Proactive Risk Assessment in the ED: Building the Safety Case

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1. Abstract

Purpose. To apply proactive risk assessment (PRA) methods to health information technologies in emergency departments (EDs).

Scope. EDs use status boards to support a variety of cognitive and coordinative functions. Replacing these artefacts by computerized versions may introduce new risks.

Methods. PRA methods were used to assess risks associated with manual and computerized status boards, under conditions of high- and low-tempo operations. Overall hazard assessments were developed by combining ordinal scale estimates of likelihood, severity, and probability of recovery. High-risk scenarios were those for which likelihood and severity were high (>1 per day and >4 on a 6-point scale) and recovery probability was low.

Results. For both manual and computerized status boards under normal tempo conditions, no high-risk scenarios were identified—although failures might occur, they were either rare, low consequence, or easily recoverable. Under high-tempo conditions, three high-risk failure modes were identified for manual status boards, but nine were identified for computerized status boards. Computerized status boards performed poorly in managing name similarities and affording evolvability. Safety assessments of information technology under normal operating conditions may not be a reliable guide to safety under stressed conditions.

Key words. Risk assessment, health information technology, emergency department

2. Purpose

This project had three broad, long-term objectives:

- To extend the techniques of proactive risk assessment (PRA) used in high-hazard industries into a healthcare setting. PRA methods have been most commonly employed in sociotechnical systems having complex technology but simple processes. Ambulatory healthcare, on the other hand, has relatively simple technology but highly complex processes that are mediated primarily by the social components of the sociotechnical system. Therefore, an assessment of the practicality and utility of PRA is such areas would be useful [1-3].
- To adapt the technique of creating a 'safety case' method for presenting or encapsulating the results of a PRA to a healthcare setting [4, p 178ff].
- To examine the concepts of resilience engineering for use in supplementing a PRA [5].

We used an organization's change from manual to computerized status boards as as a vehicle for exploring and demonstrating the feasibility and applicability of the PRA, safety case, and resilience engineering approaches. Essentially, the electronic and manual status boards served as a 'test bed' for addressing the following specific aims:

- To identify the specific ways in which the status board both supports patient safety and poses risks to patients.
- To conduct a PRA for evaulating the likelihoods and potential consequences of replacing manual with computer-based status boards in EDs.
- To produce a 'safety case' argument for that change based on the results of the PRA exercise.
- To produce a generalizable methodology for conducting such assessments.

Many adverse events in healthcare are low-frequency but high-impact episodes with multiple contributors. Therefore, traditional biomedical approaches to understanding and modeling these events, with their requirements for large numbers of episodes, are both undesirable and impractical [6,7]. New methods, such as PRA, offer an alternative procedure for prospectively identifying, analyzing, prioritizing, and mitigating risks to patients in such low-frequency, high-consequence situations. In this regard, PRA is a form of organizational sensemaking [8] to identify potential hazards and enhance learning from safety events.

3. Scope

Background. Healthcare organizations commonly institute major changes in equipment, procedures, and/or operations (for example, upgrading emergency services by opening a stroke center, etc). Considerations of patient safety or unintended consequences tend not to be considered in a systematic way in these decisions. In addition, these changes are often politically fraught and entangled with internal agendas so that, when safety considerations are raised, they are often misinterpreted.

Status Boards. EDs commonly use status boards as tools for managing clinical work. Status boards are not specifically mandated by any external authority but instead were developed spontaneously and locally as the practice of emergency medicine grew more complex over the years. Though they may seem simple and obvious to the casual observer, they are neither, and their complexity mirrors the complexity of the dynamic environment they represent. They reflect the dynamic status of patients, resources, and the environment, coded in idiosyncratic but locally meaningful ways. Interestingly, despite their central importance to the work of the ED and the safety of patients, they have hardly been studied; a substantive book on the organization and management of the ED [9] devotes only ¼ page (out of 892) to status boards.

Status boards are typically large, dry erase "whiteboards" on which patient locations are represented as rows in a grid, and columns provide a variety of relevant data (see Figure 1). They are typically located in a centrally accessible work area with easy visibility, such as the nursing station, where they can be used by all ED staff and clinicians. Status boards began as simple tracking devices for displaying patient name and location have evolved [10] to include a great deal of additional information, including any of the following:

- Patient demographic and risk information, such as chief complaint, arrival time or length of stay, name conflict alerts, pregnancy, isolation, allergies
- Staff information, such as responsible ED physician, nurse, tech, private physician
- Process information, such as pending or completed procedures, laboratory or imaging studies, partial plans (e.g., "nebs x 3", or "4 hr obs")
- Patient status information, such as pending consultations, admission/discharge status, bed status
- Department or hospital level information (for example, no critical care beds).

Status boards are important tools for providing safe care in the ED by supporting shared memory, latent processes, collaboration, shared cognition, communication, and coordination. Status boards are, in effect, a dynamic representation of the complex work of the emergency department and are particularly useful in reducing interruptions [11-14] by supporting asynchronous communication among ED staff in a manner that reduces the memory burden on both sender and receiver [15]. Thus, changes in status boards, such as converting from manual to computer based, risk affecting their meaning, use, continued evolution, and development and maintenance of shared cognition among ED (and other) staff [16,17].

For a variety of reasons, many EDs are replacing their manual status boards with electronic, computer-supported versions (see Figure 2). The motivations for this change are complex and typically involve general themes of improving accuracy of information, providing better information to management or other "back end" processes, and improving patient safety [18-20]. However, the manual and computerized tools have different strengths and weaknesses, and the insertion of technology into a complex work place such as the ED is never a straightforward substitution of new for old [21,22].

Setting. The study was conducted in the ED of Shands Jacksonville Medical Center, a large, inner-city, academic medical center. The ED is a level-1 trauma center with an annual volume of 90,000 patient visits, 27,000 of whom are children cared for in an internal pediatric ED. It is divided into five large treatment areas and is staffed by 150 nursing, ancillary and administrative support staff, six physician assistants, and an emergency medicine (EM) training program with 54 EM residents and fellows supervised by 28 EM attending physicians.

Four of the principal treatment areas in the ED use status boards for patient tracking and other communication and coordination functions. Three of these were the primary focus of this study, as they provide the bulk of emergency treatment.

In 2005, the hospital installed a commercially available, institution-wide patient tracking system. The original expectation was that this system would replace the existing manual status boards in the ED. However, the manual status boards continued to be used as the primary shared informational artefact, and the electronic tracking system was used in an adjunctive way. This dual use of cognitive artefacts in a single setting afforded the opportunity to evaluate the risks associated with either the manual or the computerized instantiation of a status board.

4. Methods

Time course

The project evolved in three major phases.

Phase 1. Mapping cognitive properties of the status board onto patient safety. A comprehensive description of the status board as a cognitive and artefact was developed with specific focus on describing how its function influences ED safety.

Phase 2. Creation of PRA logic models. Fault trees (for critical activities) and event trees (for possible outcomes) relevant to the status board's role in supporting safety were constructed, using standard PRA methods and conventions [1,2,23]. We developed separate models for normal *vs* 'high-tempo' ED operations, with these representing the most easily distinguished states.

Phase 3. Quantitative analysis and interpretation. The various branches of the fault and event trees were assigned ordinal values on three separate dimensions: a) probability of occurrence; b) severity of outcome; and c) likelihood of rescue, prevention, or mitigation. After completing these assignments, an external consultant board consisting of emergency physicians (from clinical organizations other than the study site) and human factors engineers reviewed the models and tentative outputs for face validity and generality with consensus obtained in an iterative manner.

Data sources and methods

This section describes the technical approaches used to elicit and analyze the data required to accomplish the tasks listed above. These data were gathered by a combination of direct observations of ED work, small focus groups, and interview with key personnel, except as otherwise noted.

Develop patient safety scenarios and the relationship of status board design to patient safety. As a means of mapping the cognitive properties of the status board to functionality relevant to patient safety, we used a modification of the "heuristic walkthrough" method [24]. This enabled subject matter experts to provide insights into the relevant characteristics of the work, the status board, and their interaction and the human factors experts to gain additional insight into the semantics of the work domain, which supported their direct observations of the use of the status board in clinical work.

Develop event tree and fault tree models for PRA and quantify probabilities of events. Fault and event trees were created to represent the pathways by which undesired events might arise or propagate. Early in the project, it became apparent that PRA in this specific instance would be characterized by large numbers of relative shallow fault or event trees. Therefore, in order to allow for an overview of the entire hazard space, a tabular representation was used instead of more traditional fault/event tree diagrams.

The elicitation process was based on the technique developed in the US nuclear industry to provide quantification of failures for which knowledge was tacit, as is the case here. In that method [25], the emphasis is on making explicit the basis for judgments through the citing of evidence, not just general recollections as is often the case with expert-elicitation based studies. This enables differences of opinion to be explored and reconciled, for example, rather than simply averaged (again a common approach used elsewhere). Attempts at quantification on a ratio (i.e., 0 to 1) scale proved problematic due to the lack of systematic recording of events and uncertainty as to the appropriate denominator (for example, what exactly constitutes an 'opportunity' for failure or 'exposure' to hazard); we used an ordinal scale approach to quantification. This is supported by Reason's work, in which he notes that, although domain experts may be relatively poor at accurate probability assessments, they typically perform well when sorting hazards into some order of riskiness [4,26].

To summarize and finalize the suite of estimates, a series of face-to-face meetings was held in close proximity to the ED to allow the immediate additional observations as needed over the course of a week. Two sets of quantification were made for (1) normal pace of operations and (2) high-tempo operations, and estimates were made for:

- How frequently a scenario was likely to occur
- The worst consequence that was reasonably likely to occur
- What opportunities there were for recognition and recovery from potential harm

In order to allow the judges to make estimates in a consistent manner, ranges for the above variable were constructed to allow the selection of ordinal values that covered the orders of magnitude relevant to the project's goals. The range for the frequencies of scenarios in terms of events per unit time was:

1/shift – 1/day – 1/week – 1/month – 1/year – 1/year

A similar ordinal rating scale for the severity of harm was adapted from one developed and published by ECRI and the Pennsylvania Patient Safety Authority [27]; it is illustrated in Table 1. Table 2 shows a rating scale for the likelihood of recovery.

All assessments were performed for both normal and high-tempo conditions. High-tempo conditions were defined as extraordinarily busy ED operations but ones that did not trigger special organization procedures (such as external disasters). High-tempo conditions were estimated to occur about four times per year, typically lasting up to 8 hours.

Preparation of a Safety Case. The validated results of the PRA exercise described above used to build an example safety case argument. The safety case documents the hazards latent in use of status boards, with particular emphasis on ways in which those induced hazards might be managed by better design, implementation, procedures, or training. A safety case is generally be defined as "a documented body of evidence that provides a convincing a valid argument that a system is adequately safe for a given application in a given environment"[28]. It consists of a written report that makes an explicit set of claims about the system, produces supporting evidence for those claims, provides a set of safety arguments that link the claims to the evidence, makes clear the assumptions and judgments underlying the arguments, and allows different viewpoints and different levels of detail. A safety case should become a continuing argument, updated periodically as new information becomes available (for example, after a near miss or adverse event) [29]. The Adelard Assurance and Safety Case Environment (v 3.5, Adelard Corporation, Northampton Square, London, UK) was used to develop the example safety case. Although several formalisms are useful in safety case development, the assertion – argument – evidence formalism was used for safety case development [30].

5. Results

Only the most salient and illustrative results are discussed in this report, in order to keep within the page limit requirement. Extensive details are available on request and may be included in manuscripts currently in preparation.

Identification of failure modes and their impact on patient safety

Table 3 is one of a series of 10 tables summarizing the risk assessment process and demonstrates one high-risk scenario noted under high-tempo operations. The additional tables (not shown) represent the problems (for both electronic and manual status boards), such as data not entered, data entered incorrectly, data updated incorrectly, more patient data entered than space provided, data missing from system, etc.

Normal Operations

No cases were identified in association with normal operations in which the risk of harm to patients was high defined as the frequency is high (1/shift), the potential severity was high (5 or 6 of 6), and the possibility of recovery is low or very low.

High-Tempo Operations

For high-tempo operations, three cases of high risk were identified with use of the manual status board, and nine situations of high risk were associated with use of the electronic board. These cases are explicated below.

Physical white board

Look-alike and sound-alike names. In this case, the risk is dominated by the possibility of two (or more) patients being confused with each other and one patient receiving tests or treatment intended for the other. Many times, the physical white board was annotated to show the existence of multiple patients with sound-alike or look-alike names in the ED (see Figure 4). However under the high-tempo conditions, there is a significant chance that the board will not be suitably annotated in every such situation.

Wrong status. In this case, the risk results from the use of the 'board within a board' (Figure 5) during periods of ED overcrowding, in which it can be unclear which items of information are associated with which patient. Compared with normal conditions, the likelihood of it being recovered is lower because of the higher workload of the staff.

Wrong disposition. In this case, during high-tempo and overcrowded conditions, a patient is inadvertently given a wrong disposition, such as being discharged rather than being admitted or discharged prematurely before completion of further testing or treatment. The most likely result is that the patient would return to the ED with the same or a more serious condition after a period of time. However, it is also very possible that the patient's condition could worsen and result in serious complications or death prior to their seeking additional care. A second state of risk would be if the patient has suffered non-accident injuries (for example, from an abusive spouse or caretaker) and they incorrectly returned to the setting in which those injuries occurred, when the intention was to retain the patient and arrange for them to be taken into some protected setting (e.g., a shelter or child protective services).

Electronic White Board

Look-alike and sound-alike names. In contrast to the physical status board, the computerized board offered no facility for marking or otherwise alerting users to the presence of two or more patients with look-alike/sound-alike names in the same treatment area. This risk was exacerbated by the use of two-letter abbreviations for first and last names (see Figure 2), even though the computerized board was situated in a position in which it could not be viewed from other than inside the unit's nursing station.

No name entered. During high-tempo periods, the patient's name is not entered into the electronic white board, because there is no open line on the status board grid despite their physical presence in the area. Thus, the patient can wait for a long time (up to 90 minutes) before staff realize that a new patient has been added to the overcrowded ED. This is particularly of concern when the patient is located somewhere within the treatment area that is difficult to visualize. Often someone (such as the patient's family) may bring the clinical staff's attention to the patient, but, under high-tempo conditions, this may be missed. Under normal conditions, the patient's paper chart would act as a recovery reminder, but, under the high-tempo conditions, the chart is not reliable, because it often lags behind the patient due to registration delays.

Name entered in non-standard location. This is a variant of the previous case: the patient's name is entered into the electronic status board but in a non-standard location, (e.g., a closed treatment area, such as the 'jail clinic') but then is not recognized by the clinical staff as someone in need of attention. This occurs as a work-around for the lack of flexibility in data entry when the allocated data entry spaces are full.

Patient data initially entered incorrectly - wrong name. In this case, the white board and the patient's wrist band are both wrong but in agreement with each other (Case 4 in Table 4) and is one of several cases involving the wrong name being entered for the patient. In this case, previous records for the patient may not be requested from the hospital records (so, for example, a drug allergy may be missed) or retrieved under the wrong name, introducing data that is misleading for the clinical decisionmakers. This is most likely to be a concern when the patient is admitted in an unconscious or confused state and therefore is unable to correct the mistake.

Patient data initially entered incorrectly - wrong location. In this case, the patient is recorded as being in one location of the ED and is actually in another. Relying on this information (especially when the patient is unconscious or in a confused state), clinical staff can delayed in or be misled into administering inappropriate medications or other treatments to patients, as staff often use location (e.g., bed number) to identify patients.

Patient data initially entered incorrectly - wrong clinical data. In this case, the wrong symptoms are entered into the electronic white board and, as a result, the patient's priority is assessed wrongly. Thus, if the patient is in critical need, it is possible that they do not get seen as urgently, particularly if they are located out of the sight of the clinical staff. Under normal operations, it is most likely that they would be observed and attended to despite the erroneous information in the electronic board, but under high-tempo conditions, the information is less likely to be questioned and the patient is not appropriately prioritized. The external review board noted one additional mechanism leading to this failure mode, that of previously entered data scrolling off-screen and thus being unobservable.

Patient data initially entered incorrectly - incorrect clinical staff data. In this case, the wrong identification of clinical staff members assigned to the patient results in an extended delay in the patient being initially seen. As with other cases above, if the patient is in a deteriorating condition and is not seen for up to 90 minutes, they may become critical or expire before being seen or treated. Under normal operations, it is most likely that they would be observed and attended to despite the erroneous information in the electronic board, but under high-tempo conditions, they may simply be overlooked because of the workload.

Patient temporarily moved out of the ED but entry erased from electronic white board. In this case, the patient has been moved to another location in the hospital (for testing, dialysis or similar reasons) and their records as active patients have been deleted from the system (as if they have been discharged; on some occasions, ED patients have been shown on the computerized status board as having been transferred to an inpatient ward without having left the ED). On their return, there is no active record of them, their condition, and the plan for treatment. The patient then is left by transport in the ED, with no indication of why they are there. Under the high-tempo conditions, there can be an extensive wait before their presence is recognized and treatment restarted. If they are in a vulnerable state, the risk a worsening of their condition and death.

Wrong disposition. As with the physical white board case for the same outcome, this case involves a patient inadvertently receiving a wrong disposition, such as being discharged rather than being admitted or discharged prematurely before completion of further testing or treatment. The most likely result is that the patient would return to the ED with the same or a more serious condition after a period of time; however, it is also very possible that the patient's condition could worsen prior to their seeking additional care. An additional risk exists in that the patient may be returned to an abusive situation, as discussed above with the manual status board.

Safety case argument

Figure 3 provides a high-level graphic summarizing the safety case argument for the manual status board. (The full safety case for each board comprises approximately 13 pages and so is not included here). Because the safety case methodology is new to healthcare, this diagram shows that the safety argument is incomplete. Evidence that should support arguments, which in turn supports claims, is missing: there is no hazard log that could provide support for the argument that the system has been historically safe; there is no IT safety management plan in the organization that could provide evidence that the safety management systems are adequate; and there are no relevant external standards by which arguments that risks have been both adequately identified and adequately controlled could be supported.

6. Conclusions

Safety assessments using PRA methods can be effective in evaluating the risks from information technologies. The results above lead to four major conclusions, one related to process and three related to content.

First, the environment in which PRA was developed typically showed small numbers of deep trees involving multiple interacting failures, but the PRA in this project revealed large numbers of relatively shallow trees, suggesting that, in the setting studied, single point failures are more common than has been thought. This may be reflect the narrow scope of application (the status board technology, as opposed to ED care as a whole).

Second, tempo of operations is a critical factor in risk in this setting. Under normal conditions, both technologies appear to be adequate in that no high-risk scenarios were identified. However, under high-tempo conditions, both technologies gave rise to high-risk scenarios: the physical whiteboard to three and the computerized whiteboard to eight. The increased number with the electronic board were partly the result of 1) the system only displaying part of the information associated with patient management at any one time ('keyholing'); 2) the system not being as readily updated by users; and (3) less immediate feedback in the event that displayed data is deleted. The analysis demonstrates that safety evaluations under "normal" conditions can be misleading guides to safety under 'real-world' conditions. In addition, as a side observation, it can be seen that, if the electronic system becomes perceived as less reliable by users at the 'sharp end' of care, the likelihood of high-risk scenarios will increase and may become a major concern. To date, there are no standards for the reliability of information technology in healthcare. The approach used here could provide one means to estimate the levels of reliability that should be required of such systems.

Third, the potential for name confusion, although it exists for both modalities, is greater for the computerized than for the manual status board. This seems ironic, because computer technology to identify and highlight look-alike, sound-alike names is well developed and could easily have been provided in the computer-based system. (As an aside, we are not aware of this capability in any other commercially available ED information system.)

Fourth, the mechanism by which the computerized status board degrades more rapidly under high-tempo conditions is its lack of evolvability [10]. The ability to manipulate the manual board in new and easily grasped ways in response to unusual or unexampled conditions affords a degree of resilience in responding to the unexpected that the computerized status board cannot match. Although this malleability leads to risks of its own, they seem to be more than balanced by the risks of having to use an inflexible system that is not well suited to the demands of the moment.

Finally, the safety case formalism seems easily adaptable to healthcare settings. Although there are many areas in which the disjoint assumptions of the method and healthcare operations (e.g., 'relevant safety standards exist') result in somewhat simplistic statements of obvious, the utility of the method lies exactly in making those implicit but obvious assumptions both explicit and unacceptable.

7. Lists of Publications and Products

Academic papers

Perry SJ, Wears RL, Chozos N. "It came from within": clinical impact of latent IT failures on patient safety. *Proceedings of the 2008 International Conference on Healthcare Ergonomics and Patient Safety,* Strasbourg, FR; 2008.

Pennarthur P, Guarrera TK, Bisantz AM, Fairbanks RJ, Perry SJ, Wears, RL. Cognitive artifacts in transition: an analysis of information content changes between manual and electronic patient tracking systems. Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting: p 363 - 367. New York, NY: Human Factors and Ergonomics Society; 2008.

Wears RL, Bisantz AM, Xiao Y, *et al.* Computerized Status Boards in Acute Care Settings: Promises and Pitfalls. *Proceedings of the American Medical Informatics Association 2008 Annual Symposium* Washington, DC: AMIA; 2008.

Papers submitted for presentation

Wears RL, Perry SJ, Wreathall J, *et al.* Proactive risk assessment of computerized and manual status boards in the emergency department. Society for Academic Emergency Medicine 2009 Annual Meeting, New Orleans, LA

Wears RL, Perry SJ, Wreathall J, *et al.* Adapting safety case methodology to healthcare settings. Society for Academic Emergency Medicine 2009 Annual Meeting, New Orleans, LA

Other works

Wears R, Leveson NG. "Safeware": safety-critical computing and healthcare information technology. In: K H, Battles JB, Keyes MA, *et al.*, eds. *Advances in patient safety: New directions and alternative approaches.* AHRQ Publication No. 08-0034-4 ed. Rockville, MD: Agency for Healthcare Research and Quality; 2008: pp 1-10.

A follow-up project to this work, aimed at addressing some of the hazards identified here, has been submitted and funded under RFA-HS-08-004, "Risk Informed Intervention Development and Implementation of Safe Practices in Ambulatory Care."

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Table 1. Rating scale for severity of harm.

Scale	Severity
1	Event occurred with no harm to the patient
2	Increased patient assessment and monitoring but no harm
3	Treatment or intervention required, temporary harm
4	Initial or prolonged hospitalization required with temporary harm
5	Permanent harm or near death
6	Death of patient

Table 2. Rating scale for likelihood of recovery.

Scale	Recovery opportunity
Very high	Greater than 95%
High	Very good chance (greater than about 75%)
Medium	Moderate chance (greater than about 25% but less than about 75%)
Low	Poor chance (less than about 25%)
Very low	Less than 5%

Table 3. Patient data does not match status, electronic white board (Degree of shading indicates low-, moderate-, and high-risk conditions)

Failure mode	Likelihood	Severity	Recovery	Likelihood – hi tempo	Severity – hi tempo	Recovery – hi tempo	Notes
Data partially erased	1/week	1-3	High (Eventually)	Low	1-3	Moderate	Partial erasure unlikely with a computerized system. Complete erasure much more likely
Data completely erased	1/day	3-4	High (paper chart in rack is important cue)	High	3-4	Depends on location (Low if out of sight)	
Patient discharged but data not updated	1/shift	2-3	High (Eventually)	High	2-3	Moderate	
Patient discharged but data partially erased	1/shift	2-3	High (Eventually)	High	2-3	Moderate	
Patient dispositioned but data not erased	1/shift	2-3	High (Eventually)	High	2-3	Moderate	
Patient dispositioned but data partially erased	1/shift	2-3	High (Eventually)	High	2-3	Moderate	
Patient moved but not updated	1/shift	2-3	High (Eventually)	High	2-3	Moderate	
Patient moved to EIA (admit/hold) but not updated	1/shift	3-4	High (Eventually)	High	3-5	Moderate	
Patient temporarily moved out of ED but entry erased	1/day	3-6	Moderate	High	3-6	Low	Gone for tests, dialysis, etc. May not be obvious paper trail at ED for recovery. Patient should have

Failure mode	Likelihood	Severity	Recovery	Likelihood – hi tempo	Severity – hi tempo	Recovery – hi tempo	Notes
							blue wrist band indicating entered system via ED
Patient temporarily moved to admit/hold and entry erased	1/day	2-3	High (Eventually)	High	2-3	Moderate	Paperwork chart will be incomplete and may act as reminder

Table 4. Modes of Possible Name Confusion

Case	Patient name	Name as recorded in admin system	Name as recorded on status board
1	Amy	Amy	Amy
2	Amy	Amy	Beth
3	Amy	Beth	Amy
4	Amy	Beth	Beth
5	Amy	Beth	Cathy

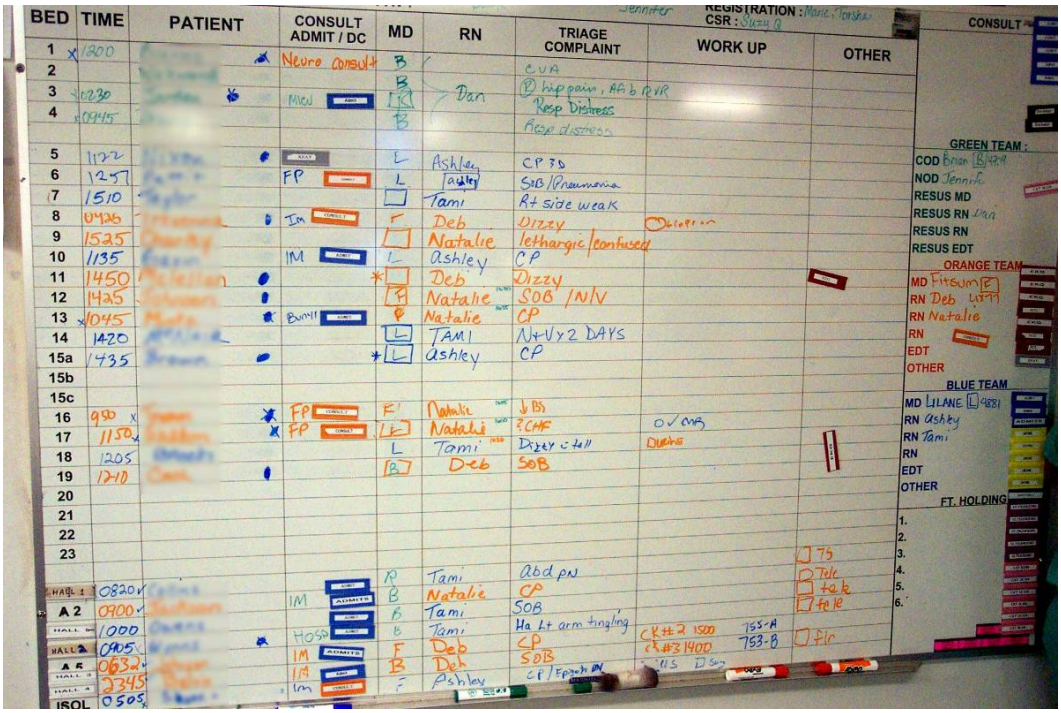

Figure 1. Manual white board for one treatment area at normal operating tempo.

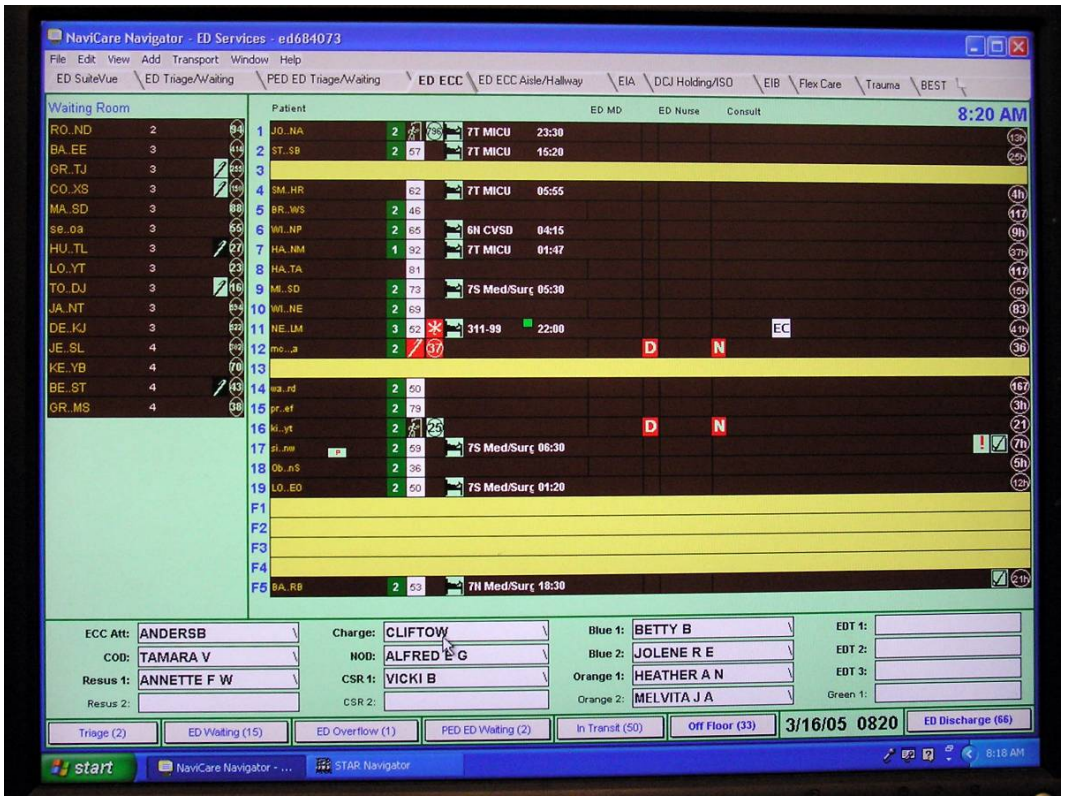

Figure 2. Computerized status board, showing the screen for the same treatment area as Figure 1, at normal operating tempo.

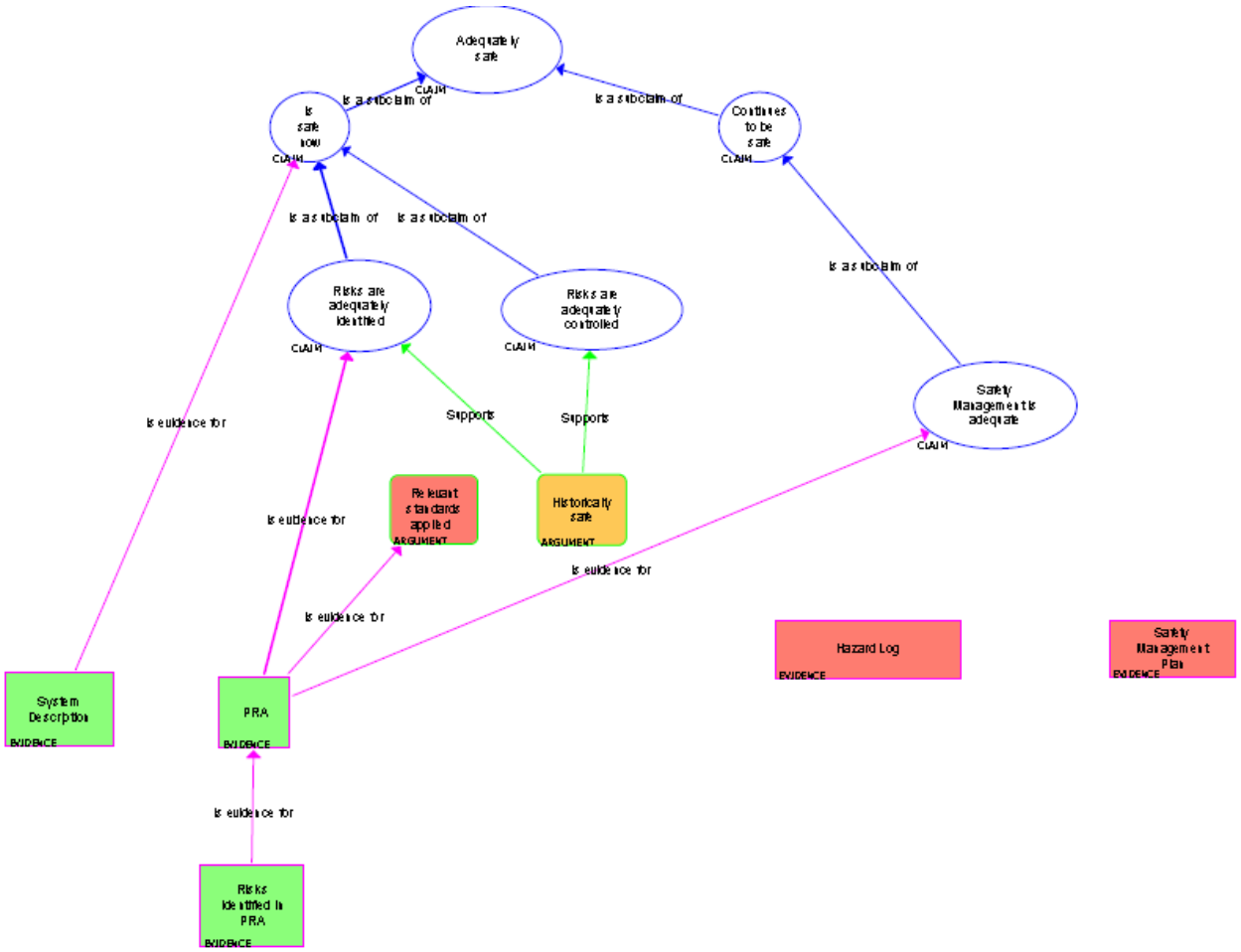

Figure 3. High-level graphic of safety case argument for the manual status board. Claims are supported by arguments or evidence; arguments are supported by evidence. Boxes containing strong support are indicated by green shading; intermediate, by yellow; and poor to absent evidence, by red. Strength of support also is indicated by the width of the associated links.

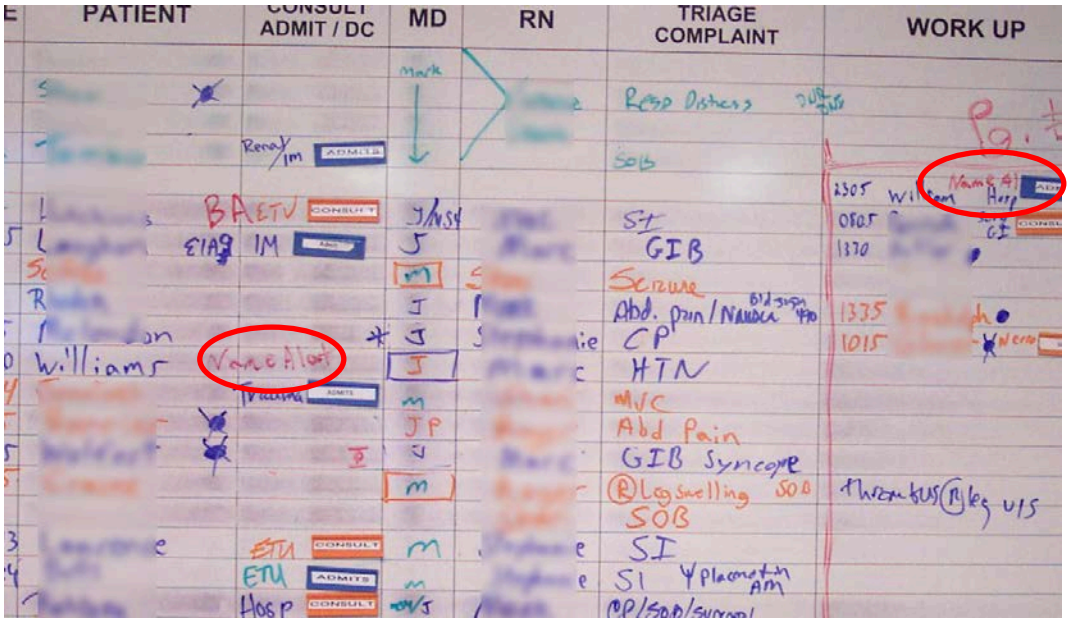

Figure 4. Manual status board showing alerts for look-alike/sound-alike names.

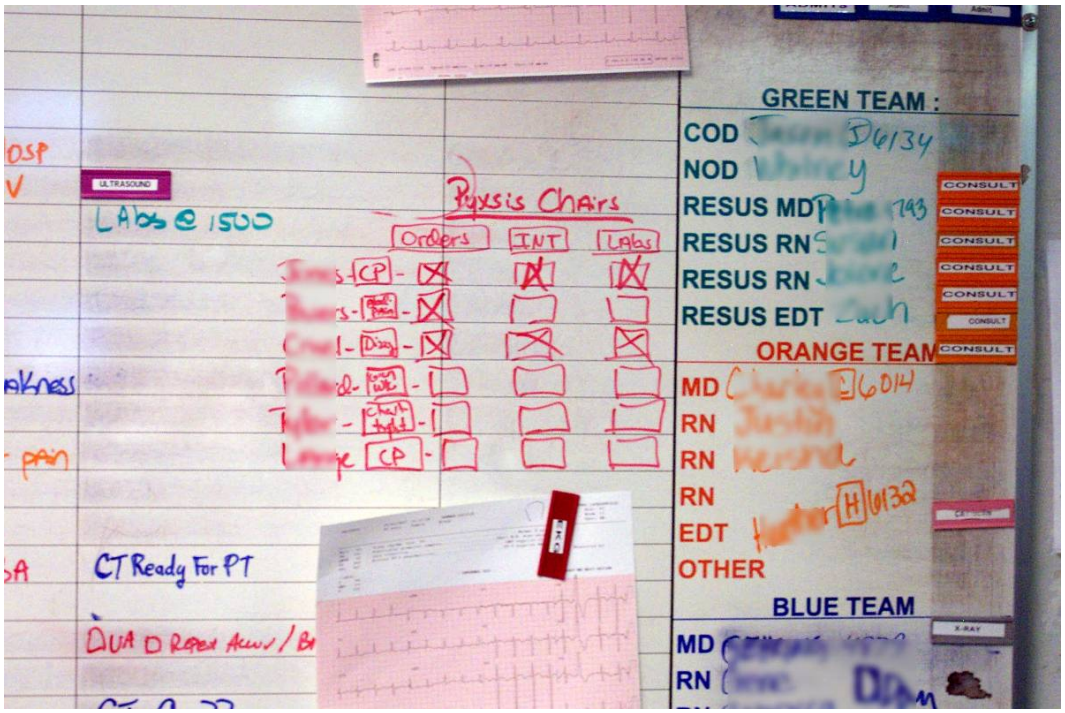

Figure 5. Manual whiteboard, showing evolvability (creation of new space in a 'board-within-a-board' when the main board is full) and a new hazard, as information entered here may be wrongly attributed to another patient on the same row.