# An In-depth Needs Analysis to Design a Data Visualization Dashboard Prototype for Critical Care Setting

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## ABSTRACT

Intensive Care Units (ICUs) regularly generate a high volume of data for their patients. ICU care providers often find interpreting and presenting the voluminous data generated to be time-consuming during daily care routines. In the same light, a medical ICU at the University of Missouri (MU) Hospital in Columbia, Missouri, employed a visualization dashboard for effective team communication from easily accessible patient data visualization. However, the current dashboard has been underutilized due to many internal and external factors. Therefore, we aimed to re-design the ICU data visualization dashboard called IC-DASH that can overcome the challenges in the existing dashboard and seamlessly integrate it into the workflow of critical care. This paper presents the steps of an in-depth needs analysis implemented to build an ICU data visualization prototype called IC-DASH.

**Keywords**: ICU data visualization dashboard, needs analysis, mixed approach, reduce workload in critical care, promote team communication

**Index Terms**: Visual Analytics, Needs Analysis, Data Visualization Dashboard, Intensive Care Unit, Critical Care Unit, Reduce Workload

## 1 INTRODUCTION

Patients admitted to Intensive Care Units (ICU) are often critically ill and require continuous monitoring using bedside monitoring devices, which results in a high volume of data every hour, if not seconds [1], [2]. With the large amount of data produced every day, ICU care providers often find interpreting those data to be time-consuming and challenging to present in a meaningful way during handoffs, daily rounds, and providing care at critical moments. Subsequently, this causes ineffective communication and creates barriers to team collaboration and safe patient care [3], [4].

A medical ICU at the University of Missouri (MU) Hospital in Columbia, Missouri, employed a visualization dashboard to facilitate daily patient care and promote team communication and collaboration. Despite the effort, the current dashboard has been underutilized due to many internal and external factors, defeating the purpose of its implementation in improving team communication. One ICU nurse, who is a regular user of the current ICU dashboard, revealed in an in-person interview, "*I have to really squint my eyes and try to look what it says on the board*." Also, one attending physician remarked, "*I always try to look for it, oftentimes that monitors were not on… It's extremely difficult for me to round without this*."

We realize the significant presence of barriers and lack of satisfaction among the care providers in using the current ICU dashboard from the interviews and comprehend the importance of re-designing the ICU visualization dashboard to cater to the needs of its users and deliver its purpose. Therefore, this paper presents the steps of an in-depth needs analysis implemented to build an ICU data visualization prototype called IC-DASH. The main objective is to build features that can be useful in the clinical decision-making and day-to-day care process and seamlessly integrate into the workflow of the ICU care providers. The following sections include the design process, results, proposed solution, discussion, future work, and conclusion.

## 2 DESIGN PROCESS

We began our design process intending to understand the current dashboard features and usages, followed by a thorough needs analysis process including understanding the users, a systematic literature review, a mixed approach using an embedded design with semi-structured interviews, and a survey tool (support dataset).

### 2.1 Current ICU dashboard features and usages

The MU hospital medical ICU includes 36 beds for critically ill patients with medical problems related to respiratory issues, septic shock, gastrointestinal bleed, and COVID cases. Figure 1 shows the ICU visualization dashboard, which is located in each patient's room and displays patient demographics, vital signs, ventilator settings (if any), and intake and output.

The main features of this existing dashboard are: (i) data is pulled from EHR directly and updated automatically, (ii) negative output is highlighted in red color, i.e., negative fluid balance, fluid removed from dialysis, (iii) graph box shows the vital sign trends within the 24-hour range, and (iv) customized metrics applicable to the patient's condition are displayed, i.e., when the patient received a blood transfusion, the dashboard will show relative information such as PRBC volume infused. The main uses of the dashboard are during morning rounds to discuss the plan of care for the day based on an overview of the patient's status, during any procedure timeout to verify the patient's identity and planned procedure, and overviewing patient demographic information from the dashboard while providing patient care each time.

### 2.2 Needs Analysis

Figure 1: Current displayed ICU data visualization dashboard from patient's room.

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Users are the core of our design; therefore, our goal was to implement a User-Centered Design (UCD) process to design the IC-DASH. We followed an iterative evaluation and re-design process on understanding and building the solutions for the needs of the dashboard users. Our IC-DASH users are clinicians from different health professions, such as cardiologists, pulmonologists, nephrologists, oncologists, and nurses- all providing care to ICU patients. Therefore, we focused on gaining an in-depth understanding of the users' needs, expectations, and requirements and how the new design facilitates and supports the ICU workflow.

#### 2.2.1 Understanding the Users

We considered two important aspects of studying users in our design development process: cognition and social interaction. The concept of cognition is focused on how individual users interact with the dashboard with their abilities and limitations. To understand the users' cognitive processes, we addressed three aspects: attention, perception, memory, and decision-making. Our goal is to build a data visualization dashboard with visual appeal that can draw the users' attention to the different parts of the display with less confusion, more focus, and minimum memorization requirement while making important decisions during the treatment process. This motivated us to actively involve some users early ahead in the design development process for iterative evaluation and feedback.

#### 2.2.2 Systematic Literature Review (SLR)

A thorough SLR was conducted using Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines to identify the articles presenting the most recent advances in ICU data visualization dashboards, including the designing process, essential features, as well as its clinical impacts. We searched PubMed to include articles published between January 2010 and April 2020. The search query we used was "ICU AND (data display OR data visualization OR dashboard)" and the following search terms were applied in PubMed: 1) ("intensive care units"[MeSH Terms] OR ("intensive"[All Fields] AND "care"[All Fields] AND "units"[All Fields]) OR "intensive care units"[All Fields] OR "icu"[All Fields]), AND 2) (("data display"[MeSH Terms] OR ("data"[All Fields] AND "display"[All Fields]) OR "data display"[All Fields]) OR ("data visualization"[MeSH Terms] OR ("data"[All Fields] AND "visualization"[All Fields]) OR "data visualization"[All Fields]) OR dashboard[All Fields]).

The inclusion criteria include: (1) the setting of the study is in the ICU, (2) utilizing ICU data for information visualization, (3) the study involves designing or evaluating the visualization tool. We excluded any articles not written in English. We also excluded articles that focus on predictive modeling, or the targeted population cannot be applied to the general ICU patient population. To understand the most recent advances, we included articles published between 2015 and 2020. Figure 2 shows the flow diagram of the SLR process that identified 13 articles eligible for review.

#### 2.2.3 Mixed Approach (Embedded Design)

Both semi-structured interviews and a survey method (see Appendix A) was applied to gather information about the needs and requirements of the users. Twelve current users of the ICU dashboard were recruited, including 5 MDs, 6 nurses, and 1 respiratory therapist, to participate in a semi-structured interview. The participants were asked to share their perceptions of the current dashboard and provide recommendations to help optimize its use. Interviews were audio-recorded, transcribed verbatim, and transcripts were subsequently anonymized. In the next phase, findings from the previous interviews were analyzed and used to construct a survey tool to validate the data collected from the interviews. The survey questionnaires were distributed through REDCap, a HIPAA-compliant web application, to collect quantitative responses from the participants of the interview stage. The University has approved this study by Missouri's Institutional Review Board.

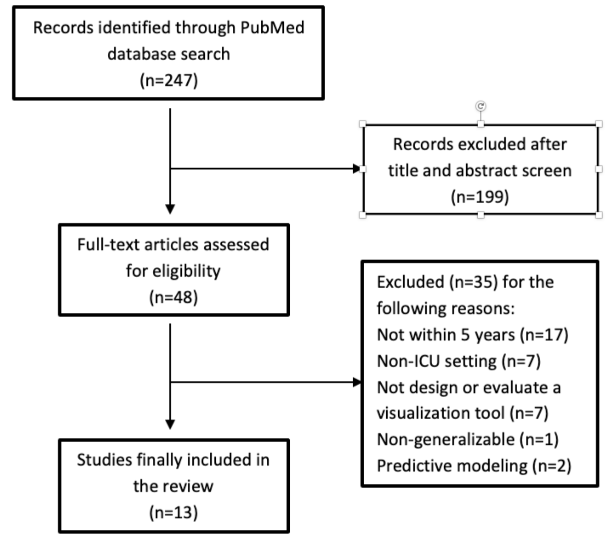


Figure 2: The SLR process identified 13 articles eligible for the review.

Data Analysis: Qualitative content analysis was used to analyze the interview data with an inductive approach. The interview transcripts were compiled and read line by line. First, a preliminary interpretation was made to identify the general category of the subject. Then a coding scheme for the identified categories was developed and used to extract the relevant information.

We extracted the survey results from REDCap as csv format and used RStudio (version 1.2.5033) to analyze the results. We created frequency distribution table for the questions on user demographics such as job title, age, gender, and years of experience in ICU and frequency distribution graphs for questions related to the perceptions of the users of the ICU dashboard. We applied basic text mining strategies to find the high frequency words from the comments or suggestion box provided in the survey. All text mining steps and creation of wordcloud and barplot were executed in R using library tm, SnowballC, and wordcloud.

## 3 Results

### 3.1 Essential Features from SLR

Of the 13 articles, 2 articles discussed the designing process, 9 articles evaluated the effectiveness of the dashboards based on their purposes, and 2 articles included both the design and evaluation process. Most of the dashboards were evaluated or tested using data retrieved from EHR directly (n=9). In contrast, one used the MIMIC-III database for evaluation purposes (n=1), one used a Microsoft Excel data loop that was pre-loaded into the computer for scenario tasks (n=1), and one solely discussed design without integrating data (n=1). The type of the ICU these dashboards are designed to use or implemented were the following: all adult ICU (n=5), Burn ICU (n=1), Medical ICU (n=2), Surgical ICU (n=2), Neuro ICU (n=1), and Pediatric ICU (n=2). The purpose of the dashboards can be classified into three main purposes: 1) to support clinician decision-making and team communication (n=4), 2) to improve patient safety and clinical outcomes (n=6), and 3) to assist with clinical data management (n=1).

The essential features identified from the 13 articles are summarized in Table 1. The most mentioned essential feature of the dashboards was color or symbol-coded values/texts for a status update and/or anomaly detection. By highlighting abnormal values in different colors, i.e., green, red, or yellow, users could identify any deterioration of the patient's status within seconds. Some were also using green checkmarks to show the task completion, which enables team members to track task progression, thus increasing awareness and compliance with guidelines and protocols.

| | Automatic data retrieval and updates from EHR | Score calculation based on clinical scale | Automatic text reminders/ alerts | Customize displays based on clinical roles or info required | Message feature for team communication | Color/symbol coding for status updates or anomaly detection | Support clinical annotation |
|---|---|---|---|---|---|---|---|
| [5] | x | x | x | | | | |
| [6] | | | x | x | x | | |
| [7] | | | x | | | x | |
| [8] | | | | x | | x | |
| [9] | | | x | | | x | |
| [10] | | | x | x | x | | |
| [4] | | | | | | x | x |
| [11] | | | x | x | | x | |
| [12] | x | | | | | x | |
| [13] | x | | | | | x | |
| [14] | x | | | | | x | |
| [15] | | | | x | | | |

Table 1. Essential features identified from SLR on the 13

## 3.2 Issues Identified from Interviews and Survey

We identified the following major issues with the current dashboard from the mixed approach: (i) Accessibility and visibility: The major complaint of the current dashboard is that it is often not turned on, which makes it less accessible to the ICU care providers. The decreased visibility also prevents any potential users from adopting the habit of utilizing the dashboard during work, as they may not be aware of the existence of the dashboard. (ii) Display and location: The major issues with the display are: (a) font size is too small to read, (b) users tend to lose track of numbers with too many columns, (c) the blue/black background color is not visually appealing, (d) the trend box color coding is vague and not easily interpretable, and (e) information overload with crowded redundant metrics. Also, the dashboard is currently located right above the patient's head in the ICU room, making it difficult for the users to read at a closer stance and adding effort to turn the dashboard back on when it's off, as both will require users to overcome obstacles such as ventilator machine or IV pump to reaching over. Moreover, the dashboard may interfere with a patient's sleep during the night when it's on due to its location, subsequently resulting in it being turned off overnight by the night staff.

# 4 PROPOSED SOLUTION

We propose to design an interactive ICU data visualization dashboard that can overcome the pitfalls existing in the current dashboard. We implemented the idea into a web design using JavaScript (backend: node js and frontend: Vue js). The web design prototype can be accessed from https://icdash.vercel.app/.

Figure 3 shows the prototype of IC-DASH. The features included in IC-DASH were chosen based on our observations of the user's needs, data collected from interviews and surveys, and literature review. Thus, IC-DASH not only includes the existing features in the current dashboard (demographics, vitals, intake-output, ventilator settings, a blood pressure graph box) but also includes other interesting representations of EHR data relevant to critical care. The features of IC-DASH with their potential usefulness (key features are underlined) in clinical decision-making are listed as follows.

1. To reduce the overcrowded information on the display of the current dashboard, we decided to create separate segments by grouping similar features, using different color codes for title labeling and increasing the font size to increase visibility. The composition of the display is non-uniform, which can help the providers to focus and draw attention to specific features without confusion. Some indicators are shown as visual graphics, and others as text values, which can help reduce the cognition load of the care providers. We used icons as affordances to help the users with associated memory to easily identify the indicator shown on display.

2. We chose to show only the hourly systolic, diastolic, and mean arterial pressure on a graphical display with distinct color coding for the three categories. This can help the care providers to understand the trend in the blood pressure levels. Underneath the blood pressure graph box, we included a graph for the vasopressors rate of dosage. Only the hours at which the vasopressors rate was changed will be displayed as a bar. These two graphs together can play a vital role while the clinicians decide on the rate of vasopressors, which can alter the blood pressure level in the patients.

3. We displayed the important events, including labs, procedures, diagnosis, and prescription for a patient during the ICU stay, as a timeline (daily) with color-coded labeling for each occurrence. For instance, the timeline will show a blue dot if a lab was taken on a particular day. If the care provider clicks on the blue dot, it will show the name of the labs in a box. This patient timeline provides a simple and concise display of the journey of the patient in the ICU. Care providers can use this timeline to find out important events and correlate that with the treatment plan.

4. We took the concept of a whiteboard and dedicated space on the dashboard display for a notepad that the care providers can use to enter any important information as an upcoming treatment plan. For instance, the clinician asked the nurse to monitor the fluid balance for 24 hours. If the notepad displays this information, even after shift changes, the information helps the new nurse on duty to remember it easily. To enter the whiteboard information, nurses can access the dashboard from their workstation and enter the information using the keyboard.

5. A table is situated on the top of the dashboard showing the care team for the patient including the physician names and their home departments. This information can be useful for any clinician or nurse to know whom to contact to discuss any specific observation regarding the patient or design a collaborative treatment plan.


Figure 3: The figure shows IC-DASH Prototype designed using JavaScript. The labelled numbers indicate the features, and the description are provided in the proposed solution.

6. The body weight of patients can fluctuate during their stay in ICU depending on the fluid balance, nutrition balance, and presence of comorbidities. The changes in body weight are associated with clinical outcomes, especially among critically ill patients. IC-DASH not only shows the current weight of a patient, but it also shows a graph of how the body weight changed over the days starting from the day of admission. Such illustration of body weights helps a clinician to capture the weight variation immediately and tailor the treatment accordingly.

7. The fluid balance chart is a significant illustration of an ICU dashboard as it helps clinicians to make crucial clinical decisions, such as surgical or medication intervention. Depending on the severity of the illness, a clinician may want to look at the hourly balance chart or a cumulative balance chart. IC-DASH offers the functionality of choosing different time intervals with a simple click on the screen.

8. In addition to the balance chart, individual elements of the intake and output chart are significant additions to IC-DASH. It shows the intake and output volume of the elements over the chosen time window. Moreover, the up and down arrows indicate whether the volumes have changed and how much those have changed from the previous time window. It can help clinicians quickly identify the balance chart's key contributing factors.

9. Our design accommodates the medication list and diet order inside the INTAKE-OUTPUT panel. A patient may not be allowed to eat anything by mouth, and this diet order on the dashboard will help the nurse to act accordingly. Information about the medication list and diet order can help the attending nurses follow the care plan and save them the trouble of looking into the EHR.

10. Code Status essentially means the type of emergent treatment a person would or would not receive if their heart or breathing were to stop. Adding coding status to the ICU dashboard highlighted with different colors helps physicians to make decisions to perform or not perform CPR in the event of cardiac or respiratory arrest based on the patient's preference. A full code means a person will allow all interventions needed to get their heart started. A patient who is a DNR does not want any resuscitation measures taken. A limited code is somewhere in between a full code and a DNR. A limited code means the patient wants some interventions, but not all. Limited code orders must specify what the patient will and will not allow.

11. The PaO2/FiO2 ratio is widely used in ICUs because it quickly and easily provides data on the oxygenation status of critically ill patients. A low PaO2/FiO2 value has been associated with increased mortality, and hospital stay in patients admitted to the intensive care unit (ICU)6. Including PaO2/FIO2 ratio helps clinicians, especially critically ill patients, as an indicator of oxygenation status and is a diagnostic criterion for acute respiratory distress syndrome in adults (ARDS).

12. Some metrics are shown as a button with a radial view of the current value inside it. This feature gives the end-users the advantage of clicking on the radial buttons and new pop-up windows, and a graph will show up to reveal more information about the specific ratio that has been clicked on. Due to the limited space of the dashboard and for reducing unnecessary information, this feature has been added as an option based on the clinicians' needs.

13. We highlighted the EKG and Ventilator mode in color text boxes. These modes are very important to display in the ICU dashboard because they convey information about the overall health status of the patient. For example, EKG mode is normal sinus rhythm mode means everything is working smoothly, and the heart beats between 60 and 100 times per minute. However, sometimes the heart's electrical system doesn't work the way it should. For example, atrial fibrillation, also called AF or AFib, is the most common type of irregular heartbeat. In addition, our team added ventilation modes to describe the pattern of breath delivery to a patient. The terms associated with ventilator modes indicate the type of breath being delivered and how the breaths are triggered, controlled, and cycled.

14. We included demographic information on the top of the dashboard, one of the most important features in this dashboard, which provides for all the vital information such as the patient's name, gender, DOB, admit date, blood type, patient's medical number, and LOS. All this information can help the care team identify the patients.

## 5 DISCUSSION AND FUTURE WORK

Our current prototype includes only the patient-room display, and we will continue our efforts to concretize the entire framework. This prototype has undergone iterative evaluation processes at various design steps. In addition, we will perform usability testing with a group of end-users, including nurses and physicians of various specializations. Finally, during the pilot deployment, we plan to prepare a mock-up patient room to thoroughly evaluate the IC-DASH in a mock-up clinical setting. At the first stage of the evaluation, the IC-DASH will be placed by the existing dashboard, and each user will be asked to evaluate both the dashboards. Questionnaires based on the System Usability Scale (SUS) will be used to evaluate the easiness of use for both the dashboards. In addition, we will design tasks based on specific scenarios mostly seen in ICUs and ask the end-users to carry out the tasks. The user will be encouraged to talk during the evaluation so that the designers can take note of what the users are thinking and where they are facing problems. The usability testing will assess the intended improvement of the existing dashboard and lead to system enhancement. In the future, we also plan to work with the Division of Critical Care of the University of Missouri (MU) Hospital to integrate IC-DASH into the ICU clinics across the university system.

## 6 CONCLUSION

We designed the ICU dashboard with features that can be useful in the clinical decision making and day-to-day care process. Our design includes a visually appealing display with color-coded labeling and mixed use of graphical displays and textboxes showing the demographics, vitals, intake-output, ventilator settings, and blood pressure graphs with vasopressors, and PaO2/FiO2 ratio visualization. For future implementation, web and mobile applications will be created to increase accessibility to the care providers and patient family from large displays in the patient room, tablets, cell phones, laptops, etc. In conclusion, the proposed solution will overcome the limitations of the current dashboard, reduce information load from the ICU care providers and improve team communication, clinicians' satisfaction, and overall care quality.

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