A Bed-Management System Proposal for the Urgent and Emergency Care System of a Municipal Health Network in Brazil: Technical Proposal and System Architecture

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Abstract: In many municipal networks, bed availability is still updated manually across non-interoperable systems, which causes delays, rework, and misallocation. This article presents a technical architecture and implementation blueprint for an Internet of Medical Things (IoMT)-enabled Emergency Medical Services (EMS) integrated real-time bed management system. Bed-mounted load cell sensors infer occupancy and temporary unavailability, reconcile these states with hospital information systems, and publish updates in real time to the bed management dashboard and to the Mobile Emergency Care Service (SAMU, Brazil's EMS). This replaces manual status calls and improves the accuracy and speed of bed availability communication. The approach aligns with the cybersociety and IoMT concepts and provides a continuous data stream for hospital quality indicators. In this proposal, the accumulation of data over time enables strategic analysis that supports resource optimization and continuous improvement in health services. **Keywords: Hospital bed management · Bed allocation/dispatch · Internet of Medical Things · Health interoperability · Mobile Emergency Care Service** **Abbreviations: SAMU, Brazil's Mobile Emergency Care Service · EMS, Emergency Medical Services · ICU, Intensive Care Unit · PNHOSP, National Hospital Care Policy · SUS, Unified Health System · HIE, Health Information Exchange · NIR, Internal Dispatch Nucleus · NB-IoT, Narrowband Internet of Things · IoMT, Internet of Medical Things · API, Application Programming Interfaces.**

1. Introduction

Brazil's emergency and urgent care network is based on coordinated communication between mobile prehospital units such as the Mobile Emergency Care Service (SAMU), emergency medical dispatch and hospital networks. This coordination is prescribed by the National Hospital Care Policy (PNHOSP), which links entry points, emergency medical dispatch, and hospitals to organize access and bed occupancy within the Unified Health System (SUS) [1, 2]. The destination of a critically ill patient is generally determined after the mobile unit contacts the medical dispatcher, who then consults the hospitals and checks the availability of beds. Hospital selection and prioritization are determined on a case-by-case basis depending on the type of emergency and hospital specialty. The heavy reliance on telephone calls and fragmented records leads to delays and rework, particularly when bed information is not updated promptly [3]. The health information exchange literature identifies the prehospital environment as a key area for data integration to reduce information gaps between the scene, the medical dispatcher, and the receiving hospital [4].

Within hospitals, creating Internal Dispatch Nuclei (NIR) to coordinate admissions, discharges, and surgical schedules has improved operational and care indicators and strengthened dialogue with medical dispatch centers [5]. However, inter-operability gaps between clinical and administrative systems and varying processes still limit visibility into real-time bed status and obstruct patient flow, especially in high-demand emergency departments [6]. These shortcomings delay destination decisions, extend waiting times at entry points, and create conflicts about receiving critically ill patients when occupancy is high. They underscore the need for digital solutions that continuously update bed availability, standardize information flows, and integrate prehospital care, dispatcher, and hospital operations [3, 4, 6].

This paper proposes a real-time bed management system integrated into the municipal emergency and urgent care flow. The contributions are: (i) to outline a technical and organizational architecture focused on integration and automated bed status updates; (ii) to define interoperability and governance requirements aligned with PNHOSP; and (iii) to discuss how real-time data can shorten referral times, improve bed turnover, and ease overcrowding in emergency services [1, 2, 3, 4, 5].

2. Technologies in Emergency Medical Services

Internet of Medical Things (IoMT) encompasses clinical sensors, wearables, gateways, and interoperable platforms that connect prehospital settings (ambulances and medical dispatcher) to hospital environments such as emergency departments, urgent care units, intensive care units, and internal dispatcher nuclei (NIRs). In emergency medical services (EMS), IoMT supports early diagnosis and dispatch, navigation, and near real-time allocation of resources and beds[7]. Wearable and vital sign sensors - such as electrocardiograms (ECG), peripheral capillary oxygen saturation (SpO_2), blood pressure, temperature, and capnography - enable continuous monitoring and issue alerts before hospital arrival. Prehospital transmission of 12-lead ECG within care pathways shortens revascularization times and improves outcomes in ST segment elevation myocardial infarction[8]. In hospitals, bed occupancy sensors and smart beds update bed management dashboards automatically, reducing under-reporting and human error[9, 10].

The connectivity layer combines body area networks (WBAN) with low-power wide-area networks (LPWAN). Standards such as IEEE 802.15.6 and Bluetooth Low Energy are suitable for short-range, low-latency links on the patient's body, whereas LoRaWAN and NB-IoT extend coverage with high energy autonomy, useful for telemetry of assets and hospital infrastructure. Comparative studies indicate higher efficiency of 802.15.6 for WBAN use and advantages of LoRaWAN in range and power consumption [11]. Network design, however, must account for threats such as jamming and denial-of-service in LoRaWAN, applying specific countermeasures [12].

Interoperability depends on open standards capable of integrating prehospital and in-hospital care. HL7 FHIR, via RESTful APIs, standardizes the exchange of clinical resources; in the EMS context, NEMSIS structures prehospital care records and facilitates integration with emergency departments, regulation centers, and municipal data lakes [13, 14]. Evidence from the literature on health information exchange and electronic health records suggests improved patient flow and operational indicators when information is available at the point of care [4, 6, 15].

To reduce latency and prioritize critical data, edge/fog-computing architectures perform local detection of events (such as arrhythmias and hypoxia) and offload the cloud, maintaining continuity of care during transport [16, 17]. Synchronous teleconsultation between field teams and specialists complements risk stratification, and unmanned aerial vehicles (drones) have been explored for delivering AEDs, blood products, and medications in hard-to-reach scenarios, provided they are integrated with CAD/AVL and regulatory requirements [18].

The expansion of this ecosystem increases the attack surface, requiring robust authentication, end-to-end encryption, key management, gateway hardening, secure firmware updates, and reliable audit trails, as highlighted by recent reviews on IoMT cybersecurity [19].

In Brazil, Ordinance No. 3,390/2013 (PNHOSP) designates the NIR as an institutional coordination body and the interface with medical dispatch centers, including bed management [20]. In practice, reliance on phone calls and outdated spreadsheets creates information asymmetry and delays in selecting the destination hospital. National studies show that coordination between medical dispatcher and bed management based on integrated information improves patient flow and critical time intervals [3, 5]. In this context, IoMT contributes by automating bed status through sensing, exposing availability and constraints via FHIR-compatible APIs in near real time, transmitting prehospital clinical data (tele-ECG and vital parameters) to support risk classification and patient–specialty–resource matching, and integrating CAD/AVL with operational indicators (occupancy rate, length of stay, and turnover) [6].

Taken together, this technical framework underpins data-driven regulation and supports this work's solution proposal, centered on integrating bed sensing, prehospital clinical telemetry, and interoperability via FHIR/NEMSIS in the context of the NIR and medical dispatch centers.

3. Emergency Care Systems in Brazil

Ordinance 3,390/2013 (PNHOSP) lays out guidelines for the hospital component of the Health Care Network and assigns the Internal Bed Regulation Unit (NIR) for centralized bed management and liaison with regulatory centers [21]. In emergency contexts, the success of this arrangement depends on reliable, timely information on bed availability and patient flow. Well-implemented bed management systems optimize resource use, reduce waiting times, and improve care, affecting admissions, transfers, and discharges of critically ill patients [3]. A study in a Brazilian public university hospital found that the establishment of a NIR increased urgent and elective admissions, created norms and pathways for surgical patients, and improved bed planning, despite resistance to new routines [5].

Prehospital triage tools such as qSOFA, mRST, MEWS, and PRESEP do not identify all critically ill patients on their own, highlighting the need for integrated, real-time clinical and operational data to support decision making [22]. Governance analyzes note that regulatory frameworks are necessary but insufficient; Effective access to emergency care also requires metrics such as refusal rates, response times, and bed occupancy, and a robust information infrastructure for monitoring and transparency [23]. Integrating NIRs, regulation centers and prehospital services such as SAMU through interoperable real-time information systems is therefore a priority to equitably distribute demand, reduce delays and support clinical and logistical decisions [3, 21].

3.1 Problems at the Regulation Interface

The interface where SAMU teams, regulation centers, and NIRs negotiate destinations, priorities, and beds suffers from information gaps and operational delays. Studies in municipal regulation centers reveal structural issues such as insufficient or inaccurate bed control, incorrect records, difficulties with SISREG, and breakdowns in the information flow between primary care and regulation [24]. These problems lead to delayed decisions, repeated requests, and loops that extend time to definitive care and increase queues at hospital doors.

Communication in the prehospital phase still relies mainly on voice channels, which are prone to noise and loss of context. SAMU services report frequent radio failures, inadequate operator training, and limited access to nursing coordination, all of which degrade the quality of clinical data used in regulation [25]. Lacking complete, standardized information, regulators can err on the side of caution (overtriage) or fail to identify hidden severity (undertriage), worsening the allocation of patients.

Documentation and traceability of the regulatory process remain weak. Web-based regulation platforms in Brazil improve transparency and provide process indicators, but adoption can be uneven, leaving blind spots [26]. Our proposal aims to reduce delays and standardize data at the source, making supply and demand visible in real time. System-level interoperability between SAMU, NIR, hospital systems and SISREG is low, restricting automated exchange of operational and clinical data. The National Health Data Network (RNDS) uses the HL7 FHIR standard to define resources, profiles and APIs for secure clinical data exchange, offering a technical pathway to connect regulation with electronic health records and bed dashboards [27, 28]. Adoption remains uneven, and without adapter layers at the point of care, the standard does not yield data useful for minute-by-minute decisions.

These interface frictions manifest at hospital doors as crowding, access blocks and ambulance offload delays. Simplifying administrative tasks and accelerating discharge reduce the number of patients waiting in emergency departments and improve the connection between regulation and bed turnover [29]. The issue is thus less about absolute resource scarcity than about coordination and synchronising states across subsystems. Brazil's Urgent and Emergency Care Network already mandates integration between regulation complexes and entry points, with protocols and timely information as governance pillars [30]. Our proposal aligns with this framework by adding an integration layer linked to SAMU and NIR workflows that collects structured data at source (severity checklists, bed availability, temporary blocks), exposes them via FHIR-compatible APIs and supplies regulatory decision-making with operational telemetry (times, queues, refusals, occupancy). This reduces reliance on phone calls, free-text messages and manual records.

4. Proposed Solution

We propose an automated system that provides real-time availability of intensive care unit (ICU) beds to regulation centers and emergency medical services (EMS). A low-cost device attached to the hospital bed (a load cell in a simple waterproof enclosure) continuously infers bed occupancy and publishes state events. Operational categories follow Table 1 and are enriched through integration with clinical systems.

4.1 Architecture and data integration

As shown in Figure 1, narrowband Internet of Things (NBIoT) devices installed in beds transmit telemetry over licensed cellular networks directly to an Internet of Things (IoT) platform. The platform centralizes device identity and health management, data ingestion using message queueing telemetry transport (MQTT) and hypertext transfer protocol (HTTP), time series storage, rules and alerts, and exposes application programming interfaces (APIs) for upstream systems.

Regulation centers consume, through API, a consolidated real-time feed of bed availability and can issue actions through the platform, such as reserving a bed, triggering cleaning or linen ser-

Table 1: Improved bed statuses

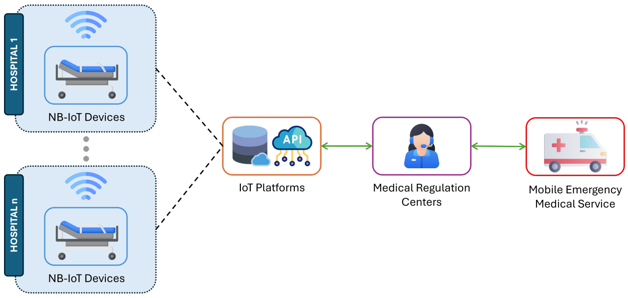
CODE	STATUS	DESCRIPTION
0000	Out of Service	Device communication failure.
0001	Occupied	Bed currently being used by a patient.
0010	Vacant	Bed is suitable for use and is not currently occupied by a patient.
0011	Reserved	Reserved bed.
0100	Patient Out for Procedure	Bed is empty, but the patient is undergoing a procedure or exam away from the bed.
0101	Patient in Transfer	Patient is being transferred to another hospital ward. Bed will be available soon.
0110	Patient Discharged	The patient has been discharged. Bed will be available soon.

vices, or requesting device health checks. Communication with EMS is bidirectional: the regulation sends destination recommendations and receives prehospital status updates (en route, on scene, diversion). Where available, integrations with the hospital's Hospital Information System (HIS) or Electronic Medical Record (EMR) - admission, discharge, and transfer events and exam or procedure scheduling - or with the local bed management application enrich the interpretation of 'in movement', 'in transition' and 'discharged'. All traffic is encrypted and segregated via a private access point name (APN), keeping telemetry independent of the hospital's wired local area network (LAN) and providing a single source for dispatch, dispatch and audit across the network.

4.2 Connectivity

We adopted NB-IoT in licensed spectrum because it balances simplicity of deployment, total cost, and operational predictability in hospital environ-

Figure 1: Architecture overview showing bed sensing and data integration

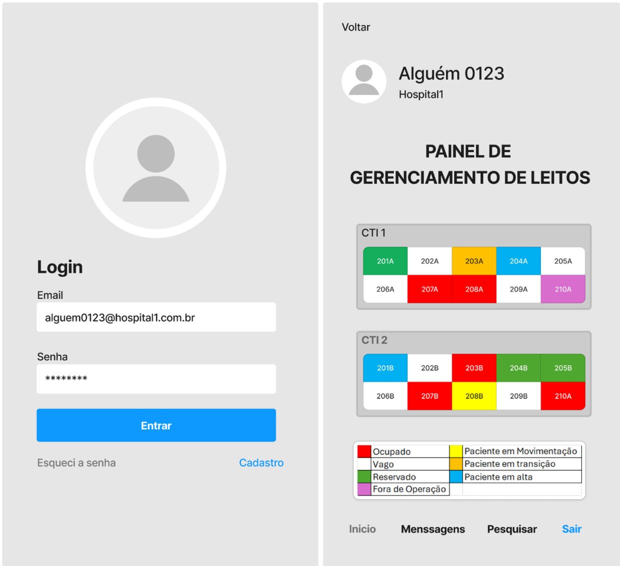


ments. Unlike private LoRa/LoRaWAN (Long Range Wide Area Network) networks, the solution does not require the installation and maintenance of gateways, antennas or network servers, reducing capital expenditure (CAPEX) and technical complexity; each device only needs a NB-IoT module with SIM / eSIM to operate on the existing carrier infrastructure. Compared with a wired local area network, it avoids new Ethernet drops and switch ports per bed, as well as construction work and reconfiguration whenever beds are relocated (a common ICU practice), while also reducing exposed cabling, which benefits hygiene and electrical safety. Operationally, telemetry remains independent of the hospital's internal LAN, minimizing the impact of LAN maintenance or incidents and simplifying multi-hospital governance. Traffic is encrypted and segmented through a private APN, reducing the attack surface of the clinical network (HIS / EMR) and strengthening logical isolation. Connectivity costs shift to operational predictable (OPEX) per device, well-suited to the low-volume, periodic messaging profile of bed telemetry, while licensed indoor coverage under carrier management improves reliability in complex areas.

4.3 Operational orchestration

The local dashboard (Figure 2) displays occupancy and movements in real time, flags device faults, highlights above normal movement or transition times, and, after discharge, automatically triggers cleaning and linen services to prepare the bed.

Figure 2: Local bed management dashboard



In the central repository, the regulation sees a consolidated view of availability and receives destination recommendations based on availability, distance, and specialty. Upon confirmation, the system notifies the selected hospital to reserve the bed and anticipate emergency provisions (staff allocation and equipment preparation), reducing phone calls and door-to-ICU time.

4.4 Indicators and continuous improvement

Two main axes are recommended. **Flow and access (Dispatch/EMS):** bed confirmation time, door-to-ICU time, reservation diversion or cancelation rate, and adherence to system recommendations. **Capacity and efficiency:** ICU occupancy, bed turnover, length of stay (median and tail), bed turnaround time after discharge, and nonclinical unavailability. Stratify by hospital, unit, and shift and set targets with dashboard alerts to enable rapid adjustments.

5. Conclusion and Future Work

The implementation of automated systems for ICU bed management represents a significant advance in the efficiency of health services, particularly in urgent and emergency contexts. The proposal described in this article offers a low-cost and robust solution capable of automating bed status updates, reducing reliance on manual interventions, and minimizing delays and errors in patient care coordination. Furthermore, the centralization of data in a single system, accessible to SAMU's regulatory physicians, eliminates the need for manual verifications and phone calls, optimizing bed allocation and accelerating the availability of specialized resources.

Although this work presents an innovative technical architecture, the absence of empirical results is acknowledged as a limitation that reduces the robustness of the discussion. As next steps, laboratory prototypes will be developed to validate load cell measurement accuracy, NB-IoT transmission reliability, and integration with hospital information systems. In parallel, computational simulations of bed occupancy and regulation scenarios will be conducted to evaluate reductions in response time and the expected impact on operational indicators.

Additionally, case studies in collaboration with hospitals and regulation centers will enable pilot implementations at small scale, allowing the collection of practical metrics such as bed confirmation time, divergence rate, door-to-ICU time, and effects on occupancy rate. A qualitative validation process with SAMU regulatory physicians and hospital managers is also planned, through structured interviews and surveys, to assess the applicability and acceptance of the proposed solution.

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