Abstract

Modeling the behavior of a dynamic system demands a view into the inner workings and practices of that specific system. In light of past publications highlighting medical errors and various measures taken to reduce these events, this research seeks to characterize the hospital Operating Room (OR) performance envelope in the context of Rasmussen's model of system dynamics. In previous work, this approach was introduced in the context of naval submarine mishaps [Lamb 2010] and further extrapolated to the OR setting [Severinghaus and Combs 2011]. The current effort seeks to refine this work and set the stage for research to further provide detail on the components of error in the OR. This model illustrates the movement of an OR team within a safety envelope, provides insight into the human- and system-based errors of the OR, and highlights the main contributing factors of pressure on OR teams. The complexity of OR team workload and varying levels of clinical urgency are explored in the contexts of acceptable and unacceptable levels of performance and OR culture.

1. INTRODUCTION

Every sociotechnical system is unique, and the hospital OR is a small but complex example: a collection of individuals, including surgeon, circulating nurse, scrub tech, and anesthesiologist, working in concert with technology on a patient with unique physiology and needs. It can be difficult to understand the workings of such systems from the outside, though in the case of medicine, this kind of understanding is highly desirable as a result of studies of the errors that occur in such systems, and the reporting of error statistics in the media locally, nationally, and abroad.

Medical errors occupy a space of elevated awareness in society today, with great demand and response to the demand for increased patient safety. Modeling OR systems can be helpful to better understand the interactions that influence team behavior, as these interactions can create conditions that lead to errors impacting patient safety. We suggest that such modeling efforts, focused on surgical teams and procedures, can be assisted by a clearer understanding of what dynamics are at work in this setting.

2. ERROR: DEFINITION AND CONTEXT

To Err is Human [Institute of Medicine 2001] set the standard for the terms and definitions used in this report. An error is defined as the failure of a planned action to be completed as intended, or the use of a wrong plan to achieve an aim [Reason 1990]. An adverse event is an injury caused by medical management rather than by the underlying condition of the patient [Brennan et al. 1991]. In practice, occurrences of error and adverse events can either overlap or be mutually exclusive, depending on the circumstances. For example, errors are sometimes fatal and sometimes near misses. We define near misses as errors or imminent errors which, due to a timely correction or just plain luck, do not become adverse events. This definition is similar to those found in other research defining near misses: near miss as constructive interruption in the pathway of error [Jeffs et al. 2008]. In the current research, we are concerned with preventable errors, and with modeling the conditions that lead to adverse events that are caused by errors.

Bosk [1979] highlights several types of preventable error as a result of his direct, long-term observations of attending surgeons and their services, with specific emphasis on the surgeon: technical error, judgmental error, normative error, and quasi-normative error. As quasi-normative errors are unique to a given surgical team and may not be errors in practice at all, we focus our discussion on the first three types only:

- Technical errors are errors in skill and/or technique. They are expected to occur to all surgeons. The designation of this type of error relies upon two criteria: immediate recognition, reporting, and treatment; and rarity. Satisfaction of these conditions implies that the surgeon was conscientious, had good intentions, and the error was evidence of a lapse rather than a pattern of performance.
- Errors in judgment are errors in the chosen treatment plan. These errors are realized with
clinical results and include instances when a treatment plan may be considered “correct” given known conditions, but some unknown circumstance caused it to fail. Common types of judgment error span the continuum of treatment decisions, from failure to define a clear plan of treatment when a patient’s status is in question, to operating when the benefits may not outweigh the risks, or failing to operate when surgery is the correct intervention.

- **Normative error** includes the failure to properly fulfill role obligations. These are errors of responsibility and/or social obligation that affect the patient indirectly but significantly. Examples may include failure to inform superiors of changing conditions and failure to maintain professional working conditions with other staff.

While these descriptions do not overtly refer to other members of the surgical team, we believe technical, judgment, and normative errors can be generally applied as defined to all staff on the OR team and are important considerations in the determination of conditions and influences on performance. Each shows how both team make-up and environment can influence performance.

3. **DRIFT AND ITS RELATIONSHIP TO MEDICAL ERRORS**

Drift is a term used to describe a systematic propagation towards error-supporting conditions. Originally developed to explain aviation accidents, Dekker defines drift into failure as the “slow, incremental movement of systems operations towards the edge of their safety envelope” [Dekker 2005]. Drift occurs as small deviations from accepted practice, which may be seen as compromises or negligible decrements from accepted norms in response to current environmental conditions. However, as decrements build upon one another, what was once a slight modification to a widely accepted way of doing things becomes a huge deviation from stated safety practices. Dekker [2011a] makes clear that this tendency to “drift into failure” is just as much a consequence of an ability to adapt successfully to an ever-changing set of conditions with the refinement and fine-tuning implicit in the continued evolution of a system of practice. Therefore, drift is difficult to trace, to pinpoint, and to correct before an error occurs – and sometimes even after the error has occurred.

Cushieri [2005], in the context of surgical endoscopy, has also developed a taxonomy of errors, one specific to the operating room. His findings in many ways reflects Bosk’s observations and adds to them: cognitive errors of judgment, procedural and execution errors, misinterpretation and misuse of technology errors, and errors in recognizing iatrogenic injury and complications. His research also reports on distal errors committed by surgeons, such as diagnostic and management errors, situation awareness errors, and prophylaxis errors. The term ‘distal’ can be compared to ‘latent’ in Reason’s Swiss cheese model of system accidents [Reason, 2000]. Like Reason, Cushieri distinguishes between errors that are committed by persons in direct contact with the patient and have immediate impact (active errors), and those which occur at a higher level of design and/or management (latent errors) and rather set the conditions for active errors to occur. Many of his findings describe active errors; however, it is also important to consider the environment in which active errors occur, i.e., the latent errors that set the conditions for that environment.

Latent error examples include understaffing, inexperience or inadequate training, and faulty equipment. These also map to Jeffs and colleagues’ Theme 1 of near misses as a metaphor of system vulnerabilities [Jeffs et al. 2008] wherein contributors to over-workload are described by healthcare professionals. In such cases, medical personnel are forced to adapt and otherwise compensate for suboptimal conditions. These compensations can start individuals and teams on a path towards unsafe practice or unacceptable performance.

While there is no doubt that errors occur, we agree with Rasmussen [1997] that simply stating “root causes” is not enough to communicate the significance of errors both to practitioners and to the layperson. As Rasmussen suggested, a bottom up approach cannot adequately capture the conditions of a dynamic system, as the whole is greater than the sum of its parts. Likewise, the hospital OR is an entity separate from the surgical team, the patient, and the equipment; the hospital OR is an environment inside which human lives are affected. Therefore, this effort follows an approach of “functional abstraction” in the tradition of Rasmussen’s Dynamic Safety Model, first introduced in 1997 and reproduced and modified in follow-on research in the years since.

3.1 **The Dynamic Safety Model and its application to patient safety**
Rasmussen's Dynamic Safety Model (Figure 1) describes a dynamic system inside a performance envelope, wherein a boundary of acceptable performance and parallel error margin mark the point at which errors in performance may occur [Rasmussen 1997]. The model shows economic considerations and workload pressures acting on the system, which can persuade the system away from safe performance closer to the margin of error. Succumbing to one or both of these pressures can result in crossing over the boundary of acceptable performance. This original version of the dynamic safety model was a result of years of research and analysis into large scale accidents and protocols in hazardous industrial process plants.

Figure 1. The Dynamic Safety Model [Rasmussen 1997].

Cook and Rasmussen [2005] later built upon this model and applied it to the domain of patient safety at the hospital level, wherein they cite the phenomenon of “going solid.” Going solid is a state of tight coupling or “extreme efficiency” wherein activities at one node are critically dependent on the input and output of other nodes. For example, a critically injured man cannot be treated until a bed in the trauma bay is free, which depends on another patient moving to ICU, which is dependent on the availability of a room with equipment critical to that patient’s survival, and so on. Going solid occurs as a result of increased workload and economic pressures and can be a cause of threatened patient safety as practitioner compensations edge them closer and closer to the boundaries of the performance envelope [Pedroja 2008].

In the 2005 report, the researchers describe the visual representation of the operating point, or the system of interest, in the envelope (see Figure 2). Stable, high-risk systems are illustrated by a smaller point area and small incremental movement near the margin of error, while stable, low-risk systems are shown with small point area and small incremental movement far from the margin of error. Further, an unstable high-risk system is described by a large operating point area and large incremental movement near the margin of error. The boundaries of acceptable performance and of error are dynamic in and of themselves, as a cyclical result of drift and new norms, errors, and safety measures.

Figure 2. The Dynamic Safety Model [Cook and Rasmussen 2005].

Miller and Xiao [2007] also explore the application of the Dynamic Safety model to hospital services in the context of a surgical unit, focusing on how hospital staff adapt to high demand pressures. This effort takes into account multiple levels of management, utilizing interviews with the surgical unit medical director, schedulers, and charge nurses. Representative themes for each participant type were identified in relation to model boundaries: patient demand or volume for the medical director, workload for the schedulers, and maintaining safe practices for charge nurses. Efficiency pressures did not emerge as a primary theme for any group. This study highlights the differentiation in performance envelope conditions based on role and also calls attention to the need for buffers at each level in order to increase organizational resilience.

In 2010, Lamb and colleagues investigated the concept of drift with regard to maritime mishaps, asserting that the label of human error is not sufficient to explain human performance failures in this environment [Lamb et al. 2010]. Their analysis resulted in an adaptation of the Dynamic Safety Model to submarine tactical operations at sea (Figure 3). This approach allowed them to suggest two ways of
mitigating error based on the structure of the model, either by tightening the operating point, or by enlarging the safety envelope or making the boundaries less constraining. A noteworthy aspect of this adaptation is that Lamb and colleagues modified the Economic Failure boundary of the original model to Mission Failure, highlighting that critical component of influence on this particular system.

Figure 3. Adaptation of the Dynamic Safety Model to submarine tactical operations at sea [Lamb et al. 2010].

3.2 The Dynamic Safety Model and the Hospital OR

In 2008, it was estimated that there are 234 million operations performed annually worldwide [Weiser et al. 2008]. In addition, according to large scale analyses of medical errors in the US [Thomas et al. 1999] and in Australia [Wilson et al. 1995], the percentage of all medical errors that occur in the operating room is between 40 and 50%, with at least half deemed preventable in nature. These statistics, along with the IOM report and a natural heightened sense of anxiety surrounding the event of an operation, suggest an in-depth look at system dynamics in the context of the hospital OR. Previous work identified several important foci towards this end, including OR team experience, patient physiological limits, and workload limits, which comprise the boundaries of safe performance as illustrated in Figure 4 [Severinghaus and Combs 2011].

Figure 4. The Dynamic Safety Model applied to the hospital OR [Severinghaus and Combs 2011].

The extent to which a team can stay within these boundaries determines how much drift the environment (OR) and its team can tolerate without failure, while the size of the envelope is a function of how constraining each of the three boundaries is at the time. The workload failure boundary represents factors such as fatigue, competing tasks, and distractions. The ‘functional capability’ of the OR team operating point is illustrated by the size and positioning of the circle within the envelope. Similar to Cook and Rasmussen, the smaller the circle, the less performance is expected to vary, and the circle’s distance from boundaries is a qualitative indicator of an existing/current buffer, or margin, to the limits.

This model shows how unique the OR system is in comparison to past development and applications of the Dynamic Safety Model, especially when the focus is on the OR team itself, the so-called pointy-end of patient care, rather than on the larger hospital establishment. This initial work suggested that the development of an OR team specific performance model would contribute significantly to initiatives focused on reducing errors in the OR and in improving patient outcomes.

4. DYNAMIC OR SAFETY MODEL

In the following paragraphs, we describe a refinement of this model illustrating a continued research effort towards the characterization of safe practice in the hospital OR. The model of the dynamic OR team system must characterize the performance envelop of the system on a more granular level than previous examples; these aspects are system-dependent. This results in the re-identification of appropriate and applicable boundaries that exert an influence on the system’s performance. Figure 5 is an illustration of the updated dynamic safety model for the
hospital OR, termed Dynamic Operating Room Safety Model, or DORS model.

Figure 5. Dynamic Operating Room Safety (DORS) Model.

DORS reflects the dynamics of previous Dynamic Safety Models and is a description of OR team dynamics at the so-called “pointy end” and errors that are classified as active [Reason 1990]. An operating point, the system at work, resides within a performance envelope, which is defined by boundary conditions. The boundaries reflect environment-specific pressures that both represent undesirable conditions if crossed and exert pressure on the position of the operating point. The dashed line represents the concept of a buffer zone, between the operating point and a boundary. Such buffer zones exist for each of the boundaries of Unacceptable Performance, Workload, and Patient Limit. Each of the model’s boundaries can be breached, illustrating undesired yet not necessarily erroneous performance. In the case of a team operating in the space between a dashed line and a boundary, performance may not necessarily result in an adverse event; near misses are also likely to occur in these regions.

As with previous applications of the Dynamic Safety model, Unacceptable Performance is recognized as highly likely to result in an adverse event. At the same time, it must be recognized that, on occasion, a boundary may be crossed intentionally in execution of necessary and appropriate patient care (e.g., on occurrence of an unexpected emergency during surgery due to unrecognized patient condition). Safety measures can exert pressure on the operating point away from this boundary [Cook and Rasmussen 2005], acting to keep performance within the envelope. Examples in the medical field include pre-op briefs or time-outs [Hurlbert and Garrett 2009], checklists [Haynes et al. 2009], and Team STEPPS communication and teamwork training [Agency for Research Healthcare and Quality 2012].

Workload is a multifaceted boundary which represents the challenges of schedule, efficient and effective information organization, shift change mentalities, comfort zone, and fatigue. Each of these items can increase workload upon a team member and, as a consequence, on the team as a whole. For example, for a replacement nurse unused to the rest of the OR team and to the current procedure, each step taken requires more thought and more attention than it might if she was more comfortable with the conditions. This increases her cognitive workload and occupies attentional resources which might otherwise be applied to prevent her actions from moving the system closer to the boundary. Overloaded work schedules are another example of workload pressures that can lead to error [Leape 1997]. Exceeding the workload boundary indicates that an OR team is unable to perform in the face of attentional and physical demands that are too great.

The boundary of Patient Limits represents the life of the patient, which must be maintained and protected by the OR team. Within the model, this is a boundary uniquely unique to healthcare, where a single action can be fatal or injurious. Even in the best situations, the OR Team must act to keep the patient alive, e.g., monitoring vitals, administering and maintaining the correct concentration of anesthesia drugs, watching for uncontrolled bleeding, etc. As the purpose of the OR team is both to perform a surgical procedure (to better the life of the patient) and to maintain the patient’s life during procedure execution and patient recovery, the physiological requirements of life are always present influence on OR team performance. Exceeding this boundary is an indication of death or impending death; the patient’s physiological limits have been exceeded, whatever the cause.
The DORS operating point represents the OR team; it varies in size and movement depending on a combination of team proficiency and culture. An OR team’s objective is to have as small a circle diameter as possible, and to have the circle located as far as possible from all three boundaries. The greater the team proficiency, the smaller the operating point will be. Team proficiency applies to the current procedure/procedure(s) in use, and includes the knowledge, skills, and abilities (KSA’s) of each team member with respect to his or her specific job and role, and how those KSA’s are applied in working with other team members. Team culture includes items such as how well team members communicate, the level of respect members have for one another, and their ability to work well together. Team culture also speaks directly to non-technical skill level, which research has shown figures greatly into surgical performance and error rates [Yule et al. 2006; Mishra et al. 2008] and is related to normative error referenced above. It also encompasses the term complacency as well, defined as a feeling of meaninglessness in clinical practice resulting in lack of attention, carelessness, and lack of adherence to standards of care [Jeffs et al. 2008]. This form of complacency occurs when there is a disconnect: instances in which a procedure is so routine that practitioners merely “go through the motions,” without giving the procedure enough attention. Such situations can lead to cognitive fixation in which the team misses an out-of-context occurrence or ignores it, clinging to an internal assumption that nothing can go wrong [Dekker 2011b]. Such influence can also push the operating point closer to the Patient Limit or the boundary of unacceptable performance. How these factors interact with one another as well as with the environment of the performance envelope can affect the size of each movement increment.

5. FUTURE RESEARCH: MAKING BOUNDARIES VISIBLE AND COPING STRATEGIES

Past efforts toward making boundaries visible are both old and new, and in many ways boil down to efforts to help the OR team maintain and improve team performance. Examples include the patient monitor that continuously displays a patient’s vital signs, as well as time-outs and surgical checklists. Miller and Xiao [2007] describe ways to utilize technology for promoting awareness, such as by using displays to represent marginal boundary indicators, such as capacity buffers, and the types of information to be displayed. Other technological design goals included time-scale artifacts specific to each level of management, support to the varying modes of social interaction, and role-based support. Again, this study shows the importance of system context to a team’s response to conditions and pressures.

Unlike hazardous industrial process plants, where error management exercises are conducted on a predictive basis, medical errors are more often evaluated after the fact. There is an effort in progress to adapt an industry methodology for ensuring optimal performance, Human Reliability Assessment (HRA), to the clinical environment. Cuschieri [2000] described HRA and the required modifications to make it applicable to clinical practice. This approach, Observational Clinical HRA (OCHRRA), has had some success [Cuschieri 2005] in identifying “hazard zones” for specific operations; however, it is research intensive and not practical for repeated, real-world use. As a result, a Surgical Error Reduction System (SERS) is being developed as a subject matter expert-driven means of evaluation and prescription for specific surgical procedures. Future work will show whether this initiative is a valid prospective approach for reducing error in the operating room.

Once aware of boundary existence and proximity, practitioners need to become proficient in coping strategies should the team ever approach any of the three boundaries, such as instances when crossing the margin of error does not (yet) result in life-threatening circumstances – how does the OR team cope in these instances? This is where a targeted effort toward the reporting, gathering, and analysis of near misses can be helpful. In cases where an error was made or the team had the foresight to see an error in process, a near miss is when these conditions were recognized and reversed before an adverse event occurs. Because these instances are not classified as failures, they often go unnoticed and the opportunity to learn from them is lost. Next steps in this effort include identification and evaluation of near miss records towards this end, in addition to suggesting enhancements to existing reporting systems to capture these occurrences.

6. CONCLUSION

We have presented a novel adaption of Rasmussen’s Dynamic Safety System to a “pointy end” of the hospital system – the Operating Room – and labeled it the DORS Model. This research has resulted in a refinement of previous work highlighting conditions and pressures on individuals and teams in a surgical environment, and how those pressures and conditions can affect team performance in ways that
lead to reductions in margins to errors and increased risk to surgical patients during OR procedures. The DORS Model is offered as an informative, detailed OR team performance model that is well suited to serve as a foundation to guide future research towards improving both patient safety and outcomes in a surgical environment. In line with Rasmussen's suggestions for evaluation of risk management modeling, critical next steps for this domain of research include research to further identify the factors (behavioral, technical and procedural) impacting each of the three boundaries, and research exploring behavioral and team interaction dynamics impacting, in terms of the DORS model, the size and location of the Operating Point illustrated in Figure 5. The objectives of these research thrusts should include finding ways to make visible team approaches to DORS boundaries in real time, and include research to identify and provide coping strategies to minimize drift towards failure. Research into team performance, conditions, and environments incident to near-misses as defined in this paper offers one approach for making progress towards achieving these suggested research activities.

References


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