A Web-based Information System for the Management of ICU Beds During the Coronavirus Outbreak

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***Abstract*—With the world pandemic generated by Covid-19, many places in the world are not able to rapidly measure the number of intensive care unit (ICU) beds existing and available in a city, state, or country. Knowing precisely the number of ICU beds in real-time is very important to estimate the health system collapse and to create strategies for the government to provide new ICU beds for patients. Thus, at Rio Grande do Norte, a state in Brazil, the State Health Department requested us to rapidly develop a technology to integrate ICU beds and patient data related explicitly to Covid-19 from the 58 health units (hospitals and clinics) in the state. Thus, this article presents the methodology and strategies used for the development and implementation of a web information system, called Leitos, for the management of ICU and semi-ICU beds assigned to Covid-19 patients. Nowadays, more than 200 government agents and clinical unit staff are using this system that presents the real-time situation of the ICU beds in this state.**

***Index Terms*—Covid-19; web-based information system; ICU beds; real-time**

I. Introduction

Traditionally, the motivation for using modern Information and Communication Technologies (ICT) in the healthcare system is to offer promising solutions for efficiently delivering all kinds of medical healthcare services to patients such as electronic record systems, telemedicine systems, personalized devices for diagnosis, and others, which are named e-health [1]. At the heart of e-health is the idea of improving the quality of the health information, strengthening national health systems, and ensuring accessible, high-quality health care for all [2].

The coronavirus outbreak is stressing the health system of many countries in the globe, revealing the need to develop and grow the surge capacity for acute and intensive care. However, to measuring, monitoring and accounting the availability of intensive care unit (ICU) beds in a city, state, or country, in real-time, is a hard job for many governments. As a response to this, the European office of the World Health Organization (WHO) recommends policies and strategic actions to expand the capacity for communication in order to ensure ongoing and proactive coordination for a better surge capacity response [3]. Such activities become even more urgent as some countries have reached warning numbers, e.g., in Italy, 39.8% of Covid-19 positive cases have been hospitalized, and 6.6% admitted to ICUs [4], while in China, the mean duration of hospitalization was 12.8 days [5].

Moreover, the reasons for variations in hospital admissions, severity, and mortality rates point to different population structures, hospitalization guidelines and thresholds, hospital capacities, testing practices, data collection methods, implementation of infection prevention and control (IPC) measures, time taken to provide care, as well as the risk factors among the infected people (age and comorbidities) [3].

In this context, the accurate knowledge of the number of ICU beds available in real-time is essential to estimate the collapse of the health system, to speed up patient transfer, and to create government strategies to provide new ICU and semi-ICU beds.

Considering these aspects, combating the Covid-19 pandemic is more critical in poor and emerging countries since they usually have fewer hospital and ICU beds per capita. In Brazil, there were, in 2017, 2.3 hospital beds per 1,000 people - which is less than half the average (4.7) of hospital beds across OECD countries [6]. This scenario becomes even worse under the reported high demand for ICU beds in Covid-19 cases. According to a study conducted by the Brazilian Medical Association of Intensive Care Medicine, there were only 0.203 ICU beds per 1,000 people in Brazil [7].

The coronavirus has already become a real problem in Brazil. In the first week of May 2020, there were more than 135,000 confirmed cases and more than 9,000 deaths caused by the coronavirus in Brazil [8].

Seeking for an effective way to monitor and account the ICU, semi-ICU and extra beds usage, as well as the patients admitted suspected of having Covid-19, the State Health Department (SESAP/RN) of Rio Grande do Norte - a Brazilian federal state with 0.166 ICU beds per 1,000 people [7] – required us to quickly develop a technology to integrate hospital beds and patient data explicitly related to Covid-19 of the 58 health units (hospitals and clinics) in the state.

Thus, this article presents the methodology and strategies used for the development and implementation of a web information system called Leitos, for the management of ICU and semi-ICU beds allocated to patients suspected of having Covid-19.

The rest of the article is structured as follows: Section II presents the system's requirements and software architecture issues; Section III presents the Web-based Information System called Leitos; and, finally, Section IV presents the conclusions and future work.

II. System's Architecture and Conceptual Data Model

To elicit the functional and non-functional requirements of the web information system focused on bed management for Covid-19, we held meetings with the regulation sector of the SESAP/RN. Given the fast advance of Covid-19 in the state of Rio Grande do Norte (RN), the system had to be ready and available in only three days.

After a few meetings with the SESAP team, it became clear that the primary purpose of this system was to provide panels showing analytical and synthetic information covering suspected, confirmed, and discarded cases, as well as patients' deaths in all of the hospital beds dedicated to the Covid-19 cases in the state of RN.

In this sense, still based on the meetings, we identified that the proposed information system had two main actors: the administrator of the State Health Department and the health professional linked to health units. Besides, it had to have the following functionalities for the administrators:

- Create, visualize, delete, and update health units. These units can be private or public from the state or municipal network;
- Create, visualize, delete, and update users. These users can be administrators or be associated with one or more health units;
- Daily basis and real-time reports of suspected, confirmed, and discarded cases and deaths by Covid-19. Administrators can easily access this information through the panels and the reports (PDF and Excel) available;
- Information on bed usage (free, occupied, or blocked hospital beds), patients, diagnoses, and exams in each health unit, presented analytically and synthetically for administrators.

Concerning the users in health units (clinical staff), they have the following features:

- Create, visualize, delete, and update health unit beds. These beds can be free, occupied or blocked (for example, due to renovation lack of equipment and human resources);
- Create, visualize, delete, and update patients in health units;
- Association between diagnostics and patients. This functionality allows the confirmation or disposal of a suspicious case for Covid-19. Also, it allows the information of the exam requisition number to be associated with the diagnosis;
- Create, visualize, delete, and update patient admission, discharge, and death records.

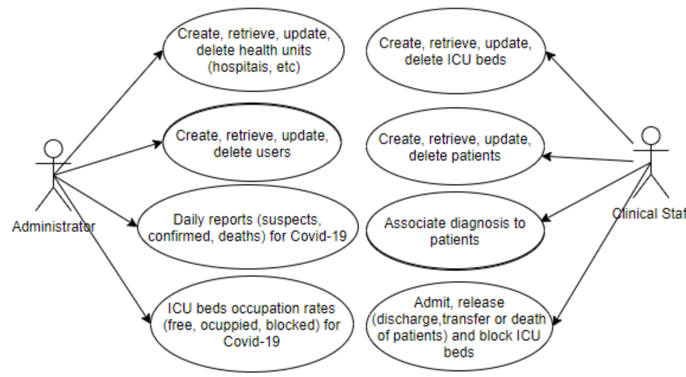

Fig. 1. User case diagram.

The actors and features are presented in the use case diagram in Figure 1. With the definition of the application's functional requirements and also through meetings, it was possible to elicit the functional requirements related to security, patient information privacy, availability and performance of the application, and traceability of the data inserted, altered, and removed. Thus, the application provides encryption, authentication, and authorization strategies to access its features. Besides, it allows the access of multiple users simultaneously and records log data (date and user) regarding the operations of inserting, changing, and removing information from the system.

After eliciting the functional and non-functional requirements, we structured the application's domain diagram. This diagram, shown in Figure 2, has domains related to the type of health unit (public or private), health units, users, beds, bed status (free, occupied, or blocked), patients, municipalities, hospitalizations and hospitalization status (discharge, transfer, or death). The municipality's information becomes essential in this context due to possible needs for patient transfers between different health units in the same municipality.

With the definition of the domains, we designed the application's component diagram shown in Figure 3. Thus, we defined components for the controllers, validators, repositories, configurations, utilities, helpers, services, domain, enums, and tasks. It is important to note that the motivation for creating these packages is mainly due to the use of the Domain Model, Page Controller, Model View Controller, and Repository design patterns [9], which were used for the design of the application.

We started the development of the proposed web information system based on the elicited functional and non-functional requirements, the domain diagram, and the component di-

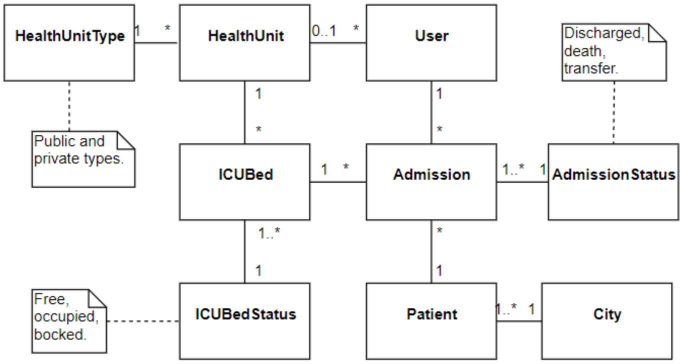

Fig. 2. Domain diagram.

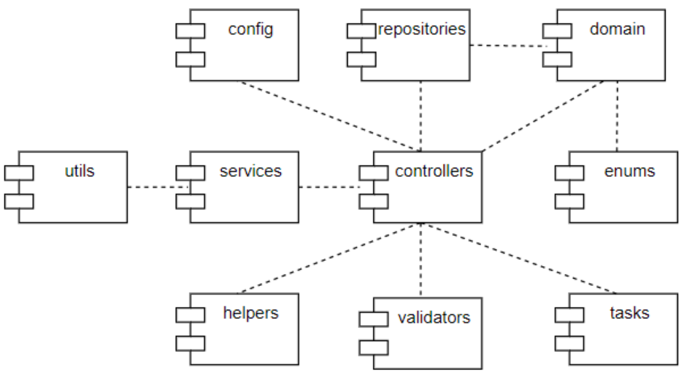

Fig. 3. Components diagram.

agram projected. We use the Java platform and the Spring Framework as technologies for implementation.

During the development, we used the Agile Scrum [10] Methodology. Our team was composed of two professors and five students (two postgraduate and three undergraduate). The first sprint took three days and was focused on the development of the main features, covering approximately 70% of the proposed requirements. One of the teachers assumed the role of Scrum Master while the other assumed the role of the Product Owner. The students assumed the role of the team. During the execution of the sprint, daily meetings were held. After the first sprint, we present the first version of the system (revision and retrospective of the sprint).

During this process, we also created rapid prototypes of interfaces for validation with the Product Owner and, in some cases, with the staff of the State Health Department. Testing techniques, such as unit tests and acceptance tests, were also used. Unfortunately, due to the time it was not possible to carry out code review, automated tests, and stress tests to guarantee the improvement of the software quality.

With the lack of functional tests, most of them were carried out with the information system in operation and being used by stakeholders. Thus, after the release of the first sprint, some bugs were detected in the functionalities provided, which were quickly corrected in small sprints focused on solving bugs.

The following sprints were alternated between improvement sprints, contemplating the completion of requirements and new demands by stakeholders, and bug correction sprints. One should note that the team's effort was essential to meet the established deadlines. Moreover, given the importance of the system, it was possible to perceive the team's responsibility and dedication to reach the deadlines defined in the sprints. In this sense, we believe that characteristics such as self-management, responsibility, and proactivity were evident during the application of Scrum in this project.

The resulting information system is based on a web server infrastructure running within a CentOS container. We used a set of free software programs commonly employed together to support the information system, such as Java, SpringFramework, Thymeleaf, Apache Tomcat, and PostgreSQL. The combination of these technologies follows a twofold goal: first, to avoid issues regarding the license of use; and second, to facilitate technology transfer since all of these technologies have an established support community.

III. The Web-based Information System

Fig. 4. ICU beds dashboard.

Figure 4 shows the Covid-19 data panel accessed by administrators. When writing this paper, the hospital bed management information system[1] has been in operation for nearly a month. At this time, it has approximately 200 users and 58 registered health units, adding up to a total of 558 beds for Covid-19. Although the numbers vary daily, as an illustration, when we wrote this paper, a total of 202 cases of Covid-19 (among suspected, confirmed, and discarded) and 55 deaths were registered in the system by health unit users. Also, through this system, it is possible to obtain the number and percentage of free, occupied, and blocked hospital beds in real-time, where we currently have 281 (50.36%) free, 202 (36.20%) occupied and 75 (13.44%) blocked bed. These blockages are mainly due to renovations that are being carried out in health units to expand the beds for Covid-19.

We emphasize that also on the dashboard it is possible to see in detail the numbers of hospital beds usage for all health units, as shown in Figures 5 and 6. For privacy reasons, we crossed out all the sensitive data.

[1]https://leitoscovidrn.imd.ufrn.br/

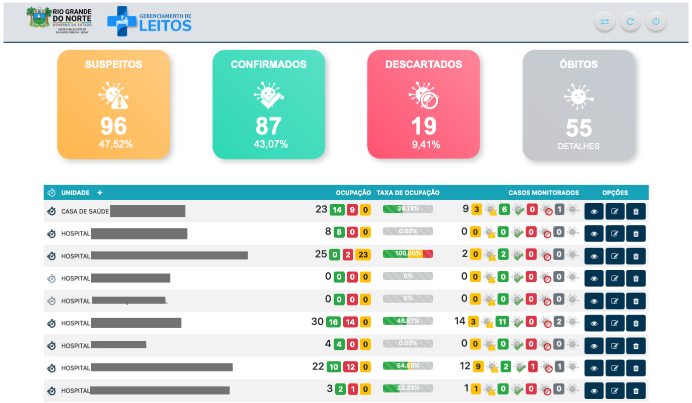

Fig. 5. ICU beds dashboard.

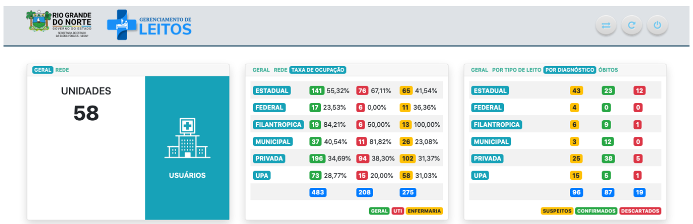

Fig. 6. Statistics for each health unit group.

Figure 7 shows the health units' user panel, which displays information about beds, patients, age, diagnosis, length of stay, among other information. For privacy reasons, we crossed out the name of the health units and patients.

In this panel, it is possible to create, update, remove and block beds, launch exam requisition numbers, and admit, release and transfer patients. We used color-coding [11] techniques and icons to facilitate the usability and presentation of occupancy data and monitored cases for each unit. For example, in Figure 5, it is possible to see that the occupied beds are highlighted in light red, the blocked beds in yellow, and the free beds are detached in light green color.

Finally, we created automatic e-mail alert mechanisms to notify the administrator users of the lack of usage updates for the day for a particular health unit.

IV. Conclusions and Lessons Learned

In this work, we presented the methodology and strategies used to develop a web information system to monitor the ICU and semi-ICU bed usage in the state of Rio Grande do Norte during the coronavirus outbreak.

The system has been in use for approximately a month by the SESAP/RN and its health units and is providing helpful information to guide decision making regarding availability and need of opening new ICU beds for Covid-19 cases. Hospital beds are essential inputs for the battle against this pandemic and the lives of patients, and this system makes it possible to monitor them analytically and synthetically in real-time.

Fig. 7. Health unit dashboard.

After the system was made available and widely used by stakeholders, the Federal Public Attorney's Office of Rio Grande do Norte (MPF/RN), which has the role of monitoring the demands for the state's hospital beds, required access to the system. As a solution, viewing-only access to the administration panel was made available to facilitate the MPF/RN's work.

Finally, as future work, we are developing an application programming interface (API) to enable the integration of the system developed with other systems, such as electronic medical records and patient regulation systems. Besides, we intend to make this solution available as an open-source to help other countries, states, and municipalities with similar needs.

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