

Healthcare IT as a Source of Resilience

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Abstract—Healthcare information technology (IT) systems can be used to inform workers and managers about changes to workplace vulnerabilities and new means that may be available to meet challenges such as widely varying demand. IT system success, though, depends on adaptability in the face of change, which is a property that IT systems do not currently demonstrate. Resilience engineering seeks to create and maintain systems that can cope and adapt to complex, changing environments and can be used to develop IT systems that are capable of adaptation as the sharp (operator) end of healthcare requires. Research into resilience needs to address questions that have genuine import for healthcare and IT systems that are intended to support it.

I. INTRODUCTION

System performance in healthcare pivots on the ability to match demand for care with the resources to provide it. Care demand varies widely in amount, timing, and type. Patient condition and diagnoses, as well as their treatment, are highly specific to each individual. Reserves of resources such as sophisticated equipment and clinicians are limited by practical considerations such as qualifications and cost. Some organizations (e.g., cardiac surgical hospitals) limit variability in care demand by performing a reduced set of procedures. However, the general population of patients requires an acute care system that stands ready to serve their needs.

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, recent reports of unexpected results indicate that IT alone cannot solve such issues. IT systems that are intended to support such work must match the same complexity as the work domain it is intended to aid [1]. A broader approach is called for to understand the nature of systems and their ability to perform and survive under duress: in other words, to be *resilient*.

II. CLINICAL COGNITIVE WORK

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Healthcare relies on the accurate, timely description of process and condition. The cognitive work that clinicians undertake is necessarily contingent, interdependent, distributed among many who are responsible for a patient's care, and performed with information that is often incomplete. Multiple individuals care for multiple patients and frequently start, stop and resume among care tasks. In order to manage such workplace complexity, clinicians in acute care facilities have developed various protocols such as advance planning calendars and the call schedules [2].

For each acute care patient, multiple diagnostic and therapeutic processes are underway, about to be started, or 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 the clinician to pursue diagnostic and therapeutic interventions that may be performed in parallel rather than sequentially. 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 [3]. Some practitioners contend that much of medical practice takes place where there is little proven knowledge and anticipated harms/benefits are equivocal [4].

The presentation of information 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 place even greater need for the reliable exchange of information in instances such as between-shift hand-offs.

III. IT SUPPORT FOR CLINICAL WORK

IT systems were used through the 1990's to shift workload to portions of the organization that had available productive capacity. This had the simultaneous effect of also shifting risks, as well as consequences, elsewhere in the organization. [5] Such shifting produced new interactions among individuals and groups. The number of possible interactions became unknowable, and no real tools were provided to manage the results of those interactions. As long as the scale

and stakes were small, the unanticipated results from such subtle changes could be tolerated as inconvenient interruptions in the clerical and management setting. At the sharp end of healthcare, the cognitive work, the systems that are needed to aid it, and the stakes involved are far different than its blunt end.

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

upper portion of Figure 1). All this happens in the context of caring for multiple patients who each have unique needs and care trajectories that must be planned and coordinated.

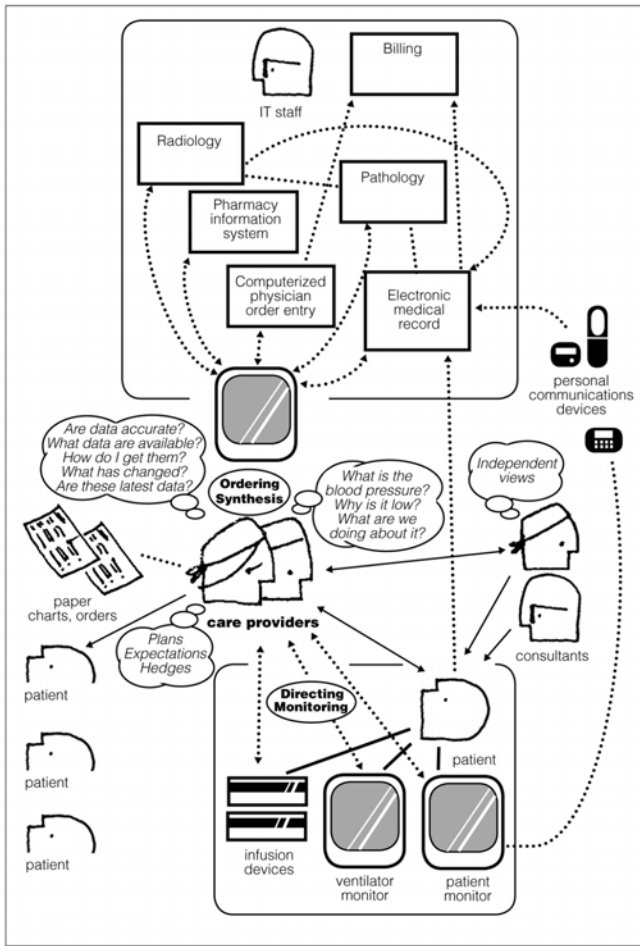
Three elements in this ecology serve as an example of the current state of support for care provider cognition: medical devices, medical records, and decision aids.

Medical *devices* such as infusion pumps increasingly feature complex control and display interfaces. Even highly experienced clinicians who have used infusion devices for years get “lost in menospace” when they perform even the simplest tasks [7]. Collections of such complex devices occur in acute care, particularly in the intensive care unit (ICU) and emergency department (ED).

Electronic versions of *medical records* (EMR) attempt to make the large amount of information that they contain useable. Despite these efforts, clinicians find the EMR is a poor match for the kinds of cognitive work that they must perform. This mismatch arises from increasing reliance on the medical record to support billing for clinical activity, configuration of records to assist billing and not clinical purposes, difficulty in locating critical information among the vast amount of information that the record contains, and the inability to use the record for important clinical activities such as the comparison of data. Now that it no longer serves a clinical role, clinicians have resorted to performing additional work to create their own informal solution: the sign out sheet. Each shift, clinicians list each of the patients on a unit along with critical items of information that are related to their condition and care [8].

Clinical *decision aids* (shown in the upper portion of Figure 1) have sought to help physicians synthesize complex considerations into rule-based guidance on patient care decisions. Berg [9] describes how such computer-based approaches to support clinician cognitive work attempt to create rule-based aids for patient medical care decisions, with mixed results. Decision support systems need to be constantly monitored to determine whether their suggestions fit a particular case. Also, the number of branching points may become so great to accommodate exceptions that the system is impossible to use and maintain [10]. The failure of this approach demonstrates that decision making under clinical conditions is far more complex and less tractable than proponents of these early systems believed. As a result, clinical decision support systems’ effect on practitioner performance and patient health remain as inconsistent as they were 15 years ago [11]. Relatively few clinical decision support systems (CDSS) are in use after their introduction over 25 years ago [12].

Recent developments have made ever greater amounts of data related to patients available to clinicians. Data availability, however, does not equal data utility. In order to be useful, data must be easy to manage so that it supports clinical cognitive work. This simple statement belies the depth and



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Figure 1: Clinician information ecology

state of support for clinical healthcare cognition. Care providers attend to individual patients (shown as direct contact by black lines) using their own observation, consultant views, and patient self-reports. They direct and monitor (through indirect contact shown by dotted lines) therapeutic and diagnostic equipment that is shown in the lower portion of Figure 1. Such devices have recently been connected to communication networks to “push” significant information to clinicians and related systems. They consult physical cognitive artifacts such as paper charts, orders, and status boards [6]. They request and synthesize data from a variety of information systems and departments (shown in the

complexity it involves. Misperceptions about user-device interaction have substantial consequences for clinical work. Recent reports of failures due to unexpected results [13, 14] from automation surprises indicate that IT demonstrates *brittle* properties [5] that result from poor understanding of the work settings that they are intended to support. Indeed, IT systems are often installed in an attempt to fix problems that are actually embedded in the social organization [15].

IV. ADAPTATION AND RESILIENCE

Representations of data that simultaneously show both constraints and possible solutions are crucial to orient and re-orient clinicians. Shortcomings in the current IT support for clinical work point to the need for an approach that enables systems to adapt to the work they are intended to support. Workers and managers need information on changing vulnerabilities and new means in order to meet challenges, and IT systems have the potential to serve that role. The inherent flexibility of IT can be exploited to aid clinical cognitive work. IT systems can be used to improve the provision of healthcare services by supporting information access, retrieval, display, communication, and cognitive aiding.

Proponents of high reliability [16] have recommended the approach for healthcare [17]. However, healthcare's high variability, diversity, partition between workers and managers, and production pressure make it difficult to employ essential aspects of high reliability organizations (HROs) such as redundancy and extensive training. Success in this setting depends on adaptability in the face of change. Schulman [18] proposed having sufficient rational resources or *conceptual slack* available makes it possible to cope with work domain constraints.

The newly evolving notion of *resilience* is the ability of systems to survive and return to normal operation despite challenges. Resilience engineering [19] stems primarily from the complexity study [20] and seeks to create and maintain systems that can cope and adapt to complex, changing environments such as clinical healthcare. Notions of resilience have evolved in multiple disciplines. Organizational research views it as the need for collective mindfulness [21-22]. Traditional risk assessment [23] has approached resilience as a minor variation in performance due to over- or under- adaptation. Complexity studies [24] approach resilience as an engineering and ecological issue. This third ecological sense provides an opportunity to consider how IT systems can be developed to contribute to healthcare joint cognitive system [25] resilience.

How can IT systems be created so that they adapt to the fluid, variable clinical healthcare work setting? 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 [26]. 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 [27]. Workers create cognitive artifacts [28] 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 [29] and derive design guidance for IT systems to support such work settings, because the artifacts embody only the essential elements of a work domain [30]. This makes it possible to pursue a design approach from the user to the system. How can IT systems be configured in order to support such an approach? Klein, *et.al.* (2004) [31] propose traits that IT systems need in order to participate in a highly adaptive human work domain such as clinical healthcare. Indeed, Butler and Gray [32] have suggested IT as a means to improve mindfulness in the face of complex technologies and surprising environments.

These are ten challenges for automation to participate in joint activity—extended actions carried out by an ensemble of people who are coordinating with each other, that set a longer-term agenda for IT system development:

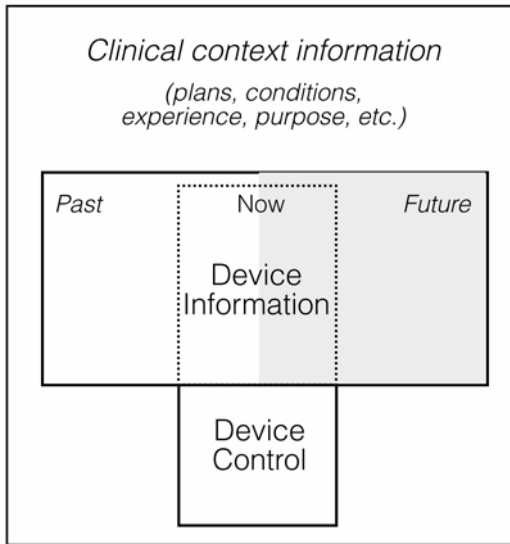
- 1) Fulfill the requirements of a Basic Compact to engage in “common grounding” activities—an agreement to facilitate coordination, to work toward shared goals, and to prevent team coordination breakdowns
- 2) Able to adequately model other participants' actions *vis-à-vis* the joint activity's state and evolution—Able to coherently manage mutual responsibilities and commitments to facilitate recovery from unanticipated problems
- 3) Be mutually predictable—The mental act of seeing ahead, with the frequent practical implication of preparing for what will happen.
- 4) Be directable—Able to deliberately assess and modify others' actions as conditions and priorities change.
- 5) Able to make pertinent aspects of their status and intentions obvious to their teammates—Make targets, states, capacities, intentions, changes, and upcoming actions obvious
- 6) Able to observe and interpret signals of status and intentions—Able to signal and form models of teammates.
- 7) Able to engage in negotiation
- 8) Enable a collaborative approach
- 9) Able to participate in managing attention
- 10) Help to control the costs of coordinated activity

V. EXAMPLE OF RESILIENT HEALTHCARE IT

The following example demonstrates how IT can follow these ten principles in order to develop a more resilient infusion pump interface. Most infusions in U.S. hospitals are now provided by such devices [33], making it the most widely used IT-controlled equipment in the acute care environment. Microprocessor-based infusion devices are associated with significant clinical accidents, resulting in patient morbidity and mortality. Problems with current commercially available

infusion devices arise from the complexity of clinical care and the need to handle complex infusion programming through a limited “keyhole” interface.

Improving the compatibility between infusion pumps and work requirements is not a matter of fixing a particular aspect of a particular design, such as making type larger. Instead, it is a matter of developing a new approach to representation that aids the work of clinicians who perform infusions. A new design needs to follow the ten principles that were described in the Section IV to make the pump’s operation evident, to demonstrate implications of current programming for the future, and to make it possible for others (in addition to the clinician who programmed the pump) to make informed decisions in light of this information. Figure 2 illustrates how



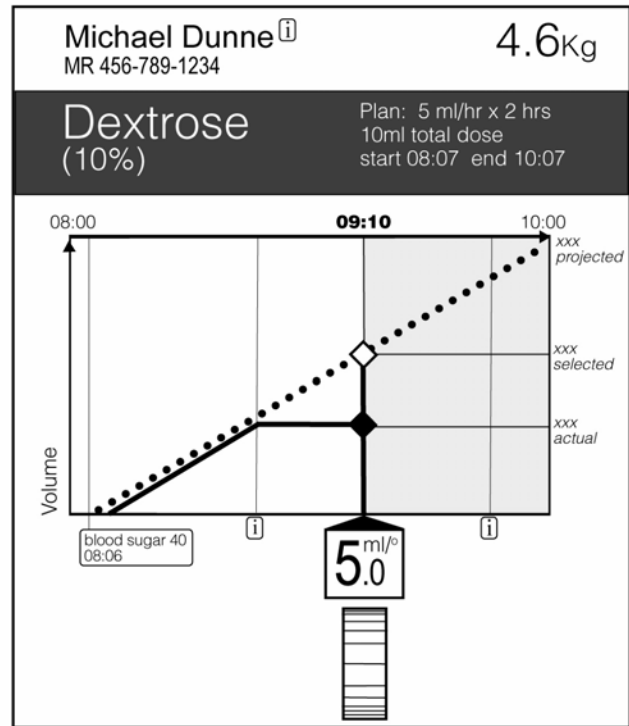
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Figure 2: Infusion Device Interface Schematic

an interface could provide information about device display and control through time to see operating history, current state, and implications for the future. Including clinical context information makes it possible to interpret device behavior in terms of its clinical use. Figure 3 depicts an infusion device interface concept that reflects the schematic design in Figure 2. In this example, a pediatric patient is receiving an infusion of dextrose that was started at 08:07 and is programmed to be completed at 10:07. At this point (09:20) the infusion is about halfway completed. The display shows volume/time (rate) parameters, current- past system status, and the expected course if current parameters are maintained. The device controls remain fixed, while the data “scroll” from left to right as time passes.

A “thumb wheel” control at lower center would make it possible for a clinician to control the rate of infusion. Moving the control up or down would adjust the rate to various settings. Values for each variable would change to show the implications of a rate change. After evaluating the various

options and their implications, the clinician could select and enact a new rate. Only then would the rate change.



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Figure 3: Infusion Device Interface Supporting Resilience

The graphic representation makes it possible for clinicians to use pattern recognition to determine how infusions are programmed and progressing. Alphanumeric characters will provide values for specific discrete variables that are necessary for accuracy. The display is predictive, so it will also make it possible to immediately recognize the kinds of dose limit errors plaguing current infusion displays that are programmed using only numbers. Additional information (indicated by “i” symbols) can be opened. In Figure 3, the item at lower left provides blood glucose test results that were reported at 08:06.

Rather than a narrow “keyhole” display showing only current system state, the display in Figure 3 provides context and indicates implications for the future. The concept reflects many of Klein, *et al.*’s traits from Section IV, making it better suited to participate in joint activity with clinicians. Making clinical and programming information explicit facilitates coordination and prevents team coordination breakdowns. Providing past, current and anticipated states, and making connections with related data such as lab results, facilitate recovery from unanticipated problems. Showing projected values supports the mental act of seeing ahead to assist preparation for what will happen. Controls that make it possible to explore contingencies before committing to a final decision enable the clinician to evaluate trade-off decisions. Integrating controls with displayed information makes it possible to deliberately assess and modify programmed

actions as conditions and priorities change. The combination of graphic and alphanumeric information makes pertinent aspects of the device target, status, capacities, programming intentions, and upcoming actions obvious to members of the clinical team. These are the kinds of observable and controllable traits that would improve IT support for healthcare system resilience.

VI. SUMMARY

Healthcare that is resilient readily adapts to changing demands. IT systems have the ability to change rapidly and to convey needed information in the face of changes and challenges that clinicians face. Research into resilience is a promising avenue to influence the course of development for healthcare IT by addressing questions that have genuine import for healthcare and the systems that are intended to support it.

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