

For Resilient IT: Don't Mimic the Past, Leverage the Future

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Abstract

Healthcare workers and managers require information about changes to workplace vulnerabilities as well as potential ways to change their systems to meet challenges to their work domain. Information technology (IT) is an essential, and particularly versatile, information conduit that must be able to adapt in the face of change. The newly-evolving concept of resilience engineering (RE) seeks to create and maintain systems that can cope and adapt to complex, changing environments such as healthcare and can be used to develop IT systems that are able to adapt as the sharp (operator) end of healthcare requires. Research into actual clinical work will make it possible to create a better match with volatile work domains and to leverage IT system capabilities. We present an infusion device interface concept as an example of resilient healthcare IT.

Introduction

As a service sector, healthcare relies on the timely use of accurate information. Information technology (IT) has been used at the blunt (management) end of organizations to support billing and patient records. More recently, IT has been advocated as a means to improve healthcare efficiency, safety and reliability at the sharp (operator) end. However, sharp end cognitive work is far more complex. IT systems that are intended to support sharp end work must match the same complexity as the work domain they are intended to aid (Ashby 1956). This requires a different approach to IT system development in order to understand the nature of systems and their ability to perform and survive under duress: in other words, to be *resilient*.

The cognitive work that clinicians perform can be considered at the level of both individual patient care, and at the level of technical work (Cook, Woods and Miller 1998)--the planning and management of care among and across individual patients.

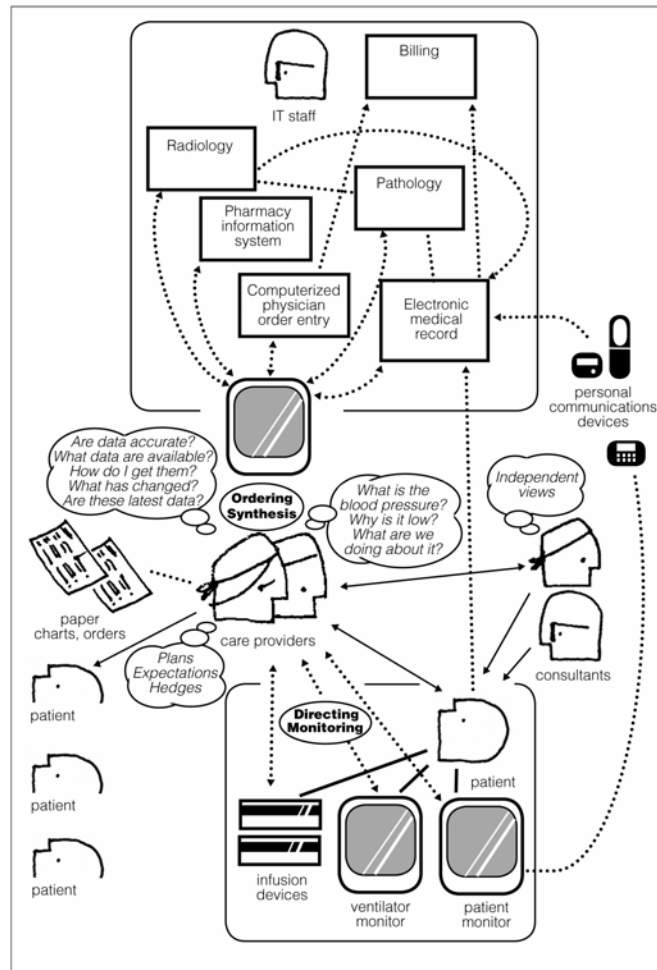
Individual Patient Care. For each acute care patient, multiple diagnostic and therapeutic processes are underway, about to be started, or are being concluded. Each patient's condition can be accounted for by a spectrum of variables that are interrelated, and the interactions among those variables exceed the ability of clinicians to perceive them. Despite uncertain circumstances, the clinician *must* act on behalf of the clinically ill patient. This compels clinicians to pursue diagnostic and therapeutic interventions that are convenient, rather than sequential. The decision to proceed with a certain treatment relies in part on the trade-offs between what is known about certain courses of treatment and their anticipated harms and benefits. The majority of these activities do not occur in what could be described as familiar territory, in which the data are sufficient and the patient's recovery is certain. Instead, patient condition and prognosis often exist in the kind of circumstances in which the available evidence on what to do is weak (Sharpe

and Faden 1998). Some practitioners contend that much of medical practice takes place where there is little proven knowledge and anticipated harms and benefits are equivocal (Nemeth 2005).

Unit Level Planning and Management. The cognitive work that clinicians perform is necessarily contingent, interdependent, performed with information that is often incomplete, and is distributed among many who are responsible for a patient’s care. Multiple individuals care for multiple patients. Clinicians frequently start, stop, and resume care tasks. They also initiate simultaneous parallel diagnostic and therapeutic activity, as they cannot wait for results before deciding the next action. In order to manage such workplace complexity, clinicians in general acute care facilities have developed various protocols such as advance planning calendars and the call schedules (Nemeth, *et al.* 2007)

Current Information Ecology

Care providers currently exist in an information ecology that includes the patient, other clinicians, devices, information systems, and physical artifacts. Figure 1 shows the current state



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Figure 1. Current information ecology for clinicians

of information technology support for clinical healthcare cognition. Care providers care for individual patients using their own observation, consultant views, and patient self-reports. They direct and monitor therapeutic and diagnostic equipment (shown in the figure's lower portion). Such devices have recently been connected to communication networks to "push" significant information to clinicians and related systems via network connections, and telecommunications devices such as cell phones and pagers. They also consult physical cognitive artifacts (Hutchins 2000) such as paper charts, orders, and status boards. They request and synthesize data from a variety of information systems and departments (shown in the figure's upper portion). This focus of attention in multiple directions is replicated across each of the patients who are under the clinician's care. Each patient has unique needs and care trajectories that must be planned and coordinated. Whether and when diagnostic and therapeutic resources are available are part of the technical work considerations that influence who gets what care and how they receive it.

Each of the elements in Figure 1 is used collectively for the benefit of each patient. However, they have been developed, and are operated, separately. For example, even though the infusion devices, ventilator monitor and patient monitor are connected to one patient, none are connected to each other. Each of the information systems are managed as separate entities by IT staff who have little or no connection with the clinical setting. This imposes a burden on clinicians to integrate data that each of these elements present. It also passes up the opportunity to take advantage of capabilities that are inherent in IT systems, such as supporting "what if?" speculations and modeling the implications of trade-off decisions. Further, even though care demands change, the IT systems do not. This distance between the clinical care domain and IT systems produces *brittle* (Sarter, *et al.* 1997) performance that requires clinicians to create a "work-around" to bridge each gap between what systems should, but cannot, do.

Service-Oriented Architectures

Service-oriented architectures are intended to provide web-based services that are tailored to the needs of service users through flexible, standardized modules that connect applications and data (Papazoglou 2003). SOA can be a way of thinking about building software, both an architecture and a programming model (Channabasavaiah *et al.* 2004). The multi-platform information ecology in Figure 1 suggests that SOA could play a role in healthcare IT support. At the moment, SOAs are developed from the viewpoint of IT systems (see Agrawal *et al.* 2002; Haller, *et al.* 2005). The technical perspective that is used to develop SOAs relies on a static context in order to optimize the use of software modules. This is difficult to reconcile with a business perspective that is fluid (Perrey and Lycett 2003). The problem becomes more pronounced in complex, dynamic work settings that are poorly bounded, such as healthcare.

If SOAs work, we should get well-tailored systems that serve users—but we do not. Why is that? It is not due to a lack of interest, but a lack of insight. Experience shows that user-guided development is a failure. Expert operators are neither good objective sources of information on their own work, nor do they have the skills to study what is necessary to develop well-articulated requirements for IT support. For example, clinical practitioners are poor judges of their own diagnostic reasoning (McNutt, Abrams and Hasler 2005) and have difficulty with objective descriptions and analysis of this crucial cognitive task. Instead, insight into actual work processes that are performed in the real world comes from researchers who study human performance (see Nemeth, Cook, and Woods 2004; Nemeth 2007).

Engineering for Resilience

The way that information is presented directly affects clinicians' ability to develop an effective mental representation of past, current and prospective states of the patients who are under their care. Even under the best circumstances, there is an irreducible uncertainty that dogs clinicians' ability to fully grasp the phenomena for which they are accountable. Recent increases in coordination demands due to staff resource limits impose an even greater need for the reliable exchange and use of information. For these reasons, the success of IT systems at the sharp (operator) end of healthcare depends on adaptability in the face of change.

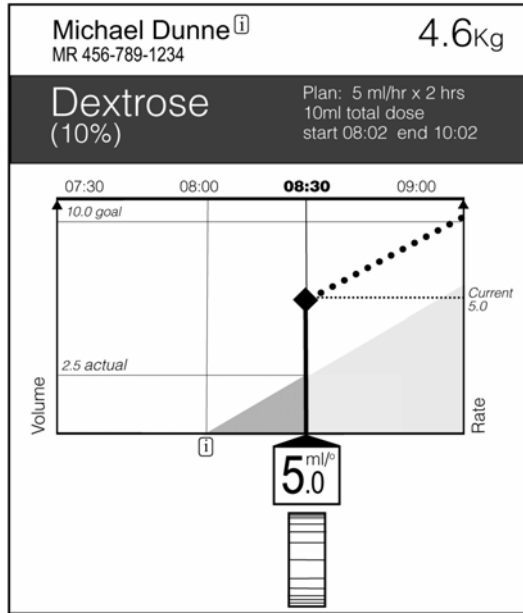
Resilience is the newly-evolving notion of creating systems that can survive and return to normal operation despite significant challenges. Examples of resilient performance span a range of high hazard settings, from aviation (deMata, *et al.* 2006; Sheridan 2006) municipal disaster response (Mendonça and Wallace 2006), nuclear power generation (de Carvalho *et al.* 2006), and emergency healthcare (Wears, Perry and McFauls 2006). Resilience engineering (Hollnagel, Woods and Leveson 2006) stems primarily from the complexity study Carlson and Doyle 2002) and seeks to create and maintain systems that can cope and adapt to complex, changing environments such as clinical healthcare.

In the context of research, design and development, the role of design has the responsibility to link the adaptive power of people as goal-directed agents to technological capability (Alexander 1997). People actively manage the dynamic characteristics of their work place by drawing on a deep knowledge of their work domain to create and use artifacts (Blumer 1986). Workers create cognitive artifacts (Hutchins 2002) in physical (order forms, checklists, schedules) and digital (equipment control and display interfaces, information) form to aid their cognitive work. Prior work has shown how these artifacts can be used to understand (Xiao *et al.* 2001) and derive design guidance for IT systems to support such work settings, because the artifacts embody only the essential elements of a work domain (Nemeth 2003).

How can IT systems be created so that they adapt to the fluid, variable clinical healthcare work setting? IT systems are traditionally designed on the basis of system capability. Developers build out from a database toward the end user by adding an information system, or a browser. Work settings that are as complex and variable as clinical healthcare need an approach that starts with the user, then articulates needs that the IT system are to fulfill.

Example of Resilient IT: Infusion Device Interface

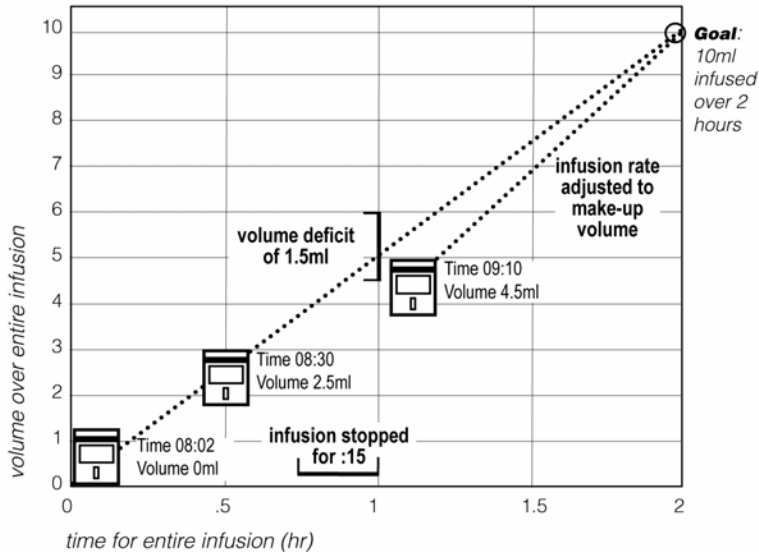
The following example demonstrates how IT can develop a more resilient healthcare system at the sharp end. Most infusions in U.S. hospitals are now provided by such devices (Hunt-Smith, *et al.* 1999), making it the most widely used information technology in the acute care environment. Differences between infusion device programming and the ways that clinicians compute doses, and the need to program using a limited "keyhole" interface, make commercially available infusion devices problematic (Nunnally, *et al.* 2004). In fact, microprocessor-based infusion devices are associated with significant clinical accidents that can result in patient morbidity and mortality. Making infusion pumps more compatible with clinical work requires a new approach to data representation that *aids* the work of clinicians who perform infusions. An improved design needs to make its operation evident, demonstrate implications for the future, and make it possible for clinicians to make informed decisions in light of this information. Figure 2 depicts an infusion device interface concept that reflects aspects of current clinician infusion



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Figure 2: Infusion device display concept supporting resilience

practices. The design is organized into mechanical information (the diagram at center), mechanical control (at bottom), and context information (around the diagram). The display shows volume/time (rate) parameters, current and past system status, and the expected course if current parameters are maintained. The control position remains fixed, while the data “scroll” from left to right of the diagram as time passes. Figure 3 shows the data space for a hypothetical infusion

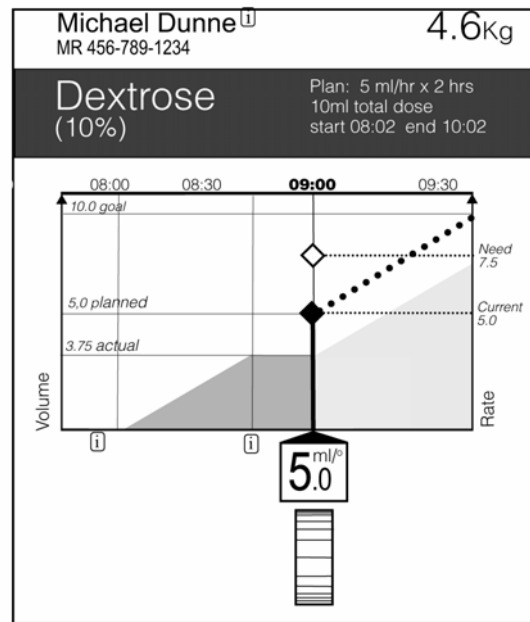


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Figure 3: Overview of hypothetical 2-hour infusion

of 10% Dextrose that would be delivered to a 4.6kg infant over 2 hours. Figure 2 shows how the interface would look 30 minutes into a dextrose infusion for a pediatric patient that was started at 08:02 and is programmed to end at 10:02.

Certain procedures can require that infusions be paused, then resumed. Pausing the infusion for 15 minutes (such as Figure 3 shows) would result in a 1.5ml deficit (indicated in the diagram of Figure 4) that would need to be made up by adjusting the rate. A “thumb wheel” control at



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Figure 4: Display one hour into infusion

lower center makes it possible to control the rate of infusion. Moving that control up or down, like a wheel, would adjust the rate (indicated by the dotted diagonal line) to various settings. Values for each variable such as the actual setting that are displayed at the edges of the diagram would change to indicate the implications of various rate changes. This would make it possible for a clinician to examine different rate settings and to choose which one best fits the patient’s needs. It also shows what would happen in the future if a rate is chosen. After examining the various options and making a choice, the clinician can select it and the pump would then change the rate.

Both the mechanical and context information change through time and the display would reflect those changes. The diagram shows fluid volume already delivered, and fluid volume to be delivered at the rate that is selected. As a predictive display, the design makes it possible to immediately recognize the kinds of dose limit errors that now plague current infusion displays that are programmed using only numbers. Additional information (indicated by “i” symbols) can be opened. For example, both items at lower edge of the diagram could be opened to obtain more information on programming that was done at 08:00 and 08:45.

Rather than a narrow “keyhole” display showing only current system state, the display concept provides context and indicates implications for the future. The state of the device and the state of the world in which the device is operating are inter-related. This makes it possible for the clinician to make informed decisions regarding device performance in the context of patient care.

These are the kinds of observable and controllable traits that would improve IT support for healthcare system resilience.

Further research work on this approach would document various mental models that clinicians use while programming infusion devices, develop interactive simulations to dynamically model this and other interface concepts, ask clinicians to perform programming tasks using the simulations, and collect quantitative performance as well as qualitative preference data. These data would make it possible to compare the new approach with current device interfaces and to refine further research activity.

Summary

IT systems have the potential to move from making healthcare more *brittle* to adding to its *resilience*. Rather than mimicking previous “survival forms” of information display, IT system capabilities can be leveraged to create tools that create truly are useful to clinicians. Their potential can be realized through well-grounded understanding of clinical work developed through rigorous research into actual work as it is performed (Nemeth, *et al.* 2004; Nemeth 2007) and a design process that is human-centered (Billings 1991), rather than technology-centered.

Acknowledgement

Dr. Nemeth’s research is made possible by grants from the Agency for Healthcare Research and Quality, and the U.S. Food and Drug Administration Center for Device and Radiological Health.

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Biography

Christopher Nemeth, PhD, CHFP studies human performance in complex high hazard environments as a Research Associate (Assistant Professor) at The University of Chicago’s Cognitive Technologies Laboratory. Recent research interests include technical work in complex high stakes settings, research methods in individual and distributed cognition, and understanding how information technology erodes or enhances system resilience. His design and human factors consulting practice and his corporate career have encompassed a variety of application areas, including health care, transportation and manufacturing. His book on human factors research methods, *Human Factors Methods for Design*, is now available from Taylor and Francis/CRC Press.

Mark Nunnally, MD is a physician, educator and researcher at the University of Chicago. As a clinician, Dr. Nunnally performs surgical procedure anesthesia in the operating room. He also performs critical care medicine as an attending intensivist in the Surgical, Cardiothoracic and Burn Intensive Care Units (ICUs). Dr. Nunnally’s research interests concern the role of technology in patient safety. His work explores a *technology fallacy*: that technology, instead of consistently improving patient safety, often contributes to failure in novel, unexpected ways. His work to date has focused on infusion devices, delivery systems and incident reporting.

Michael O’Connor, MD is a physician, educator and researcher at the University of Chicago. His clinical work is a combination of critical care medicine, and operating room anesthesia, where his activity has been centered on anesthesia for liver transplantation. His educational activity is centered around his clinical activity. His clinical research has included new drug development, clinical research in critical care (bedside assessment of autoPEEP, use of propofol as a sedative, management of sedation in critically ill patients), and now patient safety. He has lectured about the social science of accidents in a variety of settings.

Richard Cook, MD is a physician, educator, and researcher at the University of Chicago. His current research interests include the study of human error, the role of technology in human expert performance, and patient safety. Dr. Cook is internationally recognized as a leading expert on medical accidents, complex system failures, and human performance at the sharp end of these systems. Dr. Cook's most often cited publications are “Gaps in the continuity of patient care and progress in patient safety”, "Operating at the Sharp End: The complexity of human error", “Adapting to New Technology in the Operating Room”, and the report “*A Tale of Two Stories: Contrasting Views of Patient Safety*.”