**Health information technology as an intervention**

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# Abstract

Health information technologies (HIT) comprise an increasing proportion of health expenditures by both public and private payers. Measures of value-for-money arising from HIT investments have proved elusive, partly because the conceptual and empirical foundations for measuring HIT implementation require further development. This paper reviews the concepts of maturity and interoperability, two common dimensions of HIT implementation. Using the concept of information transactions within a directed graph, these two dimensions emerge as equivalent expressions of HIT implementation. Further, the percentage of electronic to total information transactions offers a straightforward empirical measurement of degree of HIT implementation. This supports value-for-money assessment of HIT benefits as a function of degree of HIT implementation.

# Health information technology: questions of value persist

The literature on the measurement of the benefits arising from the investment in health IT has focussed on the immediate benefits for the provider, typically the physician. [[10]](#footnote-10) However, measurements of health system benefit and value-for-money to payers (government and insurers) still rely on simplistic projections of the value of time savings and other immediate outcomes produced by specific features of HIT. There seem to be few measures of more general health benefits, such as increases in quality of life, reduction in the direct costs of service provision, or mitigation of pain and suffering. Two explanations exist for this. First, HIT is not usually framed as an intervention per se. This impedes implementation of evaluations based on comparison groups and other inferential mechanisms. Second, no general framework for evaluating the link between HIT implementation and outcomes appears to exist, with the result that the assessment of this major innovation remains fragmentary.

This paper addresses the first deficiency by proposing a direct method for conceptualizing and measuring the implementation of HIT within a “jurisdiction” by examining two core concepts — maturity and interoperability. This paper shows how both concepts may be characterized as information flows and that this characterization becomes the basis for supporting benefit assessment. The goal is to create an operational measure of HIT implementation that serves as an independent variable in the assessment of value-for-money arising from investments in eHealth.

**Maturity and interoperability – the first step in measuring HIT value**

Maturity has been defined in many ways, including operational ideas about what organizations can do with improved information (Sharma, 2008), measures of adoption of certain types of patient management software (Tamburis, Mangia, & Rossi 2011), or in terms of meaningful use (Ontario eHealth 2011). The concept is simple in principle — maturity refers to the percentage of EMR software features actively used by the provider team. However, upon a little reflection, the idea gains dimensionality and complexity based on the extent to which features are present in the software, the extent of adoption by all provider staff, and most importantly, the capacity of all users (health care professionals and patients) to participate in supplying and using information within the provider unit.

Interoperability is a general feature of IT. In a network, it refers to the capacity and existence of diverse elements (health provider nodes) of the health care system to exchange and act upon shared information. Typical definitions and usages appear in Weber-Jahnke, Peyton, and Topaloglou (2012); Kuperman (2011); and Atalag, Kingsford, Paton, and Warren (2010). A health provider node may be a clinic, diagnostic unit, laboratory, or hospital. Intuitively, interoperability is a function of the “density” of interconnection among health provider nodes.

Together, these two concepts appear to be two unrelated aspects of HIT implementation. In fact, each rests on the same platform of information transactions, which in turn becomes the process for measuring HIT as an intervention.

**HIT maturity – concept and measurement**

A maturity model is a device or measurement system that shows the transformation and development of organizational capacity (Rocha, 2012; Earl 1989; Becker, Knackstedt, & Pöppelbuß, 2009). By focussing on the electronic medical record implemented by a provider, such as a primary health clinic, this section summarizes the relationship between EMR attributes, benefits, and maturity.

Most maturity definitions focus on the individual organization or health provider. For example, the HIMSS model charts seven stages of cumulative capacity starting from Stage 0 (no hardware, software, or training implemented) through to Stage 7, where the health care provider uses no paper to share the full spectrum of health data information among the various units within the organization. (HIMSS, 2009). Quintegra (Sharma, 2008) proposes a maturity schema that includes all service providers within the jurisdiction. For Quintegra, maturity moves from an immature stage (with no implementation at local levels) to a national stage (with full implementation across all "actors" within the health care system).[[11]](#footnote-11) Other maturity measures focus on a hospital setting. For example, Holland, Piai, and Dunbrack (2008) develop a model of five stages of maturity, with each stage building on the capacities developed in the prior stage. Yet another model has been developed for the National Health Service (NHS) in the UK, which features six stages of cascading capabilities.

Finally, a variety of adoption measures have served as a proxy for EMR maturity. For example, Keshavjee, Troyan, Holbrook, and Vandermolen (2003) have developed questionnaire-based measures of adoption to be administered in primary care clinical settings. While adoption is one element of a maturity model, it is not sufficient to measure implementation by whether a clinic has ordered EMR software (or whether it received financial assistance for the acquisition), since the software could still be in its shrink wrap. Many estimates of the time required between ordering the software and full implementation throughout the provider setting suggest that the time between decision to adopt and competent implementation is a matter of months at a minimum and is usually closer to two years.

## Maturity Model

The concept of a maturity model in information systems dates from the early seventies (Nolan, 1973). Within health care, contributions from Wetering and Batenberg (2009), Sharma (2008), and Filterrer and Rohner (2010) reflect different approaches and refinements to modelling the maturation process for a HIT. An obvious issue is that several maturity models exist and little consensus appears to exist on the nature of maturity or the set of attributes and their constituent features.

One useful conceptual structure uses a matrix to describe the dimensions of HIT (Rocha, 2012). Three elements serve to capture maturity in this representation:

1. Attributes refer to the HIT themes that support various dimensions of health care service.
2. Features are specific dimensions of each theme.
3. Stages are the developmental markers that reflect the increasing extent to which capacity of any given health IT system incorporates additional features within an attribute. It tracks the increase in features within an attribute.

In general, increased maturity is reflected by any move in a south east direction, as shown by the arrow.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Table 1: Generic maturity model** | | | | |
| **Attributes** | **Stage 1** | **Stage 2** | **..** | **Stage L** |
| 1 | - Feature 1 | - Feature 1  - Feature 2 | .. | - Feature 1  - Feature 2  :  - Feature K |
| 2 | - Feature 1 | - Feature 1  - Feature 2  - Feature 3 | .. | - Feature 1  - Feature 2  :  - Feature J |
| : |  |  |  |  |
| K | - Feature 1 | - Feature 1  - Feature 2  - Feature 3 | .. | - Feature 1  - Feature 2  :  - Feature I |
| Adapted from Rocha (2012) | | | | |

Management at each health provider setting will acquire software/hardware systems that have the potential to support certain attributes and features. Within any attribute, features that reflect increasing diversity of health information capabilities reflect increased maturity. An upper bound exists on the number of features within any attribute that are available to users. A challenge in the current environment is that vendors update and add to the attribute/feature set for HIT technologies. Further, little consensus appears to exist on the desirable set of attributes or their constituent features.

Any measure or index of maturity at a specific provider location is a function of three dimensions: 1) the number of attributes; 2) the number of features within each attribute; 3) the extent to which each feature of each attribute is actually used by health professionals at a provider location. For Attribute 1, Stage L means that all professions actively use electronic data for managing all features. The actual implementation level of a provider is a function of adoption by each of the professionals within the health provider setting.

Table 2 presents one possible adaption of the generic construct presented in Table 1. Within each attribute, it is possible to have features, or levels, of implementation that some authors appear to identify as the maturity of the EMR system. Here, the maturity of the implementation depends on the number of attributes available within the system. Under Attribute 1, patient information comprises up to five features, each representing a class of information. Stage L reflects a scenario when all professionals at a specific location actively use the HIT system to enter and access patient information for all features.

| **Table 2: High-level EMR attributes and benefits inventory (within single delivery clinic)\*** | | | |
| --- | --- | --- | --- |
| **Attribute** | **Stage of implementation** | | |
| **1** | **2** | **L** |
| 1. Patient information | * patient demographics | * patient demographics * medical/surgical history | * patient demographics * medical/surgical history * allergy record * family history * genetic tests |
| 1. Lab management | * ordering tests/ diagnostic images | * ordering tests/diagnostic images * receiving results | * ordering tests/diagnostic images * receiving results * interpretation (AI) * next tests * diagnosis |
| 1. Pharmaceutical management | * Prescribing | * prescribing * renewals | * prescribing * renewals * interaction assessment * cost control |
| 1. Decision support | * screening scheduling | * screening (based on patient demographics) * chronic care testing monitoring | * screening (based on patient demographics and family history) * chronic care testing monitoring * medical management across classes of patients |
| 1. Patient engagement | * information sharing | * education * information sharing | * education * motivation * information sharing |
| 1. Administration | * scheduling (online) | * scheduling (online) * billing | * scheduling (online) * billing * referrals |
| 1. Practice management | * patient wait time optimization | * patient wait times optimization * physician wait time optimization * evaluation of individual and team performance | * patient wait times * physician wait time optimization * evaluation of individual and team performance * use of collected data for research |
| \*Adapted from Price, Lau, & Lai (2010) | | | |

We use this seven-attribute, multi-feature framework (shown in Table 2) as the basis for conceptualizing and quantifying HIT maturity.

## Toward a measure of maturity

Consider for a moment an EMR system as implemented by a single provider (primary care clinic, lab, or hospital) comprising four attributes (a1 to a4), as shown in Figure 1. Setting aside, for the moment, what each attribute measures or a measurement scale for the attributes, it is possible to conceptualize levels of implementation for each attribute. Designate  as the maximum feasible implementation for Attribute “i” within the current technology and as the actual implementation for any provider. Figure 1 shows that the actual implementation for Attribute 4 lags the maximum possible (with the technical limits of the IT implementation and with respect to Attribute 1, the actual implementation equals the maximum).

Base attribute model.emf**Base attribute model_2 EMRs.emf**

**Figure 1: A four attribute HIT**

**Figure 2: Two HIT implementations**

Figure 2 portrays two HIT implementations, where one implementation dominates in two attributes (A in a2 and a3) and the other in the remaining two (B in a1 and a4.). Table 2 presented a seven dimensional model for maturity. Movement down the features at any stage represents movement along the axes in Figure 1. This unites the representation in Table 1 with the representation in Figures 1 and 2.

Pursuing the simple model as presented in Figures 1 to 2 and assuming that we have the seven-attribute EMR as suggested by Table 1, with each attribute comprising a single dimension, it is possible to arrive at a simple conceptual measure of EMR implementation. In brief, we propose that this simply be the percentage of all information exchanges within the provider unit (clinic) that are electronic for a particular attribute/feature. This proposition rests on three requirements:

1. A consensus must exist on the attributes and features that comprise a “standard,” minimum and maximum implementation of an HIT.[[12]](#footnote-12)
2. Each attribute and feature must be expressed quantitatively as information flows or transactions. Processes must exist within IT systems adopted by a health provider to measure the information flows competed automatically and manually for each attribute. (Technical Appendix A presents some informal expressions for various dimensions of maturity.)
3. The total information transactions within the unit need to be continuously counted and sorted into manual and electronic.

The important idea is that measurement of the attributes can be cast in terms of “transactions” or data flows. Consider how selected attributes from Table 2 may be expressed as information flows:

* Patient information (patient demographics, medical/surgical history, allergy record, family history, genetic tests, etc.). Patient information typically requires initial manual input as a result of interviews. HIT should eliminate the need to repeat this manual collection and information exchanges will be electronic. Updates (new conditions, treatment, outcomes) entered electronically replace the need for manual verification and updating.
* Decision support (screening scheduling — based on patient demographics and family history can support chronic care testing monitoring and medical management across classes of patients). The extent to which the implemented HIT supports screening functions based on patient demographics, history, and standards of primary care, and issues reminders electronically to the physician, represents an added dimension to typical primary care practice. Compared to primary care in traditional settings, screening often relied on the provider to remember to indicate to the patient the need for screening. The existence of algorithms to remind providers to schedule tests represents additional dimensions that previously did not exist. If the HIT uses patient availability (obtained at the time of the visit) and schedules the screening with other providers, electronic information transactions replace manual appointment scheduling. The portability of patient attributes supports this functionality as patients move among providers.

This concept of maturity rests on transactions and information flows. The other element of HIT implementation is the idea of interoperability, which can be represented also as transactions and information flows. This leads to the proposition that both aspects of HIT implementation may be represented by the same information exchange metric.

# Interoperability

The term “interoperability” refers to the extent to which system elements connect and communicate. In the context of eHealth, the idea refers to the capacity and existence of the diverse elements (nodes) of the health care system to exchange and act on information collected and archived at each node. The central idea of this paper is that a node may be a practitioner within a clinic, the clinic itselfcomprising several practitioners, diagnostic and service units (eg., laboratory, pharmacy), or an large hospital with many internal nodes.

**A conceptual representation of interoperability**

Interoperability represents information flows in a directed graph or “digraph,” such as appears in Figure 3. This graph may apply to information flows within a clinic/hospital/lab, as well as information flows between these service delivery units.

Basic Interoperability.emfAs a digraph, it is possible to depict the relationships in Figure 3 using an *adjacency matrix*, as shown in Equation 1.[[13]](#footnote-13) Two vertices are adjacent if connected by a communication “line.” Therefore, in Figure 3, nodes A and B are connected, but neither B&C nor C&E have any connection. The existence of a connection is signalled in a binary notation (0,1), a quantitative measure using natural numbers (volume of discrete transaction), or qualitatively as a relative “strength” (w – weak; m – medium; and s – strong). In this case, there are N=5 nodes, with a total of 20 possible two-way lines or N(N-1).

**Figure 3: Basic interoperability**

The label axes are read “from-to”. Therefore, since a line exists from B to E, one can signal this with a value of 1, but since no line exists that from E to B, it has the value of 0. The interoperability matrix appears as Equation 1.

 (1)

Assigning informational weights to the line produces a somewhat more refined view. The qualitative designation of *w* (weak), *m* (medium), and s (strong) could be replaced by the ratio of electronic to information transactions.

 (2)

The *information weight* (adjacency matrix) of the network is simply the sum of all connections (less the internal connections implied by the assumption that each node [health provider] has full internal communication). In the case of a graph where all nodes are connected by 1, the maximum weight is N(N-1) (excluding the internal communications reflected down the main diagonal). However, more realistically, information lines between nodes will reflect a weight and in this, the maximum weight is simply the sum of line weights (*wi)* less the main sum of the main diagonal or:

 (3)

For the moment, assume that the weight wi varies between 0 and 1, with 0 denoting non-existence of information exchange and 1 indicating some maximum value using a metric to be defined. For the network depicted in Figure 6, assume that the values of *w,* *m,* and *s* are .2, .5, and 1 respectively; therefore, the system weight or “interoperability” of this network is 5.1. Measuring the proportion of inter-node electronic information transactions to total transaction seems an obvious interpretation of the weight of the adjacency matrix.

**Measuring interoperability**

Measuring interoperability of the system would appear to be a simple matter of counting the weights of all interconnections actually initiated. However, several important issues exist:

* The nodes are not at the same scale. Some may comprise a small primary care practice, while others will be large health care institutions, such as regional hospitals. The interoperability map in Figure 3 implicitly assumes each node is at the same level. Varying this assumption is the key to unifying the concepts of maturity and interoperability.
* The nature of the communication among the nodes also requires definition and measurement. The actual data transfer may comprise a variety of formats and content levels. It may be episodic (such as making referrals to a specialist), or it may be continuous, such as an intensive care unit providing the primary care physician and associated specialists with real time information on a critically ill patient. The eHealth literature has not devoted much attention to the characterization of communication among health providers.
* Where two-way communication occurs, such as between A&B and A&C, there need not be equivalency in the information content of the medium values (.5) and the combination of strong and weak information links. The matrix AM need not be symmetric. Further, not all links need to be two-way to have functional interoperability.

# Maturity and interoperability

Maturity and interoperability share an equivalent representation as models of information exchange involving the process of acquiring, processing, and distributing information. Collocating diverse health services increases productivity by increasing the exchange of qualitative information (e.g. pharmacist- physician interaction) and the reduction in transactions costs. Transactions costs refer generically to the costs of acquiring, processing, and exchanging information; a reduction in transactions costs is always associated with increased information flows.

For the moment, assume that health providers are physically and electronically separate. Referring to Figure 3, imagine that units A, B, and C decide to merge (physically). Figure 4 presents a revised model of the health care system in Figure 3. This immediately increases the interoperability of the system.

Collocation and Interoperability.emf

**Figure 4: Revised health network after collocation**

The information matrix now appears as:

 (10)

with the system weight rising from 5.1 to 9.5. This occurs because the diverse units A, B, and C have merged (collocated). This leads to the observation that HIT maturity may be viewed as intra-unit interoperability. This further suggests a continuum where the health provider node is, in fact, a network of discrete internal information nodes comprising clinical staff and patients. Maturity of the provider node and interoperability of the system of nodes emerge as measuring the same information transaction along a continuum. Therefore, in the same way it makes sense to refer to the maturity of implementation at any node as the percentage of information transactions that are electronic, the maturity of the HIT implementation across the system simply expands the concept to all health care agents and nodes.

This leads to a simple proxy measure for HIT implementation that rests on three principles:

1. The definition of the health information system uses a map of node and networks, where nodes are defined at the lowest level (the individual health practitioner).
2. The definition and counting of all information transactions as electronic and non-electronic (manual) forms the empirical core of maturity and interoperability.
3. The weight of the information matrix should never decrease with collocation, after an implementation period, since the goal of collocation is to reduce transactions costs.

The apparent simplicity of this quantification can obscure the important work that remains to be done in translating HIT attributes into information transactional equivalents for the individual health delivery node. Some of the implications and questions that remain to be explored within this conceptual model include the following:

* The unit of analysis within the provider unit is the individual practitioner. Increasing facility with HIT simply means that a high percentage of information exchanges are electronic.
* Not all information exchange is capable of electronic representation. Examples include provider patient interactions and provider consultations.
* Counting electronic transactions can be implemented within most HIT systems. However, physical audits of the provider using a sampling strategy are needed to support quantification of the non-electronic transactions.
* As HIT technology advances, new features will emerge. This likely will mean that electronic interactions will emerge that have no current practice manual analogue. Diagnostic support algorithms that ensure physicians use evidence bases to identify conditions might be an example. For practical measurement of HIT implementation, it may make sense to define a minimum capability where electronic data exchange has current manual analogues (e.g. prescriptions, tests).
* Development of HIT is continuous with constant innovation in attributes and features. Payers within a jurisdiction that subsidise the adoption of this technology need to define the dimensionality of the systems and then set target levels of implementation for each dimension.

# Summary

This paper has suggested that HIT maturity and interoperability both may be interpreted as information flows. Therefore, maturity and interoperability refer to data transactions, the first referencing *intra*-provider andthe second referencing *inter-*provider information exchange. However, these concepts become indistinguishable when mapped as a graph and its corresponding information matrix.

The percentage of these transactions that are electronic serves as a proxy measure of HIT implementation. The next step is to translate attribute and stage models of HIT maturity into information transaction equivalencies and then to measure the level of electronic inter-provider data transactions. At that point, it becomes possible to develop a quantitative measure of electronic data interchange as a proportion of all data transactions — this becomes the needed independent variable in the estimation of eHealth value for money.

**Technical Appendix**

**Measurement of maturity**

Reflecting back to the four-attribute model, define four measures as



The end points are the maximum implementation for an attribute. Imagine that each axes may be represented by some index, therefore the maximum across all attributes (indexed by i).

 (1)

The implemented level any given EMR “j” appears as:

 (2)

Across all j EMR installations, actual implementation, EMR’ appears as:

 (3)

With the maximum potential appearing as

 (4)

Finally, the extent of implementation across a set of j EMR installations, that is, the “maturity of the system” appears as:

 (5)

The simplest metric for EMR maturity at any provider site (node) may be the percentage of information that is collected, stored, and potentially exchangeable using electronic methods referenced to some norm (the regulated, average, or maximum values)

, (6a)

which is maximum level of information flows for Attribute i relative to the norm for i across all j provider nodes.

, (6b)

which is average level of information flows for Attribute i relative to the norm for i across all j provider nodes.

, (6c)

which is actual level of information flows for Attribute i relative to the norm for i across all j provider nodes.

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10. Canadian EMR is a comprehensive source for understanding many of the issues involved in the implementation and adoption of EMRs. It offers many examples of EMR benefits offered by physicians and presents ongoing discussion of implementation issues. <http://www.canadianemr.ca/index.aspx> [↑](#footnote-ref-10)
11. As will become apparent, this approach merges the ideas of maturity and interoperability. [↑](#footnote-ref-11)
12. Some jurisdictions (Alberta) have designated specific providers as those for which adopting primary care clinics will receive support, but this only indirectly identifies attributes and features. [↑](#footnote-ref-12)
13. Also referred to as organizational linkage and coded linkage matrix. [↑](#footnote-ref-13)