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Situation Awareness-Oriented Dashboard in ICUs in Support of Resource Management in Time of Pandemics

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ABSTRACT In a pediatric intensive care unit (PICU) of 32 beds, clinicians manage resources 24 hours a day, 7 days a week, from a large-screen dashboard implemented in 2017. This resource management dashboard efficiently replaces the handwriting information displayed on a whiteboard, offering a synthetic view of the bed's layout and specific information on staff and equipment at bedside. However, in 2020 when COVID-19 hit, the resource management dashboard showed several limitations. Mainly, its visualization offered to the clinicians limited situation awareness (SA) to perceive, understand and predict the impacts on resource management and decision-making of an unusual flow of patients affected by the most severe form of coronavirus. To identify the SA requirements during a pandemic, we conducted goal-oriented interviews with 11 clinicians working in ICUs. The result is the design of an SA-oriented dashboard with 22 key indicators (KIs): 1 on the admission capacity, 15 at bedside and 6 displayed as statistics in the central area. We conducted a usability evaluation of the SA-oriented dashboard compared to the resource management dashboard with 6 clinicians. The results showed five usability improvements of the SA-oriented dashboard and five limitations. Our work contributes to new knowledge on the clinicians' SA requirements to support resource management and decision-making in ICUs in times of pandemics.

INDEX TERMS Clinical decision support system, clinical dashboard, critical care, intensive care unit, situation awareness.

I. INTRODUCTION

When coping with a pandemic, Intensive Care Units' (ICU) teamwork and resource management are under pressure [1]. The teams need to know the medical staff on duty, their skills and competencies, the materials and medical supplies available or lacking, as well as the beds spaces available to treat patients [2]. They need tools to improve the situation awareness (SA) in support of clinical decision-making.

In many countries, ICUs lacked the tools to admit and effectively manage the flow of patients affected by the most severe effects of COVID-19.The ICUs were initially ill prepared with a lack of medical equipment, personnel, and space shortage [3], [4]. Staffing was the most limited resource [5].

In Canada, the province of Quebec experienced the highest death toll in the country due to the lack of institutional preparation in long-term care facilities and critical shortage of staff, equipment, and spaces [6]. To monitor and control the pandemic, the Canadian health authorities and its 10 provinces and 3 territories needed to report daily beds occupancy in hospital, admissions in ICUs and COVID-19 deaths [7], [8].

Backtracking to the situation at the start of the COVID-19 pandemic, our research team decided to design a dashboard to cope with the Quebec public health measures and clinicians' requirements in ICUs. Soon, we hypothesized that visualizing key indicators would improve resource management and decision-making in ICUs. It would play a key role in lessening clinicians' cognitive load, in helping to perceive the current situation, the information's meaning and to plan immediate and future actions. Thus, this paper developed a

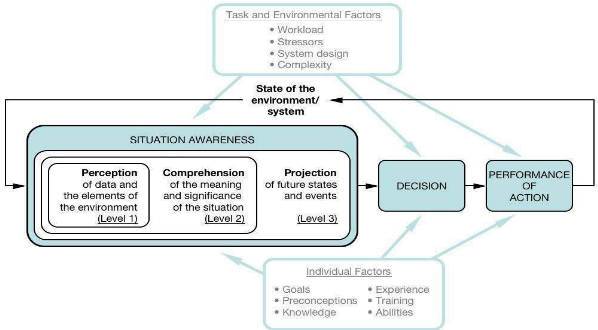

FIGURE 1. Situation awareness model [9]. (Reprinted with permission from Endsley, M.R. Hum. Factors, 37(1), 32, 1995. Copyright 1995 by the human factors and ergonomics society. all rights reserved).

technological solution to address an unmet clinical need on key factors to situation awareness and resource management in critical care settings.

The rest of this article is organized as follows. In Section II, we include a review of related work. Section III describes the research context. Section IV describes the methodology used to design and evaluate the SA-oriented dashboard. Section V presents the results. The discussion in Section VI includes improvements and limitations of the SA-oriented dashboard. We conclude in Section VI.

II. RELATED WORK

We reviewed related work in two sections. First, we present the SA model and its implications in medical settings. Second, we review the use of dashboards in ICUs to support resource management and decision-making.

A. SITUATION AWARENESS

The concept of situation awareness is defined as ''the perception of the elements in the environment within a volume of space and time, the understanding of their meaning, and the projection of their status in the future'' [9]. SA was originally developed in the field of aviation to study the origins of human errors in aircraft accidents [10], [11] and has since made its way to other complex, dynamic settings to improve the operator's assessment and decision-making in military operations [12], marine navigation [13] and medicine [14].

Situation awareness in medicine can be used as a measurement and design tool. Clinicians' SA can be measured using direct or indirect methods [15]. Direct methods measure clinicians' knowledge of the current situation by using probe queries covering the three SA levels that can be answered as the events unfold [16]. It was successfully applied to measure SA of health practitioners in nursing [17], anesthesia [18], and obstetrics [19]. Indirect methods measure the clinician's efficiency using other cognitive constructs. The most notable indirect methods are performance-based completion measures during task execution, and verbal protocol analysis where the clinician is asked to verbalize his or her clinical reasoning during task-oriented scenarios to identify the pieces of information relevant to the decision-making process. Indirect methods assume that better SA translates into better behavioral and cognitive performance [20]. System design, encapsulated in the task and environmental factors of Endsley's SA model, is critical to the clinician's SA as the medical equipment, digital tools and displays are a primary source to collect information and to make sense of a situation from a dynamic process of clinical decision-making [21].

The SA model illustrated in figure 1 presents three ascending levels of situation awareness, the task and environmental factors affecting it, as well as the individual and cognitive factors making the SA construction possible.

Level 1 SA is the first step in achieving SA. It is the perception of relevant information in the environment. Level 1 SA involves the detection and recognition of the surrounding elements, as well as the awareness of their current states. At this stage, there is no interpretation of the meaning of the information perceived, as the individual is collecting the facts presented in relation to the task. A clinician having achieved level 1 SA in the context of a clinical dashboard would have adequately perceived all signals displayed on the screen, including the current values of indicators, color-coded symbols, and icons, as well as their relative location in space.

Level 2 SA involves synthesizing the Level 1 SA elements to develop an understanding of the current situation. It includes the process of interpretation and pattern recognition to develop a comprehensive picture of the circumstances. At this stage, the person relates the individual pieces of information together, compares them with mental patterns stored in long-term memory of similar situations, assesses the current situation in contrast to his or her objectives, and judges whether the situation is progressing as expected. Level 2 SA is when the ''big picture'' understanding emerges, and the person correctly assesses the state of the current situation. A clinician using a clinical dashboard achieved Level 2 SA when she makes the right judgment on the status of the ICU based on the information displayed and her clinical knowledge.

Level 3 SA is the projection of the future state of the situation and how it will evolve in time in relation to the current goal. It reflects a person's ability to predict the situation's dynamics and anticipate the next course of actions. Level 3 SA requires a highly developed mental model of the system's dynamics and is a characteristic of experts in the field. Expert confidence in projections may reflect familiarity with the situation or similar situations, and the level of variability in outcome possibilities. For a clinical dashboard, this means that the clinician can forecast the directions and gravity of the changes. Based on data trends of key factors, projected values of variables, and their implicit knowledge of the dynamics, clinicians can predict the future state of the situation.

The three levels of SA represent ascending and not linear levels, as they feed one into another [22]. For instance, an intensivist judges that the ICU has limited admission capacity (level 2) and will likely need to redirect incoming patients to other services (level 3) based on her mental model of previous similar situations. Then, she directs her attention to individual pieces of information (level 1) to confirm her judgment, such as the nurse-to-patient ratio and expected departures.

B. DASHBOARDS IN HOSPITALS AND ICUs SETTINGS

A dashboard is defined as a visual display consolidated in a way that the information can be found and understood at a glance [23].

With the increase demand for critical care during the COVID-19 pandemic, digital dashboards can improve the performance of an ICU team. The dashboard can offer immediate access to information, structure the care of common goals, improve adherence to quality guidelines, and help improve patient outcomes [24]. However, the study concluded on the lack of evidence on how clinicians use and integrate the information provided by the dashboards into clinical reasoning and decision-making. It also highlighted two types of dashboards used in medical settings: quality and clinical dashboards.

Quality dashboards are administrative-oriented informational tools, the most common of which being the balanced scorecard (BSC) inherited from the business sector [25]. BSC tracks a set of key performance indicators (KPIs) ''balanced'' from different categories to support leaders' strategies and decision-making at a unit or organizational level [26]. They are effective at improving managerial and strategic objectives when unit-level activities are aligned with the KPI tracked and can translate into operational practices [27].

Hospitals' BSC adopted a business perspective, through a balanced view on performance from the following four categories: financial indicators, customer satisfaction, business processes, and learning/growth. However, hospitals are healthcare-provider organizations where management differs from other organizations in that they must balance the overall costs with care accessibility and quality. The main limitation of a business-oriented dashboard in hospital settings is the absence of information on care delivery and clinicians' tasks [28]. Even if these act as a barrier to performance in hospital, they are part of the KPIs [29].

A clinical dashboard is a visual data-driven decision-support tool impacting the quality of care and hospital performance [30], [31]. It is defined as a set of visual displays developed to provide clinicians with the relevant and timely information they need to inform daily decisions that improve the quality of patient care [32]. Clinically-oriented dashboards support the physicians in comprehensively visualize increasingly complex patient histories in a short span of time [33]. Previous works showed that the use of clinical dashboards in ICUs, designed around specific tasks, reduced cognitive load which in turn lessened the number of medical errors and the costs of a patient prolonged long-term stay in hospital [34].

To gain an up-to-date understanding on the impact of SA-oriented information in Clinical Decision Support Systems (CDSS) in critical care settings, we conducted a five-year literature review (2017-2022). The findings suggest two contributions to the understanding of the impact of CDSS SA-oriented information.

First, we identified four categories of CDSS in use in critical care: Electronic Health Record (EHR) [35], [36], Mobile application [37], Decision Support Systems [38], [39] and Predictive decision-making tools [40].

Second, there are seven categories of impacts on SA-oriented information in CDSS: reasoning patterns [35], integration of monitoring and therapeutic devices [37], [41], sociotechnical levels of awareness [38], shared understanding of patients' care transitions [39], predictions on the allocation of limited resources [42] on clinicians' workload [36] and ICUs' admissions and in-hospital death [40]. Surprisingly, we did not find previous work on SA dashboard in ICU. This study aims to fill this gap in literature with the design of a SA-oriented dashboard.

Therefore, the research team's main hypothesis was: ''SA-oriented dashboard improves resource manamgenet and decision-making in critical care units.''

III. RESEARCH CONTEXT

In 2016, our PICU research partner benefited from an expansion in spaces from a 20 to 32-bed capacity, and renewal of equipment and materials. The whiteboard they used to manage the unit became obsolete as it was too small to display handwritten information on staffing at bedside, patients' admissions and departures, and bed occupancy. In 2017 they designed a resource management dashboard displayed on a large screen TV in the unit's main entrance (see Figure 2). It is operational 24 hours a day, seven days a week, presenting a mapping of 32 beds numbered from 1 to 12 and 14 to 33. Similar to other hospitals' intensive care wards, there is no bed number 13 due to beliefs of its impact on patients' survival chances [43].

The resource management dashboard offers significant gains compared to the whiteboard previously used. It allows a multidisciplinary team to view beds' occupancy and characteristics such as negative pressure, patients' name, equipment required (ventilator, hemodialysis), pediatricians and nurses assigned to patients, admissions or departures, rankings of patients' health condition (Pelod-2) and nurses' workload (Quantis). A higher Pelod-2 score correlates with a higher risk of mortality [44]. A higher Quantis score correlates with the patients' bedside nursing monitoring and surveillance requirements.

However, in March 2020, to cope with the public health rules in force to fight the COVID-19 pandemic and the sudden increase of patients in emergency and ICUs, the resource management dashboard needed modifications, for the following reasons:

- The original design did not anticipate a situation where an overflow of patients requires additional beds spaces, nor measures to address it.

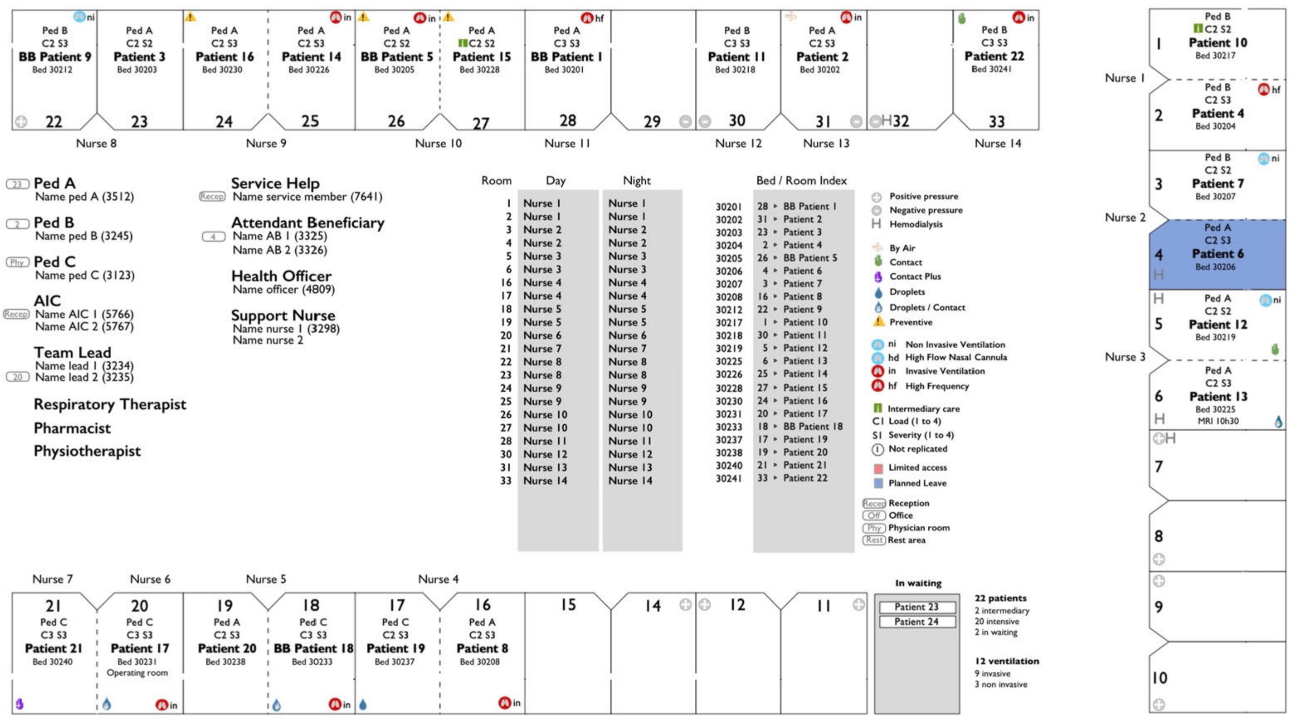

FIGURE 2. Resource management dashboard in use at the partnering PICU.

- It was not flexible to adapt to new situations such as the display of the secured spaces reserved to COVID-19 patients.
- It lacked situation awareness-oriented information, e.g., to perceive the current situation, understand its meanings and project future actions.

From there on, the objectives of our study were to 1) Identify the key factors of a SA-oriented dashboard to improve resource management and decision-making in ICUs in times of a pandemic and 2) Evaluate its usability.

We adopted a participatory methodology and conducted interviews to capture and categorize the clinicians' requirements into SA key factors. To this end, we partnered with Sainte-Justine children hospital, located in Montreal, Quebec.

IV. METHODS AND PROCEDURES

The research project consisted of two user-centered design (UCD) phases based on the method prescribed in ISO 9241-210 [45]. The UCD iterative processes and activities were conducted remotely due to the COVID-19 containment measures in force during the study. We refer the reader to [46] for more details on the UCD processes and activities that we completed for this project.

A first UCD phase aimed to understand the context of use, define the clinicians' requirements, produce and evaluate mockups from back-and-forth interviews until a prototype was ready to implement. A second UCD phase evaluated and improved the prototype from a comparative usability evaluation with the resources management dashboard. The prototype was identified as a SA-oriented dashboard.

A. PROJECT PHASE I: CLINICIANS' SA REQUIREMENTS

Project phase I was dedicated to the identification of the clinicians' SA requirements and the design of mockups. We conducted remote, semi-structured interviews to understand the clinicians' goals, tasks, and roles in the context of the COVID-19 pandemic. We interviewed 11 healthcare professionals: 6 from the PICU and 5 from other Quebec healthcare institutions. There were 2 pediatric intensivists, 1 public health specialist, 4 pediatric residents, 3 registered nurses and 1 beneficiary attendant. The individual interviews lasted 45 minutes to an hour. The teleconference tool Webex was used to conduct and record the interviews. We used seven themes to structure our interview guide to cover the main information requirements for a clinical dashboard and to understand the clinicians' cognitive goals: 1. COVID-19 bed zones, 2. patient's health status, 3. staffing resources, 4. performance indicators, 5. material and equipment, 6. ergonomic display and usability, 7. technological tools and data integration to the hospital network.

The project team defined the clinicians' SA requirements from a Cognitive Task Analysis methodology called Goal-Directed Task Analysis [47]. This allowed identifying the hierarchical structure of cognitive goals and subgoals (i.e., what the clinician wants to achieve). We structured the Goal-Directed Task Analysis from the Space, Staff, Stuff and System of care requirements as they are suggested in

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TABLE 1. **Cognitive goals task analysis from the clinicians' staff-stuff-space-system-of-care (4S) requirements.**

	Goals	Level 1 Perception	Level 2 Comprehension	Level 3 Projection
Staff requirements				
Unit-level	Determine staff requirements	Staffing requirements: on duty, needed, ratio.	Target ratio.	Capacity to admit, Compare staffing shifts.
Bedside-level	Determine health severity	Patient health severity (low, moderate, high)	Recovery capacity (%), Incident Risk assessment.	Therapeutic evaluation (7 days)
	Evaluate nurse's workload	Quantis score	Nurse-to-Patient ratios: 1-20 1:2, 21-70 1:1 or 2:1.	Therapeutic monitoring (7 days)
	Evaluate patients' health status	Pelod-2 score	Pelod-2 value from <20 to 120: stable to critical.	Predicted health condition (7 days)
	Assign staff	Nurse: name, room #	Patient: Nurse ratio.	
Stuff requirements				
Unit-level	Manage ventilation material	Ventilation type : invasive; non-invasive.	% per type Material availability	Evolution of material used in the last 7 days
Bedside-level	Allocate ventilation material	Duration (start date)	Duration (estimated end date)	Patient recovery capacity (%)
	Evaluate oxygen saturation	Oxygen saturation (%)	Threshold measure (alert)	
	Determine room pressurization	Negative or positive pressure room		
Space requirements				
Unit-level	Manage patients flow and bed occupancy	Discharge, Transfers: operation rooms, urgency, outpatient clinics.	Admission capacity: decision to admit or not.	Expected admission number in the next shift. Expected patients' workload.
	Identify Covid-19 zones	Red (+), Yellow (investigation), Blue (-).	Statistics: workload meaning per zone: % red/yellow/blue.	Expected Beds availability per COVID-19 zones.
Bedside-level	Manage bed occupancy	Admission status: admitted, transfer, discharge.	Staff workload meaning.	
	Identify patient	Patient first name Caregiver/relative full name	New or reentering patient.	
	Display patient's health status	Pelod-2 score. Ventilation type: invasive, non-invasive	Doctors' workload and material required.	
System-of-care requirements				
Hospital level	Report COVID-19: hospitalization, PICU admission, Staff-Stuff-Space requirements.	Beds occupancy (numbers, %), type of care	Contingency plan updates, Evaluate the quality of care.	Predict the hospital capacity to admit COVID and non-COVID patients, PICU status.

issues related to the allocation of scarce resources in pediatric critical care during a pandemic [48]. Finally, we assigned information requirements to one of the three SA levels based on whether it described characteristics independent of cognitive goals (level 1), informed on the completion of cognitive goals (level 2), or evolution of the situation in the near future (level 3) [49].

The clinicians' SA requirements guided the mockup designs. The evaluation of each mockup usability was an iterative process. We designed using the software Adobe XD and targeted the display platform to be a 55 in. HDTV (1920 x 1080 pixels). We assumed a reading distance of 4 meters from the screen, which is how far clinicians are located from the TV during their briefing before their shift. The research team designed several iterations to translate the clinicians' requirements into SA key indicators. The feedback allowed us to improve the dashboard design until the clinicians and project team agreed on a prototype identified as a SA-oriented dashboard. We then proceeded to a comparative usability evaluation between the new dashboard and the former dashboard in use in the PICU.

B. PROJECT PHASE II: COMPARATIVE EVALUATION OF USABILITY

Six participants took part in the comparative usability evaluation: 4 intensive pediatricians, 1 respiratory therapist and 1 head nurse. All participants were clinicians at the PICU and familiar with the resource management dashboard, but it was their first exposure to the SA-oriented dashboard. We produced static mockups of the new and former dashboards. Mockups were based on three scenarios of increasing patient load. These scenarios assumed a 32-bed ward, with 5 beds for COVID-positive patients ('hot' zone), 7 beds for COVID-under investigations ('mild' zone) and 20 beds for regular patients (without COVID, 'cold' zone). In case the maximum bed capacity was reached, the mitigation measure was to transfer up to 12 non-COVID patients in another unit, e.g., neonatology.

The participant and the researchers used their own computer and conducted the evaluation remotely using the teleconferencing application WebEx. The researcher shared her screen to show one mockup at a time and asked 15 SA-oriented questions categorized in four themes: space (admission), patient health status (bedside), staff and stuff (equipment), system of care (regulation). The participant verbalized his or her thought process using a talk-aloud protocol and identified the information requirements used to answer the questions. When asked whether the unit could admit more patients, we measured the time the participant took to decide. The researcher introduced both dashboards, summarized their main features and key indicators. Then, the researcher presented mockups in an order of increasing patient load (i.e., scenario 1, then 2 and 3). The participant evaluated all six conditions (3 scenarios × 2 dashboards). The evaluation lasted one hour and was recorded for further analysis.

We transcribed interviews and used an inductive approach to identify the information requirements verbalized by participants, their decision-making strategies and clinical reasoning. We compared the information requirements verbalized with the list of SA requirements defined in phase I. This method allowed us to evaluate the correctness of the SA key indicators. It offered insights into the clinicians' decision-making process and how the SA-oriented dashboard can best support decision-making for resource management.

V. RESULTS AND DISCUSSION

A. PROJECT PHASE I-SYSTEM DESIGN

The clinicians' SA requirements were extracted from the first round of interviews (see Table 1). During these interviews, clinicians expressed that staff, "stuff", space and system of care requirements varied according to the organizational level they were operating with. To this end, we classified information requirements based on three organization levels: bedside-level focused on a single patient, unit-level concerned the PICU operation and hospital-level.

During the interviews, two user roles emerged as the clinicians were either an information seeker or information provider. **Information seekers** used the dashboard to perceive what is the current situation, what does the information mean and what might occur next. Most clinicians, nurses, patients, and caregivers fell into this category. We also noted that clinicians would keep a printed copy of the dashboard during the ward rounds and use it as a notepad to write down medical information next to the patient's room. This use of the dashboard as a memory aid was done by 5 clinicians out of the 11 interviewed. The information written down was intended for their individual use (i.e., it was not displayed on the large screen TV).

Information providers were responsible for keeping the dashboard up to date throughout the shift and for modifying it to reflect staff rotation, patient admission and departure. These users had a data-entry intensive role and welcomed any feature that could reduce the need for manual modification, more specifically, integrating with the hospital's EHR. When we started our study, the management dashboard presented at the PICU used a local database that was not connected to the EHR. As a result, administrative staff had to replicate data entry in both systems to keep them up to date. This task was performed by the PICU chief, head nurse and assistant head nurses. When managing the dashboard information, they worked from a computer located in the staff support area.

At this point, it became clear that a large-screen TV for everyone to see needed two functionalities. First, an interactive application to manage and update the ICU staffing information and making sure the dashboard information on work shifts were up to date. Second, a non-interactive interface to display the SA key indicators derived from four key factors: staff, stuff, space, and system-of-care (4S). With this in mind, for the rest of this article, we will focus our attention on the non-interactive dashboard, its design and usability evaluation, as it is the interface offering the SA-oriented information.

The SA key indicators were developed from the UCD iterative cycle. This led to three milestone revisions of the dashboard. The first mockup illustrated in Figure 3-A borrowed from the current resource management dashboard and replicated the unit's U-shaped layout, list of on-duty personnel and the list of patients' location. We added a color outline around the rooms identifying the three COVID isolation zones: red for COVID positive patients under isolation, yellow for patients under investigation and blue for non-COVID patients. The SA key indicators were in the upper-left corner of the screen. Although this first iteration presented most of the SA information requirements identified, it lacked visual clarity. Participants expressed having difficulty knowing where to look due to the patient's information being too visually cluttered.

The second mockup (Figure 3-B) improved the presentation of information by grouping related information into boxes with a labelled title and structured the main groups based on their importance from left (unit status) to right (on-duty personnel). It used three-character sizes, based on design principles, to structure the saliency of information: large for titles, medium for key information such as the patient's name and small for list items or medical information [63]. The unit topographical view remained but the aisles were positioned on the outskirts of the screen to make room for the SA indicators at the center. SA indicators were presented in numeric format and in a color-coded stack bar. This graphical representation provides the context needed to interpret the data correctly. For instance, the staff can quickly see the relative proportion of occupied beds compared to the unit's total number of beds.

The main changes made on the third mockup (Figure 3-D) were the display of the number of admissible patients, the ratios of doctors-to-patient and nurse-to-patient and the reduction of unnecessary information (e.g., the room index is removed from the bottom left corner and replaced by a

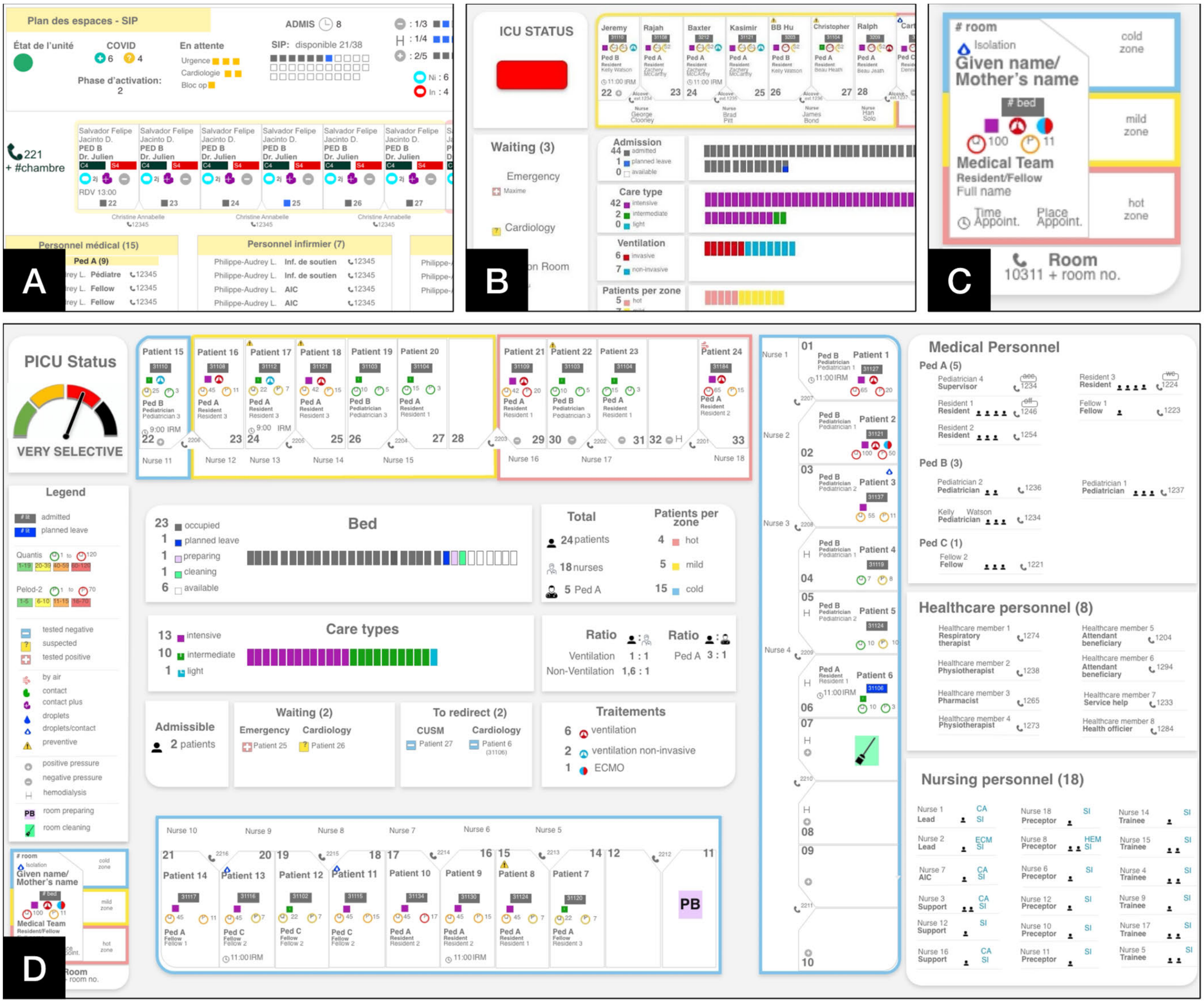

FIGURE 3. (A) Extract of the first iteration of the dashboard showing the initial layout of SA KIs in the upper-left corner. (B) Extract of the second iteration with an improved grouping of information and cleanliness. (C) The dashboard showed up to 15 SA KIs at bedside related to the patient's condition. (D) Final version of the SA-oriented dashboard.

legend and bedside information). The use of white space between groups of information improved the dashboard's overall clarity and cleanliness. This third iteration was the final version of the SA-oriented dashboard that we use for usability testing.

The SA-oriented dashboard designation originates from the display of the SA key indicators (SA KIs) in the central area. It allows one to actively perceive the current situation by seeking first where salient information is, and then what is its meaning [50]. The upper left area displays the PICU status: open to admission (green), selective (yellow), very selective (red), reorientation (black). The central area displays 6 SA KIs: bed occupancy, COVID and non-COVID counts, care types, nurse-to-patient, and doctor-to-patient ratios, waiting to admission and treatment types. The patient's area displays the 32-bed layout, allowing it to extend to 12 additional beds. The staff area displays information on nurses, doctors, and healthcare professionals. The legend area displays the meaning of the icons used.

Figure 3-C presents the 15 SA KIs displayed at bedside: COVID (red, yellow) or non-COVID (blue), room number, isolation type, given name or mother's name, bed number, care types, ventilation type, treatments (ECMO), nurse activities score (Quantis), the pediatric logistic organ dysfunction score (Pelod-2), the medical team identification (Ped A/B/C), the resident/fellow full name, the schedule of appointments (time, place), room and telephone numbers.

B. PROJECT PHASE II-COMPARATIVE USABILITY EVALUATION

The comparative usability evaluation was conducted from three scenarios of increasing patient load. These were displayed in sequence on the resource management dashboard (Figure 2) and on the SA-oriented dashboard (Figure 3-D).

TABLE 2. Results of the comparative usability evaluation with the list of KIs supporting the decision and observations on the decision-making process.

SA requirements		Resource Management Dashboard	SA-Oriented Dashboard
1. Space (32 beds layout)	**KI**	4 KIs: (1) patients admitted; (2) type of care (3) waiting (4) type of ventilation.	8 KIs: (1) PICU status (2) bed layout (3) COVID zones (4) patient-to-nurse/doctor ratios (5) admissible (6) on leave (7) waiting (8) redirect.
	Obs.	Decision to admit was time consuming, from 30 to 60 seconds. Clinicians figured out the possibilities to reassign nurses at bedside.	Decision to admit took less than 30 seconds.
2. Patients' health status (bedside)	**KI**	10 KIs at bedside.	15 KIs at bedside.
	Obs.	Health status is evaluated from the number of patients affected to each nurse, Pelod-2 and Quantis scores.	The COVID indicator at bedside facilitated the understanding on how many patients were battling for their life, along with the Pelod-2 and Quantis scores.
3. Staff and 'stuff' (equipment)	**KI**	2 KIs: Staffs (nurses, doctors) at bedside.	6 KIs: Staffs (nurses, doctors) at bedside, Patient-to-nurse ratio, Patient-to-doctor ratio, type of care, type of ventilation.
	Obs.	The capacity to admit new patients depended on the nursing load and equipment required at bedside. Clinicians computed mentally the ratios.	Clinicians read both ratios and looked at the overall staff allocation to confirm the values. Ratios were key to the clinicians' understanding of the staff load.
4. System of care (regulation)	**KI**	0 KI.	2 KIs: PICU status, COVID zones.
	Obs.	Predictions on how the situation may evolve was time consuming, from the analysis of the overall situation.	Predictions on how the situation may evolve were accelerated by the PICU status and the COVID indicators (mild, hot).

Table 2 presents the main findings in terms of KIs mentioned by the clinicians and how it impacted their decision-making for resource management. We found that the SA-oriented dashboard led to faster decision time on the admission capacity and improved SA for all three scenarios. This was surprising as clinicians were all familiar with the resource management dashboard, whereas it was their first exposure to the SA-oriented dashboard. These results are supported by the findings on five usability improvements and five limitations.

C. IMPROVEMENTS

First, since the SA-oriented dashboard displayed more KIs than the resource management dashboard, it sped up decision-making. We found that for all three scenarios, the mean decision time to admit new patients took less than 30 seconds with the SA dashboard and 30 to 60 seconds with the resource management dashboard. These results present evidence that clinicians visualize and comprehend the key indicators according to their priorities [28]. Their cognitive processes are based on mental patterns recognition, as well as expertise in unknown situations.

Second, the resource management dashboard did not provide information on patient-to-nurse ratio, and the staff had to calculate the ratio manually. By displaying the patient-to-nurse ratio on the SA-dashboard, it quickened the decision to admit new patients. This adds evidence that the staffing of nurses is pivotal to admission capacity planning and decision-making in ICUs. We found that the visualization of the 32 beds' occupancy was not the major indicator of the overall admission capacity. Rather, the number of nurses available was the most influential factor on deciding the number of patients admissible. This is aligned with the evidence in the literature that keeping a lower patient-to-nurse ratio is associated with a decrease in nursing workload and lower in-hospital mortality [51].

Third, the display of the room availability status along its life cycle on the SA-oriented dashboard was perceived as a facilitator in the decision to admit new patients: beds occupied (grey), planned leave (dark blue), preparation (pale purple), cleaning (cyan) and available (white). On the resource management dashboard, the clinicians perceived only some states of the room: available (empty), occupied (filed) and planned leave (dark blue) at bedside.

Fourth, in the central area of the SA-oriented dashboard, key indicators of care types are presented as statistics. The number of patients under intensive (dark purple), intermediate (green) and light (soft blue) treatments helped the clinicians to perceive the nursing loads while this was not possible with the resource management dashboard. A high proportion of intensive care compared with an intermediate or light care suggests that higher therapeutic monitoring is needed. This affects the patient-to-nurse ratio, especially the nursing load requirements at bedside.

Fifth, the PICU status indicator in the SA-oriented dashboard contributed to the clinicians' sensemaking on what was going on in the unit. This was not possible with the resource management dashboard, as clinicians had to figure out the overall situation to admit new patients from the analysis of the beds' occupancy, nursing at bedside and patient-to-nurse ratio.

Overall, the five improvements emerging from the usability evaluation contribute to the knowledge on the impacts of SA on decision-making in the Endsley model (see figure 1). By introducing SA key indicators on the dashboard, we were able to provide a better clinical decision support systems for critical care units.

D. LIMITATIONS

This study has five main limitations that can be addressed in future research. First, the evaluation focused on the unit resource management and admission time, but we did not evaluate the impact of the dashboard on the quality of clinical reasoning. To this end, future work should investigate the implementation of the SA-oriented dashboard in the unit to measure whether its use can improve patient outcomes.

Second, the comparative evaluation took place when the public health measures were in force, and our research team could not have access to the PICU. The interviews were conducted remotely from a computer screen rather than from the display of a large-screen dashboard in the PICU.

Third, the dashboard layout reflected the physical layout of the 32 beds in the partnering PICU. The dashboard was not designed to adapt to other hospitals' PICUs bed space occupancy, and this limits its usability in other critical care settings.

Fourth, the SA-oriented dashboard lacks predictive indicators to provide perspective on what might happen in the PICU in the upcoming days and weeks. This would allow for level-3 SA (projection to future status and events) in the SA model 3 (see figure 1).

Fifth, the PICU status indicator relies on the clinicians' perceptions and understandings of the overall situation and manual data entry. During the evaluation sessions, clinicians explained the ratios thresholds they used to decide on the PICU status. Replacing the status evaluation by a real-time algorithm based on the KIs values could be more efficient, as it could reduce the time required by the clinicians to figure out the PICU status. This could be evaluated in future works.

VI. CONCLUSION

In this study, we designed a SA-oriented dashboard to improve resource management and decision-making in ICUs in times of a pandemic. We partnered with a PICU in a major children hospital in Montreal, Canada and translated the clinicians' thought process to manage the unit's resource into a technological solution. A user-centered design method allowed to identify 22 key indicators from the clinician's staff, stuff, space, and system of care requirements (4S). We identified one PICU status indicator, 15 KIs at bedside and 6KIs displayed in the central area of the dashboard. Furthermore, we conducted a comparative usability evaluation to assess the KIs impacts on resource management and decision-making. The results showed five improvements and four limitations.

Among the improvements, we found evidence that the SA-oriented dashboard speeds up decision-making to admit new patients under 30 seconds. We also found that multi-key indicators at bedside and a patient-to-nurse ratio were drivers of the decision on the capacity to admit patients. These PICU status indicators provide the clinicians with the upcoming evolution of the situation. These cues are critical as they affect the decision to admit patients.

The overall results confirm the potential of the visualization of key indicators to the improvement of the clinicians' 3 levels of SA: perception, comprehension, projection. Drawing on the theory of the fast and slow systems, their visualization requires less cognitive effort, allowing the clinicians to rely on the fastest "thinking system" [52]. This is of great help in the context of critical care where quick decision-making is often required. Conversely, the resource management dashboard is a rational tool pushing the clinicians to rely on a more efficient but slower "thinking system", when the context is unusual such as the arrival of an unusual flow of patients affected by the most severe form of the COVID-19 disease. Finally, the dashboard was not designed to adapt to other PICUs bed space occupancy. This limits its usability in other hospitals as well as collaboration among the clinicians. Therefore, in future work, we expect to extend the usability of the SA-oriented dashboard to allow its adoption in other PICUs.

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