Development and Usability Test of the Real-Time Comprehensive Dashboard for Emergency Department: A 5-Year Experience Case Study

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Abstract

Background: The task of monitoring and managing the entire emergency department (ED) is becoming important to the ED staff since EDs get increasingly crowded and treatments become more complex. Recently, dashboards have received the spotlight as health information technology to support these tasks.

Objective: This study aimed to describe the process of developing a real-time comprehensive dashboard for ED and to evaluate its usability by clinical staffs.

Methods: We developed a dashboard based on three dashboard principles —“anytime, anywhere, at a glance”; “minimal interruption to workflow”; and “protect patient privacy”— and three design concepts—“geographic layout,” “patient-level alert,” and “real-time summary data.” The measurements on the dashboard were selected based on the throughput factor of the conceptual model of ED crowding. We also surveyed ED physicians and nurses using a system usability scale (SUS) and situation awareness index, a questionnaire we created based on the construct of the situation awareness rating technique.

Results: The first ED dashboard was successfully launched in 2013 and has undergone three major revisions because of geographical change to the ED and to improve usability. A total of 52 ED staff members participated in the survey. The average SUS score of the dashboard was 67.6 points. The participants also evaluated the dashboard as good at “concentration support” (4.15), “complexity representation” (4.02), “variability representation” (3.96), “information quality provided” (3.94), and “familiarity of dashboard” (3.94). However, the “division of attention” was rated 2.25 points.

Conclusions: We developed the ED dashboard and successfully used it for five years. The ED physicians and nurses evaluated its usability as “OK to Good.”

Trial Registration: IRB File No - SMC 2018-01-040-001

Keywords: Emergency Department; Dashboard; Health Information Technology; Development; Evaluation; Usability; Situation Awareness; Overcrowding
Introduction

An emergency department (ED) is a complex system designed to treat patients with various conditions simultaneously. Even though ED providers try to triage patients according to their clinical needs while managing scarce resources, these activities are often overwhelmed by the complexity and volume of patients. Emergency physicians are required to treat multiple individual patients while maintaining situational awareness of their ED surroundings.[1] This task is very challenging because it requires acquisition, processing, integration, and archiving of large data at multiple levels.[2] Thus, physicians frequently feel they are losing control over the ED, which aggravates burnout and affects performance.[3, 4]

Moreover, a many EDs are already overcrowded, causing more complexity.[5-7] While ED overcrowding remains a major healthcare issue, it significantly and adversely affects quality of care. Influenced are such major quality factors as timeliness, effectiveness, efficiency, safety, and patient-centeredness, resulting in increased mortality and morbidity.[5,8-10] Multiple studies have suggested using system engineering and science to improve ED performance, streamlining process and improving throughput.[11-13] However, a strategic approach to finding process delays and supply–demand mismatch by traditional hospital information systems (HISs) is not feasible. Monitoring and managing the ED as a whole is important.

The dashboard is “a visual display of the most important information needed to achieve one or more objectives.”[14] Because the situation in the ED affects the quality of care and patient outcomes, clinicians have different diagnostic and treatment strategies depending on the situation.[15] Therefore, recognizing the correct situation is becoming increasingly important to emergency medical clinicians.[16] A dashboard that fits the changing situation of the ED in real time must have the characteristics of both quality and clinical dashboards.[17] In particular, ensuring real-time availability is challenging and important, because non-real-time dashboards cannot support decision making.[15]

This study aimed to describe the process of developing a real-time organizational dashboard for ED and to evaluate its usability.
Methods
This study was approved by the institutional review board of the study site. (IRB File No: SMC 2018-01-040-001)

Study Setting
The study was carried out in a metropolis, Seoul. The study was undertaken at an ED with an annual visit volume of 79,000 in a tertiary academic teaching hospital. The hospital has about 2,000 inpatient beds with about 9,000 outpatients per day. The ED is one of the most overcrowded in the country.[18]

Its HIS was in use since 1994 with full support of electronic medical records (EMRs) and a picture archiving and communication system (PACS). Although the history of HIS was long and the level of technique was one of the most advanced in the country, there had been no ED-specific dashboard system before.

Development
“The Happinovation” and “The Happy ER Team”
In 2012, an institution-wide project, the “Happinovation” (Happy innovation), was initiated to enhance patient and provider happiness through process and hardware innovation. The “Happy Emergency Room Team” was formed as a satellite team of the overall project. The team focused on visualizing the ED process for providers and patients.

Two subprojects were formed. One was a visualization project for providers—an electrical dashboard to develop a visualize ED performance status on both wall-mounted monitors and PCs. The other was a visualization project for patients and their families—a wall-mounted electrical dashboard, kiosks, and tablets.

The Happy ER team was a multi-disciplinary team including physicians, nurses, designers, administrators, consultants, and designers. While hospital staff provided input, consultants and designers tried to stand at patients’ sides, balancing the conclusion. Several rounds of discussions and debates took place before the first concept was made.

Dashboard Principle
The team had agreed on principles before going into the design process.
1. Anytime, anywhere, at a glance
First, the dashboard was designed to be like a traditional whiteboard for the ED, which means it should be mounted on a wall and visible to providers about 2–5 meters away. It should be in a static mode without flipping the screen so providers would not waste any seconds to see the desired information.[19] Since multiple providers should be able to access the information, interactivity was not feasible. We did not include the writing and communicating function from the dashboard. It was designed to give a provider overall ED status at a glance, which distinguishes it from previous electronic whiteboards.[20]
2. Minimal interruption to workflow
Second, there should be no additional work by providers for the dashboard. This means that all data should come from the legacy system. All information on the dashboard is generated automatically from previous columns of the HIS. For example, the moments of inputting order by doctors or barcode reading clinical samples by nurses are interconnected in the dashboard system so that the whole operating process could be automatically marked and shown without additional inputting processes. It is also different from whiteboards.[21]

3. Protect patient privacy
Third, patients’ privacy should be secured.[22] Because the screen is physically accessible to patients and families, most information should be deidentified and symbolized to prevent unnecessary misunderstanding and debates.

**Design Concept**
The team had adopted three design concepts for the dashboard.

1. Geographic layout

![Figure 1. Geographical layout of the ED.](image)

First, the dashboard should indicate the ED floor plan. A geographic layout would give intuitive information to ED providers on what is going on where in the ED. It is also very common that ED providers recognize and communicate about patients with their bed locations and not with their numbers or names, which made it more intuitive and effective to use a geographic layout rather than a patient list (Figure 1).

2. Patient-level alert
Second, each bed and chair was symbolized to stand for a patient to give the patient-specific information to ED clinician. Additional information at the patient level was added to give a real-time alert to providers through encoded colors and symbols, especially on the process delays. The main objective of this concept was to provide
ED staffs with patient-level alerts such that a provider could immediately notice delays occurring to certain patients at a glance.

3. Real-time summary data
Finally, the dashboard would show summary statistics over ED performance in real time. While in-depth information for each patient is available with preexisting HISs, a summary in real time depends mostly on vague assumptions. With summary data, providers would be able to reschedule clinical processes for their patients’ efficient journey. For example, a nurse could direct a patient to the x-ray if co-ordered computed tomography is crowded with a long queue.

Prototyping
Initially, multiple measures were suggested for the dashboard. Measures were chosen and categorized based on a “conceptual model of ED crowding.” The model consisted of three factors, among which the throughput factors were mostly demonstrated with the dashboard. [13]

Among input factors, we included patient severity and measure of visits. Cautions on infection information were also included since they were well correlated with severity and patient allocation within the ED and hospital. Throughput factors were divided into two sections: structures and functions. Output factors as boarding and discharge data were included.

Figure 2. EMR and PACS data to ED visual architecture platform.
We used a Windows server as an ED visualization platform supporting various devices in the ED, not only the dashboard but also kiosks for patients and mobile devices. Our entire platform was developed and deployed on two servers on Windows 2008 each with a 1200-GB hard drive and 20 GB memory and two Intel Xeon 2.4Ghz processors with 4core. The servers queried the measurements mentioned above from the EMR and PACS servers. A Windows communication foundation was used as a visualization tool (Figure 2).

_The Evolution of the ED Dashboard_
We developed and updated the dashboard for five years. During the observation, the ED had gone through a Middle East Respiratory Syndrome (MERS) outbreak followed by a major structural and functional renovation.[23] The ED dashboard had adopted such changes and evolved through the process.

_Evaluation_

_Selection of Participants_
Inclusion criteria were those of the ED doctors and triage or charge nurses who agreed to participate in the study. Candidates for participation were currently working in the ED using the dashboard. The exclusion criterion was disagreement. Participants were recruited from January 1 to February 10, 2018.

_Intervention_
Participants responded to 20 questions on a 5-point Likert scale after completing a consent form. The first 10 items of the questionnaire came from the System Usability Scale (SUS) to investigate usability of the dashboard.[24] The last 10 items were from the Situation Awareness Index (SAI), which we composed based on the construction of the Situation Awareness Rating Technique (SART),[25] and were intended to investigate whether ED doctors and nurses were using the dashboard to help in recognizing the situation.

After completing the questionnaire, the participants received about 8 dollars as compensation for participating in the survey.

_Outcome Analysis_
The SUS score calculation formula is

\[
SUS = \left( \frac{Q_1 - 1 + Q_3 - 1 + Q_5 - 1 + Q_7 - 1 + Q_9 - 1 + 5 - Q_2 + 5 - Q_4 + 5 - Q_6 + 5 - Q_8 + 5 - Q_10}{10} \right) \times 2.5
\]

The SUS scores were interpreted using an adjective rating scale,[26] and subgroup analysis was performed by occupation.

The SAI score calculation formula is

\[
SAI = \frac{Q_{11} + Q_{12} + Q_{13} + Q_{14} + Q_{15} + Q_{16} + 6 - Q_{17} + Q_{18} + Q_{19} + Q_{20}}{10}
\]
The SAI scores were also examined using descriptive and subgroup analysis.

**Results**

**Design and Structure**

*Introduction to the First Version of the ED Dashboard*

In the upper central area, there is the hemi-circle shape indicator that represents the complexity of the ED and is the expected mean length of stay of a current patient in the ED. The hemi-circle borrows the scheme of the traffic light so that the user intuitively grasps the current situation of the ED.

![First version of the ED dashboard. A, semi-transparent, colored square represents each section of the ED and matches the geographical layout in Figure 1. The squares are not visible on the actual dashboard. Small icons, such as in the red circle, indicate patients and intuitively inform about the patients' journey though the color corresponding to the patient process on the left.](image)

On the left side of the dashboard is a summary of the patient process. This information allows the doctor to set up a patient diagnosis strategy, and the nurse can determine the order of the various tests. The center area of the dashboard reflects the geographical layout of the ED. Here, individual patients’ specific information was displayed, such as real-time clinical process. On the right side of the dashboard, the number of patients by zone is indicated, thereby enabling efficient distribution of medical labor (Figure 3).

*The Evolution of the ED Dashboard*
The major difference between dashboard versions 1 and 2 is that version 2 reflects a geographical change. In 2015, the ED of the study sites underwent a MERS outbreak, and a respiratory isolation area was established and operated. This structural change to the ED was reflected in the dashboard (Figure 4-a).

In version 3, a revision was made to improve usability. We performed an update to change the overall color coding. By doing so, we were able to reflect the users’ suggestions, such as “difficulty to identify bed status” (Figure 4-b).

A major change in version 4 is the improvement of patient-specific information. The circle next to the patient is indicated by mapping the Korean Triage and Acuity Scale score from 1 to 5 to red to green. Additionally, the rectangle next to the patient reflects “infection caution,” such as “air caution” and “blood caution” (Figure 4-c).
Evaluation

Participant Characteristics

Table 1. Characteristics of participants.

<table>
<thead>
<tr>
<th></th>
<th>Physician (n = 25)</th>
<th>Nurse (n = 27)</th>
<th>Total (n = 52)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age, n(%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20s</td>
<td>2 (8.0)</td>
<td>6 (22.2)</td>
<td>8 (15.4)</td>
</tr>
<tr>
<td>30s</td>
<td>19 (76.0)</td>
<td>19 (70.4)</td>
<td>38 (73.1)</td>
</tr>
<tr>
<td>40s</td>
<td>1 (4.0)</td>
<td>2 (7.4)</td>
<td>3 (5.8)</td>
</tr>
<tr>
<td>50s</td>
<td>3 (12.0)</td>
<td>0 (0.0)</td>
<td>3 (5.8)</td>
</tr>
<tr>
<td><strong>Sex, n(%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>17 (68.0)</td>
<td>2 (7.4)</td>
<td>19 (36.5)</td>
</tr>
<tr>
<td>Female</td>
<td>8 (32.0)</td>
<td>25 (92.6)</td>
<td>33 (63.5)</td>
</tr>
<tr>
<td><strong>Career, n(%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0~3 yr</td>
<td>8 (32.0)</td>
<td>0 (0.0)</td>
<td>8 (15.4)</td>
</tr>
<tr>
<td>3~5 yr</td>
<td>6 (24.0)</td>
<td>4 (14.8)</td>
<td>10 (19.2)</td>
</tr>
<tr>
<td>5~10 yr</td>
<td>4 (16.0)</td>
<td>15 (55.6)</td>
<td>19 (36.5)</td>
</tr>
<tr>
<td>&gt; 10 yr</td>
<td>7 (28.0)</td>
<td>8 (29.6)</td>
<td>15 (28.8)</td>
</tr>
</tbody>
</table>

A total of 52 participants were recruited; 25 were physicians, and 27 were nurses. In the physician group, 17 were male, and 8 were female while, in the nurse group, only 2 were male, and 25 were female. The participants' years of hospital career were also varied; 8 had less than 3 years, 10 had 3–5 years, 19 had 5–10 years, and 15 had over 10 years (Table 1).
### System Usability Scale

Table 2. Scores on SUS.

<table>
<thead>
<tr>
<th>Item</th>
<th>Physician</th>
<th>Nurse</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1. I think that I would like to use this dashboard frequently.</td>
<td>4.52 (0.7)</td>
<td>4.15 (0.5)</td>
<td>4.33 (0.6)</td>
</tr>
<tr>
<td>Q2. I found the dashboard unnecessarily complex.</td>
<td>2.44 (0.9)</td>
<td>2.52 (1.0)</td>
<td>2.48 (0.9)</td>
</tr>
<tr>
<td>Q3. I thought the dashboard was easy to use.</td>
<td>3.76 (0.7)</td>
<td>3.85 (0.6)</td>
<td>3.81 (0.7)</td>
</tr>
<tr>
<td>Q4. I think that I would need the support of a technical person to</td>
<td>3.08 (1.1)</td>
<td>2.89 (1.1)</td>
<td>2.98 (1.1)</td>
</tr>
<tr>
<td>be able to use this dashboard.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q5. I found that the various functions in this dashboard were</td>
<td>3.56 (0.8)</td>
<td>3.78 (0.7)</td>
<td>3.67 (0.7)</td>
</tr>
<tr>
<td>well integrated.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q6. I thought there was too much inconsistency in this dashboard.</td>
<td>2.24 (0.9)</td>
<td>2.07 (0.7)</td>
<td>2.15 (0.8)</td>
</tr>
<tr>
<td>Q7. I would imagine that most people would learn to use this</td>
<td>3.72 (0.9)</td>
<td>3.93 (0.6)</td>
<td>3.83 (0.8)</td>
</tr>
<tr>
<td>dashboard very quickly.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q8. I found the dashboard very cumbersome to use.</td>
<td>2.12 (0.7)</td>
<td>2.11 (0.6)</td>
<td>2.12 (0.7)</td>
</tr>
<tr>
<td>Q9. I felt very confident using the dashboard.</td>
<td>3.84 (0.9)</td>
<td>3.67 (0.8)</td>
<td>3.75 (0.9)</td>
</tr>
<tr>
<td>Q10. I needed to learn a lot of things before I could get going</td>
<td>2.52 (1.1)</td>
<td>2.70 (1.1)</td>
<td>2.62 (1.1)</td>
</tr>
<tr>
<td>with this dashboard.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SUS score**

<table>
<thead>
<tr>
<th>Physician</th>
<th>Nurse</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>67.50</td>
<td>67.69</td>
<td>67.60</td>
</tr>
<tr>
<td>(12.0)</td>
<td>(11.0)</td>
<td>(11.4)</td>
</tr>
</tbody>
</table>

Note: The number corresponding to each item is the mean, and the number in parentheses is the standard deviation. The SUS score was calculated using the equation written in the Method section.

The SUS score of the ED dashboard system was 67.6 points. The SUS score showed a slight difference between the two groups by receiving 67.5 and 67.69 points in the physician and nurse group, respectively. We cannot verify statistical significance by t-test (Table 2).
### Situation Awareness Index

Table 3. Situation awareness and dashboard results.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Item</th>
<th>Physician</th>
<th>Nurse</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instability representation</td>
<td>Q11. The dashboard adequately represents the instability of the ED.</td>
<td>3.96 (1.0)</td>
<td>3.78 (0.7)</td>
<td>3.87 (0.8)</td>
</tr>
<tr>
<td>Complexity representation</td>
<td>Q12. The dashboard adequately represents the complexity of the ED.</td>
<td>4.12 (0.9)</td>
<td>3.93 (0.6)</td>
<td>4.02 (0.8)</td>
</tr>
<tr>
<td>Variability representation</td>
<td>Q13. The dashboard contains key elements that are changing in the ED.</td>
<td>4.08 (0.6)</td>
<td>3.85 (0.8)</td>
<td>3.96 (0.7)</td>
</tr>
<tr>
<td>Arousal support</td>
<td>Q14. The dashboard helps me be alert and clearer.</td>
<td>3.92 (0.9)</td>
<td>3.74 (0.7)</td>
<td>3.83 (0.8)</td>
</tr>
<tr>
<td>Concentration support</td>
<td>Q15. The dashboard helps me focus on the situation in the ED.</td>
<td>4.20 (0.6)</td>
<td>4.11 (0.6)</td>
<td>4.15 (0.6)</td>
</tr>
<tr>
<td>Spare mental capacity support</td>
<td>Q16. I can acquire additional mental capacity in a pressing ED</td>
<td>3.60 (1.2)</td>
<td>3.48 (0.9)</td>
<td>3.54 (1.0)</td>
</tr>
<tr>
<td>Division of attention</td>
<td>Q17. The dashboard distracts attention from important tasks of the ED.</td>
<td>2.12 (0.7)</td>
<td>2.37 (0.9)</td>
<td>2.25 (0.8)</td>
</tr>
<tr>
<td>Information quantity provided</td>
<td>Q18. The quantity of information provided by the dashboard is</td>
<td>3.84 (0.9)</td>
<td>3.67 (0.8)</td>
<td>3.75 (0.8)</td>
</tr>
<tr>
<td>Information quality provided</td>
<td>Q19. The quality of information provided by the dashboard is</td>
<td>3.92 (1.0)</td>
<td>3.96 (0.6)</td>
<td>3.94 (0.8)</td>
</tr>
<tr>
<td>Familiarity of dashboard</td>
<td>Q20. I can perform ED tasks more proficiently using the dashboard.</td>
<td>4.00 (0.9)</td>
<td>3.89 (0.8)</td>
<td>3.94 (0.9)</td>
</tr>
<tr>
<td>SAI score</td>
<td></td>
<td>3.95 (0.6)</td>
<td>3.80 (0.5)</td>
<td>3.87 (0.6)</td>
</tr>
</tbody>
</table>

Note: The number corresponding to each item is the mean, and the number in parentheses is the standard deviation.
The results of the SAI were as follows. The overall SAI score was 3.87, and the score of the doctor group (3.95) was higher than that of the nurses group (3.80). The items rated as the top five were “concentration support” with 4.15 points, “complexity representation” with 4.02 points, “variability representation” with 3.96 points, “information quality provided” with 3.94 points, and “familiarity of dashboard” with 3.94 points. However, the “division of attention” was rated with 2.25 points (Table 3).
Discussion

Principal Results
The ED dashboard was successfully developed and implemented. The system is independent of manual input and fully connected to the legacy HIS. The graphical and statistical concepts were determined during the developing period and upgraded gradually. Though there have been clinical dashboards for EDs from other studies,[15,27-29] this is the first to show its long-term use, not to mention its serial upgrades.

We used an SUS, a formal usability test, and obtained 67.6 points by ED physicians and nurses. Bangor et al. developed a technique that is highly correlated with the acceptability and adjective rating scale with the SUS by analyzing the results of approximately 1000 SUS evaluations.[26] According to this research, we could interpret our result as follows: Acceptability of the dashboard was "Marginal High," and the adjective rating was "OK to Good."

Clinical Aspect
It has been one of major responsibilities of ED staff to keep patients’ process on track and ensure its result in a timely manner.[30] To do so, ED providers had to call numerous departments and browse through multiple windows repeatedly during their duty time. As the tasks and volume of ED work-ups grew, this timekeeping function had become significantly heavy. The ED dashboard in this article focused on visualizing these “hidden” figures of the ED process so that ED providers could plan and carry out their tasks proactively.

Visualized measures were about not only individual patients’ process but also the department’s performance scales. As government and insurance companies focus on performance as a group of patients, it has become an essential job for the system administrator to be able to assess the real-time statistics. ED providers' responsibility as administrators demands tools like our dashboard during their work.

A major difference of our system from other electrical boards is that it does not allow manual direct input about patient-specific information. We have fully synchronized with the legacy system so that physicians and nurses did not need additional input to use the dashboard. The research team worried that such input requests would make the dashboard unusable by reducing its usability by busy clinicians.

Limitations
First, this is a single-center case with its unique HIS. Its feasibility and usability should be validated in other institutions. Since the propagation of its application has occasionally been witnessed, an investigation on ED dashboard utilization is expected in the near future.
Second, the measures used for the dashboard are not universally agreed upon. They are mainly for the study institute, an academic, highly crowded ED. When used in smaller EDs, measures of interest would be different. Additionally, the measures were not compared with the national standard, which will require further studies.

Third, the device was only for a 65-inch wall-mounted TV initially. Though the device has extended to a 55-inch ceiling-connected TV and 22-inch PC monitors lately, its usability with various devices has not been thoroughly evaluated. Moreover, possible mobile usage would be necessary due to its efficiency and portability.

Fourth, the SAI score has not been validated. We searched for questionnaires for investigating the relationship between dashboards and situation awareness, but we could not find a suitable one for our purpose. Therefore, we developed a questionnaire ourselves from the SART and applied it to this study. However, this questionnaire is not validated, so its interpretation is limited.

**Conclusions**

We developed the ED dashboard and successfully used it for five years. The ED physicians and nurses evaluated the usability of ED dashboard at 67.6 points, which means “OK to Good” and marginal high acceptability. We realize that continuous maintenance is important because the dashboard should reflect the situation of the ED.

**Acknowledgements**

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**Conflicts of Interest**

None declared.

**Abbreviations**

ED: Emergency Department  
EMR: Electronic Medical Record  
HIS: Hospital Information System  
MERS: Middle East Respiratory Syndrome  
PACS: Picture Archiving and Communication System  
SART: Situation Awareness Rating Technique  
SUS: System Usability Scale
Multimedia Appendix 1

References


