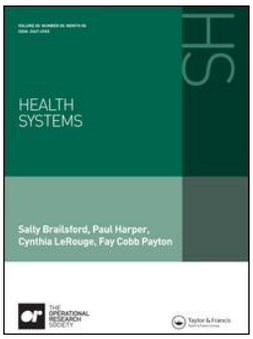

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POSITION PAPER

Expanding the boundaries of clinical informatics for interdisciplinary systems research

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Abstract
Health-care organizations and the information they exchange are increasingly complex and difficult to understand necessitating fresh methodological approaches on the part of clinical informatics researchers. Looking at the interplay between health-care information technology (HIT), clinical workflow, and the surrounding organization requires some notion of a system and an interdisciplinary orientation toward research. The paper offers practical advice grounded in the systems approach to researchers who wish to view HIT holistically and part of an integrated system. Examples from literature describe the importance of expanding system boundaries, looking for relationships within those boundaries, simplifying complexity, and accounting for social behavior.
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Keywords: clinical informatics; systems approach; social and organizational context; system boundaries

Introduction

The complexity of health care and the effectiveness of using health-care information technology (HIT) drive the discussion of policymakers and implementing organizations. The inaugural editorial of the *Health Systems* journal, addressing these challenges, states 'all aspects of health and health care delivery can be viewed from a systems perspective, which benefits from interdisciplinary collaborations' (Brailsford *et al*, 2012, p. 5). While most health care utilizes some form of HIT, the basis for its reported effectiveness comes primarily from the internally developed HIT within four academic institutions (Chaudhry *et al*, 2006). Clinical informatics researchers must now evaluate increasingly complex and often inter-organizational HIT-centric phenomena that extend beyond its academic roots, to facilitate widespread adoption.

An interdisciplinary definition for clinical informatics integrates the clinical and management perspective. The American Board of Medical Specialties defines the clinical informatics subspecialty as 'transform[ing] health care by analyzing, designing, implementing, and evaluating information and communication systems that enhance individual and population health outcomes, improve patient care, and strengthen the clinician-patient relationship' (Gardner *et al*, 2009, p. 153). The Health-care Information and Management Systems Society define clinical informatics on their website as conveying '… the understanding and integration of information technology into healthcare to ensure the effective provision and to support the business objectives of clinicians in healthcare industries'. Both of these definitions, representing the clinical and management perspectives, emphasize the central role of HIT.

The composite definition used in this paper views clinical informatics as bringing together clinical workflow and business strategies of a

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health-care organization through timely and accurate exchanges of information. Chaudhry *et al* (2006), in their systematic review, point out that who pays and who benefits from HIT (e.g., stakeholders) is unclear. To understand the impact of HIT on clinical workflow and stakeholders requires an understanding of social and behavioral processes (Anderson & Aydin, 2005; Ash *et al*, 2008). The most insightful clinical informatics papers take a systems perspective that clearly articulates the context of use while incorporating interdisciplinary perspectives needed to make sense of increasingly complex and interconnected technologies and the organizations in which they are embedded. In addition to the clinical disciplines relevant for a specific HIT research question (e.g., radiology for imaging systems), a clinical informatics study would likely also include perspectives on human–computer interaction, clinical processes, health economics, and even public health.

One challenge in taking a systems perspective, which this paper seeks to address, revolves around deciding what to include in the system. What system principles can a research team grasp upon to transcend diverse disciplinary perspectives? This paper offers pragmatic advice for researchers, drawn from the health-care literature at large, to view increasingly complex HIT-centric phenomena holistically and as part of an integrated system. First, the paper defines a systems perspective in terms of clinical informatics and points out shortcomings in the absence of a broader view of HIT. Second, the means of using the four characteristics of a systems approach is described using extent literature. The paper concludes with lessons learned from applying the systems approach in three research situations.

Clinical informatics as a health system

Health Systems promotes a whole systems approach to study the health-care landscape. Whole systems are complex health-care interventions with roots in the context of patient healing (Boon *et al*, 2007). Examples of whole health systems research include patient empowerment (Kennedy & Rogers, 2001), cancer care (Verhoef *et al*, 2006), integrated care (Edgren, 2008), and population health problems (Diez-Roux, 2011). However, technology does not play a significant role in these examples as it does in clinical informatics research that focuses on HIT.

The whole system definition used by Brailsford *et al* (2012) for the *Health Systems* journal explicitly includes technology as part of a broader system: 'integration of multiple components (people, organizations, technology, and resources) and perspectives' (p. 2). This paper goes further by suggesting that the whole system also includes the interplay between clinical workflow, business strategies, and the social and behavioral dimensions of people and organizations within the system. The remainder of this section describes the need to look at clinical informatics in the context of health systems and also defines a systems research perspective.

Rationale for a systems perspective

The push toward a systems perspective to clinical informatics research stems in part from a long history of HIT failures. One impetus for research in clinical informatics has been the slow adoption of HIT and unexpected issues that arise when such technology has been implemented. Electronic health record (EHR) user surveys continue to point out these concerns. Medscape's 2012 survey (Kane, 2012) of 21,202 physicians found decreased productivity (26% of respondents), a negative impact on doctor–patient relationship (30%), and unhappiness with their EHR though unwilling to change because of effort already invested (38%). Something is clearly at odds with the normal explanation for slow HIT adoption: immature standards, lack of stakeholder involvement, and poor implementation practices (e.g., Friedman *et al*, 2009).

Some of these HIT failures might have been prevented if a more inclusive set of disciplines had participated to address other elements of a system. For example, Lawler *et al* (2011) look at the human factors that should have been considered in HIT implementation. Heeks (2006) points to a number of gaps that make HIT failure more likely such as rationality dominating the design and context for design differing from use. Ball *et al* (2008) point to the need for flexibility and customization of clinicians' workspace. For example, a map of clinician's daily work could be provided rather than turn-by-turn instructions (Nemeth *et al*, 2005).

While inclusion of these clinician-centric interventions may improve usability to the clinician, any HIT operates in a system that requires the participation of more than the clinician. Chaudhry *et al* (2006) point to the absence of HIT studies relevant to consumers and interoperability. Kaplan & Harris-Salamone (2009), reflecting on a workshop on HIT failure at the AMIA Fall 2006 Symposium, point out that a 'consensus is emerging that problems with health care IT projects, as in other sectors, are due to sociological, cultural, and financial issues, and hence, are more managerial in nature than technical' (p. 292). While the managerial may be overlooked, the impact of technology upon the broader health system cannot be ignored. For example, a policy mandate for an inter-operable EHR ripples beyond tertiary (inpatient) care to primary (outpatient) care that sends and follows up patients. While the need for a system perspective for HIT implementation has been established, the next section suggests that HIT research would also benefit from broadening their view of the system.

Systems approach for research

While the growing interest in evaluating complex (whole) systems of health care is promising (e.g., Boon *et al*, 2007), much remains to be done. Just because system is used in the name 'information systems (IS)' or 'health systems' does not mean a systems approach has been used for research. The IS research field, with wide applicability to health-care informatics (e.g., Chiasson & Davidson, 2004), has struggled to take a systems approach. Furthermore, few

Table 1 Characteristics of a systems approach

Characteristic from Mingers & White (2010)	*Heuristic*
'viewing the situation holistically, as opposed to reductionistically, as a set of diverse interacting elements within an environment'	Expand system boundary
'recognizing that the relationships or interactions between elements are more important than the elements themselves in determining the behavior of the system'	Look for relationships
'recognizing a hierarchy of levels of systems and the consequent ideas of properties emerging at different levels, and mutual causality both within and between levels'	Simplify complexity
'accepting, especially in social systems that people will act in accordance with differing purposes or rationalities'	Account for social behavior

papers actually take a systems approach in medicine and health (Mingers & White, 2010).

The systems approach has roots in general systems thinking (Churchman, 1968; Klir, 1969; Weinberg & Wiley, 1975). For medicine and health, Mingers & White (2010) argue that the systems approach 'leads to a more inclusive and less reductionist view of a problematic situation' (p. 1156). They point out that a reductionist approach sees errors and failures as one-time events often attributable to human error. In contrast, a systems approach sees these errors arising from the context of use and underlying processes. The inaugural editorial of this journal drew upon the Mingers & White (2010) characterization of the systems approach (left column of Table 1), to call for an interdisciplinary systems perspective to clinical informatics research. The remainder of this sub-section describes the current state of HIT research and how the Mingers & White (2010) characterization can be used to take a systems approach in research (right column).

The first characteristic of a systems approach speaks to the elements included in the system. While the clinical informatics field needs careful studies that take a singular focus on the efficacy of a feature or function within a specific HIT, such research rarely captures the upstream or downstream impact to a health-care system. For example, the systematic review of 87 randomized control trials (RCT) for medication management information technology (MMIT) by McKibbon *et al* (2012) found that half the studies showed process improvement but few measured clinical outcomes. Furthermore, McKibbon *et al* (2012) conclude 'Few studies addressed order communication, dispensing, or administering, non-physician prescribers or pharmacists and their MMIT tools, or patients and caregivers' (p. 22), which are integral parts of medication management. The fault may not lie with the RCT approach (Liu & Wyatt, 2011), a reductionist view of research, but whether the system effects can be identified *a priori* and measured empirically.

The second characteristic focuses on interactions between elements. The researcher chooses additional elements within an expanded system boundary with an eye toward interaction. These interactions may not be directly related to the technology but may be antecedents or outcomes. Given the business component in the definition of clinical informatics, the economics of an HIT system should be at least one consideration. The business orientation of IS research offers the following viewpoint. Cao *et al* (2011) argue that 'IT [information technology] is an integral part of a system of interrelated organisational factors and that a holistic approach is required to further understand when, how and why IT creates business value ' (p. 85). Yet in a systematic review of HIT for medication management, only five studies had performed a full economic evaluation (O'Reilly *et al*, 2012).

The third characteristic recognizes both a hierarchy of levels within a system and that additional system properties might emerge at different levels. The researcher must choose the proper level of analysis for each branch of a system to adequately represent the phenomena of interest. Choosing what to reveal is still a challenge. For example, Zheng *et al* (2010) note that the prevalent time and motion studies of clinician activities overlook the true flow of work. In addition, the researcher must anticipate where the properties might emerge. Yet a systematic review of e-health systems found that previous research focused on implementation rather than the complex inter-twining of technology and organizations (Potts *et al*, 2011).

The fourth characteristic of a system emphasizes the role of people. Yet the social element has typically been overlooked. A systematic review of health technology adoption found that few studies of organizational processes actually studied organizational context with process-based methods (Robert *et al*, 2010). Greenhalgh *et al* (2010) argue that evaluations of e-health initiatives fail because of emphasis on scientific testing rather than of the social practice.

To conclude this section, most previous research provides limited insight because of drawing narrow boundaries around the phenomena being observed. A system perspective for research uses tools, such as the systems approach, to view HIT holistically as part of an integrated system.

A systems approach for clinical informatics research

A systems perspective toward studying clinical informatics phenomena means selectively inter-twining breadth and depth. No study can look at all elements of a system at depth. The systems approach recognizes multi-level relationships and interaction between various elements that together with unexpected actor behavior act together

holistically (Mingers & White, 2010). The number of relationships and interactions under investigation must be manageable as research budgets are inevitably resource constrained.

Perhaps the most important step before taking a systems approach is recognizing that every researcher implicitly or explicitly sets a system boundary that determines the components within such as people, organizations, technology, and resources. Only then can a researcher take steps to address the four characteristics of a systems approach. Drawing boundaries to include system elements that embody phenomena relevant to the research question is the first step (Characteristic A of Table 1). This step, more art than science, typically involves expanding the original boundaries set by the dominant research discipline or sponsor. Yet merely expanding system boundaries is insufficient to make sense of the underlying phenomena without digging into multi-level relationships and interaction (Characteristic B). Researchers must simultaneously recognize the inherent complexity of systems, especially the levels at which phenomena can be observed, while simplifying the representation of the system to study it (Characteristic C). Some of this complexity stems from the unpredictable actions of social and organizational actors (Characteristic D). Taking these characteristics together, a systems approach can identify relevant observable phenomena of interest.

The following sub-sections, drawn from the health-care literature, suggest ways that each characteristic of a systems approach can be incorporated in clinical informatics research: expanding boundaries, looking for relationships, simplifying complex phenomena, and accounting for social behavior.

Expanding boundaries

Every clinical informatics study sets a study boundary that typically focuses on specific HIT functionality. This might be a particular (technological) feature or function, a collection of functions, or an integrated set of technologies. As pointed out earlier, such a technology-driven boundary limits the value of any findings. For example, related functions in medication management have frequently been omitted from consideration (McKibbon *et al*, 2012). Such a narrow focus can limit the utility of findings. For example, e-prescribing studies have found that the technology reduces illegibility errors caused by prescribers. Such a result would be expected when handwriting has been eliminated. However, the more interesting question of downstream consequences, such as unintended errors introduced by technology (e.g., Campbell *et al*, 2006) are often not addressed. Errors might also be introduced when pharmacy clerks retype digital prescriptions into the pharmacy system. Unless the source of errors is specifically included within the research boundary (e.g., users interacting with technology), they may be overlooked.

A first remedy to overlooking relevant system elements is to progressively expand the boundaries considered in the research study. When a specific technology feature is the center of the system, start by adding users of the technology within the system boundaries. Then look to the downstream impact of the feature. For e-prescribing, include the processes in the pharmacy for those who interact with the e-script. Look also at outcomes such as changes in errors reaching the patient because of the introduction of technology.

Boundary expansion should also look upstream at tasks, functionality, or policies that impact the portion of an HIT being studied. For example, do prescriber habits, such as calling in or faxing prescriptions, change once the medical practice switches to e-prescribing? Azad & King (2008) found a complex interaction between hospital clinicians to shift the documentation burden once an approval was required by the hospital medication dispensing system to dispense restricted antibiotics.

The context that any system operates within needs to be identified. Going beyond, HIT functions and integrated capabilities look for the organizational and environmental context of the system. This might be as narrow as individuals and workgroups or stretch much further. Yin (1999), in defining a health-care case study, describes how a case study might encompass phenomena within a single hospital and its context. However, a case study considering an upstream institution could include the community within which the hospital resides or the managed care system to which the hospital is affiliated. The boundaries for evaluating primary-care research networks include the inter-related organizational dimensions of structure, processes, boundaries, and network self-evaluation (Fenton *et al*, 2007). Describing the boundaries of a system, and perhaps more importantly what elements and relationships are excluded, help make sense of what remains in the studied system.

System boundaries evaluated for research are likely to be different than the boundaries of the organizations being studied. Boundaries are discontinuities or lines of distinction (Wenger, 1999). They may be social or symbolic (Lamont & Molnár, 2002). Drawing on research in governance networks, boundary construction is known to be difficult. There is no single line that defines the correct boundary (Thompson, 2003; Meadows, 2008). MacEachen's (2013) work with disability systems illustrates how different causal pathways had to be followed between work and disability before finding improvements. The drawing of systems boundary is an art that requires the perspective of multiple disciplines.

Looking for relationships

Once the boundaries are roughly defined, researchers should focus on relationships (inter-connections) and interaction between elements found within the newly drawn system boundary. A health system includes 'all the organizations, institutions, resources, and people who contribute to maintaining and improving health' (Brailsford *et al*, 2012, p. 2). Health systems are 'a dynamo of interactions, synergies and shifting sub-systems' (de Savigny & Adam,

2009, p. 32). The interactions of the various elements constitute the cohesion of a system (Von Bertalanffy, 1972).

For clinical informatics research, the interactions revolve around the technology with the most obvious candidates being users and workflow. Inter-connections with related technology, whether it is through data transfer or workflow, should also be considered. For example, Azad & King (2012) show how work practices in hospital units are enacted to decouple institutional rules embedded in a medication dispensing system.

Interactions between system elements can be quite complex. Smith & Koppel (2014) studied the misalignment between patients' physical realities, clinicians' mental models, and EHRs. They identified five general types of misrepresentation: IT data too narrowly focused; IT data too broadly focused; EHRs missing critical reality; data representations that are contradictory or confusing; distortions from data reflected back and forth across users, sensors, and others.

Health systems also relate to institutions, regulatory oversight, and policymakers that interact with elements within a system. Ludwick & Doucette (2009) report a dearth of literature that looks at the benefits or drawbacks of health IS accruing to patients even though such considerations should be of concern to adopters, payers, and jurisdictions. However, there are some studies showing such considerations that illustrate interaction between system elements. Researchers at a U.S. teaching hospital found that residents' interaction with evidence-based guidelines was complex (Dalrymple *et al*, 2010). The residents considered environmental and organizational factors with particular attention to minimizing the perceived costs to themselves and their patients. Inter-relationships within a system may not be obvious that necessitates looking at the sequence of steps that lead to an outcome. For example, a large health provider introduced to their EHR the capability of ordering for patients a decision aid (i.e., DVD). The technology contributed to the shared decision-making process that greatly reduced the use of hip replacements (Arterburn *et al*, 2012). The EHR was an enabler to get decision aids into the hands of patients that in turn led to an informed discussion with their physician.

One area receiving greater interest is the outcomes of technology using evidence-based medicine. The clinical decision support system (CDSS) has received a great deal of attention as (electronic medical record) EMR/EHR technologies have been deployed. These technologies allow evidence-based medicine to be made available at the fingertips of a physician. The findings to date show a mixed picture on the utilization of evidence-based medicine and subsequent impact on health-care costs. Roshanov *et al* (2011) examined RCTs that supported chronic disease management using CDSS. Most reported surrogate patient outcomes and only one in three trials demonstrated benefits. Similarly, a meta-systematic review (SR) by Jaspers *et al* (2011) examined 16 SRs. They found only 25 out of 82 unique studies reported evidence that CDSS positively impacted patient outcomes (30%).

Technology adoption in the health system context is a 'politically textured process of organizational change' (Berg, 1999). Physician and patient culture is a key player in utilizing evidence-based medicine. Three examples cited by Dixon-Woods *et al* (2004) illustrate the importance of looking for the unexpected. The first example found that physicians assume parents seek asthma medication, which are known to reduce morbidity and mortality (Green & Britten, 1998). However, patients or their guardians actually care about drug dependency and long-term effects of inhaled corticosteroids. In the second example, physicians seeking information on statin efficacy in one part of the United Kingdom rarely appraised the trials themselves but looked for trustworthiness of the trial source (Karen & Guro, 1998). They interpreted the evidence in the context of economic and social factors that impacted their own practice. The third example addressed the well-known evidence that antibiotics had limited effectiveness for virus-related sore throats. Researchers found the prescribing decision was in fact greatly influenced by the physician–patient relationship rather than the evidence (Butler *et al*, 1998).

Finally, interactions from within the system to its external environment should be checked. System boundaries are generally fuzzy (Plsek & Greenhalgh, 2001). Boundaries demarcate the region for appropriate systems activity but also includes the mechanisms to interact across the boundary (Katz & Kahn, 1978). Thus boundaries may need to be redrawn to include or exclude a relationship or interaction.

Simplifying complexity

Using the first two characteristics of a systems approach increases the size of a system that has to be considered so no critical phenomena is overlooked. The boundary may seem to continually expand which discourages use of the system approach. According to Stern & Barley (1996), 'fewer researchers may be willing to expend the effort necessary to grapple with complex and increasingly amorphous institutional interactions and relationships' (p. 153). The lack of coordination and outreach to other disciplines has also been noted in clinical informatics research (Embi & Payne, 2009). While at first glance the third characteristic's focus on identifying a hierarchy of levels within a system seems to add more complexity, it is also the means for simplifying the representation of the system. For example, King (2013) illustrates the overall operating philosophy of e-prescribing in the United States taking on specific meanings at the lower levels. Judicious simplification allows for the representation of a large system that can then be studied at an appropriate level with the resources available. Not all elements of the system need to be studied at the same level or for the same reasons.

The research team uses levels within a system to identify subsystems, some of which may be less important to a particular research question. According to Meadows

(2008), 'subsystems can largely take care of themselves, regulate themselves, maintain themselves, and yet serve the needs of the larger system, while the larger system coordinates and enhances the functioning of the subsystems, a stable, resilient, and effective structure results' (p. 82). Using the knowledge gained from examining the relationships and interactions with an expanded system boundary, subsystem boundaries can be drawn. By now, the researcher should have some ideas of how various system elements can be combined into subsystems.

Resist the temptation to draw these sub-boundaries around familiar system elements (e.g., modules of a particular technology). One tool for defining boundaries is the concept of health action advocated by Murray & Frenk (2000). They define a health action as 'any set of activities whose primary intent is to improve or maintain health'. Inherent in the health action are outcomes that improve health for a population. While Mechanic & Zinner (2012) do not use the terminology of health action, the principles are reflected in their study of medical groups that moved to accountable care with the associated need to develop risk-contracting expertise. These health-care providers needed to develop new competencies and infrastructure that include IS to track performance and support clinicians in delivering accountable care. Merely looking at HIT adoption itself could be misleading. They found providers struggled developing physician-level reward systems aligned with organizational goals, sound physician leadership, and an organizational commitment to supporting performance improvement (Mechanic & Zinner, 2012).

A second tool is whole networks, a public policy research perspective, which helps in putting multi-faceted systems into context. A systems perspective can (and should) be applied to localized settings (e.g., hospital and organizational units within). Yet the increased interest in broader inter-organizational collaboration should be reflected in our research. Health-care systems, whether local or nation-wide, often represent a government-led collaboration network. These are inevitably a mix of public and private entities that collectively render a service (Provan & Kenis, 2008). Collaborative networks are complex adaptive systems whose management is dissimilar to traditional hierarchical organizations especially as technology-enabled connectivity alters network norms and structures by simultaneously constraining and facilitating social control (Wellman *et al*, 1996). These networks are now being called whole networks in the public administration literature (Provan *et al*, 2007; Raab & Kenis, 2009).

Whole networks focus on the collective goods produced (Raab & Kenis, 2009), even if responsibilities are distributed across multiple agencies (Kenis & Provan, 2009). This focus on the common good may mean that the costs incurred by individual producers of a network service may be overlooked (King, 2013). These collaborative networks must be designed as a social organization (Bradley & McDonald, 2011). While a useful perspective for studies that include regulatory or institutional players, the boundaries for evaluating HIT implementation may be different than for studying network governance.

Accounting for social behavior

The system actors and their key relationships have been identified through applying the first three characteristics of the systems approach. The systems approach for implementation asks that designers anticipate the impact of change. For researchers evaluating system adoption, look also for evidence of unanticipated adaptation. The fourth characteristic reminds the researcher that these actors are inter-connected with others and likely adapting to any changes in the system (Plsek & Greenhalgh, 2001). The impact of these changes may be easy to identify. For example, Fisher & Monahan (2008) expected to find staff wary of an Radio Frequency Identification implementation because of the implications of surveillance. The unexpected finding was the concern of staff that maintenance responsibilities added to their busy days (Fisher & Monahan, 2008).

Studying the social aspect of systems may increase the mix of required research methods. In a study of the usage of summary care records, Greenhalgh *et al* (2010) went beyond the primary-care patient encounter as unit of analysis to include adoption factors, outcomes, organizational, and institutional context. They used a mixed-method multilevel case study to incorporate insights found in each system element. Studying the social side of systems adds complexity but opens the door to more insightful findings.

Using the systems approach

The four characteristics of a systems approach serve as the building blocks to evaluating systems. Putting those blocks together into a research study is the art of a systems approach. This section describes in further detail three situations that used the systems approach: longitudinal consideration of existing systems, changing frame of reference, and proper choice of system analogies. Each offers insights into applying the principles of the systems approach.

Existing systems

Researchers need to be aware that technology adoption can alter system boundaries or the embedded levels of analysis and inter-organizational relationships. A study of ambulatory e-prescribing in the United States shows how the systems approach increases visibility of the phenomena. Most e-prescribing studies have been done in a hospital context (i.e., Westbrook *et al*, 2012) so the scope of the system being studied changes dramatically when considering the inter-organizational aspects of ambulatory e-prescribing. This researcher began by tracing the flow of information and the surrounding workflow to expand the boundaries beyond the point of prescribing.

Poor handwriting on a paper prescription has been attributed to downstream medication errors for years. Pharmacists clarified most of these unclear prescriptions through educated guesses, or at last resort, calling the

physician's office. However, some errors still slipped through. One impetus for e-prescribing was to combat physicians' poor handwriting that had not been responsive to non-technological interventions. However, the true outcome measure for the prescribing process is the errors that reach the patient who requires expansion of the study boundaries.

The process for studying illegibility errors on paper prescriptions in manual prescribing was straightforward (Figure 1, top half). Physician involvement was not necessary. Just count the prescriptions received at a pharmacy and determine how many clarification interventions were based on illegible handwriting (i.e., legibility check). If the prescription was legible, the pharmacy still needs to determine if the prescription is complete and properly filled out (e.g., instructions and dosage). The completed prescription then goes through adjudication. The first step determines if the insurance company will cover the requested medication. The second step determines if this medication interacts with other drugs the patient is taking (i.e., Drug–Drug Interaction or DDI). The researcher could measure the number of pharmacy interventions during adjudication because DDI is an important error prevention step. Finally, the responsible pharmacist makes one final check before the medication reaches a patient. However, the wrong medication can still reach a patient despite all these checks at the pharmacy.

Studying e-prescribing illegibility errors must consider new organizational roles and relationships. Furthermore, the existence of an existing system (i.e., manual prescribing) means that the new system has to consider historical interactions and relationships. Data entry takes place in the medical practice by an e-prescriber using an e-prescribing module associated with an EMR/EHR. Most of the studies to date look only at the illegibility errors at the point-of-prescribing. Given the extensive use of pick lists in most e-prescribing modules, illegibility errors have found to be negligible. Logically, the absence of illegibility errors means few medication errors will reach the patient. The reality is different. A perfectly legible digital e-script can (and do) have errors (Palchuk *et al*, 2010; Lapane *et al*, 2011; Lockwood, 2012).

The researcher who only draws the boundary around the point-of-prescribing misses the downstream error-checking that takes place at the pharmacy. They also miss the complexity introduced into study design by the adoption of e-prescribing. How do you sample a prescribing transaction that crosses organizational boundaries?

Herein is the research challenge for studying e-prescribing medication errors. In manual prescribing, pharmacists receive prescriptions from a number of different physicians so there is a sampling of those physicians working in the surrounding area. However, the researcher has no need to track the individual physician. The unit of analysis is the prescription. The researcher increases the prescription sample size by adding more pharmacies. This is important because the error-checking process in pharmacies do vary.

While the e-prescribing unit of analysis is similar to the paper prescription, the e-script, the context has changed. These e-scripts are generated at a number of medical practices by a number of e-prescribers. If you are interested in medication errors that reach patients, the researcher must now find out where those e-scripts were sent. Thus the unit of analysis has become the e-script transaction – not the artifact itself. How can the researcher realistically follow all the transactions sent by a set of e-prescribers? While it is technically possible to collect the destination of every e-script during a period of time, will every receiving

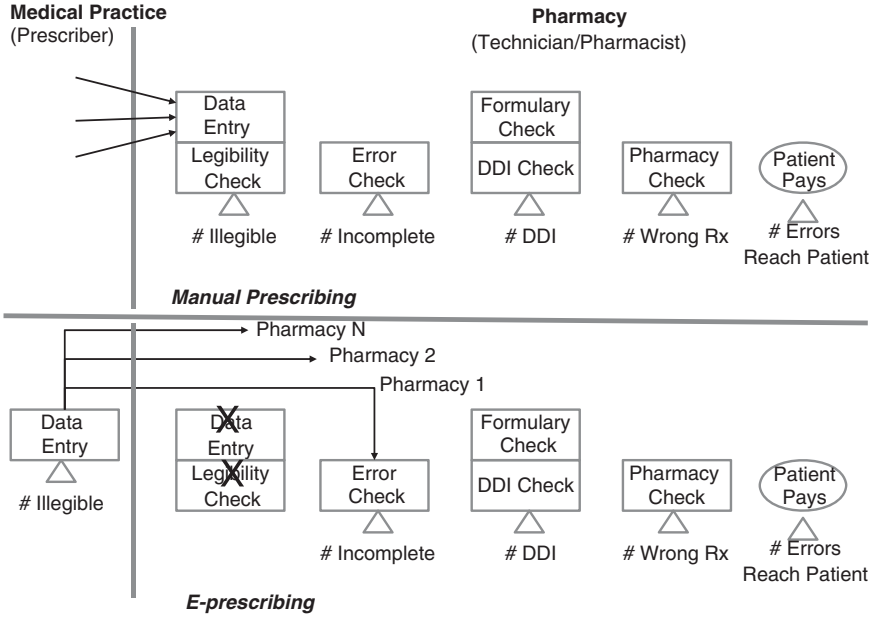

Figure 1 Impact of e-prescribing on research design.

pharmacy be willing to give access? Furthermore, the pharmacy does not typically track the errors they have discovered through the various steps. They only count the errors that reach the patient.

The research dilemma is to stay at the pharmacy and then track down the e-prescribers or stay with the e-prescribers and follow the e-script to surrounding pharmacies. Either way seems untenable from a research perspective. In the former, controlling for physician illegibility before e-prescribing is unlikely. In the latter, the resources are prohibitive to track down the e-scripts that can be sent in a large radius. A small independent pharmacy I studied in the past received prescriptions from over a hundred prescribers.

Here we see in this simple example of serial coordination (e.g., e-prescriber to pharmacy) that choice of system boundaries alters research approaches. Merely studying the efficacy at the point-of-prescribing does not mean these findings can be extended to the errors that reach patients. E-iatrogenesis is a serious concern introduced by perfectly legible e-scripts that are in fact incomplete (e.g., Palchuk *et al*, 2010) or have perfectly legible but incorrect medications specified. A boundary that includes the existing system allows the researcher to establish a richer context for studying the new system.

Changing frame of reference

The importance of identifying relationships across all levels within an expanded system boundary cannot be understated. Waterson (2009) conducted a critical review of the patient safety literature. He found that most studies focused on the individual without crossing system boundaries or the linkages between the various levels of analysis that exist in a health system. Very few studies look at the 'dynamics that exist across system boundaries and the interconnections that link decisions, policies, and change in general at one level, with other levels of analysis' (Waterson, 2009, p. 1192).

The frame of reference combined with the choice of boundaries has a great influence on research results. For example, Azad & King (2008) examined computer workarounds in a single hospital. They limited their research to the boundary of a single process to focus on the social interactions of embedded workarounds. This narrow process-centric boundary allowed them to explore in-depth the surrounding context, especially the interaction between clinicians. The workarounds were found to bypass operational obstacles and implicitly reinforce role relationships. The system in this example represented only the interplay between social and technical aspects of an HIT.

Expanding the boundary and looking at the interconnections allows these same workarounds to be cast in a different light. Azad & King (2012) revisited the same hospital in conjunction with a parallel study of an e-government project. They redrew the research boundaries at an institutional level (e.g., worldwide fight against antimicrobial resistance for the hospital) rather than just a focus on an inter-departmental process. They then found that the same workarounds also served as a means to decouple the clinical staff from these external institutional pressures.

System analogies

The background of a researcher influences the systems approach through the analogies chosen. The downside from drawing too heavily on existing theoretical frameworks and analogies from one's discipline are missing the specific context of health care. These analogies influence the way that relationships and interactions among system elements are viewed. As an associate editor for several journals, I've seen a number of manuscripts that are missing the interdisciplinary authorship that would allow a more thoughtful use of borrowed analogies. For example, lean production methods used in the automobile industry was proposed to reduce waste in hospitals. However, the auto industry builds cars as efficiently as possible – not fix them.

Playing the devil's advocate that automobile manufacturing can be the analogy, I see health care more as the repair of an automobile rather than manufacturing a new one. Hence, one should ask: where can lean techniques be applied to repair/troubleshooting? Repair is the situation where poor information quality definitely contributes to waste. Sometimes a car must be kept in the shop for days until the trouble can be found. Fixing a car definitely has its phases – troubleshooting followed by repair. However, I do not see much waste once the mechanic knows what to fix.

Troubleshooting and timeliness is the challenge in health care that governs the way elements of a system interact with each other. I used the following example, couched in non-value added activity terms of lean production in parentheses, to explain my point. A patient enters the emergency department and a powerful anti-microbial appears necessary. However, without a blood culture the choice of antibiotic is unclear. A broad spectrum antibiotic is immediately prescribed to save the life of the patient. The culture is taken and everyone waits until the results come back hours later (delay/waiting). The patient's vital signs do stabilize with the initial choice of antibiotic. Subsequently, the culture results arrive. However, it turns out that the initial choice of antibiotic was wrong (redundant and defect), or at least one that is less effective against the bacteria that is present. A more appropriate antibiotic is then administered (rework) and the infection quickly diminishes. I wrote to the authors: 'According to your classification, all of the above are non-value added activities … But these wasteful activities saved the life of a patient. Rework seems a necessity under some conditions'.

Yes, there are some hospital processes that could benefit from an efficiency orientation. However on the whole, the inter-organizational structure of a hospital has been built around flexibility for unexpected patient conditions. For example, surgery room scheduling faces the challenge of extreme variance (e.g., Xiao *et al*, 2001). Surgery is often exploratory so the actual conditions to be encountered are not known in advance. Yet the surgeon is expected to fix

what they encounter to avoid the infection risk of a subsequent surgery rather than keeping to the schedule. A careful balance has to be struck between underutilization and the adverse patient experience of having surgeries delayed or postponed. These trade-offs reflect the interaction among system elements.

Analogies go beyond the way work is done in a system. They also set the paradigm on how systems are viewed. According to the perspectives essay of Mandl & Kohane (2012), EHR vendors have propagated the myth that HIT is different from industrial and consumer products. The essayist specifically point to 'jamming all health care processes and workflows into constrained EHR operating environments '(p. 2240). Such concerns are similar to Rettig (2007) who questions the promise of enterprise software 'to integrate and intelligently control complex business processes'. The automation viewpoint suggests that all dynamism of a system can be captured in workflow rules. Yet research with a systems perspective, many reported in this article, continually point to unexpected findings as the lens through which a system should be viewed.

Concluding remarks

The systems approach offers researchers a way to view HIT holistically and part of an integrated system. The principles remain the same whether it is for the study of a broad health system or a more focused clinical informatics implementation. The differences are in scale with the latter starting at a much lower level of analysis. The following heuristics for the systems approach help clinical informatics researchers avoid premature reductionism.

- Err on expanding the boundaries of a system rather than prematurely excluding phenomena that may provide the greatest insight.
- Look closely at the relationships and interaction between system elements as the boundary is expanded since the most interesting research questions are likely to be found here.
- Redraw the boundary around a small slice of the system that reflects a research question that can be realistically studied.
- Explicitly consider the existing systems that embody the 'corporate memory' of an organization.
- Do consider multiple frames of reference that can lead to unexpected discoveries.
- Consider carefully the explicit or implicit analogies used for the phenomena being studied.

In closing, recognize that using a systems approach is a dynamic process that only facilitates exploration by creating opportunities to view the system from different perspectives.

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