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QA FOR RT SUPPLEMENT

TOOLS FOR DEVELOPING A QUALITY MANAGEMENT PROGRAM: HUMAN FACTORS AND SYSTEMS ENGINEERING TOOLS

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During the past 10 years, there has been growing acceptance and encouragement of partnerships between medical teams and engineers. Using human factors and systems engineering descriptions of process flows and operational sequences, the author's research laboratory has helped highlight opportunities for reducing adverse events and improving performance in health care and other high-consequence environments. This research emphasized studying human behavior that enhances system performance and a range of factors affecting adverse events, rather than a sole emphasis on human error causation. Developing a balanced evaluation requires novel approaches to causal analyses of adverse events and, more importantly, methods of recovery from adverse conditions. Recent work by the author's laboratory in collaboration with the Regenstrief Center for Healthcare Engineering has started to address possible improvements in taxonomies describing health care tasks. One major finding includes enhanced understanding of events and how event dynamics influence provider tasks and constraints. Another element of this research examines team coordination tasks that strongly affect patient care and quality management, but may be undervalued as "indirect patient care" activities. © 2008 Elsevier Inc.

Human factors, Process flow, Root-cause analysis, Systems engineering, Task analysis.

INTRODUCTION

The recent formation of the Regenstrief Center for Healthcare Engineering (RCHE) at Purdue University, West Lafayette, IN, represents a significant change in perspective for research into improving the quality of health care delivery. In several ways, RCHE represents the achievement of several goals highlighted by the National Research Council report, jointly sponsored by the National Academy of Engineering and the Institute of Medicine (1). The health care quality improvement goals emphasize the increased use of human factors engineering and systems engineering principles in addressing the prevalence of adverse events and misadministrations in health care settings. Applying human factors principles to medical systems continues a growing trend that started in the early 1990s to reduce the prevalence of human performance–related errors and adverse outcomes in medicine (2).

Human factors and systems engineering descriptions of health care delivery systems

The author's research applied human factors and systems engineering tools to study human performance, information flow, knowledge sharing, and organizational factors in several health care delivery settings. The first of these projects examined the need for documenting cycles of design, evaluation, and improvement in medical processes, such as timely laboratory testing and results response for physician requests (3, 4). One unexpected finding, which we have since reproduced in other clinic, hospital, and ancillary service units, was that many health care providers had an incomplete and often disconnected view of the processes of information flow throughout the health care delivery chain. Without clear comprehension of the origins, destinations, and processes affecting electronic and physical information flows, it was difficult for providers to effectively understand the delays and constraints affecting task coordination and shared knowledge supporting effective care delivery.

In both quality improvement projects and emerging efforts to develop adverse-event reporting tools and processes for medical systems, the author's research team noted that the systems engineering model of information and resource flows, common to many engineering practitioners, was difficult to communicate to practitioners in other domains (including medicine). When medical staffs at various levels

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were able to see a graphical representation of how their request traveled through the hospital's processes, it became much easier to recognize bottlenecks and constraints or even suggest improvements to computer-based forms or other human–machine interfaces. The requirement for a clear and easily communicated shared model of health care delivery process flows is even more significant because of several factors:

(*1*) Health care delivery is a highly cooperative coordination process, although health care literature does not widely address coordination demands.
(*2*) Modern adverse-event and root-cause analysis tools emphasize process flows and expected actions based on information and resources available to providers.
(*3*) Integrated improvements that improve operations across units and facilities, rather than piecewise information systems or user interface ''solutions,'' require enhanced analysis of how, when, and where information and resources are used in a time-critical task environment.

These issues have been of greater interest to Scandinavian researchers since the late 1990s, including a specific interest in coordination processes in radiology departments (5). The demands for appropriate coordination of information, tasks, and artifacts have particular importance in conducting root-cause and quality management analyses, as described next.

Human error and adverse-event perspectives

The author participated in a project to design an improved adverse-event and risk-mitigation tool in partnership with a transfusion medicine practice (6) (which led directly to the author's collaborations to address brachytherapy adverse events). Initial development of an adverse-event reporting system and quality assurance (QA) intervention strategy was influenced significantly by several theories of human error causal factors at individual, technological, and organizational levels of analysis. Consideration of multiple causes at different operational levels contributing to error in complex systems (7) helps address the ''blame and train'' perspective of focusing adverse-event recovery efforts solely on determining which operator is at fault. Each of several error models was coupled with its associated causal analysis tool, which needed to be adapted and integrated for medical environments. (Radiotherapy dosage errors were considered a unique application of error and adverse-event analysis because of the nuclear agency reporting requirements. Other domains had a much less structured or available error-reporting process.)

Root-cause and error analysis is influenced significantly by the nature of the error models themselves (distinguishing between classification, causal, and shaping factors models) (8). In addition, different models change the order of presentation of specific questions that address distinct causal factors. Our attempt to integrate these analysis models uncovered a challenge: each distinct model could be represented by a flow chart, with a series of decision gates attempting to identify a particular causal factor. Our analogy was that of a pinball game, in which the decision flow chart sequence was the path traveled by the pinball. When a causal factor was identified (''yes'' was the answer for a particular contributing factor), the model terminates—the pinball goes down the hole. However, adverse events in complex systems often occur because of a combination of causal contributing factors, some of which must happen together or in close proximity (in time or space) to allow errors to occur and propagate into adverse events (9). Additional causal understanding is gained by looking at patterns of adverse events, in which the clustering of events spatially or temporally helps identify a pattern of likely contributors.

Fortunately, each combination of causal errors was seen only rarely; however, this can mask underlying common factors influencing patterns of errors. For example, a specific multisite problem with length variations in remote afterloading brachytherapy seeds could have been masked by differences in patient wait times (leading to different causal attributions of patient movement), combinations of overdose and underdose errors, and differences in calibration offsets by different operators (suggesting different attributions of operator or software contributions). Attempts to repair any one of these adverse situations at any one site would prevent a broader understanding of a manufacturer's quality control error.

The adverse-event reporting system and QA process we helped develop emphasized this process of identifying as many causal contributors as possible and then looking at patterns of causation across events. Compared with the pinball process of other analysis tools, this process resembles a pachinko game, in which many balls are allowed to travel simultaneously and the game score is based on results from the entire set of balls. This approach clearly grows in value as the volume of events grows and when near-misses or error recoveries are captured, as well as actual adverse events. Several features distinguishing ''pinball'' and ''pachinko'' models of QA process are listed in Table 1.

Provider activities and team coordination

The development in 2003 of the RCHE shows a new approach to improving quality management and the use of systems engineering tools in health care delivery practice. A particular emphasis involves combinations of logistics, production systems, and human factors engineering approaches to improve task coordination and effectiveness in health care teams. One ongoing project involving observations of providers (physicians, nurses, and assistants) in clinic operations has supported the concept of resource ''foraging,'' in which providers must gather information and physical resources relevant to a patient to deliver timely quality care (10). Because many providers are managing multiple tasks simultaneously and because of the emerging nature of some delivery scenarios (such as emergencies or unexpected needs for expert consultations), the demands for obtaining resources become strongly tied to the dynamics of events in the health care setting (11). Quality improvement in this setting is no longer an example of individual task optimization of linear sequential activities, but a new focus on multidisciplinary

Table 1. Distinctions between pinball and pachinko models of QA/QM causal analysis

QA/QM issue	Pinball model	Pachinko model
No. of identified causes	Usually only 1	Multiple causes, based on thoroughness of QA
Assumed causal process	Usually 1 type, depending on model	Multiple contributing factors
Impact of order of investigation	Order of flow chart factors is critical in determining cause	Order of factors is not relevant; all contributing factors highlighted
Effect of aggregating multiple event analyses	Different error models create different causal factors, causing incompatible causal contributions	Multiple causes can be integrated over time or task type
Relationship to process flow map	Focus on 1 task/process flow element and piecewise improvement	Greater statistical and integrated examination of process flows and structures

Abbreviations: QA = quality assurance; QM = quality management.

provider teams interleaving multiple tasks within time constraints (such as radiotherapy teams conducting real-time treatment modifications).

Substantial differences exist among clinic settings for how roles and task assignments are distributed to support team-based coordination and resource foraging. These differences also lead to differences in the likelihood of resource coordination breakdowns or failures of effective information flow that could contribute to adverse events. The outcome of a particular care scenario (such as a misadministration or unnecessary duplication of a radiology test) may be the last in a sequence of activities in which providers may have had insufficient, missing, or conflicting information and resources (12). Based on clinic role definitions, resource gathering or sharing tasks might be distributed flexibly because of momentary differences in task load between providers or according to fixed role assignments. These differences in both structure and dynamic function of health care delivery coordination create different opportunities for adverse-event pathways (unfamiliarity with task based on fluid task shifting vs. task overload caused by fixed task assignments) that must be identified in each QA process. This is an example of how organizational structures and policies can become a significant and shared contributing factor to adverse-event clusters of different proximal types. (Our previous studies of brachytherapy adverse events identified organizational and communications processes between team members as critical elements affecting the progression of some scenarios to resulting in adverse events.)

ANALYZING HEALTH CARE EVENTS

Comparing provider demands for information and coordination in hospital and clinic environments with the accompanying needs to search for and share resources has raised new questions in our research efforts. Dynamics of task progressions, emerging needs for expertise and information, and changing time constraints for required actions led us to investigate and redefine the meaning of ''event'' in the health care environment. When trying to capture human performance activities, it is important to recognize that the time constraints of a provider's requirements for action (depending on dynamics of procedures or patient trajectories) may be at odds with the time to recognize that action was necessary or to acquire resources not already available (or not storable). Thus, providers often develop strategies to increase resource and task flexibility and robustness to changing situations (13); the value of these strategies may not be evident in the analysis of a single activity. The QA analyses must use an appropriate task-analysis strategy to improve understanding of individual and team tasks. In some previous cases, the health care literature used flawed methods of determining the frequency of provider activities and frequently underestimated the amount of simultaneous or supplemental activity that occurs out of view of the patient.

Our work to improve the definition and analysis of health care events emphasizes that events are not simply discrete and instantaneous activities, but processes that may be partially identified and predicted in advance. Experts are particularly attuned to identifying signals or triggers that anticipate future event states and proactively obtaining resources in advance of those states. This strategy enables the expert to more effectively respond during the event, especially if time constraints prevent reactively obtaining resources when the event is fully underway. In addition, task coordination and expertise will allow providers to delegate or share tasks to more efficiency respond to changing event states and forestall deadlines. In our recent development, an adverse event can be interpreted as a task that fails to be completed before all necessary information and resources are acquired and used. Breakdowns in task coordination or effective anticipation of event states thus can contribute to adverse events because of inadequate time, resources, or opportunities for providers to detect and respond to signal triggers before task degradation is unavoidable.

The tradition of health care (and human error) literature assumes that providers can and should conduct tasks one at a time and as individuals, thus creating cultural barriers to inappropriate interruption based on perceived status or task importance (14). In addition, definitions of appropriate care and improved patient safety stress the reduction of interruptions as a way to reduce the incidence of error. However, health care process research has rarely distinguished ''appropriate'' interruptions (team members alerting each other to necessary task shifts because of changing priorities or emerging conditions) from ''inappropriate'' interruptions (nonwork conversations or injection of lower priority non–time-critical tasks into a high-priority time-critical task).

A second potential difficulty from the literature addresses how team coordination is considered in the range of direct and indirect patient care tasks. If providers meet outside the examination room to look at a computer screen showing a animations of a patient's computed tomography and electrocardiogram results and share insights and perspectives, is that a more effective and robust coordination that should be encouraged as an additional method to reduce adverse events? Should such interactions be deemed ''indirect patient care'' (outside the examination room, not involving direct patient interaction) that can be reduced in the search for more streamlined individual provider tasks? From a QA perspective, there are substantial impacts of these differences in team coordination on quality of care and directions for performance improvement. Our ongoing research continues to address these issues and consider improvements in the taxonomies and descriptions of health care delivery from a human factors and systems engineering perspective.

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