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Interoperability Analysis Framework: Guiding Systems Integration in Radiology Context

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Abstract. In modern healthcare environment, information systems integration has become one of the key aspects that enable different health information systems work collaboratively in order to increase efficiency and lower burden of healthcare staff. In this sense, interoperability plays a vital role that determines the extent of this collaboration. In order to achieve higher interoperability, increasing use of integration approaches and interoperability measurements significantly facilitates the collaboration across healthcare information systems. However, our previous study revealed that a large number of integration projects facing difficulties because of the complexity of the domain due to human and technical factors, multi-stakeholder involved, and multidisciplinary nature of the problems. The radiology context is one of the areas that requires multi systems collaborations, and highly relies on effective communications among departments. Many barriers should be overcome towards a successful integration. In order to remove those barriers for establishing a better understanding of information exchange and interpretation, and to deal with the complexity in healthcare environment, this paper is to conduct an interoperability analysis of systems integration in the radiology context, and to purpose an interoperability analysis framework for guiding the systems integration.

Keywords: Systems Integration, Interoperability, Integration Approach, Radiology, Integration Requirement.

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1. Introduction

In modern healthcare environment, information systems integration has became one of the key aspects that enable different health information systems work collaboratively in order to increase efficiency and lower burden of healthcare staff. In this sense, interoperability plays a vital role that determines the extent of this collaboration. In order to achieve higher interoperability, increasing use of integration approaches and interoperability measurements significantly facilitates the collaboration across healthcare information systems. However, our previous study revealed that a large number of integration projects facing difficulties because of the complexity of the domain due to human and technical factors, multi-stakeholder involved, and multidisciplinary nature of the problems (Liu et al., 2014). The radiology department in hospital is one of the areas that requires multi systems collaborations, and highly relies on effective communications among departments. Many barriers should be overcome towards a successful integration. For example, the clinicians and the radiologist were normally located in different rooms, and their collaboration takes place asynchronously at most of the time, which cause the issue of information collaboration. Besides, nowadays hospitals tend to purchase their systems via various venders, who remained their competitiveness by selling only one type of systems or focusing on one specific function. This result in that the stakeholders get frustrated more often because the communication of patient's data/information fails among various information systems. The radiology department also has semantic issues because systems does not share the same ontologies; and several policy obstacles because the integration cuts across political boundaries causing changes (e.g. internal control process, work flow, staff relationships, communication patterns) in organisations (Kim and Michelman, 1990). Other barriers such as internal and external pressures, IT sophistication, and patient satisfaction have also brought much research attentions towards information systems integration in the radiology context.

In order to help establish a better understanding of information exchange and interpretation, and to deal with the complexity in healthcare environment, this study is to conduct an interoperability analysis of systems integration in radiology context, and to purpose an interoperability analysis framework for guiding the systems integration. The next section briefs background of this study including theory of organisational semiotics, and the radiology context of our study. Section 3 introduces the research approach of this study including data collection methods, and interoperability analysis process. Section 4 firstly investigates the interoperability problems in the radiology context from organisational semiotic perspective, and then articulates the interoperability barriers towards the radiology systems integration by using problem articulation method. Section 5 represents the results of the interoperability analysis including integration requirements, integration approaches, and interoperability measurements in radiology context. Section 6 purposes an interoperability analysis framework for guiding the systems integration, and discusses the supporting knowledge foundations. Section 7 ends with conclusion and discussion of future work.

2. Background

2.1 Organisational semiotics in information systems integration

Semiotics, as a discipline related to human communication, is the study of signs, their function and effect. It provides a sound theoretical foundation for understanding of the nature and characteristics of the sign-based communication. Organisational semiotics, as a branch of semiotics particularly related to organisations, is the study of the use of signs and information in organisational settings. Organisational semiotics provides a holistic view about signs, information, systems and organisations. An organisation can be seen as an information system where information is created, stored, and processed for communication and coordination and for achieving the organisational objectives. Information systems integration can be seen as a series of semiosis where different stakeholders are involved (Liu et al., 2002). The semiotic framework (Filipe, 2000; Liu, 2000; Stamper, 1973) that explains all aspects of how signs can be used and communicated for successful communication, determines the level of interoperability of information systems integration. Therefore we say systems are integrated at a certain interoperability level if signs among systems are successfully communicated at a certain semiotic framework level. Physical level is concerned with the physical connection and transmission channel in sign communication. Empiric level is concerned with the matching of coding and decoding between sign sender and receiver based on statistical properties of information. Syntactic level is concerned with rules of composing complex signs from simple ones. Semantic level is concerned with the meaning of signs. Pragmatics level ensures that processes supported by the systems in individual contexts can be aggregated to achieve the overall intended purpose. Social level ensures that the resultant interoperable systems should be coherent with the social commitment, obligation and norms in the organisation and support organisation's strategy, vision and objectives.

2.2 Radiology context

The study was conducted over a one year's period at a local hospital, one of the largest general hospital foundation trusts in the UK. The on-going project is to achieve data sharing and interoperability among Radiology Information Systems (RIS), Electronic Patient Record (EPR), and Picture Archiving and Communication Systems (PACS). The Radiology department provides diagnostic and interventional radiology for inpatients, outpatients and general practitioner referrals. Various healthcare services such as Computed Radiography (CR), Computed Tomography (CT), X-ray, and Interventional Radiology produce a huge amount of information regarding patient's healthcare delivery and clinical process. Hence a stable integration would enable their communication with each other become more efficiently within their IT infrastructure, and also eliminate costly point-to-point connections and manual-input processes.

3. Research Approach

This study adopts a qualitative research approach including various techniques (Yin, 2003). During the data collection process, we reviewed the most up-to-date working documents published by the hospital, and conducted an observation regarding the clinical process, and healthcare service delivery, and interviewed 54 department members. The hospital provides us positive support, because they were also very interested in interoperability of their radiology information systems.

3.1 Data collection

As mentioned we collected data by using the methods of documentation & literature, interviews, and observations (Gillham, 2000).

- Documentation & Literature： The documentation included literature review covering research publications, official reports, and working papers from the hospital. The research publications were sourced from several electronic databases in terms of information systems, and health informatics. The official reports were sourced from HSCIC (Health & Social Care Information Centre), which is one of the biggest NHS supported health informatics databases. The working papers were provided by the hospital IT services department.
- Observations： We conducted non-participant observations including radiology work processes, staff routine, individual activities (e.g. data entry, medication order), technologies/techniques used for integration, and methods used for interoperability measurements.
- Interviews ： 54 semi-structured interviews were conducted with relevant stakeholders including 13 radiologists, 16 referring clinicians, 13 radiographers, 6 directors of IT services, 4 receptionists, and 2 radiology secretary. The interviews lasted around 40 minutes and were on a one-to-one basis. The interviews were tape-recorded and later transcribed and rendered anonymously

3.2 Interoperability analysis process

In the radiology context, the context itself and its information systems are complex, artificial, and purposefully designed. They require integrated features as well as alignments between the processes and the system functions. Therefore, we analyse interoperability according to information system design research paradigm (Hevner et al., 2004). By following this paradigm, we develop the interoperability analysis process (depicted in figure 1) for articulating interoperability problems, indicating integration requirements, integration approaches, and interoperability measurements in radiology context in order to guide the systems integration.

In our interoperability analysis process, the first phase is interoperability problem articulation.

It is developed by using the Problem Articulation Method (PAM), which is used for analysis and design of information systems based on organisational semiotics (Liu, 2000; Stamper, 1973). This phase addresses ambiguity and identifies interoperability problems of systems integration. The second phase is interoperability analysis, which composed of three steps: integration requirements, integration approaches, and interoperability measurements. The step of integration requirements defines the problem space, which composed of goals, tasks, needs, and challenges for achieving interoperability level. The step of integration approaches is defined as methods and techniques that solve the interoperability problems and barriers, as well as span boundaries of interoperations among information systems. The step of interoperability measurement involves activities that assess the status of interoperability of existing information systems, with the purpose of identifying interoperability gaps for further improvement. The results of the interoperability analysis compose the body of the third phase, which is the guideline for systems integration in radiology context. The guideline adds knowledge foundations, which include theories, concepts, definitions, and constructs that reveal the nature of interoperability and support the phases of integration requirements and integration approaches.

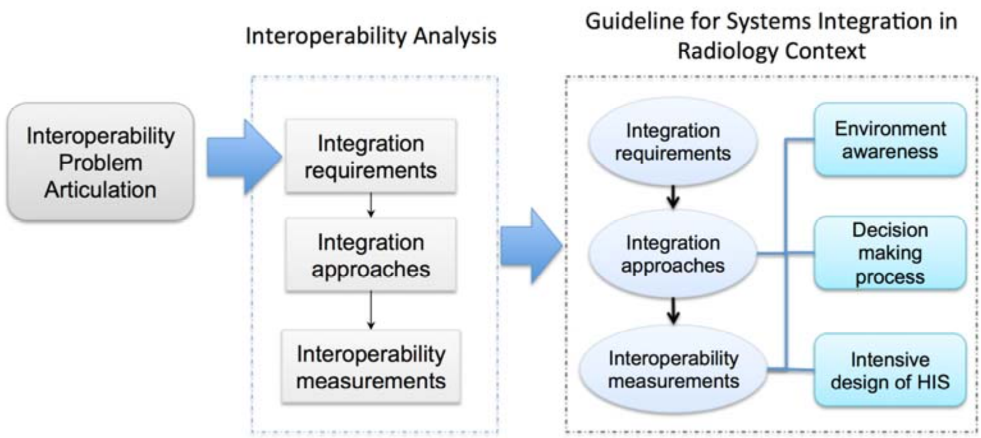

Fig. 1: Interoperability analysis process

4. Interoperability Problem Articulation

4.1 An Organisational Semiotic Perspective of Radiology Systems Integration

As mentioned organisational semiotics provides a holistic view about signs, information, systems and organisations. Hence we see the radiology department in hospital as an information system where information is exchanged for supporting collaboration of different information systems. The semiotic framework (Liu, 2000; Stamper, 1973) explains all aspects determining the level of interoperability of information systems integration. Based on the semiotic framework, we investigate the interoperability in radiology context from the six levels.

- Physical level is concerned with the physical connection and transmission channel in data communication among radiology information systems. It involves hardware, devices, networks etc.
- Empiric level is concerned with the matching of coding scheme, protocol, and transmission channel between radiology information systems.
- Syntactic level is concerned with the matching of data format, using languages, and data structure between radiology information systems.
- Semantic level is concerned with the matching of understanding of readings, interpretation of data, and shared ontologies between using systems and databases.
- Pragmatics level is concerned with the aggregation and optimisation of various clinical processes, in order to achieve intended purposes of different radiology information systems.
- Social level is concerned with coherence between the information systems and its social commitments, clinical obligations, and organisational culture.

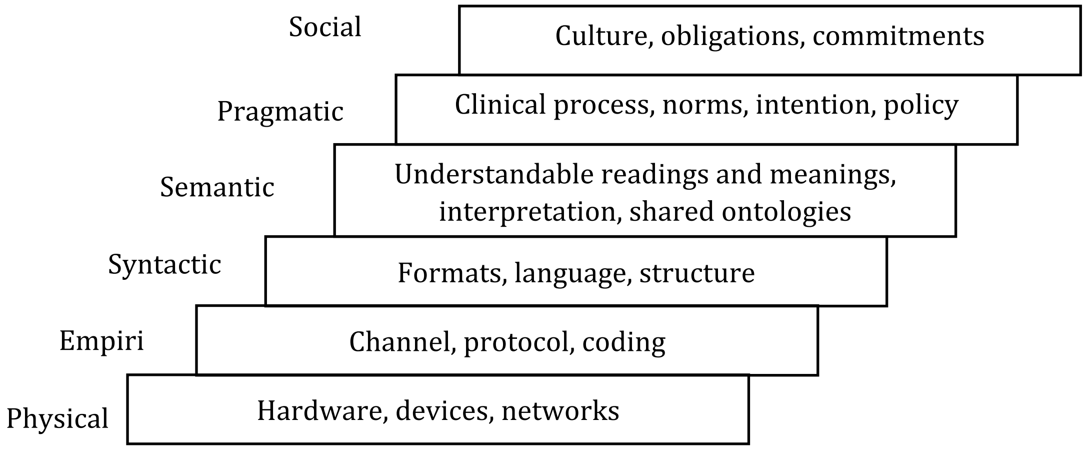

Fig. 2: Organisational semiotic perspective of radiology context (based on (Liu, 2000; Stamper, 1973))

The Radiology department in hospital can be seen as a complex sign system. Organisational semiotics can help to understand the relationships between the stakeholders and the environment. Methods and techniques developed from organisational semiotics can be used to understand the key aspects of interoperability at each level, which can lead the identification of interoperability problems. In the next section, we used those methods during data analysis and summarise the interoperability barriers towards radiology systems integration at each level.

4.2 Interoperability Barriers towards Radiology Systems Integration

We analyse the data collected from interviews, observations and working publications of hospital, and summarise the key interoperability barriers towards radiology systems integration at levels of physical, empiric, syntactic, semantic, pragmatic, and social. The following table presents the barriers and brief explanations.

Table 1: Interoperability barriers towards systems integration in radiology context

Social	Organisational issue	Different processes, management approaches, goals, legislations, cultures, and methods of work
	Responsibility	Responsibilities of different department to be defined explicitly
	Organisation	Centralised, decentralised, hierarchical, matrix, networked,

	structure	etc.
	Authority	Defines who is authorised to make clinical decisions
	Harmonized strategy	Aligned operations to be applicable on the strategic level
	Culture issue	Tacit knowledge has not been explicitly stated and shared
	Ethical issue	Appropriateness of taking actions on healthcare service delivery
	Performance constraints	Fewer investment but more effective collaboration
	Behavioural factor	Willingness to be open and to share
	Collaborative constraints	Leadership style influencing the degree of willingness of collaboration
	Cost constraints	Unexpected budget
Pragmatic	Data source interoperability	Multiple data sources (e.g. RIS, EPR, PACS) used for supporting clinical process
	Policy and procedure	Internal control process, work flow, staff relationships, communication patterns, cut-across political boundaries, etc.
	Restriction to staff behaviour	Medical staff's fear on information systems integration as restriction that might control their behaviour
	Information collaboration	Clinicians and radiologists located in different rooms, thus communication takes place asynchronously
	Varieties of purchased systems	Hospital purchased systems from various venders, which cause information communication failures
	Privacy and security	Sensitive information of patient to be protected by law
Semantic	Semantic heterogeneity	Refers to the variation of semantic meaning in information resources which will lead to the semantic conflicts and complication for data integration
	Ontology structure	Approaches that employ ontologies for information systems
	Operation/system language	The language using in both systems
	Ambiguous terminology	Differences in the use of terms across departments
Syntactic	Data representation	Contains various data representation methods such as ASCII, EBCDIC, and XML etc.
	Structure	Means that the same data will be described in different

	heterogeneity	structures by different systems because of various application systems, DBMS and operating systems
Empiric	Data link layer	Contains several functions such as framing, physical addressing, flow control, error control, access control, and media access control
	Protocol architecture	Concerns with different types of protocol architectures
	Network layer	Concerns with network routing functions such as sub-network, addressing algorithm
	Segmentation and reassembly	Refers to the process used to fragment and reassemble variable length packets into fixed length cells so as to allow them to be transported across Asynchronous Transfer Mode networks or other cell based infrastructures
	Error recovery	Allows a system administrator to configure the amount of time a drive's firmware is allowed to spend recovering from a read or write error
	Reinitiate connection	Refers to the speed and frequency responding failure of connection
	Explicit flow control	Refers to the order in which the individual statements, instructions or function calls of an imperative or a declarative program are executed or evaluated
	System overload	Is placed in a queue and is then transmitted when capacity is available, and can be measured with the sum of the messages remaining in queues
Physical	Device selection	This includes the layout of pins, voltages, line impedance, cable specifications, signal timing, hubs, repeaters, network adapters etc.
	Capacity	Is the rate at which data may be passed over time, a maximum data rate can be calculated with the operating parameters
	Connectivity	Is the representative of network connectivity and can be measured by counting the number of message initiated and the number of messages received

5. Interoperability Analysis in Radiology Context

In the previous section, we have identified the key barriers that should be overcome in order to successfully integrate information systems. The barriers at each level can lead to the requirements for each interoperability level. To meet those requirements, integration approaches such as EAI (Enterprise Application Integration), HL7 (Health Level 7), and developing web-based system have been adopted to enable systems integration. The step of integration approaches is defined as methods and techniques that solve the interoperability problems and barriers, as well as span boundaries of interoperations among information systems. Thus in following sections, we examine up-to-date approaches used for improving integration, and critically discussed the integration approaches as well as interoperability measurements adopted by the radiology department.

5.1. Integration Approaches

Results from our analysis of collected data identified the major approaches and techniques that the radiology department adopted. As the hospital consider the healthcare community as a whole, thereby its strategy aims to integrate RIS, PACS, and EPR together for supporting sharing among clinicians, radiologists, and sometimes other facilities and patients. The hospital chose EAI methodology for the integration, and used HL7 standard for exchanging documents with information systems. The whole infrastructure is delivered including several objectives: 1) to develop a central database that support information transmission between stakeholders and the data repository system; 2) to develop a web-based system for delivering applications, data, and processes; and 3) to build an integral security and navigation model for use of EPR. The objectives help to establish a best-practice approach for integration, which is a critical consideration for the better utilization of the existing information systems. The selection of integration approaches is based on the framework purposed by Themistocleous et al. (2001), which evaluates the EAI integration technologies and packages. Originally, the interviewees identified selection criteria are security, process support, confidentiality, real-time integration, flexibility, and customization. After learning the framework, they reflected that the framework covers the broader categories of the criteria, and delivers the tool for integration approaches selection. They also justified their selection with several benefits of EAI approach based on the classification model developed by Shang and Seddon (2002). Those benefits can be grouped as operational, managerial, strategic, IT infrastructure, and organisational dimensions.

HL7 is selected as the standard for exchanging information with information systems. It has been widely used in healthcare environment, and represents the foundation of many healthcare information management systems. The selection of the standards is based on the evaluation framework developed by Kitsiou et al. (2006), which defines seven criteria (i.e. reliability, scalability, heterogeneity, flexibility, reusability, complexity, maturity) for comparing the four major standards (i.e. HL7, CORBA, DCIOM, CEN/TC) used in information systems integration. The interviewees reflect that key characteristics such as reliability, complexity, and maturity are the critical consideration in selection. Thus they chose HL7 as it performs the most outstanding comparing with others.

5.2. Interoperability measurements

Interoperability measurement involves activities that assess the status of interoperability of existing information systems, with the purpose of identifying interoperability gaps for further improvement. A great amount of interoperability evaluation frameworks such as LISI (Levels of Information Systems Interoperability), OIM (Operational Interoperability Model), LCM (Levels of Conceptual Interoperability Model), and EIF (European Interoperability Framework) have been purposed during the past three decades. The selection of interoperability measurements is based on our developed comparative analysis of the existing interoperability measurements (Liu et al., 2013).

The NEHTA Interoperability Framework (NEHTA, 2005) has been chosen for the Radiology department. It aids to measure three levels of interoperability: 1) organisation, 2) information, and 3) technical, in order to support delivery of interoperability across departments. The organisational level focuses on the understanding of the rules, norms, policy, regulatory, legislative and environment in which information systems need to be deployed to support healthcare delivery. The information level focuses on representations and interpretations of clinical knowledge, work flow, processes, administrative and statistical information. The technical level is concerned with the understanding of technical functionality for supporting information systems. The NEHTA Interoperability Framework provides a holistic view for assessing the interoperability of the integration in radiology context, but is mainly from a qualitative perspective. The Radiology department also adopts another method for quantitative measurements. The Interoperability Assessment purposed by Leite (1998) develops a set of mathematical equations for addressing several issues of interoperability such as system capacity, system overload, underutilisation, and data latency. The methods also set criteria such as quality, time, and cost that can be quantified for measuring interoperability. The numerical results would help provide more empirical evidences that support the integration. However, the results cannot be collected at this stage as the project is still in progress. The whole process of interoperability measurements including data from both interviews and mathematical assessment will be completed once the project is finished.

6. Interoperability Analysis Framework for Systems Integration in Radiology Context

The results from the interoperability analysis in radiology context indicate key requirements at different levels, and the major integration approaches and interoperability measurements using in for systems integration. However, in order to guide the integration and improve its interoperability, there are other factors should be considered such as environment awareness, decision making process, etc. Therefore, based on the results, we develop an interoperability analysis framework that provides a guideline for the systems integration.

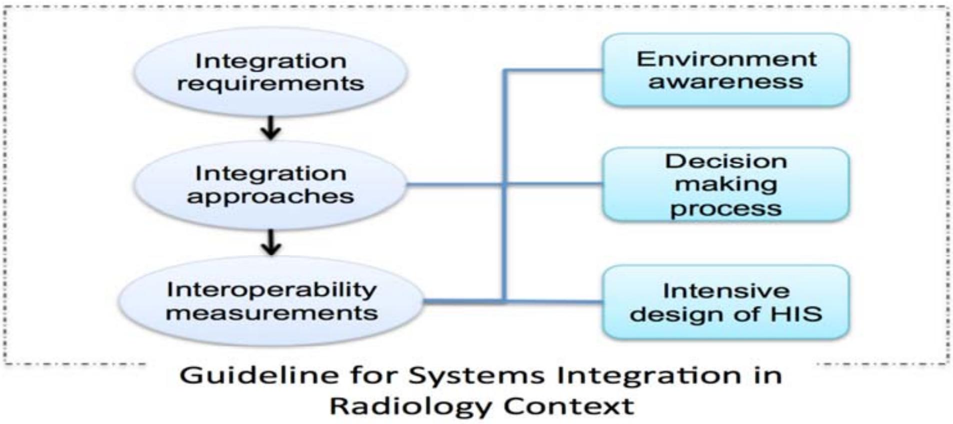

Fig. 2: Interoperability analysis framework

In the framework, the current status of systems integration in radiology context including integration requirements, using integration approaches and interoperability measurements are indicated. Besides, three key factors (environment awareness, decision making, and HIS design) play the roles of supporting elements that aid to improve selection of integration approaches and interoperability measurements. As discussed the radiology department has realised the key requirements for integration, and has selected EAI methodology and HL7 standard as the integration approaches for addressing those identified barriers. To assess the interoperability, the radiology department decides to choose the NEHTA interoperability framework for qualitative assessment, and the interoperability assessment developed by Leite (1998) for quantitative assessment. In order to more effectively support the integration, our purposed framework provides a guideline from following aspects:

6.1 Environment Awareness

The factor of environment awareness should be considered as the sharing understanding of different environments where care delivery takes place, because the radiology context involves different providers and clinical settings. The environment can be physical, organizational, and interoperable. The physical environment is related to physical systems, infrastructure, and affordances such as HIS (Health Information System), DSS (Decision Support System), EPR provided by the hospital; the organizational environment is related to policy, procedure, rules, and regulations that are maintained in radiology context; and the interoperable environment is related to communication tools, channels, and methods that are available for supporting different settings. As influenced by the environment awareness factors, our findings on interoperability analysis reveal some reasons that cause the integration barriers in radiology context. For example, the clinical staff reflected they seeing integration as restriction that control their behaviour during the interview, and the explanation from environment awareness perspective indicates that new technology would cause their fears such as the difficulties of use, and errors due to incorrect manipulation, and those errors and mistakes would lower the patient satisfaction, which may result in repealing the integration even harder. Another barrier of variety of different system venders is highly influenced by the organizational environment because the key concerns are rules, policies, and regulations of the different departments in hospital. Other interoperation concerns such as relationships between clinician and radiologist (Liu and

Gao, 2012), staff location, real-time updating (Ding, 2013) etc. also cause obstacles towards integration.

6.2 Decision Making Process

The factor of decision-making process is considered as the sharing knowledge such as rationale and background during interoperable making decisions. In radiology context, the care is delivered via multi information systems, and therefore decision making need to be understood through interoperable means. However, normally decision-making process takes place asynchronously, which can be very difficult to convey to all involved systems that their inputs have been considered and processed. Besides, most of decisions were made independent of other systems because of asynchronous settings, thus rationale of making decisions should be shared among systems and stakeholders as well. To solve these issues from the perspective of decision-making process, EAI method has been used for enabling integration not only at IT infrastructure level, but also at operational, managerial, and strategic levels. To supporting rationale sharing, HL7 has been used for consolidating semantic information exchanging. Furthermore, in order to solve the asynchronous collaboration issue, a web-based system has been developed for delivering processes in real time, and IHE (Integration Healthcare Enterprise) profiles have been used to support integration of clinical workflow. Other methods for improving semantic information sharing such as DICOM standards and LOINC codes have also been adopted for systems integration.

6.3 Intensive design of HIS

Intensive design of HIS refers to improvements and new approaches of HIS design that could better support the systems integration. As discussed the radiology context involves multiple clinical settings, and HIS provides a platform ensuring documentation and dissemination of patient status so that face to face communication, and paper based communication can be eliminated. However, the data sharing at the current stage has only been supported at semantic level, which means clinician inquiries about “what” can be answered by reading EPR, but questions of “why” and “how” cannot be addressed. Therefore, the HIS should be improved for generating data that contains more information such as description of care activities, medication change, pending procedure, cancelled procedure etc. The improved design of HIS should not limit itself to transmit data but to support collaboration efforts. Another concern of improvements is that existing HIS have been largely classified as supporting system for information retrieval, and hypothetically the HIS is pool of patient information for clinicians. However, the information tends to be dynamic as more stakeholders and systems are getting involved in a collaborative environment. Therefore, the improved HIS should allow clinicians to automatically receive the information they need such as changes of patient status. The HIS would also need to be designed to be configurable for providers in order to tailor information retrieval, and this would help to formalize communication channels and reduce redundant information flows. Other concerns including capturing and transmitting different types of data elements, and data standardization are also key improvements for the intensive design of HIS.

7. Conclusion and Future Work

This paper conducted an interoperability analysis of systems integration in radiology context, and purposed an interoperability analysis framework for guiding the systems integration. The selecting project aimed to achieve data sharing and interoperability among RIS, EPR, and PACS. Qualitative data collection and analysis methods were used. The results identified the interoperability barriers, and the adopted integration approaches and interoperability measurements for solving them. The purposed interoperability analysis framework evaluates the results from other three aspects, and provides a guideline for systems integration in terms of assessment and implementation. The future work will focus on data collection and analysis at the phase of interoperability measurement, and will also use the results to refine the whole analysis process and the interoperability analysis framework.

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