.9%), Electromechanical (n=233, 17.2%), and Medical Imaging (n=391, 14.6%).

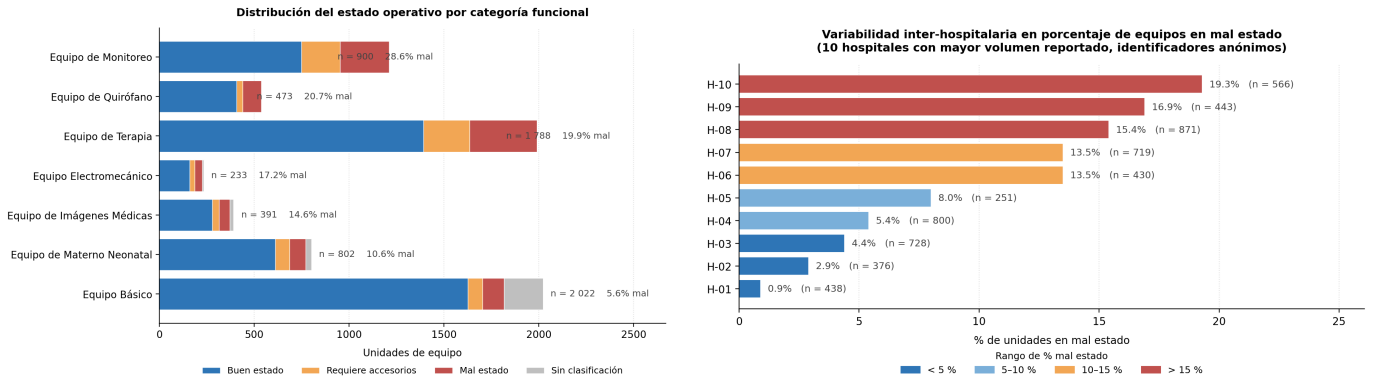
Among the ten highest-volume hospitals (251 to 871 units), comparable-volume hospitals differed sharply (0.9% to 19.3% of compromised units, Fig. 4b), so stock condition depends on institutional variables, not only volume.

Each indicator was computed only for hospitals with sufficient data: 21 reported valid operational status (IOH) and 22 had critical-catalog records (BCC). By IOH, eight hospitals were green, eight yellow, and five red, including one with null operability (Table V); the extended IOH, which adds units requiring accessories, identified stock reactivable through low-cost intervention. By BCC, 11 of 22 hospitals were red, exposing a limitation of the IOH alone: a hospital can show green IOH while lacking essential equipment types (red BCC), which separates two problems, capital investment for initial provisioning versus technical maintenance.

TABLE V
IOH CLASSIFICATION OF HOSPITALS (HOSPITALS WITH VALID STATUS)

Category	Hospitals	IOH Range
Green	8	$\geq 85\%$
Yellow	8	70-$< 85\%$
Red	5	$< 70\%$ (incl. one at 0%)

This divergence matters because each indicator points to a different budget line and responsible actor. IOH describes the equipment a hospital *has* and is addressed through maintenance, repairs, and spare parts managed by the biomedical department; BCC describes the critical types a hospital *lacks*



(a) Operational-status distribution by functional category.

(b) Poor-condition percentage in the ten highest-volume hospitals.

Fig. 4. Complementary views of equipment condition: national distribution by functional category and inter-hospital variability using anonymized identifiers.

TABLE VI
JOINT READING OF IOH AND BCC FOR DECISION SUPPORT

IOH	BCC	Reading	Suggested action
Green	Green/Yel.	Available, largely complete stock	Sustain preventive maintenance
Green	Red	Stock works; critical types missing	Provisioning or redistribution (capital)
Yel./Red	Green/Yel.	Catalog covered; units failing	Repairs, spare parts, accessories
Yel./Red	Red	Combined deficit	Joint intervention and on-site assessment

and is addressed through procurement or redistribution decided by SESAL. IOH alone would rank a well-maintained but incomplete hospital among the best, and BCC alone would hide hospitals that own the critical catalog but cannot use it. Since both are computed per hospital from the same database, they can be read jointly (Table VI), with the extended IOH as a third signal of low-cost reactivable stock. This joint reading is proposed as decision support and has not yet been validated with decision-makers.

Access is centralized through three roles (administrator, biomedical engineer, SESAL user) with per-endpoint control. The engineer portal supports batch inventory, preventive maintenance, work orders, and bulk Excel import, storing each update as a new historical record, while the SESAL portal uses the same data for national summaries, alerts, and reports (Fig. 5).

The SUS, applied to the eight participants in Table II, yielded a mean of 91.88 (SD=9.98, median=95.0, range 75.0-100.0), above the 70-point threshold and within the “excellent” category [30], exceeding the 68-point reference average [31] and comparable studies (76.3 in radiology [15], 82.99 in patient safety [32], 83.6 in emergency care [33], 73.75 in clinical recruitment [34]). No evaluator scored below 75.0.

The 16.3% poor-condition rate is close to the 17% out-of-service rate documented for Honduras [2] and below the 50-80% WHO range [1]; in rural Nepal, the absence of an assigned technician doubled non-functional equipment (14% vs. 7%) [35]. Inoperability is explained by donations without parallel management structures [2], [36]; differentiating by category lets staff prioritize by clinical impact, consistent

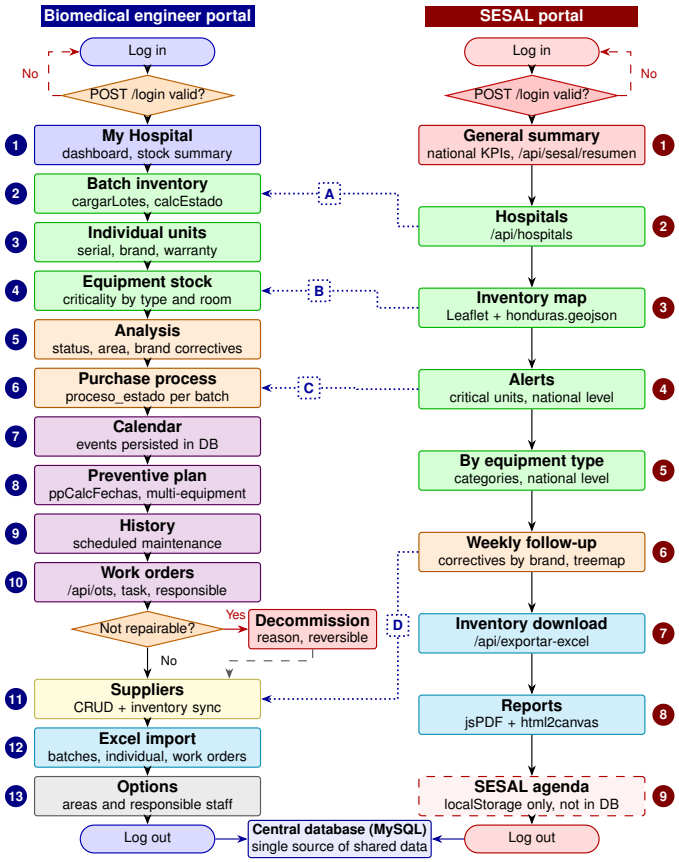


Fig. 5. Functional flow of the biomedical engineer portal (steps 1-13) and the SESAL portal (steps 1-9), which share the central MySQL database. Links A-D mark shared data: batches and hospitals (A), critical equipment (B), purchase status (C), and supplier and brand data used in the corrective treemap (D).

with the shift from corrective to preventive maintenance [37] and with replacement models based on digitized history [14]. The high SUS score supports evidence that early end-user involvement increases adoption [18].

The SESAL portal summarizes network equipment status and indicator-based alerts (Fig. 6), and the hospital directory

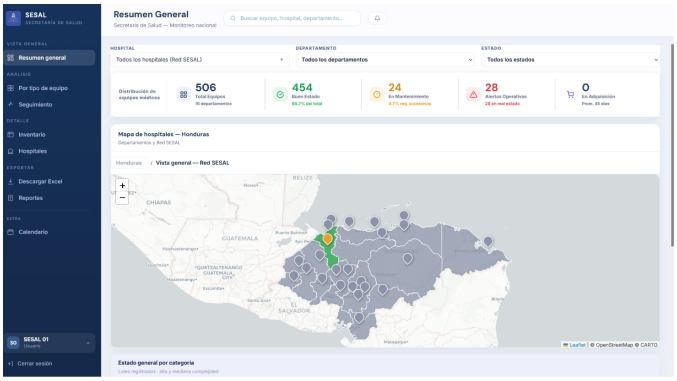


Fig. 6. SESAL national portal: hospital network summary view.

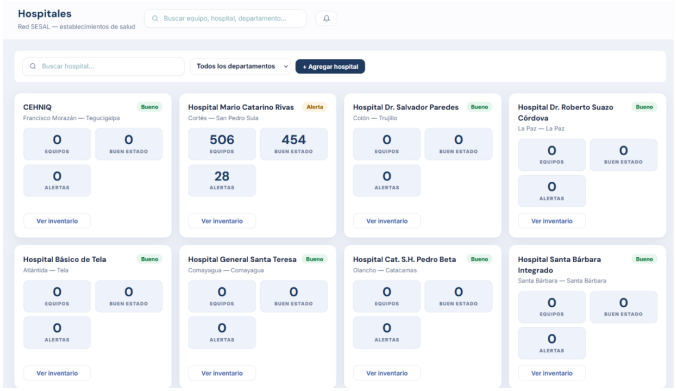


Fig. 7. National hospital directory linked to the interactive WebGIS map.

links institutional records to the interactive WebGIS map (Fig. 7).

As Table I shows, the reviewed CMMS [5], [9], [10], dashboard [15], [19], and GIS-in-health [20], [21] studies each cover one dimension; none combines the three for biomedical equipment in Latin American public health.

The study validated the platform at technical, functional, and expert levels; measuring its effect on hospital management was outside the scope of this phase. The results show that the platform works and that its indicators expose management-relevant patterns (category concentration of inoperability, differences among comparable-volume hospitals, and the IOH/BCC divergence), but not how much management improves after adoption. Quantifying that effect (e.g., equipment availability, time to repair, or the preventive-to-corrective work-order ratio before and after deployment) requires a longitudinal design, planned for future editions of this research.

Limitations include purposive non-probabilistic sampling (findings not statistically generalizable), the cross-sectional design (no causality or evolution), and small samples for requirements and usability (eight participants), similar to the single-center limitation of EmergInsight [19]; the same participants provided requirements and SUS scores, which may favor high ratings, and expert validation relied on one clinical engineer. Sample size was bounded by the institutional access authorized for this study phase, which has concluded, so results are pilot-level evidence and larger samples are planned for future editions. The 16.8% of units without explicit classification was excluded from IOH and TIC, so inoperability is likely underestimated. Finally, security and interoperability components were designed but not empirically tested.

The principal contribution is integrating, in one architecture, the three dimensions the literature addresses in isolation. Locally, the work extends the closest national precedent [5] from a single-institution prototype to a 25-hospital platform, producing a centralized, traceable registry that can feed technovigilance programs such as ARSA (Honduras), COFEPRIS (Mexico), and INVIMA (Colombia).

IV. Conclusions

This work presented a centralized, open-source platform for monitoring biomedical equipment across Honduran public hospitals. It produced a coherent national diagnosis and three context-specific indicators (IOH, TIC, BCC), with 0.0% record loss in migration and a mean SUS of 91.88/100 with real biomedical staff.

Beyond replicating international solutions, the platform provides the information basis to convert public investment in medical technology into real availability of care, especially in the most vulnerable regions. With three verifiable indicators computed directly from the database, it reduces dependence on dispersed manual reporting and offers SESAL a tool replicable in other hospital networks of the region.

This study delivered the centralized inventory and its migration, the three verified indicators, the dashboard and WebGIS, role-based access, and the usability evaluation. Planned for future editions, not delivered here, are, in the short term, multicenter piloting in hospitals with differing characteristics and larger user samples, calibration of KPI thresholds with SESAL, and a formal security assessment under a sociotechnical framework [22]; and in the medium term, a longitudinal study of management indicators (availability, time to repair, preventive-to-corrective ratio), HL7 FHIR interoperability with other national health information systems [23], national scale-up, and predictive maintenance using IoT data and machine-learning models trained on the digitized history the platform is already building.

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