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Critical care resources in surge response: towards real-time situation awareness

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ABSTRACT

In large-scale emergencies and disasters, real-time situation awareness around health resources can be lifesaving. Understanding the situation at hand, the pressing needs and the actions needed often using information systems that require manual data entry. Relying on humans to enter data manually during surge response is both error-prone and an impediment to the critical requirement of real-time situation awareness. This paper explores the potential of Ultra-High Frequency Radio Frequency Identification (UHF RFID) technology to automate the process of manual data entry followed in providing situation awareness related to critical care resources during surge response. Using design science, an RFID-based prototype was developed to identify and track intensive care resources in real-time. The system was tested in a simulated hospital ward environment to understand deployment challenges and a dashboard was developed to reflect real-time data from multiple sources simultaneously. When properly deployed, UHF RFID can be a viable approach to automating critical care reporting during surge response. Automating routine processes can enhance data quality and minimise workload on health professionals leading to better patient care and evidence based decision-making.

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Critical care resources; surge response; real-time situation awareness; automation; UHF-RFID

1. Introduction

Timely, reliable, and complete health information is critical for efficient and effective healthcare delivery. Quality information enables health professionals to make informed decisions, leading to improved health outcomes especially during surge response when resources are often limited. In health, surge capacity is defined as 'a measurable representation of a health care system's ability to manage a sudden or rapidly progressive influx of patients within the currently available resources at a given point in time' (Diplomates 2005). It does not imply additional capacity, but

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rather a capability known as 'surge response capability' which is a function of available resources and resource demand (Kelen and McCarthy 2006). In large-scale emergencies and disasters, surge response entails situation awareness around the available resources, the expected needs, and the required actions. One of the most critical datasets that need to be timely and accurately reported during surge response relates to intensive care capacity (Pilcher et al. 2021). Intensive care units (ICU) provide critical medical care to the most severely injured or ill patients in crisis. However, ICU beds are globally low with hospitals even in developed countries having few or no ICU beds to cater for surge needs (World Population Review 2023). In 2021, there were four ICU beds per 100,000 in New Zealand; a percentage which in normal circumstances provides only 15 to 25 ICU beds that are capable of accepting emergency patients nationwide (Quinn 2021). These statistics raise the question of what happens in the case of a large-scale emergency such as a natural disaster or in a potential future pandemic. In such scenarios, a national oversight of ICU capacity should be shared across emergency and critical care providers for effective utilisation of these limited resources. During surge response, datasets around critical care capacity need to be accurately and timely reported to ensure a coordinated response. This includes efficient and coordinated inter-hospital patient transfer, optimal resource mobilisation, and early emergency preparedness. ICU patients receive special care delivered by a range of specialists, including physicians, anaesthesia and surgery residents, nurse practitioners, nurses, and pharmacists (Pronovost et al. 2003). For an ICU bed to be considered available, it needs to be equipped, staffed, and unoccupied by a patient. In fact, ICU capacity is dependent upon staff availability more than the availability of equipment (Pilcher et al. 2021). Ideally, a ventilated ICU patient requires 1:1 nurse: patient ratio, whereas patients in High Dependency Unit (HDU) may be cared for under a 1:2 nurse:patient ratio (New Zealand Nurses Organisation 2020). Higher ratios may be adequate in step-down units where patients stay prior to being moved from the ICU to the general ward. These ratios explain why low ICU capacity is associated with high mortality rates (Wilcox et al. 2020). During infectious disease outbreaks when patients are required to be individually isolated, ICU admission becomes even more complex (Maves et al. 2019). These considerations emphasise the need for careful management of the limited number of ICU beds during surge response. Therefore, datasets that facilitate decision-making in regard to ICU admissions should be reported in a structured, timely, and reliable manner.

1.1. Reporting ICU datasets

Aggregate datasets can be reported using minimum datasets (MDS). An MDS is a collection of standardised datasets focused on selected aspects of a single topic and supported by a data dictionary that explains its associated meanings, usage, and format (McDaniel and McDaniel 1994). Datasets are made up of data elements each with a specific code, name, definition, and a set of possible values. This structured reporting approach, built upon specific information requirements, is both cost-effective and efficient (Ahmadi and Mirbagheri 2019). During COVID-19, datasets pertaining to the number of probable and confirmed cases, reinfections, recovered cases, and

deaths were continuously collected and shared nationally (Te Whatu Ora 2023). However, a gap was realised relating to the inability of health professionals to have a national oversight of available critical care resources in real time (Pilcher et al. 2021). In Australia and New Zealand, this gap was addressed by developing an information system that collects and disseminates a minimum dataset of critical care resources. Nevertheless, the system requires nurses to manually enter ICU capacity data twice a day into a centralised platform. This approach is prone to human errors, does not reflect data in real-time, and adds to the workload on nurses who are already stressed and stretched (Young et al. 2021). In 2020, shortages in the health workforce have been estimated at 15 million health workers globally (Boniol et al. 2022). These shortages can be attributed the growing need for care by ageing populations, limited training capacities, and increased disease burden requiring long-term medical care (Machitidze 2022). In New Zealand, the current gap in nurses and midwives is estimated at 4800 nurses and 1050 midwives (The New Zealand Nurses Organisation 2023). Health staff shortages and resource constraints are leading factors to patient harm as nurses become less focused on the details and more prone to errors (Machitidze 2022; World Health Organization (WHO) 2023). Relying on nurses to enter data manually under stressful circumstances such as large-scale emergencies and disasters amplifies the chances of error and impedes the requirement of real-time reporting.

Throughout the first two years of the COVID-19 response in New Zealand, lockdowns were enforced whenever there was a notable surge in cases to contain the spread of the virus in order to cautiously manage the limited health resources. Between March 2020 and December 2021, a four-tier alert level restrictions system was implemented in New Zealand where levels 3 and 4 constituted forms of lockdown (New Zealand Government 2023). The first lockdown was national and took place between March 25th and May 13th, 2020. Subsequently, regionalised alert levels were implemented. To examine the timeliness and reliability of manual data entry during surge response, historic data was retrieved from the national information system that was used during COVID-19 to report critical care resources in New Zealand. The extracted data was reported by 17 tertiary, metro, regional, private, and paediatric hospitals over four periods of lockdown during which all parts of the country were either in level 3 or 4. Reporting for the first lowdown was considered in this study from the 9th of April, 2020. This search revealed substantial data gaps confirming that manual data entry during surge response is neither an efficient nor reliable approach to constructing a holistic picture of available critical care resources. In many instances, even ICUs that reported data daily did so once a day instead of the required twice. Figure 1 below shows the percentage of days (in blue) during which ICU patients were manually reported by each one of the 17 hospitals in relation to the total duration of each lockdown period. The orange colour in contrast, indicates data gaps related to manual reporting of ICU patients during the same lockdown periods.

Considering these reporting gaps, it is evident that an automated, reliable, and timely approach to health capacity situation awareness is required. Such a system would facilitate decision-making with regard to resource utilisation, patient care coordination, and decompression of pressure on healthcare systems as the number of patients increases in

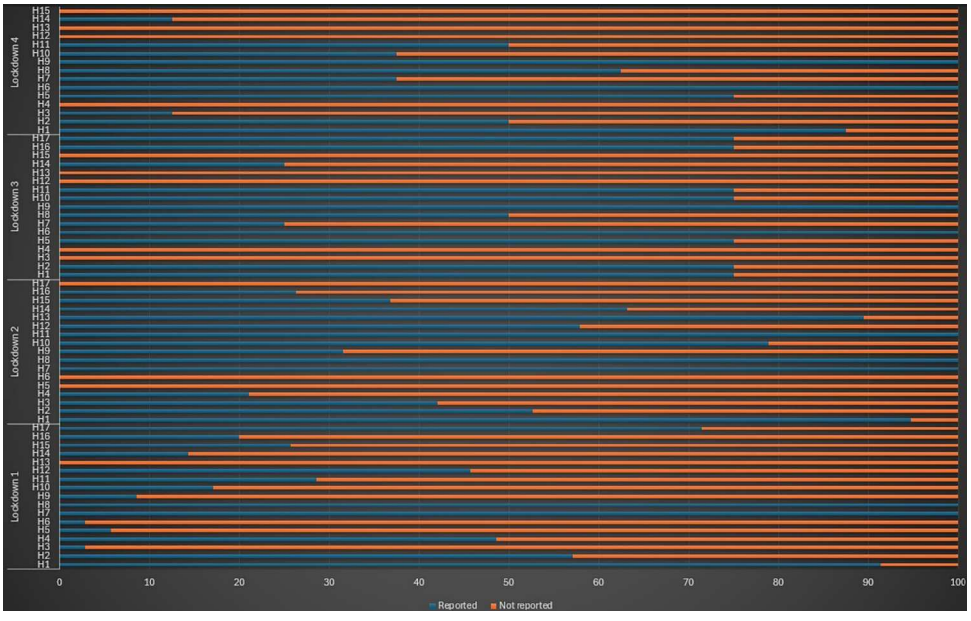

Figure 1. Gaps in manual reporting of ICU data.

crisis. This study explores the potential of utilising Ultra-High Frequency Radio Frequency Identification technology (UHF RFID) in automating ICU capacity reporting to achieve real-time situation awareness.

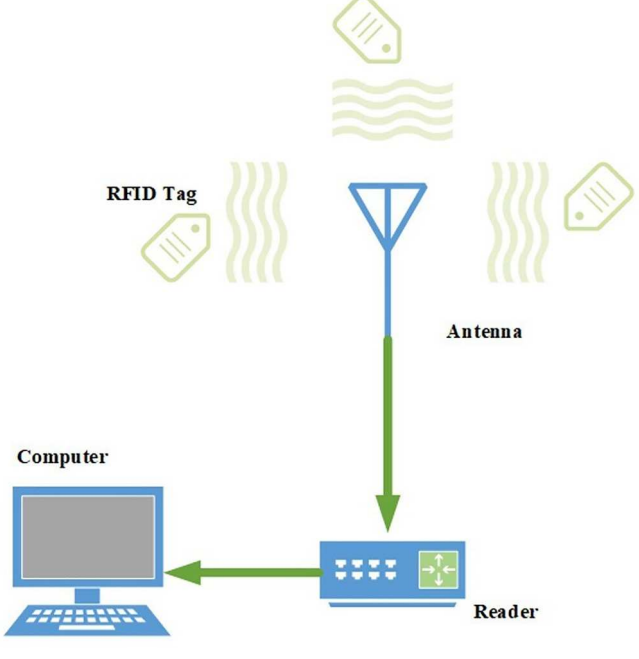

Figure 2. Basic components of an RFID system.

1.2. Radio frequency identification technology (RFID)

Radio-frequency identification (RFID) technology uses electromagnetic fields to automatically identify, and track tags attached to a person or object, thus creating a real-time location system (Mehta et al. 2020). The basic components of an RFID system consist of an RFID reader, antenna, tags with unique identification numbers, and a middle-ware (Figure 2).

When an RFID system is activated, the reader emits radio waves via its antenna. If an RFID tag exists within the reader's range, it receives the radio waves and responds by transmitting back a unique identification serial number or data to the reader. There are two types of RFID tags; active and passive. While active tags have their power source, passive tags draw power from the RFID reader's radio waves. Due to the absence of an external power source, passive tags are small in size, lightweight, cost-effective, and have no electrical expiration (Khan et al. 2009). An RFID middle-ware acts as an intermediary between the reader and the user application. It processes the data obtained by the reader and delivers it to the back-end applications. The collected data can be stored in a database or integrated into other software systems. In contrast to bar-codes, RFID technology functions without the need for a direct line of sight, enabling data reading across distances ranging from a few centimeters to several hundred meters without the need for human intervention (El Khaddar et al. 2011).

1.3. RFID tag data

RFID tag identifiers can be serial numbers assigned by a manufacturer, or Electronic Product Code (EPC) identifiers. In addition to the unique tag identifier, RFID tags can contain data fields such as product descriptions, batch numbers, expiration dates, or other information specific to the tagged item. Some RFID tags have a user memory that can store custom data such as access control data.

EPC identifiers use unique global serial numbers to identify items down to the level of an instance and its location (GS1 2014). EPC identifiers include Global Location Numbers (GLN), Global Returnable Asset Identifiers (GRAI), and Global Service Relation Numbers (GSRN) (GS1 n.d.). GLNs are the global standard for identifying physical, functional, and digital locations. GRAIs are used for identifying individual items (e.g. beds), and GSRNs are used to identify the relationship between an organisation offering services and the provider/recipient of the service, such as a nurse in relation to their work settings (hospital/department). EPC identifiers are combined with RFID and other communication systems through an internet-based global system known as the EPCglobal Network to track and trace individual items. This system uses the EPC identification numbering scheme with a database component known as an Electronic Product Code Information Service (EPCIS) that stores individual item data and event reads (GS1 New Zealand n.d.). EPCs are essential for facilitating the Internet of Things (IoT) and establishing the framework for effortless identification and tracking of objects and individuals. Hospitals can achieve real-time monitoring of the location, status, and utilisation of ICU assets by attaching RFID tags containing unique EPCs to them. This enables automatic identification of assets upon entry to or exit from a facility.

1.4. Types of RFID systems

RFID systems are categorised into low-frequency (LF), high-frequency (HF), ultra-high frequency (UHF), and microwave RFID systems based on their frequency range. (LF) RFID systems operate at a frequency that ranges between 30 and 300 kHz and are less affected by liquids and metals due to their large wavelength (Costa et al. 2021a). (HF) RFID systems operate at frequencies around 13.56 MHz. This larger reading range compared to low-frequency RFID makes them suitable for applications that require faster data exchange, such as contactless smart cards (Weis 2007). Ultra-high frequency RFID systems operate with a frequency range of 860 to 960 MHz. Nevertheless, UHF RFID are susceptible to interference from materials like metal and water (Kabachinski 2005). Finally, microwave RFID systems operate at the microwave frequency of 2.45 GHz. Their long reading range makes them suitable for vehicle access management and asset tracking (Zhang et al. 2017).

In this study, a form of passive UHF RFID technology known as RAIN RFID will be considered. It enables long-distance identification and tracking of items. The acronym RAIN (derived from RAdio frequency IdentificatioN) highlights the link between UHF RFID and the cloud, where RFID-based data can be stored, managed, and shared via the Internet (RAIN Alliance n.d.). Unlike traditional barcode systems that require line-of-sight scanning, RAIN RFID enables bulk reading of tags from a distance, even when the tags are not directly visible to the reader. RAIN RFID have several applications in various sectors including healthcare owing to numerous advantages such as scalability, extended reading distance, rapid data transfer, and easy deployment (Costa et al. 2021a). In addition, RAIN RFID tags are cost-effective because they do not have an internal power source. They draw power from the radio frequency signals emitted by RFID readers and can be rapidly read simultaneously. Utilising a UHF RFID standard defined by GS1 standards system and the International Organisation for Standardisation (ISO), RAIN RFID guarantees interoperability and global accessibility.

1.5. RFID in healthcare

The RFID technology has brought about significant changes across various industries worldwide. The use of RFID for localisation and sensing is gaining increasing popularity particularly in the realm of IoT where high demand exists for low-power, cost-effective wireless devices. Integrating RFID with IoT has led to significant advancements across a range of disciplines. Beyond simple identification, RFID has been utilised for measuring leaf temperature in crops, detecting cracks in structures, and identifying moisture intrusion in vehicle assembly lines (Costa et al. 2021b). Food sensing is another significant research area that uses RFID to detect physical and chemical parameters (Mostaccio et al. 2023). In healthcare, RFID technology has been employed for real-time monitoring of medical equipment and pharmaceuticals, ensuring the protection of patient information, and tracking physiological data (Abugabah et al. 2020; Costa et al. 2021b; Mohammad et al. 2022). RFID has recently been utilised in gesture recognition and fine-grained trajectory tracking where precise and detailed monitoring of the path or movement of an object or person can be tracked over time (Shang et al. 2023). This level of precision is useful for healthcare applications such as monitoring patient

movements. In potentially high-risk situations or when limited means of emergency communication exist, RFID has been deployed to ensure staff safety (Mehta et al. 2020). Innovative RFID applications are currently in use for infection prevention and control, reducing medical errors and for protective measures such as monitoring the state of wounds by using 'smart bandages' to provide continuous data on the healing progress (Yamashita et al. 2018; Garg et al. 2020; Islam et al. 2022; Profetto et al. 2022). The COVID-19 pandemic is seen as a catalyst for raising the profile of RFID. RFID-based applications have been widely used in contact tracing to identify and locate individuals who have been in close contact with COVID-19 patients (Weizman et al. 2020; Rajasekar 2021). Recent research has been conducted to develop an electronic health record system that incorporates RFID technology to automate real-time patient identification, thereby achieving synchronisation across healthcare facilities (Pandey et al. 2023). Collectively, these applications underscore RFID's transformative impact on patient safety and operational efficiency in healthcare settings.

2. Methodology

This work is underpinned by design science. Design science is a validated methodology in information systems research that provides technology-based solutions to relevant business problems (Hevner et al. 2004; Peffers et al. 2007). It focuses on how things ought to be rather than how things are (Simon 1996). To explore the feasibility of automating manual reporting of critical care capacity, a prototype system was developed using RAIN RFID. The prototype aims to provide a hands-free, accurate, and reliable system that identifies and tracks ICU beds, patients, devices, and equipment by creating an event that answers the questions: What is it, where is it, what is happening, and at what time? The prototype consists of an RFID reader, two antennas representing different locations, and several on-metal tags to identify and track items. A dashboard was developed using Python to read the tag data collected by the reader, store it in a

Figure 3. RFID prototype set up in a simulated hospital ward.

central database, and present it in a user-friendly layout that can be accessed by different stakeholders from different locations. The prototype was tested in a simulated hospital ward environment (Figure 3) for feasibility and reliability in terms of signal loss. Testing outcomes are discussed in light of the data quality of manual reporting (Figure 1).

2.1. Prototype configuration and data flow

The prototype compromises an Impinj R700 RFID UHF Reader, two A5010 Far Field antenna, and several ICU dummy items representing ICU beds, patients, PPE, and equipment. Initially, passive ultra-high frequency AD237 tags (70 × 15 mm) were fixed to 'ICU items' that need to be identified and tracked. The reader antenna, a Slimline A5010 circular polarised antenna, was placed at a central location to ensure maximum coverage and efficient capture of the tags. When exposed to the radio waves emitted by the antenna, the tags' circuits are activated, prompting them to transmit a back-scatter signal containing the Electronic Product Code (EPC) ID to the reader. Communication between the antenna and the reader is enabled by means of an SMA to RP TNC cable, which consistently transmits the data. The reader compiles this information into a convenient CSV file at a predetermined frequency i.e. reporting interval. The reporting interval is the time segment for which data availability is required (real-time). The CSV file includes an entry for each read tag consisting of a timestamp, EPC value, name of the antenna, and the operating frequency. These entries correspond to the item identifier (e.g. ICU bed), the time the tagged item was last spotted by the antenna, the name of the antenna which can be renamed to reflect its location (e.g. ward #1), and the operating frequency of the reader. Table 1 below is a snapshot of the CSV file obtained from the reader.

A dashboard software was developed using Python to make sense of the RFID data in the CSV file. The dashboard presents tabular and visual representations that provide healthcare professionals and administrators with a real-time overview of ICU available resources. The dashboard software carefully assigns each EPC value in the CSV file to a specific ICU resource. All antennas used in the prototype have unique IDs that signal which specific tag has been picked up by a particular antenna. The software adeptly deciphers these EPC values and antenna assignments to ensure accurate and timely updates of the corresponding status of the resources on the dashboard.

Figure 4 illustrates the data flow of the RFID prototype. This level of precision and automation streamlines resource management within the ICU, allowing for more effective allocation and real-time monitoring. Over time, historical data accumulates by regularly collecting identification and tracking data of the tagged ICU items making it possible to reflect fluctuations in the number of patients over time. These dynamic representations facilitate evidence-based decision-making thus helping to optimise resource allocation and improve ICU operations.

Table 1. CSV file obtained from the reader.

Timestamp	EPC	Antenna	Frequency
2023-10-11T19: 39:58.0509710+13:00	E200001D3712014920307E1E	1	924.25
2023-10-11T19: 49:58.0520730+13:00	E2002075650502071620 6D86	2	924.25

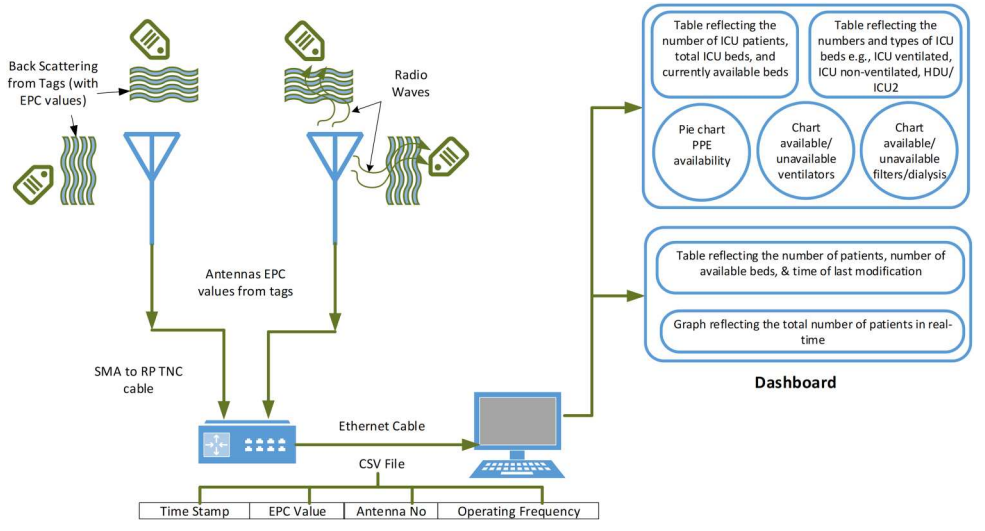

Figure 4. RFID Prototype configuration and data flow.

2.2. The dashboard data

The datasets selected for developing the dashboard are extracted from the national information system used for reporting ICU capacity in New Zealand. These datasets are a subset of the critical care resources minimum dataset. The subset is chosen as a proof of concept for the ability of UHF RFID to reflect ICU data reliably in real-time. These datasets include the number of ICU patients, HDU/ICU 2 patients, open-staffed and equipped ICU bed spaces, spare ventilators, and ICU PPE stock. Table 2 lists the selected data elements and their definitions.

3. Testing the prototype

The prototype system was tested in a simulated hospital ward environment. Testing aimed at exploring deployment challenges in a simulated ward and the ability of the dashboard to reliably report, in real-time, what the tagged items are, their locations, and when each item was last seen. A dashboard was developed to calculate numbers related to availability.

Table 2. Selected ICU-related datasets.

Data elements	Definition
ICU patients	# patients receiving at least 1:1 nursing care (e.g. invasive ventilation/CRRT/ECMO)
HDU/ICU 2 patients (under the care of ICU)	# Patients receiving 1:2 nursing care e.g. invasive monitoring and/or minimal support
Presently open staffed and equipped ICU bed spaces (incl. vacant and occupied ICU beds)	# of beds that are fully staffed to provide care
Spare ventilators	Total# of intensive care ventilators not currently in use. Does not include transport ventilators
ICU PPE stock (low < 3 days, medium + up to 7 days, OK + more than 7 days)	Stock of personal protective equipment (PPE) available in the ICU

Testing was done in two stages. In the first stage, the A5010 circular polarised far field antenna was positioned at the centre of the simulated hospital ward environment to capture all tags within its range. When the radio waves from the antenna activated the tags' circuits, the EPC IDs encoded in the tags were scattered back to the antenna. The identification data was transmitted from the antenna to the reader using a connecting cable. A CSV file that includes the EPC values of the tags was generated by the reader. The software dashboard, written in Python, read the CSV file, decoded the EPC values (e.g. patient, bed, equipment type), and updated the hospital resources tables in the dashboard. In this first testing stage, AD 237 RG tags with a read range of $>$ 4.57 m (15 ft) were used. Despite the dashboard's ability to reflect accurate real-time data, the system's performance was significantly inconsistent. Some tag signals were lost despite tags existing within the antenna reading range and other tag signals kept fluctuating. It was concluded that the performance and read range of the UHF RFID prototype system were negatively impacted by the presence of metal objects in the surrounding environment.

In stage two, the AD 237 RG tags were replaced with Confidex M4E/MQT on-metal tags, and the antenna placement was tested extensively to achieve consistent performance. On-metal tags design includes a layer that isolates the tag from the metal surface to prevent signal interference. The Confidex M4E/MQT on-metal tags specifications are shown in Table 3.

The Confidex M4E/MQT on-metal tags have a circular radiation pattern (Figure 5). Consequently, the RFID reader does not need to be positioned on the same plane or at the same height as the RFID tags. Moreover, the orientation of the tag is unrestricted. These features made a significant improvement in the system's performance as all tags were read and reflected in the dashboard consistently. These changes were detrimental to the successful deployment of the RFID prototype in an ICU-simulated environment where metal objects, including hospital beds, are usually present.

Tagged items were mobilised to reflect the changes on the dashboard in real time. Figure 6 shows how the captured EPC IDs are presented in the dashboard using simple logic to provide situation awareness around ICU capacity. The dashboard identifies the type of item to which the tag is attached (what is it? bed, ventilator, patient, etc.), its location depending on where the antenna is placed (where is it? exact ward), and the time at which the item has been spotted by the antenna (what time? providing both real-time and historical data over time). The data is then integrated into a dashboard that

Table 3. On-metal tags specifications.

Tag dimensions	115 × 30 × 3.9 mm^3
Weight	12 gram
Operational frequency	ETSI 856–869 MHz FCC 902–928 MHz
Operating temperature	−35°C to +85°C/−31°F to +185°F
Ambient temperature	−35°C to +85°C/−31°F to +185°F
Water resistance	IP68 -- well-protected against dust and can withstand submersion in water
Chemical resistance	No Physical or performance changes in: -- 168 h Sulfuric acid (10%, pH 2) exposure -- 168 h Motor oil exposure -- 168 h Saltwater (salinity 10%) exposure -- 1 h NaOH (10%, pH 13) exposure Acetone should be avoided.

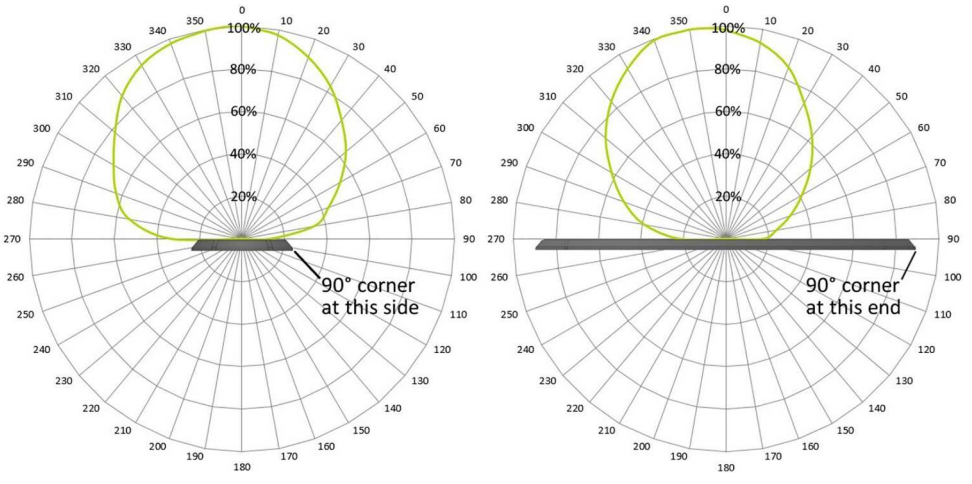

Figure 5. Radiation pattern of on-metal tags (Confidex 2022).

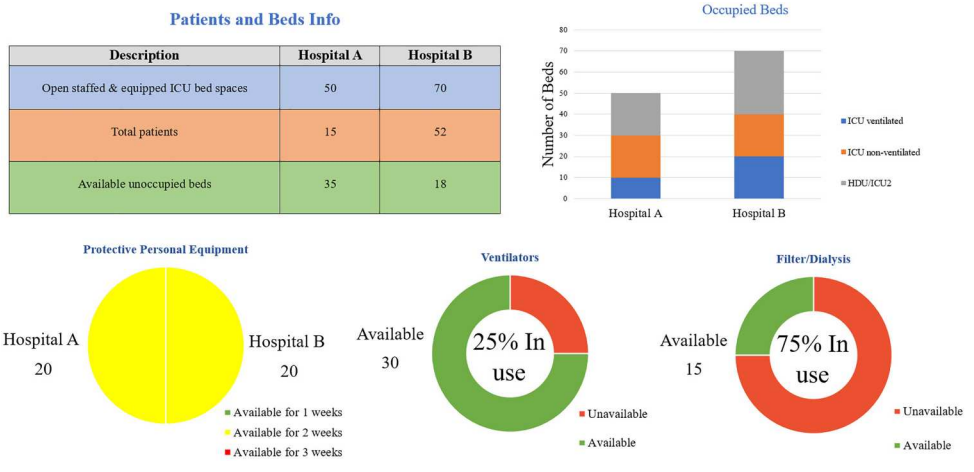

Figure 6. Critical care resources dashboard.

creates the logic to answer questions, including which beds are unoccupied and where, how many patients are currently present in a certain ICU, what are the levels of PPE in stock, etc. (what is happening?). The dashboard logic assumes that unoccupied beds within an ICU ward (the antenna reading range) are all functional and available for use. The time interval for updating the dashboard can be programmed as required.

In this prototype, the location of the antenna indicates the location of the ICU ward. In Figure 6, hospital A and B data refer to the items identified and tracked by antenna A and antenna B respectively.

4. Discussion

Although ICU capacity data can often be accessible at a regional or specific administrative level, it may not be readily accessible or efficiently obtainable on a national scale in

large scale emergencies and disasters. The lack of interoperability among health information systems leads to under-utilisation of resources and adversely affects the quality of patient care (Torab-Miandoab et al. 2023). This was exemplified by the difficulty in acquiring timely and reliable national oversight of ICU resources in real-time. While reporting such information twice a day may suffice under normal circumstances, it might not be adequate in large-scale emergencies and black swan events. Using UHF RFID, the reader can be programmed to read tags as often as required enabling real-time reporting instead of twice a day and reducing the numerous phone calls needed to arrange patient transfers. In addition, automating manual reporting prevents human error and enhances the quality of historical ICU capacity data that can be used in contingency planning.

The nursing shortages experienced worldwide and in New Zealand can have significant implications for both costs and patient outcomes. Occupational stress and burnout have been identified as primary factors contributing to the alarmingly high rates of nurse turnover (Labrague et al. 2018). To increase job satisfaction and maintain a stable nursing workforce, it is critical to adopt strategies that minimise the nursing workload. Sustaining a stable nursing workforce mitigates the cost and time associated with recruiting and training new staff. Moreover, retaining experienced nurses lowers the risk of costly errors and operational delays thereby enhancing patient outcomes which are found to be significantly impacted by the effectiveness of charge nurses (Krugman and Sanders 2016). A study on nurses' time allocation and multitasking of nursing activities revealed that 10% of nurses' time is spent on non-nursing activities (Yen et al. 2018). In the current study, a nurse estimated that manually reporting ICU resources requires an average of approximately 20 minutes per day (10 minutes per reporting session). This adds up to more than 120 hours per hospital and more than 2,068 hours across all hospitals that were required to contribute to the national reporting system. Bughin et al. stated that automating record-keeping and administrative tasks will result in a decline in the demand for office-support staff in the coming years. Similarly, streamlining workflows through RFID technology can substantially reduce costs and improve care outcomes by enhancing the accuracy and effectiveness of both clinical and administrative procedures (Paaske et al. 2017; Buettner et al. 2020). Utilising RFID to automate repetitive administrative tasks has the potential to support charge nurses in focusing on leading the front-line workforce, improving the management of departmental operations, and utilising their much-needed clinical skills more effectively. When resources are limited and clinical nurses are faced with the need to perform managerial tasks, automation not only saves valuable time which can be used for patient care, but also ensures consistency and completeness in reporting thereby supporting both nurses and the overall quality of care.

Although the initial cost of establishing a fully functioning system can be relatively high, RFID may yield a significant return on investment over time (The Danby Group n.d.). For example, a single RFID reader despite its relatively high cost, can communicate with numerous tags thereby effectively distributing the cost over multiple uses (Shang et al. 2023). An RFID system's initial implementation cost includes the cost of its components, installation, integration, and training costs. Ongoing operational costs comprise maintenance, tag replacement, and energy consumption. Nevertheless, the long-term advantages in accuracy, efficiency, and productivity render RFID a cost-effective solution

for many industries. Hence, the initial consideration for adopting an RFID solution should not be 'how much will it cost?' but rather an evaluation of the potential 'Return on Investment' (ROI) especially during surge response. To gain a comprehensive understanding of the ROI, it is essential to account for not only the upfront costs but also the potential costs associated with inaction. Qualitative benefits such as the time saved for life-saving efforts and the enhancement of decision-making capabilities during periods of significant stress, though not easily quantifiable, are of critical importance. RFID's significant potential for ROI is reflected in the growing adoption of RFID by health organisations and the increasing investment in the healthcare information technology sector worldwide (Grand View Research n.d.). In 2023, the global RFID tag market was valued at USD 15.8 billion and is projected to reach USD 40.9 billion by 2032 (Printed Electronics Now 2023). In the health domain, the medical RFID technology market is expected to reach $14.65 billion by 2030 globally with Asia Pacific expected to have the fastest growth rate in the coming years (Grand View Research n.d.). These figures demonstrate the level of innovation introduced by RFID in various sectors, including healthcare.

Healthcare systems are characterised as complex adaptive systems (CAS) due to their nested organisational inter-dependencies (Begun et al. 2003). In such complex systems, the flow of information is frequently hindered by issues related to interoperability; the ability of systems or system components to exchange and use information effectively (Geraci 1991). Key challenges in achieving interoperability include hardware and software incompatibility, conflicting data definitions, and divergent terminologies (Benson and Grieve 2021). These barriers impede the seamless transfer of information across various segments of the healthcare system, ultimately impeding the integration and efficiency of healthcare delivery. Standardisation can address interoperability challenges by establishing uniform protocols, data definitions, and terminologies thus minimising the number of connections required to link different systems (Benson and Grieve 2021). GS1 EPCs global standards were used in the development of the current UHF RFID prototype to facilitate interoperability and enhance global visibility of assets (GS1 New Zealand n.d.). Introducing a new component into the intricate ecosystem of hospital medical systems may pose challenges related to system integration. These challenges must be addressed to prevent disruptions in patient care. The proposed RFID system requires ongoing interactions and information exchange with critical systems such as Electronic Health Records (EHR) and Hospital Information Systems (HIS). Such interdependencies must work seamlessly when the system is implemented. Modern technologies such as application programming interfaces (APIs), cloud servers, and middleware solutions can enable the proposed system to connect seamlessly with other systems. Furthermore, containerisation and Robotic Process Automation (RPA) solutions can create automated workflows to reduce manual intervention and error. Certainly, clear and inclusive user interfaces and adequate training for support staff are essential for the successful implementation of RFID systems.

The ICU is a dynamic and rapidly evolving environment (Anderson and Halpern 2016). The technology that supports both the patient and equipment within an ICU is often distributed in one – or hybrid -- of three traditional configurations: headboard configuration where most electrical outlets are located on the wall behind the head of the bed, column configuration where supplies are placed on one or more possibly

mobile pillars or columns, and boom configuration where supplies are delivered via articulating arms attached to the ceiling or wall (Yodice 2020). The need for interoperable systems that facilitate the seamless integration of information and real-time data collection is emphasised in contemporary ICU design (Pérez-Fernández et al. 2020). In smart ICUs, advanced connectivity features such as automatic identification tags and data transmission units embedded in medical devices are also integrated to enable seamless data exchange within a network (Anderson and Halpern 2016). To ensure a reliable and efficient implementation of the RFID components in an ICU environment, the physical layout including how patients and equipment are co-located needs to be considered. While this prototype provides an experiential rather than observational experience to test the viability of RFID in an ICU environment, a full-scale mock-up is necessary to reveal how the patient care workflows may impact the deployment of RFID and vice versa.

As a proof of concept, the logic of the dashboard was built on the basic assumption that unoccupied beds within an ICU ward (antenna reading range) are considered functional and available for use. On-metal tags were used to enable the visibility of ICU beds in the centralised dashboard, and simple logic was used to determine which beds are available by comparing the number of trackable ICU patients to the number of available ICU beds. Nevertheless, in practice, the integration of sensors into RFID tags brings added functionalities that enable more complex scenarios to be addressed. RFID tags that can assess the operational status of ICU equipment, including monitors and ventilators, as well as measure the weight or temperature of a bed surface, are now available (Bibi et al. 2017). Moreover, tag reading intervals can be programmed and actions can be triggered based on pre-defined rules. Hence, the potential to identify whether an ICU bed is occupied at any given time can be achieved with appropriate tags and logic that accounts for all possible scenarios. Considering that every RFID application presents unique constraints and requirements, feasibility studies within the operational environments are critical to determine the most appropriate frequencies and tags (Costa et al. 2021b). Building the logic for a full-fledged automated system requires accounting for all pertinent factors associated with calculating ICU bed availability. This requires consultation with ICU professionals and should be based on health response policies and other medical considerations. For instance, if a patient is transferred from the ICU for surgery or physiotherapy, the dashboard should be programmed to ensure that the RFID system does not recognise the bed as available. Most importantly, an ICU bed cannot be considered available without being adequately staffed (Pilcher et al. 2021).

Although RFID is a fundamental necessity for the Internet of Things (Jia et al. 2012; Álvarez López et al. 2018), apprehensions exist regarding the privacy and security of RFID applications (Rosenbaum 2014; Munoz-Ausecha et al. 2021). To address these concerns, authentication and encryption mechanisms are incorporated into RFID systems to secure data transmission between the tag and the reader. Authentication protocols are designed to verify the identity of RFID tags and prevent unauthorised access to their data. In contrast, encryption schemes are designed to protect the data transmitted between RFID tags and readers from eavesdropping, tampering, or modification (Munoz-Ausecha et al. 2021). In the health context, the sensitive and personal nature of medical information puts heavy emphasis on privacy and security. The current RFID prototype gathers and transmits aggregate datasets that do not include individual patient data. This is not to underestimate the importance of privacy and security but

rather to emphasise the need to follow a risk-averse approach when considering RFID as a solution for a given problem in healthcare. In 2009, The European Commission published a recommendation for implementing privacy and data protection principles in RFID-supported applications (Reding 2009). This recommendation requires RFID operators to conduct a Privacy and Data Protection Impact Assessment (PIA) before an RFID application is deployed to help understand the application's privacy and data protection aspects. The RFID PIA framework suggested categorising RFID applications into four levels: applications that do not process personal data and where tags are only manipulated by users, applications where no personal data is processed but tags are carried by individuals, applications which process personal data but where tags themselves do not contain personal data, and applications where tags contain personal data (Mahinderjit-Singh et al. 2011). The level of security in an RFID system depends on various factors, including the type of RFID technology used, the specific implementation, and the measures taken to protect it. Hence, it is paramount to identify the potential risks associated with RFID technology before implementing it on a large scale. A large implementation scale therefore may be an indication of robustness and system safety. In North America, the large number of companies engaged in developing RFID platforms and sophisticated healthcare infrastructure placed the region at the forefront of the RFID healthcare market with 44.50% in 2022 (Grand View Research n.d.). Safeguarding security and privacy issues, managing initial and ongoing costs, and overcoming technical complexities are more likely to adopt positive implications in the future for the healthcare industry (Abugabah et al. 2020).

5. Conclusion

In situations of large-scale emergencies and disasters where health system capacity and critical medical resources are limited, a national oversight of available resources can literally save lives. UHF RFID can automate manual data entry of ICU capacity by identifying what a tagged item is, where it is located, and when it was last seen. This hands-free technology which does not require a clear line of sight, is fit for purpose for real-time data communication eliminating the need for human intervention. However, technical feasibility needs to be conducted to identify the right types of equipment that would yield maximum efficiency and fine-tune system performance. Implementing real-time situation awareness via automation can bring significant benefits to the health sector including evidence-based decision-making, minimising the workload on health professionals, and improving patient care.

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Data availability statement

The Python code for the prototype dashboard is openly available on Zenodo at https://doi.org/10.5281/zenodo.13729464.

References

Abugabah A, Nizamuddin N, Abuqabbeh A. 2020. A review of challenges and barriers implementing RFID technology in the healthcare sector. Procedia Computer Science. 170:1003–1010. doi: 10.1016/j.procs.2020.03.094

Ahmadi M, Mirbagheri E. 2019. Designing data elements and minimum data set (MDS) for creating the registry of patients with gestational diabetes mellitus. Journal of Medicine and Life. 12 (2):160. doi: 10.25122/jml-2019-0011

Álvarez López Y, Franssen J, Álvarez Narciandi G, Pagnozzi J, González-Pinto Arrillaga I, Las-Heras Andrés F. 2018. RFID technology for management and tracking: E-health applications. Sensors. 18(8):2663. doi: 10.3390/s18082663

Anderson DC, Halpern NA. 2016. Contemporary ICU design. In: Martin ND, Kaplan LJ, editors. Principles of adult surgical critical care. Cham: Springer; p. 539–549. doi: 10.1007/978-3-319-33341-0_49

Begun JW, Zimmerman B, Dooley K. 2003. Health care organizations as complex adaptive systems. Advances in Health Care Organization Theory. 253:288.

Benson T, Grieve G. 2021. Why interoperability is hard. Cham: Springer International; p. 21.40.

Bibi F, Guillaume C, Gontard N, Sorli B. 2017. A review: RFID technology having sensing aptitudes for food industry and their contribution to tracking and monitoring of food products. Trends in Food Science & Technology. 62:91–103. doi: 10.1016/j.tifs.2017.01.013

Boniol M, Kunjumen T, Nair TS, Siyam A, Campbell J, Diallo K. 2022. The global health workforce stock and distribution in 2020 and 2030: a threat to equity and 'universal' health coverage? BMJ Global Health. 7(6):e009316. doi: 10.1136/bmjgh-2022-009316

Buettner R, Clauß T, Huynh MT, Koser D. 2020. RFID tracking and localization technologies in healthcare. In: 2020 IEEE Symposium on Industrial Electronics & Applications (ISIEA). IEEE; p. 1–5.

Confidex. 2022. Confidex steelwave classic data sheet. https://www.confidex.com.

Costa F, Genovesi S, Borgese M, Michel A, Dicandia FA, Manara G. 2021a. A review of RFID sensors, the new frontier of internet of things. Sensors. 21(9):3138. doi: 10.3390/s21093138

Costa F, Genovesi S, Borgese M, Michel A, Dicandia FA, Manara G. 2021b. A review of RFID sensors, the new frontier of internet of things. Sensors. 21(9):3138. doi: 10.3390/s21093138

Diplomates FA. 2005. Health care system surge capacity recognition, preparedness, and response. Ann Emerg Med. 45:239.

El Khaddar MA, Boulmalf M, Harroud H, Elkoutbi M. 2011. RFID middleware design and architecture. In: Turcu C, editor. Designing and deploying RFID applications. IntechOpen; p. 305–326.

Garg L, Chukwu E, Nasser N, Chakraborty C, Garg G. 2020. Anonymity preserving IoT-based COVID-19 and other infectious disease contact tracing model. IEEE Access. 8:159402–159414. doi: 10.1109/ACCESS.2020.3020513

Geraci A. 1991. IEEE standard computer dictionary: compilation of IEEE standard computer glossaries. IEEE Press.

Grand View Research. n.d.. RFID in healthcare market size, share trends. https://www.grandviewresearch.com/industry-analysis/rfid-in-healthcare-market.
GS1. 2014. EPC tag data. https://www.gs1.org/sites/default/files/docs/epc/TDS_1_8_Standard_20140203.pdf.
GS1. n.d.. Gs1 identification keys. https://www.gs1.org/standards/id-keys.
GS1 New Zealand. n.d.. Global traceability in the meat industry. https://www.gs1nz.org/assets/Case-Studies/Resources/b6bedaa0d0/Global_traceability_in_the_meat_industry.pdf.
Hevner AR, March ST, Park J, Ram S. 2004. Design science in information systems research. MIS Quarterly. 28:75–106. doi: 10.2307/25148625
Islam MN, Hasan U, Islam F, Anuva ST, Zaki T, Islam AN. 2022. IoT-based serious gaming platform for improving cognitive skills of children with special needs. Journal of Educational Computing Research. 60(6):1588–1611. doi: 10.1177/07356331211067725
Jia X, Feng Q, Fan T, Lei Q. 2012. RFID technology and its applications in internet of things (IoT). In: 2012 2nd International Conference on Consumer Electronics, Communications and Networks (CECNet). IEEE; p. 1282–1285.
Kabachinski J. 2005. An introduction to RFID. Biomedical Instrumentation & Technology. 39 (2):131–134. doi: 10.2345/0899-8205-43.2.131
Kelen GD, McCarthy ML. 2006. The science of surge. Academic Emergency Medicine. 13 (11):1089–1094. doi: 10.1197/acem.2006.13.issue-11
Khan MA, Sharma M, Prabhu BR. 2009. A survey of RFID tags. International Journal of Recent Trends in Engineering. 1(4):68.
Krugman ME, Sanders CL. 2016. Implementing a nurse manager profile to improve unit performance. JONA: The Journal of Nursing Administration. 46(6):345–351. doi: 10.1097/NNA.0000000000000355
Labrague LJ, McEnroe-Petitte DM, Leocadio MC, Van Bogaert P, Cummings GG. 2018. Stress and ways of coping among nurse managers: an integrative review. Journal of Clinical Nursing. 27(7–8):1346–1359. doi: 10.1111/jocn.2018.27.issue-7pt8
Machitidze M. 2022. Impact of the nurses education and shortage on the patients care outcomes-literature review. Am J Biomed Sci Res. 15:441–443. doi: 10.34297/AJBSR
Mahinderjit-Singh M, Li X, Li Z. 2011. Security control and privacy preservation in RFID enabled wine supply chain. In: Turcu C, editor. Designing and deploying RFID applications. IntecgOpen; p. 221–250.
Maves RC, Jamros CM, Smith AG. 2019. Intensive care unit preparedness during pandemics and other biological threats. Critical Care Clinics. 35(4):609–618. doi: 10.1016/j.ccc.2019.06.001
McDaniel G, International Business Machines Corporation. 1994. IBM dictionary of computing. McGraw-Hill.
Mehta S, Grant K, Atlin C, Ackery A. 2020. Mitigating staff risk in the workplace: the use of RFID technology during a COVID-19 pandemic and beyond. BMJ Health & Care Informatics. 27(3. doi: 10.1136/bmjhci-2020-100230
Mohammad GB, Shitharth S, Syed SA, Dugyala R, Rao KS, Alenezi F, Althubiti SA, Polat K. 2022. Mechanism of internet of things (IoT) integrated with radio frequency identification (RFID) technology for healthcare system. Mathematical Problems in Engineering. 2022 (1):4167700.
Mostaccio A, Bianco GM, Marrocco G, Occhiuzzi C. 2023. RFID technology for food industry 4.0: a review of solutions and applications. IEEE Journal of Radio Frequency Identification. 7:145–157. doi: 10.1109/JRFID.2023.3278722
Munoz-Ausecha C, Ruiz-Rosero J, Ramirez-Gonzalez G. 2021. RFID applications and security review. Computation. 9(6):69. doi: 10.3390/computation9060069
New Zealand Government. 2023. Timeline of significant COVID-19 events. https://www.dpmc.govt.nz/sites/default/files/2023-10/pr-timelinesignificant-events-activities.pdf.
New Zealand Nurses Organisation. 2020. New Zealand standards for critical care nurse staffing. https://www.nzno.org.nz/.
Paaske S, Bauer A, Moser T, Seckman C. 2017. The benefits and barriers to RFID technology in healthcare. On-Line Journal of Nursing Informatics. 21(2). http://ezproxy.aut.ac.nz/login?

url=https://www.proquest.com/scholarly-journals/benefits-barriers-rfid-technology-healthcare/docview/1984766816/se-2?accountid=8440.
Pandey G, Sunar A, Yogi J, Poudel N, Koirala KR. 2023. Electronic health record management system using RFID: improving efficiency and accuracy in healthcare. Journal of Information Technology. 5(3):274–290.
Peffers K, Tuunanen T, Rothenberger MA, Chatterjee S. 2007. A design science research methodology for information systems research. Journal of Management Information Systems. 24 (3):45–77. doi: 10.2753/MIS0742-1222240302
Pérez-Fernández J, Raimondi NA, Murillo Cabezas F. 2020. Digital transformation: the smart ICU. In: Hidalgo J, Pérez-Fernández J, Rodríguez-Vega G, editors. Critical care administration: A comprehensive clinical guide. Cham: Springer; p. 111–125. doi: 10.1007/978-3-030-33808-4_9
Pilcher D, Coatsworth NR, Rosenow M, McClure J. 2021. A national system for monitoring intensive care unit demand and capacity: the critical health resources information system (CHRIS). The Medical Journal of Australia. 214(7):297. doi: 10.5694/mja2.v214.7
Printed Electronics Now. 2023. RFID industry worth 40.9Bby 2032. https://www.printedelectronicsnow.com/contents/view_breaking-news/2023-10-18/rfid-industry-worth-409b-by-2032-marketsandmarkets/#::text=The%20RFID%20market%20is%20projected,increasing%20adoption%20across%20various%20industries.
Profetto L, Gherardelli M, Iadanza E. 2022. Radio frequency identification (RFID) in health care: where are we? a scoping review. Health and Technology. 12(5):879–891. doi: 10.1007/s12553-022-00696-1
Pronovost P, Berenholtz S, Dorman T, Lipsett PA, Simmonds T, Haraden C. 2003. Improving communication in the ICU using daily goals. Journal of Critical Care. 18(2):71–75. doi: 10.1053/jcrc.2003.50008
Quinn R. 2021. 644 million boost as ICU and hospitals brace for widespread COVID-19. https://www.rnz.co.nz/news/national/457098/644-million-boostas-icu-and-hospitals-brace-for-widespread-covid-19.
RAIN Alliance. n.d.. Rain RFID technology. https://rainrfid.org/whatis-rain-rfid/.
Rajasekar SJS. 2021. An enhanced IoT based tracing and tracking model for COVID-19 cases. SN Computer Science. 2(1):42. doi: 10.1007/s42979-020-00400-y
Reding V. 2009. Commission recommendation of 12 may 2009 on the implementation of privacy and data protection principles in applications supported by radio-frequency identification. Official J Eur Union. 50(122):47–51.
Rosenbaum BP. 2014. Radio frequency identification (RFID) in health care: privacy and security concerns limiting adoption. Journal of Medical Systems. 38:1–6. doi: 10.1007/s10916-014-0019-z
Shang F, Yang P, Xiong J, Feng Y, Li X. 2023. Tamera: contactless commodity tracking, material and shopping behavior recognition using cots RFIDs. ACM Transactions on Sensor Networks. 19(2):1–24. doi: 10.1145/3563777
Simon HA. 1996. The sciences of the artificial. MIT Press.
Te Whatu Ora. 2023. COVID-19: current cases. https://www.tewhatuora.govt.nz/our-health-system/data-and-statistics/covid-19-data/covid- 19-current-cases/.
The Danby Group. n.d.. Cost-benefit analysis of an RFID asset tracking system. https://www.danbygroup.com/docs/Cost-Benefit-Analysis_of_RFID_Asset_Tracking_Danby.pdf.
The New Zealand Nurses Organisation. 2023. The Aotearoa New Zealand health system – failing or fabulous? NZNO conference. https://www.nzno.org.nz/Portals/0/Files/Documents/AGM/2023-09\%20The\%20Aotearoa\%20New\%20Zealand\%20Health\%20System\%20-\%20Failing\%20or\%20Fabulous\%20FINAL.pdf.
Torab-Miandoab A, Samad-Soltani T, Jodati A, Rezaei-Hachesu P. 2023. Interoperability of heterogeneous health information systems: a systematic literature review. BMC Medical Informatics and Decision Making. 23(1):18. doi: 10.1186/s12911-023-02115-5
Weis SA. 2007. RFID (radio frequency identification): principles and applications. System. 2(3):1–23.
Weizman Y, Tan AM, Fuss FK. 2020. Use of wearable technology to enhance response to the coronavirus (COVID-19) pandemic. Public Health. 185:221. doi: 10.1016/j.puhe.2020.06.048

Wilcox ME, Harrison DA, Patel A, Rowan KM. 2020. Higher ICU capacity strain is associated with increased acute mortality in closed ICUs. Critical Care Medicine. 48(5):709–716. doi: 10.1097/CCM.0000000000004283

World Health Organization (WHO). 2023. Patient safety. https://www.who.int/news-room/fact-sheets/detail/patient-safety.

World Population Review. 2023. ICU beds per capita by country 2023. https://worldpopulationreview.com/country-rankings/icu-beds-per-capita-bycountry.

Yamashita K, Kusuda K, Ito Y, Komino M, Tanaka K, Kurokawa S, Ameya M, Eba D, Masamune K, Muragaki Y, Rajkumar K. 2018. Evaluation of surgical instruments with radiofrequency identification tags in the operating room. Surgical Innovation. 25(4):374–379. doi: 10.1177/1553350618772771

Yen P-Y, Kellye M, Lopetegui M, Saha A, Loversidge J, Chipps EM, Gallagher-Ford L, Buck J. 2018. Nurses' time allocation and multitasking of nursing activities: a time motion study. In: AMIA Annual Symposium Proceedings, Vol. 2018. American Medical Informatics Association; p. 1137.

Yodice PC. 2020. ICU design. In: Hidalgo J, Pérez-Fernández J, Rodríguez-Vega G, editors. Critical care administration. Cham: Springer. doi: 10.1007/978-3-030-33808-4_11

Young P, Psirides A, Streat S. 2021. New zealand's staffed ICU bed capacity and COVID-19 surge capacity. New Zealand Medical Journal. Graph. 5:8–10.

Zhang J, Tian GY, Marindra AM, Sunny AI, Zhao AB. 2017. A review of passive RFID tag antenna-based sensors and systems for structural health monitoring applications. Sensors. 17(2):265. doi: 10.3390/s17020265