A Maturity Model for Interoperability in eHealth

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***Abstract* — Interoperability, the ability of different technological applications to exchange data, is viewed by many as an important goal for eHealth, as it can save money and improve the quality of care and patient safety. However, creating an interoperable infrastructure for eHealth is a difficult task. In this paper, we present a maturity model that aids eHealth developers to determine what level of interoperability they should strive for, and that allows researchers to benchmark interoperable eHealth infrastructures in terms of maturity. For each level in the model, we illustrate what the interoperable infrastructure looks like from the technical point of view, we list implications for working procedures and we discuss the role of standardization. The maturity model has five levels. At level 0, there is no interoperability: The eHealth application is a silo. At level 1, Peer-to-peer systems, single applications are linked for simple data exchange. At level 2, Distributed systems, multiple applications are linked to achieve a common objective. At level 3, Integrated systems, applications from different suppliers are linked in a closed infrastructure. And at level 4, Universal interoperability, finally, applications are linked in an open infrastructure from which everybody is free to (dis)connect. We demonstrate the application of the maturity model via the case of an interoperable eHealth infrastructure for primary care. Reaching the most technically advanced form of interoperability (level 4) is not a goal eHealth developers should always strive for. They should set their goal with regard to the desired interoperability level for their situation and should then determine what they should do in terms of technique, working procedures, and standardization.**

Keywords—Interoperability; Maturity model, Medical information exchange, Information sharing

I. INTRODUCTION

Traditionally, eHealth technologies - "health services delivered or enhanced through the Internet and related technologies" [1] - have been developed as stand-alone devices. This has led to a situation in which end-users, such as doctors and patients, have to work with a large number of applications that cannot share information. Interoperability, "the ability of different information technology systems and software applications to communicate, exchange data, and use the information that has been exchanged" [2], can tear down the walls among eHealth applications and can enable reuse of data.

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Successful implementation of an interoperable infrastructure for eHealth applications has been associated with great benefits. Improved work efficiency and quality of care were named as the two most important benefits by Zwaanswijk et al [3] after interviewing Dutch healthcare providers; two benefits that are also mentioned by Stroetmann [4]. Brailer [5] mentions a decrease in the number of errors made due to incomplete patient data, while Jiménez-Fernández and colleagues [6] foresee that interoperability will drive wider uptake of patient telemonitoring systems. Finally, the European Commission has published an 'eHealth interoperability roadmap', as they foresee that interoperability among the different health information systems in Europe will ensure high quality care for citizens that can easily and frequently cross national borders [7].

Because of these benefits, full interoperability is viewed by many as the Holy Grail for eHealth. However, full interoperability is not realized easily. In order to guide the development of an interoperable eHealth infrastructure, a maturity model will be a helpful instrument. A maturity model shows the different phases in coming towards a fully mature version of a technology, and can be used as a roadmap for creating technology, or for benchmarking purposes [8]. In the literature, different maturity models for interoperability can be found for contexts like enterprise interoperability [9] and eGovernment interoperability [10]. The eHealth context, however, differs from the commercial and governmental contexts and poses a unique set of challenges. The treatment plans that eHealth supports often affect different actors (e.g., patients, medical professionals, informal caregivers) and different organizations (e.g., medical institutions, commercial companies, government bodies), each with their own protocols, information needs and information systems. Next, in the last decade, the usage context for health technology has moved from the hospital to the home environment, where patients use a multitude of websites, mobile applications, and sensor-based technology, and all these applications need to be aligned [11].

One maturity model was developed for making a distinction among the different levels of interoperability among electronic health records [12]. This model consists of three levels: Basic interoperability (sending a message from one computer to another), Functional interoperability (sending messages among computers that can interpreted at the level of data fields), and Semantic interoperability (sending messages among computers that can use the information in data fields

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in an intelligent manner). The model has gained some following within the eHealth community, such as in [2, 13], but has a rather technical focus and limits itself to describing how fields within electronic health records can be automatically filled from external sources (whose end-users are, predominantly, healthcare professionals). Interoperability in the current eHealth landscape is broader than that and refers to "facilitating and safeguarding the exchange, understanding and acting on patient and other health information and knowledge among linguistically and culturally dispersed medical professionals, patients and other actors within and across healthcare systems in a collaborative manner" [14]. So, when creating a maturity model for interoperability for the whole eHealth landscape, the collaboration among different organizations and experts, the way in which meaningful data is utilized within procedures as described in guidelines, and the role of standards that allow for smooth data-exchange among different systems, organizations and countries, are crucial aspects.

In this paper, we present a maturity model for interoperability within the eHealth context. This context is very broad and ranges from simple data exchange between two applications to (inter)national health grids. For each level in the model, we illustrate what the interoperable infrastructure looks like from 1. the *technical* point of view, 2. the implications for working *procedures* and 3. the role of *standardization*.

II. A Maturity Model for Interoperability in eHealth

Fig. 1 shows our proposed maturity model for interoperability in eHealth. The model consists of five levels that, subsequently, describe a more mature version of an interoperable infrastructure. These levels are based upon the Levels of Information Systems Interoperability model [15], which is considered to be a solid base to develop maturity models for interoperability in different contexts [16]. The different levels are:

- Level 0: The System as Silo
- Level 1: Peer-to-Peer Systems
- Level 2: Distributed Systems
- Level 3: Integrated Systems
- Level 4: Universal Interoperability

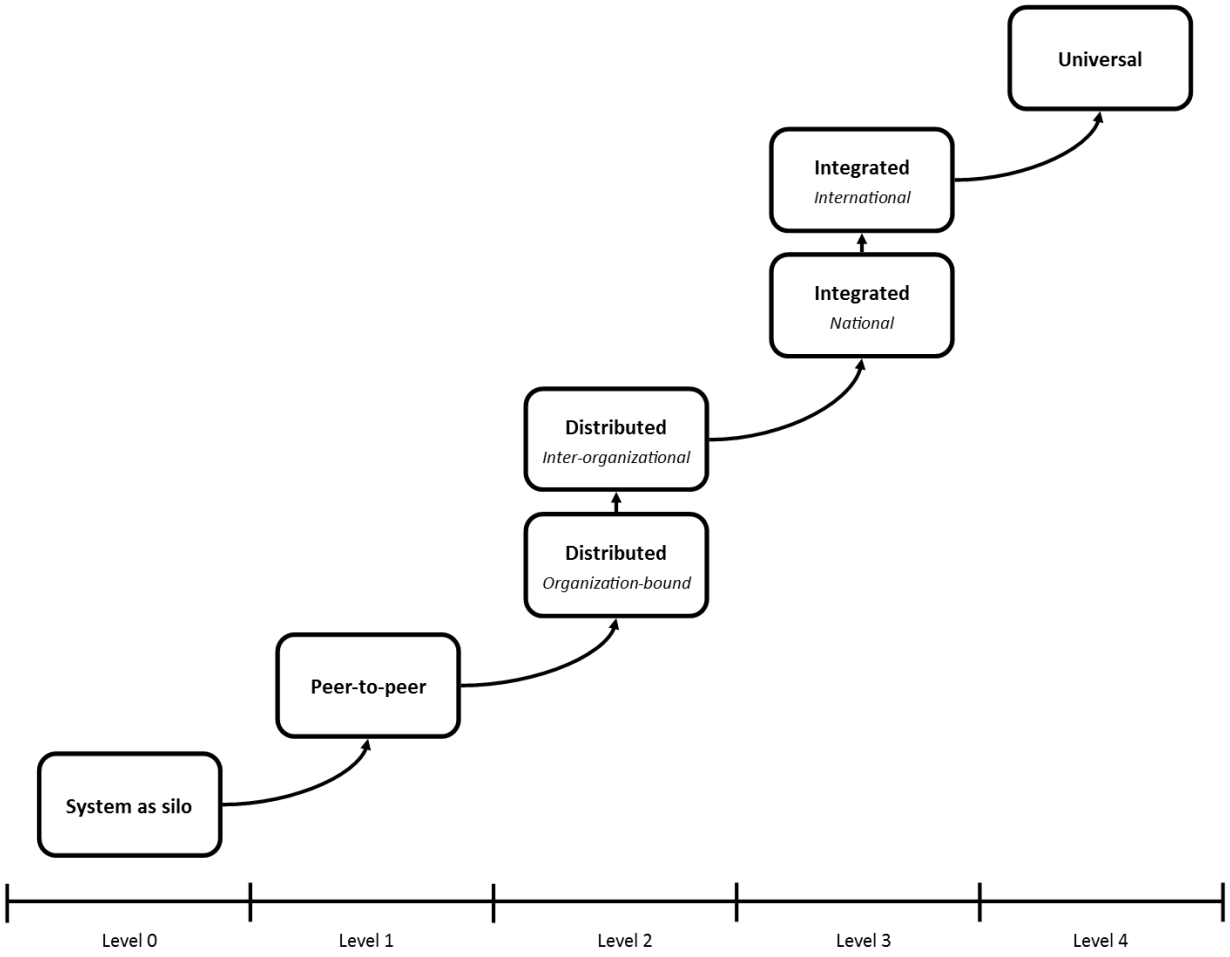

Figure 1. A Maturity Model for Interoperability in eHealth

A. Level 0: The System as Silo

Technical. At this level, an eHealth application consists of a single technology and is not connected to any other application.

Procedural. The single application does not change the nature of the task that it is supposed to serve, nor does it necessitate the redesign of medical procedures and/or protocols.

Standardization. As a single eHealth application does not need to take into account means to communicate with other technologies, no standardization is required.

B. Level 1: Peer-to-Peer Systems

Technical. At this level, a single eHealth application is directly linked to another application for simple data exchange. For example, a General Practitioner's information system can receive blood pressure data from a blood pressure measurement system situated in patient's home.

Procedural. The transfer of data happens in a context where the involved parties have made simple agreements about a working procedure. In the previous example, one could agree that the doctor's assistant will call the patient once the blood pressure value exceeds a certain threshold.

Standardization. Developers of both systems should make agreements on how to transmit data and its format. How data will be prepared before transmission, or processed afterwards, is up to the developers of each eHealth application.

C. Level 2: Distributed Systems

Technical. At this level, single eHealth applications are linked to achieve a common objective (e.g., optimizing information exchange about an individual patient within a disease-specific care path). A client/server architecture is most often used to allow multiple applications to communicate with each other via a central service. Care management systems with an Electronic Health Record are typical examples of such a set of applications. Their objective is to streamline the care path, and the different actors and their information systems, for a specific condition (e.g., diabetes). At first, the different applications are provided under control of one supplier (level 2a: Distributed, organization-bound). The next step is to cross the organizational boundary and to link different applications of different suppliers for achieving a common objective (level 2b: distributed, inter-organizational).

Procedural. Once a set of applications reach this interoperability level, streamlining medical and organizational procedures becomes a necessity [17]. Often, many actors in different organizations play a role. At this level, each actor or organization has his or her medical protocols and organizational procedures. The interoperable infrastructure should support these different protocols and working routines as much as possible. Whenever this is not possible, for example when protocols or working procedures are contradictory or non-conclusive, a solution needs to be sought in defining a new, shared procedure, which can subsequently be incorporated in the interoperable infrastructure and its services.

Standardization. Crossing the boundary between organization-bound and inter-organizational interoperability marks an important change in the need for standardization. Suppliers of inter-organizational interoperable eHealth applications can rely on their own standards. But organizations that (want to) supply eHealth applications that communicate with eHealth applications from other organizations will be forced to make agreements on how to transmit data. Currently, there are many different standards that aid uniform approaches towards sharing health data. Perhaps the most well-known and most important standards are HL7 [18] and SNOMED CT [19], which can be used as a foundation for the development of data exchange standards among eHealth systems. Health Level Seven International is an organization that provides a comprehensive framework and related standards for the exchange, integration, sharing, and retrieval of electronic health information. Where HL7 is a standard for exchanging information among different health systems, SNOMED CT is used to encode this information. SNOMED CT is a comprehensive, multilingual clinical healthcare terminology that is also mapped to other international standards, such as ICD10 and LOINC. With SNOMED CT it is possible to also express the meaning of the information, thereby enabling semantic interoperability. Because of this, SNOMED also supports the operation of clinical decision supports systems that can use data from different sources that use SNOMED CT as the interoperability standard for encoding health information.

D. Level 3: Integrated Systems

Technical. At this level, eHealth applications from different suppliers that serve a common goal are linked (e.g., allowing for self-management by patients with a chronic disease), but the applications do not need to have common objectives. So, applications that aid patients to monitor their glucose level can be connected to a GP's health information system, as well as an online service that supports self-management of asthma patients. Often, these infrastructures make use of a Service Oriented Architecture (SOA) whereby specific services and their corresponding functionalities are used only when necessary. Data storage and processing will mostly be done at the level of the individual services. At this interoperability level, we distinguish between two sub-levels: On a national level (level 3a: integrated, national) and on an international level (level 3b: integrated, international). The infrastructure is developed to offer interoperability to a selected set of eHealth suppliers. It is possible for this set to shrink and expand over time, but is never intended to be 'open for all'.

Procedural. When the possibilities that eHealth technology offer become paramount (as is the case when many, not necessarily related, eHealth applications are connected), it becomes difficult to streamline procedures. After all, there are no protocols or organizational policies that guide such a widespread exchange of data. Therefore, new use cases should be identified in which interoperable eHealth applications can play a supportive role. Then, existing protocols can be adapted. This way, technology also functions as a way to rethink how we organize healthcare. Crossing a nation's border digitally to link up with other eHealth

applications has great implications for setting up these procedures. Between countries, medical protocols can differ. This can be resolved in two ways. One, healthcare professionals and organizations that, jointly and internationally, make use of a set of integrated technologies will have to agree on a protocol that is supported by the technology. Two, the technology will have to be designed in such a way that it can support different protocols.

Standardization. When it comes to standardization, level 3 does not differ much from level 2. The same international standards and terminologies should be used to facilitate smooth data transfer among the applications in the interoperable eHealth infrastructure.

E. Level 4: Universal Interoperability

Technical. At this level, one can speak of an open, interoperable infrastructure to which all eHealth applications are free to connect and disconnect. When connected, they are able to exchange data with all other applications that make use of the infrastructure. The eHealth applications do not have to serve a common goal and can span multiple countries. Recently, such universal infrastructures have seen the light of day. Apple's Healthkit and Samsung's S Health are notable examples. Again, a Service Oriented Architecture (SOA) is the most logical architecture, whereby an online platform acts as the central hub for data exchange. In most cases, data will be stored both at the central level and at the level of the individual services, and the same applies to data processing: this happens at both levels.

Procedural. As is the case for level 3, this kind of interoperability allows for supporting existing work procedures and protocols, as well as for many, many new use cases. Furthermore, the availability of so much data in one interoperable infrastructure allows for ample data mining possibilities that may lead to, yet, even more new insights and use cases. As is the case for interoperability at level 3 (integrated), the interoperable infrastructure should be seen as supportive to (new) medical procedures, and existing or newly devised medical procedures should be the starting point for making use of universally interoperable eHealth technology. Of course, a technology push could be the instigator of a newly devised procedure but should be tested as soon as possible with the relevant actors and stakeholders for acceptance, usefulness, and usability.

Standardization. Universal, interoperable infrastructures can, of course, make use of information exchange standards like HL7 and terminologies like SNOMED. However, until now, we have only seen universal infrastructures that bring along their own standards. It is possible to build bridges between these standards and standards such as HL7 an SNOMED. Therefore, they can easily co-exist.

III. The eLabEL Case

We will demonstrate the application of our maturity model by means of a case, called eLabEL (http://www.caretechnologyresearch.nl/elabel). Within the eLabEL project, knowledge institutes, SMEs (suppliers of telemedicine applications, sensor developers, etc.), and primary care centers collaborated with the goal of developing and implementing an interoperable infrastructure for the use of eHealth in primary care in the Netherlands. More specifically, general practitioners, nurse practitioners, physical therapists, and their patients, have been provided with a suite of eHealth applications that can be accessed via one interface. These eHealth applications can also freely share data, and should be able to add data to and retrieve data from the general practitioner's or physical therapists' information system in the near future. As such, the ambition was to develop an interoperable infrastructure at level 3: A national, integrated infrastructure.

We started out our endeavor by means of an inventory of the wishes of healthcare professionals and patients. Furthermore, meetings with the participating SMEs were organized to inventory their eHealth applications and technologies (in terms of functionalities, data models), to discuss possible architectures for the interoperable infrastructure, and to explore viable governance and business models. After a set of meetings, consensus on the following points was reached:

- All applications should be accessible via a single-sign on from a central location. For the patients, this would be a personal eHealth dashboard, while for the healthcare professionals, all applications should be accessible from their information systems (their primary information system);
- Asking end-users to provide the same piece of information should be kept to a minimum;
- Data should be stored, as much as possible, at the level of the individual eHealth applications; frequently shared data should be stored in a minimal data set at a central location;
- To guarantee quality of the connected applications and to support a viable business model, the infrastructure should not be open, but should be restricted to a set of affiliated suppliers. Initially, this set should be kept stable and small (to agree upon the architecture and standards) and can be expanded later on.

The development of such an infrastructure is quite an undertaking, and therefore it was decided to start out with the development of the patient dashboard and a single sign on functionality. As such, we started to develop an interoperable infrastructure at level 2: an inter-organizational, distributed infrastructure. The common goal that was aimed for was simple and efficient access to different eHealth applications. A shared data model was drafted that includes entities such as the patient and the caregiver. Each end-user was assigned a unique eLabEL id.

The most difficult part was drafting a general procedure for registering a patient that aligns with the workplace realities of different primary care centers. Who links a patient to the eHealth applications s/he should have access to? How do we verify the identity of the patient? Since no medical data was exchanged at this point, we did not make use of medical interoperability standards, such as HL7 or SNOMED CT.

Once the distributed infrastructure was developed, tested and implemented in a real-life context, we embarked on the next step: upgrading the infrastructure towards a level 3 maturity. This step is being taken at the moment of writing. Taking the interoperable infrastructure to the next maturity level means that the infrastructure should enable the care of patients within primary care. This consists of many different objectives, such as allowing for self-management of COPD, supporting video-consultations with primary care professionals, and allowing for following an online physical therapy program by means of a personalized schedule and instruction videos. New protocols and use cases are stimulated to arise by means of shared meetings among healthcare professionals and SMEs. As patients have several objectives (e.g., a patient with COPD can make use of a self-management tool, while also working on his/her physical condition with the help of a physical therapy application) medical data exchange among the individual applications became a necessity to comply with the requirement to keep multiple requests of the same information to a bare minimum.

Because in eLabEL web based eHealth technologies and electronic health records (in the general practitioner's and physiotherapist's information system) are used, we decided to use HL7 FHIR and SNOMED CT for meaningful data exchange among the different applications in the eLabEL platform. SNOMED CT was chosen, because the information, contained in electronic health records, should be precise and the meaning of the information should be correctly understood when it is communicated to another healthcare system [19]. FHIR is an HL7 standard for exchanging digital information within and between healthcare institutions. FHIR supports interoperability via four common information exchange architectures/paradigms, namely messaging, documents, services and REST. This last paradigm facilitates real time exchange of data using web technology [20].

Our efforts within the eLabEL project have taught us that reaching a higher maturity level of eHealth interoperability is best taken by means of a stepped approach in which one first aims for lower levels of maturity. Furthermore, we experienced that the challenges within coming towards interoperability lie foremost on the procedural front, and not on the technical.

IV. Conclusions

In this article we have presented a maturity model for interoperability in eHealth. The model shows how an eHealth application can evolve from a stand-alone application to a part of a universal network for eHealth, and can serve two main goals. One, it can be used to benchmark a set of eHealth applications or infrastructures with regard to their level of interoperability. Two, it can be used as a roadmap for developing an interoperable infrastructure for eHealth applications. It is important to note that we do not think that reaching the highest level of interoperability should be the goal for every interoperable eHealth infrastructure. Rather, we think that developers should determine what level is desirable for their context and should then focus on how to reach this level by taking into account the development of use cases and working procedures, and the utilization or development of relevant standards and terminologies. This contradicts with the more 'technological' maturity model in [12], where functional interoperability is deemed better than basic interoperability, and semantic interoperability is considered to be the best.

While many initiatives approach the challenge of interoperability mainly as a technical one, we think that developing the proper technology is only part of the challenge, and perhaps not even the most difficult part. Aligning technology with workplace reality, medical protocols and human preferences and quirks might be the most difficult aspect of integrating eHealth applications. Therefore, a sociotechnical approach towards this challenge is a more promising one.

In our maturity model, we have focused mainly on three aspects: technology, procedures and standardization. However, other issues, like a wide range of legal issues [21, 22], may also play an important role and should not be neglected when developing an interoperable infrastructure for eHealth applications. Patients will need to provide consent for sharing data, liability needs to be arranged, etcetera. Next to legal issues, security and privacy issues need to be taken care of: end-users must be guaranteed that their data is stored safely and should have the option to decide who to share data with, or not [23, 24]. Finally, end-users' experience will be different from interacting with a single application. For example, trust becomes a very important issue and prerequisite for acceptance [25]. The need for applying a holistic approach when developing an interoperable eHealth infrastructure also lies at the basis of the eHealth European Interoperability Framework [26], which advocates a close cooperation among different stakeholders on different levels (e.g., legal and regulatory, care, IT).

Future research should determine to what degree the maturity model that we have presented aligns with reality. Are the levels and sub-levels we proposed valid? Alongside, of course, it would be valuable to review existing interoperable infrastructures for eHealth technology to assess their levels of maturity, so that we can determine the state of the art, and see what kind of infrastructures are more mature than others (e.g., infrastructures for primary care versus secondary care). Such insights are extremely valuable for determining barriers towards and drivers for interoperability for eHealth.

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