Measuring the Interoperability Degree of Interconnected Healthcare Information Systems Using the LISI Model

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***Abstract*—Due to the diversity of information systems in healthcare and the need of accessing data in a ubiquitous and pervasive manner, the interoperability issue has grown in importance. This work presents how the Levels of Information System Interoperability model can be applied to study the interoperability degree in order to interconnect healthcare information systems. This work presents an algorithm adapted for healthcare information system, which can determine the message exchange rate between healthcare information systems. The analysis is done looking at a hospital department (obstetrics-gynecology), general practitioner offices, radiology departments and laboratories that work together and have different information systems. This algorithm computes the interoperability degree from the technical interoperability point of view. A tool which calculates automatically the technical interoperability of a healthcare information system, based on the proposed algorithm, is under development. The benefits resulting from the calculus of the interoperability degree are reflected in the assessment of the status of informatization and degree of intercommunication in a certain healthcare environment. Also, it is helpful for software developers to know what is expected from a good application for the domain.**

Keyword-LISI; HL7 CDA; CCD; interoperability; healthcare information system.

I. INTRODUCTION

Increased life expectancy and the consequent increase in the prevalence of chronic illnesses pose serious challenges to the sustainability of the national health systems in Europe.

Seamless care is the desirable continuity of care delivered to a patient in the healthcare system across the spectrum of caregivers and their environments. Healthcare services have to be continuous and carried out without interruption such that when one caregiver ceases to be responsible for the patient's care, another one takes on the responsibility for the patient's care. Such a paradigm poses serious problems regarding the interoperability between healthcare information systems.

Interoperability is the ability of two or more systems or components to exchange information and use the information that has been exchanged [1].

Interoperability might be provided at different levels. These interoperability levels can start from simple data exchange and meaningful data exchange with agreed vocabulary to functional interoperability with agreed communication application behavior, or finally, a service-oriented interoperability [2].

Communication between different systems and their components in a complex and highly dynamic environment must fulfill some requirements: openness, scalability, flexibility, portability, distribution, standard conformance, service-oriented semantic interoperability and appropriate security and privacy services. This communication is based on a standard (e.g., HL7 version 3, HL7 Clinical Document Architecture). [3]

The Electronic Healthcare Record (EHR) is a longitudinal electronic record of patient health information generated by one or more encounters in any care delivery setting, including information about: patient demographics, progress notes, problems, medications, vital signs, medical history, immunizations, laboratory data and radiology reports [4].

The paper presents a particular environment studying the communication level between healthcare information systems for hospitals, laboratory, radiology and general practitioner offices. The major problem is that the healthcare information systems do not communicate directly one with the other making it impossible to create an electronic medical record seamless and following a timeline. The work gives an image of the current situation for which the analysis is made.

If the degree of interoperability between healthcare information systems can be evaluated, it will have benefits for assessing the status of informatization and degree of intercommunication in a certain healthcare environment and also for software developers to know what is expected from a good application for the domain.

 ISBN: 978-1-61208-224-0

Also, it is important to improve the interoperability of healthcare information systems and add more information to Electronic Health Record (EHR).

In section two, is presented the standards used in healthcare information systems communication. Section three presents the interoperability study where is described the LISI model and it is measured the degree of technical interoperability and, Section four concludes the paper solutions.

II. Standards used in healthcare information systems communication

One of the mandatory criteria to ensure the interoperability between the healthcare information systems is to use a standardized communication. In the next paragraphs, a system architecture and the standards used for communication between components is presented.

A. System architecture using standards

Figure 1 presents the system architecture using standardized communication. The system consists of three healthcare information systems for the obstetrics-gynecology, for radiology and for analysis laboratory communicating using the HL7 CDA and a healthcare information system for the general practitioner office which communicates with the hospital departments using the CCD (Continuity of Care Document) standard [5], [6].

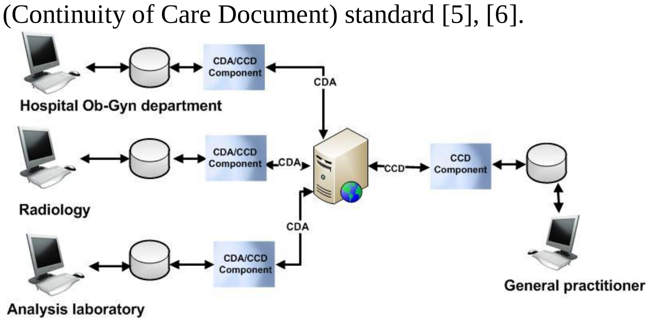

Figure 1. System architecture

The developed two Components, one for the CDA/CCD standard and the second for the CCD standard, give the possibility to extract data needed from the medical unit database (from obstetrics-gynecology, radiology, laboratory or general practitioner database). The two Components are developed in Visual Studio .NET 2008, using C# language. For the moment, the Components can extract data from a SQL Server database, but in the future will be generalized in order to extract data from different databases types. A connector was developed that extracts from XML in CDA/CCD format the data and inserts it into the proper fields and tables in database.

B. Using HL7 CDA (Clinical Document Architecture)

The HL7 CDA is a document markup standard that specifies the structure and semantics of clinical documents. The developed HL 7 CDA Component extracts the data from a local database and presents it as an HL7 CDA standard message. The CDA derives its content directly from the HL7 Reference Information Model (RIM) and therefore is specially design to integrate current HL7 technologies. The common architecture can be adapted for progress notes, radiology reports, discharge summaries, transfer notes, medications, laboratory results and patient summaries. The CDA is an XML document that consists of a header and body [7].

The HL7 CDA/CCD standard uses Logical Observation Identifiers Names and Codes (LOINC). This is a universal code system for identifying laboratory and clinical observations [8], adapted in this case for the Romanian healthcare system.

An XML in CDA format, as an example of a message from a lab, is presented in Figure 2.

```
<!--*****************Labs Section*******************-->
<component>
  <section>
    <code code="11502-2" codeSystem="2.16.840.1.113883.6.1"
     codeSystemName="LOINC" displayName="Labs" />
    <title>Blood test</title>
    <entry>
      <observation classCode="OBS" moodCode="EVN">
        <code code="19180-9" codeSystem="2.16.840.1.113883.6.1"
         codeSystemName="LOINC" displayName="beta-HCG" />
        <effectiveTime value="20110402" />
        <value xsi:type="PQ" value="15000" unit="mUI/mL" />
      </observation>
    </entry>
  </section>
</component>
```

Figure 2. CDA laboratory result

The CDA contains LOINC codes, which are used for representation of the laboratory results (e.g., LOINC code 19180-9 is used for beta-HCG analysis) and also the analysis value (in Figure 2 the beta-HCG value is presented - 15000 mUI/mL). All the LOINC codes used in this CDA message are adapted for Romanian healthcare systems.

C. Using CCD (Continuity of Care Document)

The Continuity of Care Document (CCD) is an electronic document exchange standard for sharing patient summary information among providers and within personal healthcare records. It summarizes the most commonly needed pertinent information about current and past health status in a form that can be shared by all computer applications, it respects a set of constrains on CDA that define how to use the HL7 CDA to communicate clinical summaries and it is built using HL7 CDA elements [9].

CCD is a combination between ASTM CCR (Continuity of Care Record) and HL7 CDA.

The definition given for CCD by ASTM is: a core data set of the most relevant administrative, demographic and clinical information facts about a patient's health care, covering one or more health care encounters [10].

 ISBN: 978-1-61208-224-0

CCD templates include: header, purpose, problems, procedures, family history, social history, payers, advance directives, alerts, medications, immunizations, medical equipment, vital signs, functional states, results, encounters and plan of care [9].

In the current healthcare information system, the CCD standard for communication is used to support the communication between the hospital departments and the general practitioner's office. The general practitioner sends a request in XML format containing the ID (personal numeric code – CNP, which in Romania is the unique ID for each person) to the hospital department application and the CDA/CCD Component extracts the data from the hospital department database and sends the information in CCD format to the general practitioner office.

In Figure 3, an XML sequence in CCD format is presented containing lab results sent from one of the hospital departments to the general practitioner's office and it is adapted for the Romanian health system.


```xml
- <component>
  - <observation classCode="OBS" moodCode="EVN">
      <templateID root="11"/>
      <code displayName="Eritrocite" codeSystem="2.16.840.1.113883.6.1" code="11273-0"/>
      <statusCode code="completed"/>
      <effectiveTime>20110515</effectiveTime>
      <value value="5.36" unit="x10^6/uL" xsi:type="PQ"/>
    - <methodeCode codeSystem="2.16.840.1.113883.5.84" code="460179">
      - <referenceRange>
        - <observationRange>
            <text>4.00-5.80 x10^6/uL</text>
          </observationRange>
        </referenceRange>
      </methodeCode>
    </observation>
  </component>
```


Figure 3. CCD example

The XML in CCD format contains a laboratory result: erythrocytes, which are codified with LOINC code 11273-0, adapted for Romanian health system and the value of this test result.

III. INTEROPERABILITY STUDY

A. LISI model

LISI (Levels of Information System Interoperability) is a complete, descriptive model of classification with levels of interoperability based on individual, unique project specifications [11].

LISI is a reference model for assessing information systems interoperability. It is used for defining, measuring, assessing, and certifying the degree of interoperability required or achieved between organizations or systems [11].

B. LISI Interoperability Maturity Model

LISI Interoperability Maturity Model has 5 levels [11]. In this paper and previous work [12] these levels are adapted for healthcare informatics systems.

The LISI levers are:

- Level 0 named Isolated (Environment: Manual)
- Level 1 named Connected (Environment: Peer-to-Peer)
- Level 2 named Functional (Environment: Distributed)
- Level 3 named Domain (Environment: Integrated)
- Level 4 named Enterprise (Environment: Universal)

To fit into a LISI level, we studied two types of interoperability: operational and technical. Two scores obtained from analyzing the two interoperability types will result representing the interoperability degree of the studied healthcare information system. A scale corresponding for each LISI level will be considered (e.g., if the scale is 0 the level is Level 0 - Isolated).

C. LISI Scope of Analysis

In Figure 4, the LISI scope of analysis for two HIS systems are presented. The operational interoperability has a semantic understanding. For each XML received in CDA or CCD format a tool will analyze the codes (LOINC or ICD-10-AM) and if all the analyses corresponds to the evaluation criteria then the healthcare information system will receive a score (a scale to 1 – 100). A similar analysis is presented in [13], where SNOMED codes are analyzed. Scoring the technical interoperability it will be possible to appreciate on what LISI level the healthcare information system is situated.

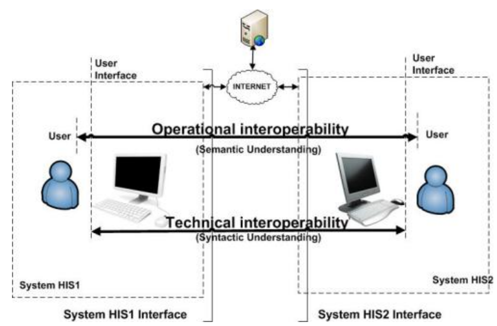

Figure 4. LISI Scope of analysis

The technical interoperability is the condition achieved among electronic system communications when information or services can be exchanged directly and satisfactory between them and their users, includes aspects such as application interfaces, open standards and data integration. If two or more healthcare information systems are capable of communicating and exchanging data, they are technical interoperable. In general, XML or SQL standards provide syntactic interoperability. In this work, an algorithm that determines the technical interoperability is presented.

D. Measuring the degree of technical interoperability

In Figure 5, the studied healthcare system architecture is presented comprising the obstetrics-gynecology department, 2 radiology (1 internal and 1 external) departments, 4 analysis laboratories (1 internal and 3 external), and 1 general practitioner office. The technical interoperability

ISBN: 978-1-61208-224-0

degree for the obstetrics-gynecology healthcare information system is studied below. This healthcare information system communicates using standards, with the radiology and analysis laboratory using HL7 CDA, and with the general practitioner using CCD.

A scale is proposed to evaluate systems interoperability potential for technical interoperability point of view:

- 0 – 35 points the systems are not interoperable that means that the system is on LISI level 0 or level 1,
- 36 – 65 points the systems are interoperable in some degree that means that the system is on LISI level 2 or 3,
- 66 – 100 points the systems are interoperable that means that the system is on LISI level 4.

To study the interoperability degree an algorithm [11] is applied adapted for healthcare information systems.

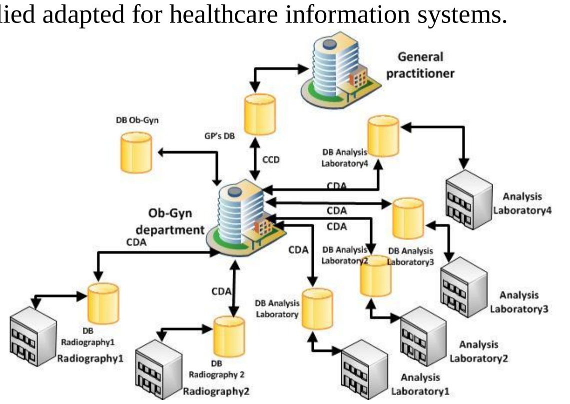

Figure 5. System architecture

For each step of the testing process, points have been associated in order to reflect the interoperability score for the systems. For each steps, a score is allocated; it represents how well the system meets the requirements (e.g., if the system has the possibility to communicate using standards, and for how many system are interconnected).In the next lines, the testing steps are presented:

Step 1 - Analyzing if the functionalities are the same

In order to establish that the system functionalities are the same, the data workflow and management between obstetrics-gynecology, radiology, laboratory and general practitioner was monitored during a week at County Emergency Hospital Timisoara, Romania – Bega Clinic, obstetrics-gynecology department. The referrals were studied and the data sets were identified and based on these, the conclusion was that the system functionalities are the same. The scored obtained at this step is 7/10.

Step 2. – Study the degree in which if the communication is based on the same standards.

We assumed that the messages are transmitted with the help of HL7 CDA standard in laboratory analysis, radiology cases and CCD for the general practitioner. For each case two Components were developed, one which extracts data for creating the CDA and the second to extract data for CCD. The score obtained in this step is 9/10.

Step 3. Analyze if the message data elements are common.

The data elements are common because the ob-gyn department sends referrals to the analysis laboratory, radiology, and the general practitioner office and receives back the same type of documents. All the communication between healthcare information systems presented here is based on CDA and CCD standards. The scores obtained at this step is 7/10.

Step 4. Calculate the connectivity index with the formula:

$$c_i = \frac{k}{n*(n-1)}$$

where: c_i = connectivity index for HIS;
k = number of connection (path between nodes),
n = number of nodes (participating units).

$$k = 7;\ n = 8;\ c_i = 0.16$$

The scored obtained at this step is 2/10.

Step 5. Monitoring the protocols and data flow in departments and analyzing the information exchange.

The ob-gyn department sends an XML file in CDA format to the analysis laboratory, to radiology and in CCD format to the general practitioner office, and so the data flow between the medical units is standardized. The scored obtained at this step is 3/10.

Step 6. Calculate the capacity of the ob-gyn department which is the rate at which data may be passed over time.

$$Q_{eff} = (Q_{\max} - Q_{oh}) * (t_f - t_p)$$

where, Q_{eff} = effective system capacity (data rate); $Q_{\max}$ = maximum data rate; Q_{oh} = system overhead data rate; t_f = time slot duration (unit transmission); t_p = unit propagation time

Another measure is the calculus of the department's overload which occurs when more data must be exchanged than the system is able to transmit. The overload is placed in a queue and it is transmitted when capacity is available.

$$M_{OL} = n_t * \sum_{y=1}^{n_t} (M_q)_y$$

where, M_{OL} = system message overload; n_t = number of transmitting nodes; M_q = messages in queue to be transmitted by node.

The system underuse was calculated, occurring when the system data rate/message load is less than full capacity but messages are waiting in queues to be transmitted.

$$Q_{uu} = M_{OL}\text{, for } M_{OL} \le (Q_{eff} - Q)$$

$$Q_{uu} = Q_{eff} - Q\text{, for } M_{OL} > (Q_{eff} - Q)$$

where, Q_{uu} = system underutilization (data rate);
Q = measured/observed data rate

Another parameter calculated was the under capacity of the system, which occurs when messages remain in queues and the system data rate is at the maximum.

$$Q_{uc} = (Q + M_{OL}) - Q_{eff}$$

where, Q_{uc} = system under capacity (data rate)

For the laboratory a maximum number of 300 messages a week were estimated, supported by the system, for the radiology internal department 100 messages a week, for the external department of radiology 80 messages a week, 50 messages for general practitioner.

 ISBN: 978-1-61208-224-0

In order to compute the interoperability score, 2 days were considered for the time of message transmission (T_f) and 4 days for the response time (T_p), because in Romanian health system the patient must wait minim 4 days to receive the laboratory results.

- Ob-gyn->Laboratory = 40 messages / day =>200 messages / week
- Ob-gyn->Radiology intern department = 15 msg / day => 75 msg / week
- Ob-gyn->Radiology extern = 10 msg / day => 50 msg / week
- Ob-gyn-> General practitioner = 10 msg/day => 50 msg/week
- $T_f = 2$ days
- $T_p = 4$ days

The results after applying the formulas are:

$$Q_{eff} = 1804;\ M_{OL} = 96;\ Q_{uu} = 96;\ Q_{uc} = -1594$$

The scored obtained at this step is 17/40.

Step 7. Interpreting the result and analyzing the data elements in HIS.

Analyzing all the steps, we concluded that: this type of system architecture benefits of a standardized communication; it is possible to add other healthcare information systems; the systems can be improved a lot; the healthcare information system can support more messages, because after computing the underuse capacity we concluded that more messages can be added without affecting the communication. The scored obtained at this step is 9/10.

Table I represents a summary of the steps analysis.

TABLE I. INTEROPERABILITY SCORE

Steps	1	2	3	4	5	6	7
Ob-gyn points	7/10	9/10	7/10	2/10	3/10	17/40	9/10
Total	54/100 points						

After applying these steps and computing the scores, the result was that the obstetrics-gynecology department has a score of 54 points, which represents a percentage of 54/100, regarding the interoperability potential with the analysis laboratory, radiology and general practitioner from the technical interoperability point of view. This score shows that the healthcare information system for ob-gyn department is ready to communicate to other healthcare information systems, but improvements have to be made.

IV. CONCLUSIONS AND FUTURE WORKS

The paper presents an algorithm adapted for healthcare information systems for assessing the technical interoperability degree of the ob-gyn department healthcare information system. After analyzing these two types interoperability, two scores will result which will show the interoperability degree of a healthcare information system, the degree in which it is ready to easy communicate with other similar ones. If the degree of interoperability between healthcare information systems can be evaluated, it will have benefits for assessing the status of informatization and degree of intercommunication in specific or general environments and the data available for the clinical staff and patients will be more consistent driving to better practice and patient healthcare status, and also will reduce medical errors. This study of interoperability degree will help the physicians to have more information about the patient, for software developer to develop more complex healthcare information systems and the most important is the patient that will benefit of a better treatment.

In the future works, we will analyze the operational interoperability, it will be develop a smart tool using the current study results determining the technical interoperability in an automated way and also a tool for operational interoperability.

ACKNOWLEDGMENT

This work was partially supported by the strategic grant POSDRU/88/1.5/S/50783, Project ID50783 (2009), cofinanced by the European Social Fund – Investing in People, within the Sectorial Operational Programme Human Resources Development 2007 -2013.

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