An Ontological Map for Meaningful Use of Healthcare Information Systems (MUHIS)

Arkalgud Ramaprasad[1, 2], Thant Syn[1] and Mohanraj Thirumalai[2]
[1]*School of Business Administration, University of Miami, 5250 University Drive, Coral Gables, FL, U.S.A.*
[2]*College of Business Administration, University of Illinois at Chicago, 601 S Morgan Street, Chicago, IL, U.S.A.*

Keywords: Ontology, Meaningful Use, Healthcare Information Systems, Electronic Health Records.

Abstract: An ontological map of meaningful use of healthcare information systems (MUHIS) is the visualization of its requirements and practices using an ontology. We map (a) the Stages 1and 2 meaningful use requirements set by the Centers for Medicaid & Medicare Services (CMS) for Electronic Health Records (EHR), and (b) the current literature on meaningful use, to derive the ontological map of the requirements and practices respectively. The map is fragmented and incomplete. The results will focus attention on the gaps (a) in the requirements, (b) in practices, and (c) between requirements and practices, and highlight the bright, light, blank, and blind spots in MUHIS. These gaps should be (a) bridged if they are important, (b) ignored if they are unimportant, or (c) reconsidered if they have been overlooked. Feedback based on incremental ontological maps over time will help to continuously improve MUHIS.

1 INTRODUCTION

Meaningful Use of Healthcare Information Systems (MUHIS) is a work-in-progress at the national level in the USA and other countries(Dermer and Morgan, 2010, Ke et al., 2012, Kim and Kim, 2012, Varroud-Vial, 2011), at the local level in many states and cities, and at the enterprise level in many hospitals, physician practices, and other healthcare providers. Its requirements and practices are evolving in tandem, and along different paths depending on the initial conditions, incentives, and the environment. It is seen as an instrument for addressing the national (USA, for example) concerns about the cost, quality, and safety of healthcare. Consequently, there is a constant pressure to continuously and rapidly improve MUHIS. To catalyze the evolution, the Centers for Medicaid & Medicare Services (CMS) in the USA has set Stages 1 and 2 meaningful use requirements for Electronic Health Records (EHR) (Centers for Medicare & Medicaid Services). The requirements specify the outcomes, associated objectives, and corresponding measures. There are incentives for meeting the objectives. Fulfilling the requirements will be necessary but not sufficient for harnessing the full potential of MUHIS; it has far greater potential than envisioned in the present requirements. The requirements and MUHIS have to evolve quickly in tandem to meet the rapidly increasing global demands on healthcare. It would be a challenge to make the MUHIS 'elephant' dance.

MUHIS is a large, complex, and ill-structured problem. It is a 'wicked' problem (Churchman, 1967). We have to manage its 'wickedness' through feedback and learning to help it evolve rapidly. To do so, we have to (a) abstract from the diverse, often contradictory, and heterogeneous requirements and practices of MUHIS, and (b) apply it to the reformulation of requirements and practices (Ramaprasad, 1979, Ramaprasad, 1983, Ramaprasad, 1987). We need a clear framework and method for abstraction and application (Ramaprasad, 1987, Ramaprasad and Mitroff, 1984) to avoid replaying the proverbial story of the five blind men each of whom imagined an elephant as a rock, an arrow, a fan, a rope, and a tree trunk after touching its body, tusk, ear, tail, and leg, respectively (Börner et al., 2003, Ramaprasad et al., 2009). A wise man settles their argument about the ontic nature of the elephant by piecing together the picture for them. Fortuitously, the wise man in the story could see and recognize the elephant; without him the blind men's argument would likely have continued ad infinitum. Analogously we need wise men and women who can see and recognize the 'big

Ramaprasad A., Syn T. and Thirumalai M..
An Ontological Map for Meaningful Use of Healthcare Information Systems (MUHIS).
DOI: 10.5220/0004734500160026
In *Proceedings of the International Conference on Health Informatics* (HEALTHINF-2014), pages 16-26
ISBN: 978-989-758-010-9
Copyright © 2014 SCITEPRESS (Science and Technology Publications, Lda.)

picture' of MUHIS. The framework should guide the abstraction, inform the application, and structure the visualization of the MUHIS. It should thus help (a) to limit the fragmentation of the requirements and practices, (b) to make the system greater than the sum of its parts, and (c) to evolve MUHIS systemically and systematically. The framework itself should be adaptable to the evolution of requirements and practices through scaling, extension, reduction, refinement, and magnification of its components.

In the following, we will present an ontology (Ramaprasad et al., 2009) for MUHIS and discuss a method of mapping it using the framework. Thus, we will present a map of the "knowledge structure" (Zhang et al., 2012) of requirements and practices of MUHIS as an ontological map. The ontological map represents a "virtual knowledge landscape" (Scharnhorst, 2001, p. 505) based on textual empirical data about the requirements and practices. It will help visually recognize the coherence and lack of it in the cumulative domain knowledge, and therefore help correct the lacuna when appropriate (Hoeffner and Smiraglia, 2013, Noar and Zimmerman, 2005). Thus, it will provide "support for navigating the knowledge landscape." (Kazimierczak et al., 2012, p. 1) Further, "[i]ncrementally computed information landscapes are an effective means to visualize longitudinal changes in large document repositories…" (Syed et al., 2012, p. 352) such as the requirements and practices of MUHIS. It will aid the continuous improvement of MUHIS.

First, we will describe an ontology of MUHIS. We will explain the conceptual foundations of the framework and its bases in MUHIS requirements and practice. We will also discuss the face, content (Brennan et al., 2011), semantic (Kotis and Vouros, 2006), and systemic validity (Horn and Lee, 1989) of the framework.

Second, we will describe the method for mapping the requirements specifications and practice literature onto the ontology and explain the mapping process. We will discuss the reliability and validity of the mapping. We will demonstrate the visualization of the ontological map from the mapped data based on the map.

Third, we will describe the gaps within requirements, within practice, and between requirements and practice using the ontological map. We will discuss the importance of these gaps and their implications for future requirements specifications and practice.

Fourth, and last, we will describe how the method can be used to develop incremental maps (Syed et al., 2012) over time to generate feedback and facilitate learning in the evolution of MUHIS. We expect that continuous assessment and improvement of MUHIS using the proposed method will eventually lead to the realization of the guiding vision.

2 ONTOLOGY OF MUHIS

Ontologies "… provide a shared and common understanding of a domain that can be communicated between people and heterogeneous and widely spread application systems." (Fensel, 2003, p.1) They "… make it possible to understand, analyze, exchange or share knowledge of a specific domain and therefore they are becoming popular in various communities. However, ontologies can be very complex and therefore visualizations can support users to understand the ontology easier. Moreover, graphical representations make ontologies with their structure more manageable. For an effective visualization, it is necessary to consider the domain for which the ontology is developed and its users with their needs and expectations." (Kriglstein and Wallner, 2013, p. 123)

Ontology is the study of being in contrast to epistemology which is the study of knowing. Its focus is on objects, their categories, and the relationships between them. Ontologies represent the conceptualization of a domain (Gruber, 2008); they organize the terminologies and taxonomies of a domain. An ontology is an "explicit specification of a conceptualization." (Gruber, 1995, p. 908) It is used to systematize the description of a complex system (Cimino, 2006). "Our acceptance of an ontology is… similar in principle to our acceptance of a scientific theory, say a system of physics; we adopt, at least insofar as we are reasonable, the simplest conceptual scheme into which the disordered fragments of raw experience can be fitted and arranged." (Quine, 1961, p. 16)

There are potentially many ways of representing a domain ranging from a natural-language narrative to a formal mathematical formulation (when possible). The ontology is a structured natural-language representation, more formal than a narrative but less formal than a mathematical formulation. It is particularly suited for 'wicked' problems such as MUHIS. It is easy to understand and apply the ontology.

The ontology for MUHIS is shown in Figure 1. It encapsulates the logic of MUHIS. It has been

		Healthcare Information Systems							
Management		**Structure**		**Function**		**Stakeholders**		**Outcome**	
Analysis	**[of]**	Technology	**[for]**	Acquisition	**[of information by/to]**	Recipients	**[to meaningfully manage]**	Efficiency	**[of/in healthcare]**
Specification		Hardware		Analysis		Patients		Quality	
Design		Software		Interpretation		Families		Safety	
Implementation		Networks		Application		Population		Disparities	
Maintenance		Processes		Distribution		Providers			
Assessment		Policies				Physicians			
		Personnel				Nurses			
						Pharmacists			
						Payers			
						Employers			
						Insurers			
						Regulators			
						Government			

SCITEPRESS
SCIENCE AND TECHNOLOGY PUBLICATIONS

Four Illustrative components of meaningful use of HIS from 3360 (6x4x5x7x4) level-1 components:

1. Specification of technology for analysis of information by providers to meaningfully manage cost of healthcare.
   Examples: electronic health records software, data mining software
2. Design of processes for acquisition of information by patients to meaningfully manage quality of healthcare.
   Examples: access to online lab results, formation of social networks
3. Implementation of policies for application of information by government to meaningfully manage disparities in healthcare.
   Examples: wellness education policies, Medicaid reimbursement policies
4. Implementation (deployment) of personnel for interpretation of information by insurers to meaningfully manage safety of healthcare.
   Examples: data mining specialists

Figure 1: Ontology for Meaningful Use of Healthcare Information Systems (MUHIS).

formulated manually by the authors from the meaningful use outcomes, objectives, and measures (Centers for Medicare & Medicaid Services) and their knowledge of the structure and functions of an information systems. There is no computerized method for extracting such an ontology (a) at this level of granularity, (b) which is parsimonious (fits a letter size page with legible font), and (c) has high semantic validity (Kotis and Vouros, 2006) (each combination is a natural English sentence as explained below). During the formulation two of the authors iterated between abstraction of the framework from and its application(Ramaprasad and Mitroff, 1984) to the requirements until the model (a) was logically complete, and (b) covered all the objectives, requirements, and criteria. It is similar to the process described by Ramaprasad & Mitroff (1984) and Ramaprasad (1987) for the formulation of strategic problems.

The ontology has five columns representing the five dimensions of MUHIS; two of the dimensions together comprise the Health Information Systems. Each dimension is defined by a one- or two-level taxonomy. The dimensions are linked by words/phrases interleaved between the respective columns. The columns are ordered left to right such that the concatenation of a word from each column with the interleaved words/phrases results in a meaningful natural English sentence. Four such concatenated sentences are shown, with examples, at the bottom of Figure 1. In the following we will discuss the dimensions, the taxonomies, and the concatenations in greater detail.

2.1 Dimensions of the Ontology

The rightmost column is 'Outcome' and it lists the four critical healthcare outcomes which need to be meaningfully managed using HIS. They are efficiency, quality, and safety of healthcare and disparities in healthcare – a Core and Menu Set outcome (Centers for Medicare & Medicaid Services). There are many other Core and Menu Set outcomes. We interpret them as means to the four outcomes in the ontology. For example, consider the Core outcome to 'Engage patients and families in their healthcare'. In the ontology patients and families are stakeholders in achieving the desired healthcare outcomes using the Health Information System. Similarly, consider the Menu Set outcome to 'Improve population and public health' – the Population is a stakeholder receiving healthcare to achieve the desired outcomes. We have been able to relate all the present Stages 1 and 2 outcomes to the four outcomes. In the future, additional outcomes or subcategories of outcomes can be added, or some of the outcomes deleted for application to a particular context.

The second column from the right (Stakeholders) is a taxonomy of stakeholders in HIS. They are the recipients of healthcare (patients, families, and the population as a whole), the providers of healthcare (physicians, nurses, and pharmacists), payers for healthcare, employers of recipients, insurers of recipients, regulators of healthcare, and the government. The categories of stakeholders are not mutually exclusive – an entity may have multiple roles. For example, a recipient may also be a payer, and a self-insured employer may also be the insurer. The categories may not also be exhaustive – they may need to be extended or reduced. The present taxonomy is a generic, parsimonious list of stakeholders whose interests and roles in meaningfully managing the healthcare outcomes need to be considered.

The third and fourth columns (Structure, Function) from the right are the common structural and functional components of an information system. They have been adapted to the CMS terminology (Centers for Medicare & Medicaid Services). The structural components of HIS are the technology (hardware, software, and networks), processes, policies, and personnel. The functional components are acquisition, analysis, interpretation, application, and distribution of information.

The leftmost column (Management) lists the functions necessary to manage HIS to assure their meaningful use. These are common functions in the analysis, design, and assessment of any information system. They are analysis, specification, design, implementation, maintenance, and assessment; they have been derived from the HealthIT terminology (HealthIT.gov).

2.2 Illustrative Components

Each concatenation of words/phrases across the framework is a potential component of MUHIS. There are 3360 (6x4x5x7x4) level-1 and 7920 (6x6x5x11x4) level-2 components. We will focus our discussion on the level-1 components and subsume within them the details of the second level. Four level-1 components are listed at the bottom of Figure 1 with an example for each; they are discussed below.

First, consider 'Specification of technology for analysis of information by providers to meaningfully manage cost of healthcare.' This could include specification of cost-effective electronic health records software to provide the type of clinical decision support required by CMS for meaningful use. It could also include data mining software to be used by a large regional Health Maintenance Organization (HMO) to determine the most efficacious drugs for a commonly occurring chronic condition.

Second, consider 'Design of processes for acquisition of information by patients to meaningfully manage quality of healthcare.' It could include design of processes for online access of lab results (required by CMS in Stages 1 and 2), or processes to foster formation of social networks of cancer patients to acquire information from each other and form support groups.

Third, consider 'Implementation of policies for application of information by government to meaningfully manage disparities in healthcare.' It could include policies to transmit health data to government agencies, wellness education policies for those living in the 'food deserts', and reimbursement policies which help counter the imbalance due to socio-economic status.

Fourth, and last, consider 'Implementation (deployment) of personnel for interpretation of information by insurers to meaningfully manage safety of healthcare.' It could entail deployment of data mining specialists to discover early warnings about new potentially unsafe drugs.

Further, as shown in the examples, each component may be instantiated in multiple ways. The many instantiations constitute the MUHIS. We note that some components may not be instantiated at all in a given context. For example, without health insurance the fourth illustrative component above may be irrelevant. In general, the absence of instantiation may reflect either an error of omission (blind spot) or an irrelevant component (blank spot) in that context.

2.3 Validity of the Ontology

In assessing the validity of the framework we note that it is an ontology not the ontology for MUHIS; we recognize that there can be other equally valid frameworks. Each framework can be a lens to study the domain; each lens can offer different insights about the domain. Given that the MUHIS problem is complex and ill-structured, 'wicked' (Churchman, 1967), a singular ontology is unlikely. We offer a framework and its associated insights. It derives its validity from its (a) logical construction, (b) comprehensiveness, (c) interpretability, and (d) completeness.

First, the logic of the MUHIS ontology's dimensions can be deconstructed as follows:

Meaningful Use of Healthcare Information Systems = Meaningful Use + Healthcare Information Systems

Meaningful Use = Management + Stakeholders + Outcome

Healthcare Information Systems = Structure + Function

Thus, the dimensions comprehensively cover the connotation of MUHIS. They can be easily interpreted by a user.

Second, the categories of the taxonomy for each dimension are logical and generally accepted in the respective disciplines. Moreover, should a category or subcategory be missing from a taxonomy, it can be easily added. By the same token, a redundant category or subcategory can be easily removed. These corrections of potential errors of omission and commission will not invalidate the rest of the framework. Thus, the taxonomies of the dimensions are comprehensive and interpretable.

Third, the ordering of the dimensions fits the rules of English grammar – thus rendering the concatenations in natural English and making them meaningful and hence interpretable. Further, all the components (concatenations) encapsulated in the framework taken together provide a complete, closed description of MUHIS.

Fourth, and last, the parsimonious representation of the ontology provides a panoptic view of MUHIS which can be analyzed with minimal cognitive strain. A user can conveniently and meaningfully explore its dimensions, elements, and components at different levels of granularity.

Thus, we believe that the framework's face validity (Brennan et al., 2011), content validity (Brennan et al., 2011), systemic validity (Horn and Lee, 1989), and semantic validity (Kotis and Vouros, 2006) are high. It parsimoniously encapsulates the complexities of the system; it makes the MUHIS 'elephant' known and visible and hence can be used to map MUHIS systemically and systematically. It is a simple, powerful tool to synthesize and visualize the MUHIS knowledge domain, to analyze the accumulation of knowledge over time, and visualize its trajectory. It provides a holistic approach to visualize the map and guide the progress of a domain, for example, to answer the question: How can we continuously improve MUHIS? We explore these possibilities in the following.

3 METHOD

3.1 Mapping MUHIS Requirements

We mapped all the Stages 1 and 2 requirements onto the ontology through consensus mapping. The requirements were obtained from the CMS website (Centers for Medicare & Medicaid Services). Each objective was mapped individually, considering it in the context of the associated outcome and measures. The total number of objectives mapped = 51. All the objectives were first mapped by one author, reviewed and modified by the other, and the discrepancies between the two discussed and resolved in the final mapping. The mapping does not distinguish between the core and menu objectives, and those for eligible professionals, eligible hospitals, and CAHs (Critical Access Hospitals). We provide two examples of mapping in the following.

Consider the Stage 1 core objective of "Implement drug-drug and drug-allergy interaction checks." It is one of a set of objectives with the stated outcome of "Improving quality, safety, efficiency, and reducing health disparities." We mapped the objective for quality, safety, and efficiency outcomes but not for disparities; we could not see a direct link from the discussion of the objective and its measures to managing disparities. We mapped it to the ontology as: "Implementation of technology/processes for application of information by providers to meaningfully manage efficiency/quality/safety." We note that the objective corresponds to six components of the ontology, not just one.

Consider the Stage 2 core objective of “Provide patients the ability to view online, download and transmit their health information within four business days of the information being available to the EP.” Although the stated outcome of the objective is “Patient Electronic Access”, we inferred the ultimate outcome to be primarily quality. It could be efficiency and safety too, but we did not find sufficient evidence to justify them. We mapped the objective to the ontology as: “Implementation of technology for distribution of information by/to recipients/providers to meaningfully manage quality.” Again, we note that the objective corresponds to two components of the ontology.

Mapping the meaningful use objectives was straightforward in most cases. It required little interpretation except in the mapping the outcomes of a few objectives as illustrated above. The mapping was recorded on an Excel spreadsheet using one row per objective and a column per element of the ontology. All but 2 of the 51 objectives were mapped to all the five dimensions of the framework for a total of 65 full and 10 partial components.

3.2 Mapping MUHIS Practice

We mapped all the articles indexed in PubMed that contain the term "Meaningful Use" in the title/abstract and belong to the following MeSH major topics: "Medical Informatics", "Medical Records Systems, Computerized", "Electronic Prescribing", and "Computer Communication Networks". In addition, we also included articles specifically designated to MeSH major topic "Meaningful Use". The combined result was filtered by date (2009 – March 1, 2013) as well as the availability of abstract. We obtained a total of 200 articles. Of these, 43 were announcements, editorials, etc. and 7 were non-US. They were excluded from the study. The remaining 150 articles were mapped by the authors onto the ontology based on their titles and abstracts. Each article was mapped by one author and validated by the other. Differences in mapping between the two were resolved through discussion. As with the requirements an article could be coded (a) on all or some of the dimensions, and (b) into a single or multiple components of the framework. Of the 150 articles, 63 were coded on all the dimensions and 87 on a subset, for a total of 214 components and 1964 partial components. All the data were maintained and mapped on spreadsheets (Google Docs and Excel).

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS

4 RESULTS

4.1 Ontological Map of MUHIS Requirements

The ontological map of MUHIS requirements is shown in Figure 2. The elements correspond to the first level of the ontology. The number in parenthesis adjacent to each element is the frequency

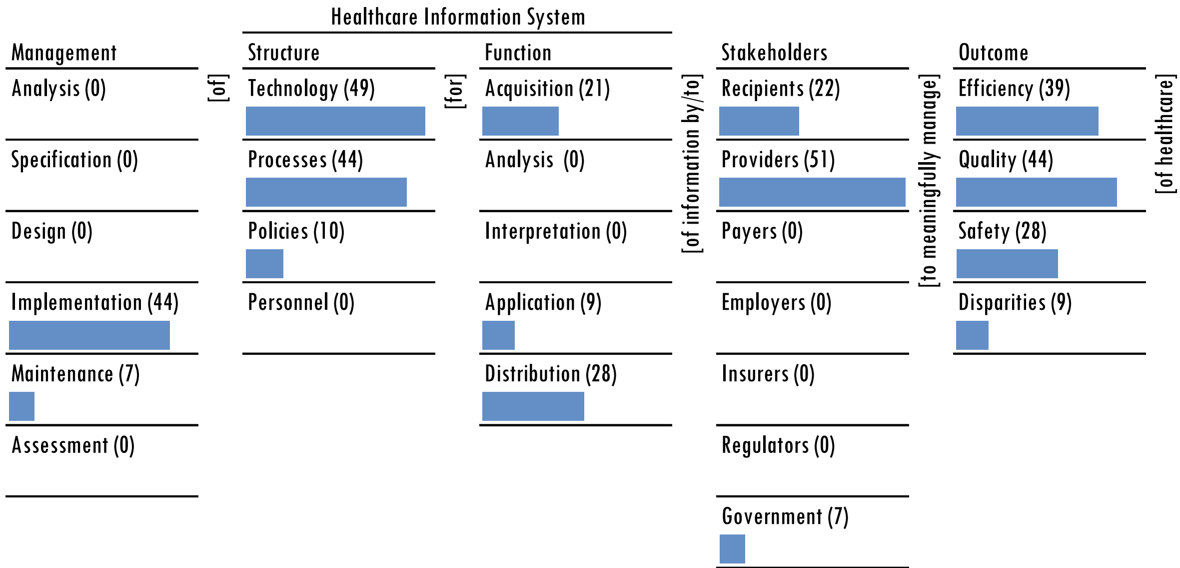

Figure 2: Ontological map of Stages 1 and 2 meaningful use requirements.

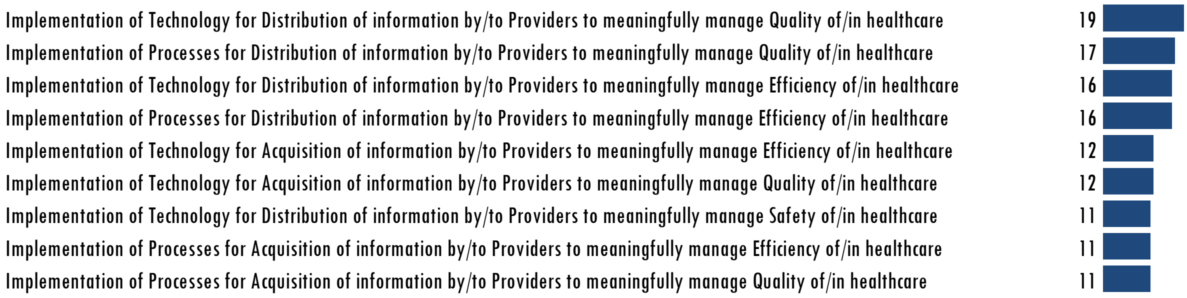

Figure 3: Partial histogram of Stages 1 and 2 meaningful use requirements.

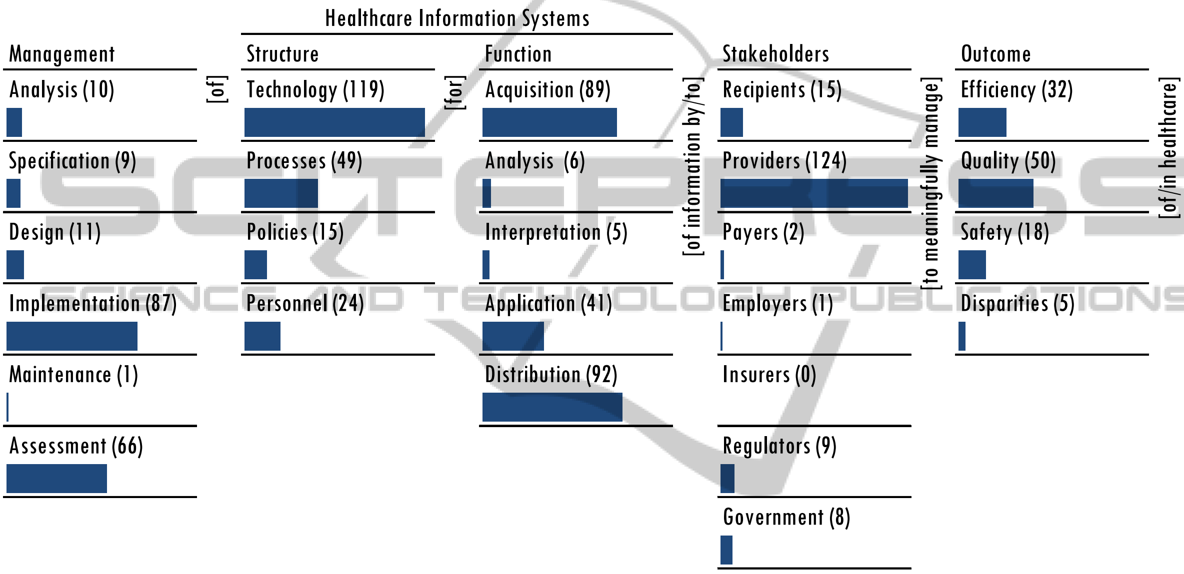

Figure 4: Ontological map of meaningful use practice.

of its occurrence in the set of objectives. The bar below the element is proportional to the frequency using the total number of objectives (51) as the denominator. The profile is very similar for Stages 1 and 2 requirements and hence they are not shown separately. The total frequency for elements in a column may exceed the total number of CMS objectives due to one to many mapping of objectives to components as illustrated and explained earlier.

The mosaic of the MUHIS requirements as a whole is evident from the ontological map. It has many bright spots (high frequency elements), light spots (low frequency elements), and blank/blind spots (no frequency elements). The no frequency elements may be 'blank' by choice or 'blind' by oversight – it cannot be resolved based on the data. The mosaic may be summarized in a complex sentence with higher frequency elements in bold and decreasing frequency left to right as follows:

> **Implementation**/ maintenance of **technology**/ **processes**/ policies for **distribution**/ **acquisition**/ application of information by/to **providers**/**recipients**/ government to meaningfully manage **quality**/**efficiency**/**safety**/disparities of healthcare.

The partial histogram of Stages 1 and 2 meaningful use requirements shown in Figure 3 highlights the most common components of the requirements using the structured construction of the ontology – the bright spots. On the left is the synthetic requirement based on the ontology, and on the right the total frequency of its occurrence and a proportional bar. As we have noted earlier, a CMS requirement may be deconstructed into multiple synthetic requirements. The full histogram (not shown due to space constraint) portrays the bright, light, and blank/blind spots at the component level, in contrast to the element level visualization in the ontological map.

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS

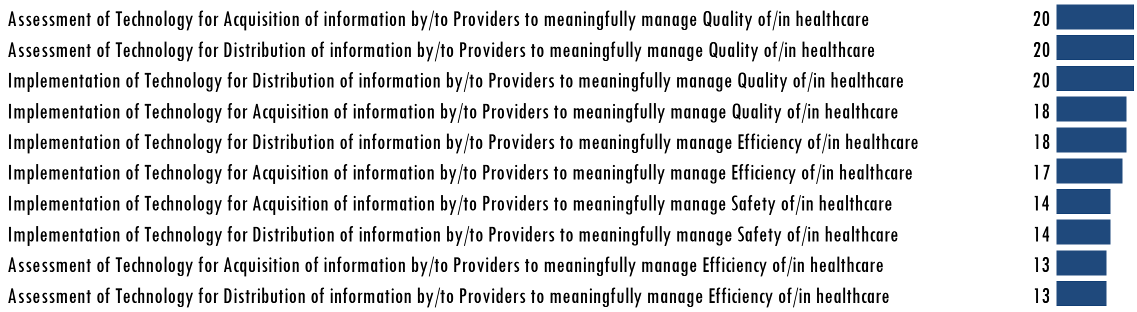

Figure 5: Partial histogram of meaningful use practice.

4.2 Ontological Map of MUHIS Practice

The ontological map of MUHIS practice mirrors that of the requirements, as one would expect, but with the following significant exceptions: (a) in Management there is a greater emphasis on Assessment and virtually no emphasis on Maintenance in practice; (b) in Structure, there is less emphasis on Processes and slightly more emphasis on Personnel in practice; and (c) among Stake holders there is less emphasis on Recipients in practice. The Function and the Outcome profiles of the requirements and practice are similar.

The mosaic of the MUHIS practice as a whole is evident from the ontological map. As with the map of requirements it has many bright spots, light spots, and blank/blind spots. The mosaic may be summarized in a complex sentence with higher frequency elements in bold and decreasing frequency left to right as follows:

> **Implementation**/ **assessment**/ design/ analysis/ specification/ maintenance of **technology**/ **processes**/ personnel/ policies for **distribution**/ **acquisition**/ application/ analysis/ interpretation of information by/to **providers**/ recipients/ government/ regulators/ payers/ insurers to meaningfully manage **quality/efficiency/safety**/disparities of healthcare.

The partial histogram of meaningful use practice shown in Figure 5 highlights the bright spots using the synthetic components of the ontology. Its construction is similar to Figure 3.

5 DISCUSSION

Words matter. The formulation of a problem can be inclusive or restrictive, depending on the choice of words and their connotations. We have formulated meaningful use inclusively in the MUHIS ontology (Figure 1). The Management dimension includes all the major steps of a system development cycle; the primary components of the Structure and Function of a Health Information System are incorporated; and so are all the key Stakeholders and Outcomes. Meaningful use should be 'meaningful' for all the stakeholders for all the key 'uses' (outcomes). The inclusive formulation makes the MUHIS 'elephant' fully visible – doing so can diminish the costs of fragmentation and drive the benefits of integration.

CMS has formulated meaningful use narrowly in its Stages 1 and 2 requirements, as shown in the ontological map in Figure 2. The narrow formulation may be driven by its mission – their primary site for MUHIS is 'HealthIT.gov' not 'HealthIS.gov', emphasizing technology not the system. It may be motivated by the strategy for implementation – to start where there may be greatest leverage and to proceed in stages. It may also be determined by their decisions about their role. They may see motivating recipients and providers as their role but not motivating payers and employers. Similarly, they may see motivating implementation as part of their role but not analysis, specification, and design – the latter could be the EMR vendors' role. Last, the similarity of Stages 1 and 2 maps suggest a continuity of focus. We cannot adduce the reasons for the map shown in Figure 2 and its continuity but we can assert that the Stages 1 and 2 requirements by themselves are unlikely to result in MUHIS in its panoptic connotation expressed in the ontology. The narrow formulation is likely to be suboptimal if not dysfunctional.

Consider the Stage 1 objective: 'Implement drug-drug and drug-allergy interaction checks'. These checks will directly affect the Quality and Safety (Crosson et al., 2012, Rahmner et al., 2012, Spina et al., 2011) Outcomes of healthcare (Classen et al., 2011). Their effectiveness will depend upon the providers' response to the alerts issued based on the checks. Recent Assessment shows that more than 90% of the alerts are overridden due to alert fatigue (Smithburger et al., 2011, Phansalkar et al., 2012b, Crosson et al., 2012), information overload (Callen et al., 2011), poor user interface Design (Seidling et al., 2011, Gaikwad et al., 2007, Rahmner et al., 2012), poor Specification of the critical interactions (Gaikwad et al., 2007), and inadequate Analysis (Phansalkar et al., 2012a, Takarabe et al., 2011) of the interactions. It will be necessary to include most of the blank elements in the map of Stages 1 and 2 (Figure 2) to improve the effectiveness of the checks. First, it would be necessary to Assess (Saverno et al., 2011, Warholak et al., 2011) the current system to provide feedback (Smithburger et al., 2011) for Analysis (Phansalkar et al., 2012a, Takarabe et al., 2011), Specification, and Design of the system. Second, the Assessment could be done internally by a provider, locally, or by a conference of all the Stakeholders (Phansalkar et al., 2012b, Phansalkar et al., 2012a, Hines et al., 2012). Third, any Assessment and feedback will entail extensive Analysis (Phansalkar et al., 2012a, Takarabe et al., 2011) and Interpretation (Dhabali et al., 2012) of empirical data (Haueis et al., 2011). Thus, the success of a large number of components encapsulated in the ontology will be essential for effectively implementing the 'drug-drug and drug-allergy interaction checks'. In absence of a systematic systemic (Saverno et al., 2011) perspective, the checks may be implemented but they may be meaningless, especially if they are overridden constantly (Yu et al., 2011).

6 CONCLUSIONS

The ontological maps and histograms provide clear visualizations of the gaps within each and between them. Some of these gaps definitely need to be bridged, as in the case of decision support for drug-drug and drug-allergy interactions. The policy makers and practitioners have to assess the importance of the other gaps and change requirements and practices to bridge them. This process of feedback and change has to be ongoing for continuous improvement of MUHIS. Ontological maps such as the ones presented in this paper can provide the foundations for visualizing the domain, monitoring the incremental changes, and making it complete and integrated.

In summary, we present an ontological meta-analysis and synthesis of MUHIS requirements and practice (Ramaprasad and Syn, 2013). It highlights the domain's bright spots which are heavily emphasized, the light spots which are lightly emphasized, the blank spots which are not emphasized, and the blind spots which have been overlooked. It also highlights the biases and asymmetries in MUHIS requirements and practice; they can be realigned to make them stronger and more effective.

As we have emphasized earlier our ontology is one lens through which one can study MUHIS. There can be other equally valid frameworks. Each lens will likely yield a different map and thus different insights into the bright, light, and blank/blind spots. Each of these sets of insights will be a product of observing the phenomenon systematically through a systemic framework, of a different way of making the 'elephant' visible. Reconciling these differences, in addition to changing the map of each will advance knowledge of MUHIS and can set the research/practice agenda for the domain.

The ontology is extensible and reducible, and hence the method is adaptable to the developments in MUHIS. Should a new Function or Stakeholder of MUHIS emerge in the future, they can be added to the framework. Or, should a new subcategory of Providers becomes a key Stakeholder, the framework can be extended to accommodate the change. By the same token, if a category becomes irrelevant, it could be eliminated from consideration. The extensibility and reducibility will also help trace the evolution of the constructs in and the logic of MUHIS.

Last, but not the least, visualization is key to making sense of and interpreting 'big text data' like the emerging requirements and practice of MUHIS. The ontology provides an easy and intuitively understandable vehicle for visualization. Note, for example, the ontological maps can be used to study the evolution of MUHIS over time by creating maps for different cross-sections of time. It can also be used to study the map at different levels of granularity using more refined/coarsened taxonomies. These are works in progress. Feedback based on incremental ontological maps will help to continuously improve MUHIS. With the current ontological map of MUHIS requirements and practice it is unlikely that the full vision of meaningful use will be realized – they have to evolve a lot.

The evolution has to balance the emphasis on the categories, dimensions, and components of the ontology. It has to balance the bright, light, blank, and blind spots. Following are three examples:

- The emphasis on the Stakeholders has to be balanced. All the stakeholders, individually and in interaction with each other, collectively affect the outcome.
- With the increasing role of 'big data' and data mining in healthcare the low emphasis on Analysis and Interpretation will likely have to increased significantly
- Meaningful Use is itself a dynamic concept which will evolve with time. MUHIS too has to be equally dynamic. To do so the emphasis on Analysis, Specification, Design, and Maintenance (in Management) will have to be increased considerably.

The ontological map can guide the evolution.

REFERENCES

Börner, K., Chen, C. & Boyack, K. W. 2003. Visualizing knowledge domains. *Annual Review of Information Science and Technology,* 37**,** 179-255.

Brennan, L., Voros, J. & Brady, E. 2011. Paradigms at play and implications for validity in social marketing research. *Journal of Social Marketing,* 1**,** 3-3.

Callen, J. L., Westbrook, J. I., Georgiou, A. & Li, J. 2011. Failure to Follow-Up Test Results for Ambulatory Patients: A Systematic Review. *Journal of General Internal Medicine,* 27**,** 1334-1348.

Centers for Medicare & Medicaid Services. *Meaningful Use* (Online). Available: https://www.cms.gov/ Regulations-and-Guidance/ Legislation/EHRIncentivePrograms/Meaningful_Use. html.

Churchman, C. W. 1967. Wicked Problems. *Management Science,* 14**,** B-141.

Cimino, J. J. 2006. In defense of the Desiderata. *Journal of Biomedical Informatics,* 39**,** 299-306.

Classen, D. C., Phansalkar, S. & Bates, D. W. 2011. Critical drug-drug interactions for use in electronic health records systems with computerized physician order entry: review of leading approaches. *Journal of Patient Safety,* 7**,** 61-65.

Crosson, J. C., Schueth, A. J., Isaacson, N. & Bell, D. S. 2012. Early adopters of electronic prescribing struggle to make meaningful use of formulary checks and medication history documentation. *The Journal of the American Board of Family Medicine,* 25**,** 24-32.

Dermer, M. & Morgan, M. 2010. Certification of primary care electronic medical records: lessons learned from Canada. *J Healthc Inf Manag,* 24**,** 49-55.

Dhabali, A. A. H., Awang, R. & Zyoud, S. H. 2012. Clinically important drug–drug interactions in primary care. *Journal of clinical pharmacy and therapeutics*.

Fensel, D. 2003. *Ontologies: A Silver Bullet for Knowledge Management and Electronic Commerce*, Springer.

Gaikwad, R., Sketris, I., Shepherd, M. & Duffy, J. 2007. Evaluation of accuracy of drug interaction alerts triggered by two electronic medical record systems in primary healthcare. *Health informatics journal,* 13**,** 163-177.

Gruber, T. R. 1995. Toward Principles for the Design of Ontologies Used for Knowledge Sharing. *International Journal Human-Computer Studies,* 43**,** 907-928.

Gruber, T. R. 2008. Ontology. *In:* LIU, L. & OZSU, M. T. (eds.) *Encyclopedia of Database Systems.* Springer-Verlag.

Haueis, P., Greil, W., Huber, M., Grohmann, R., Kullak-Ublick, G. A. & Russmann, S. 2011. Evaluation of drug interactions in a large sample of psychiatric inpatients: a data interface for mass analysis with clinical decision support software. *Clinical Pharmacology & Therapeutics,* 90**,** 588-596.

HealthIT.gov. Available: http://www.healthit.gov/ providers-professionals.

Hines, L. E., Malone, D. C. & Murphy, J. E. 2012. Recommendations for Generating, Evaluating, and Implementing Drug□Drug Interaction Evidence. *Pharmacotherapy: The Journal of Human Pharmacology and Drug Therapy,* 32**,** 304-313.

Hoeffner, L. & Smiraglia, R. 2013. Visualizing Domain Coherence: Social Informatics as a Case Study. *Advances In Classification Research Online,* 23**,** 49-51.

Horn, B. R. & Lee, I. H. Toward integrated interdisciplinary information and communication sciences: a general systems perspective. Proceedings of the Hawaii International Conference on System Sciences, 1989 Hawaii. IEEE, 244-255 vol. 4.

Kazimierczak, K. A., Skea, Z. C., Dixon-Woods, M., Entwistle, V. A., Feldman-Stewart, D., N'Dow, J. M. O. & MacLennan, S. J. 2012. Provision of cancer information as a "support for navigating the knowledge landscape": Findings from a critical interpretive literature synthesis. *European Journal of Oncology Nursing***,** 1-10.

Ke, W. C., Hsieh, Y. C., Chen, Y. C., Lin, E. T. & Chiu, H. W. 2012. Trend analysis and future development of Taiwan electronic medical records. *Stud Health Technol Inform,* 180**,** 1230-2.

Kim, H. & Kim, S. 2012. Legislation direction for implementation of health information exchange in Korea. *Asia Pac J Public Health,* 24**,** 880-6.

Kotis, K. & Vouros, G. 2006. Human-centered ontology engineering: The HCOME methodology. *Knowledge and Information Systems,* 10**,** 109-131.

Kriglstein, S. & Wallner, G. 2013. Human Centered Design in Practice: A Case Study with the Ontology Visualization Tool Knoocks. *In:* CSURKA, G., KRAUS, M., MESTETSKIY, L., RICHARD, P. & BRAZ, J. (eds.) *Computer Vision, Imaging and Computer Graphics. Theory and Applications.* Springer Berlin Heidelberg.

Noar, S. M. & Zimmerman, R. S. 2005. Health Behavior Theory and cumulative knowledge regarding health behaviors: are we moving in the right direction?

Health Education Research, 20**,** 275-290.

Phansalkar, S., Desai, A. A., Bell, D., Yoshida, E., Doole, J., Czochanski, M., Middleton, B. & Bates, D. W. 2012a. High-priority drug–drug interactions for use in electronic health records. *Journal of the American Medical Informatics Association,* 19**,** 735-743.

Phansalkar, S., van der Sijs, H., Tucker, A. D., Desai, A. A., Bell, D. S., Teich, J. M., Middleton, B. & Bates, D. W. 2012b. Drug–drug interactions that should be non-interruptive in order to reduce alert fatigue in electronic health records. *Journal of the American Medical Informatics Association*.

Quine, W. V. O. 1961. *From a Logical Point of View,* Boston, MA, USA, Harvard University Press.

Rahmner, P. B., Eiermann, B., Korkmaz, S., Gustafsson, L. L., Gruvén, M., Maxwell, S., Eichle, H.-G. & Vég, A. 2012. Physicians' reported needs of drug information at point of care in Sweden. *British Journal of Clinical Pharmacology,* 73**,** 115-125.

Ramaprasad, A. 1979. Role of Feedback in Organizational-Change - Review and Redefinition. *Cybernetica,* 22**,** 105-113.

Ramaprasad, A. 1983. On the Definition of Feedback. *Behavioral Science,* 28**,** 4-13.

Ramaprasad, A. 1987. Cognitive Process as a Basis for MIS and DSS Design. *Management Science,* 33**,** 139-148.

Ramaprasad, A. & Mitroff, I. I. 1984. On Formulating Strategic Problems. *Academy of Management Review,* 9**,** 597-605.

Ramaprasad, A. & Syn, T. 2013. Ontological Meta-Analysis and Synthesis. *Proceedings of the Nineteenth Americas Conference on Information Systems, Chicago, Illinois, August 15-17, 2013.*

Ramaprasad, A., Valenta, A. L. & Brooks, I. 2009. Clinical and Translational Science Informatics: Translating Information to Transform Health Care. *In:* AZEVEDO, L. & LONDRAL, A. R. (eds.) *Proceedings of HEALTHINF 2009 – Second International Conference on Health Informatics.* Porto, Portugal: INSTICC Press.

Saverno, K. R., Hines, L. E., Warholak, T. L., Grizzle, A. J., Babits, L., Clark, C., Taylor, A. M. & Malone, D. C. 2011. Ability of pharmacy clinical decision-support software to alert users about clinically important drug–drug interactions. *Journal of the American Medical Informatics Association,* 18**,** 32-37.

Scharnhorst, A. 2001. Constructing Knowledge Landscapes Within the Framework of Geometrically Oriented Evolutionary Theories. *In:* MATHIES, M., MALCHOW, H. & KRIZ, J. (eds.) *Inegrative Systems Approaches to Natural Social Dynamics.* http://www.virtualknowledgestudio.nl/staff/andrea-scharnhorst/documents/constructing- knowledge-landscapes.pdf: Springer.

Seidling, H. M., Phansalkar, S., Seger, D. L., Paterno, M. D., Shaykevich, S., Haefeli, W. E. & Bates, D. W. 2011. Factors influencing alert acceptance: a novel approach for predicting the success of clinical decision support. *Journal of the American Medical Informatics Association,* 18**,** 479-484.

Smithburger, P. L., Buckley, M. S., Bejian, S., Burenheide, K. & Kane-Gill, S. L. 2011. A critical evaluation of clinical decision support for the detection of drug-drug interactions. *Expert Opinion on Drug Safety,* 10**,** 871-882.

Spina, J. R., Glassman, P. A., Simon, B., Lanto, A., Lee, M., Cunningham, F. & Good, C. B. 2011. Potential Safety Gaps in Order Entry and Automated Drug Alerts: A Nationwide Survey of VA Physician Self-Reported Practices With Computerized Order Entry. *Medical Care,* 49**,** 904-910.

Syed, K., Kröll, M., Sabol, V., Scharl, A., Gindl, S., Granitzer, M. & Weichselbraun, A. 2012. Dynamic Topography Information Landscapes–An Incremental Approach to Visual Knowledge Discovery. *Data Warehousing and Knowledge Discovery***,** 352-363.

Takarabe, M., Shigemizu, D., Kotera, M., Goto, S. & Kanehisa, M. 2011. Network-Based Analysis and Characterization of Adverse Drug–Drug Interactions. *Journal of chemical information and modeling,* 51**,** 2977-2985.

Varroud-Vial, M. 2011. Improving diabetes management with electronic medical records. *Diabetes Metab,* 37 Suppl 4**,** S48-52.

Warholak, T. L., Hines, L. E., Saverno, K. R., Grizzle, A. J. & Malone, D. C. 2011. Assessment tool for pharmacy drug–drug interaction software. *Journal of the American Pharmacists Association,* 51**,** 418-424.

Yu, D. T., Seger, D. L., Lasser, K. E., Karson, A. S., Fiskio, J. M., Seger, A. C. & Bates, D. W. 2011. Impact of implementing alerts about medication black□box warnings in electronic health records. *Pharmacoepidemiology and drug safety,* 20**,** 192-202.

Zhang, J., Xie, J., Hou, W., Tu, X., Xu, J., Song, F., Wang, Z. & Lu, Z. 2012. Mapping the Knowledge Structure of Research on Patient Adherence: Knowledge Domain Visualization Based Co-Word Analysis and Social Network Analysis. *PLoS ONE,* 7.

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS