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A Systematic Review of Interoperability Models

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***Abstract*—Interoperability is the ability in which systems and enterprises could interrelate and incorporate to each other. With the purpose of improvement of interoperability between systems, an interoperability model is required. This study aims at reviewing existing research on interoperability models in order to identify a comprehensive interoperability model. In this review study, all of the existing models for interoperability are presented. The majority of the interoperability models focuses only on three of four interoperability types. The existing models are also not at a satisfactory level of development for improvement of interoperability between systems. Thus structuring interoperability models into one single comprehensive and complete interoperability model is necessary in order to ensure consistency and avoid redundancy. In addition, we need to identify metrics and properties to allow better development of interoperability between systems.**

***Keywords*—Interoperability, Framework, Type, Attribute, Dimension.**

I. Introduction

Interoperability has been an important and widely discussed topic over the past decade, and continues to be so. A search of thirty years of definitions and types of interoperability indicates the recent surge in popularity of the subject [1]. There have been different definitions for interoperability. For instance, the following definition of interoperability has been given by IEEE [2]: "The ability of two or more systems or elements to exchange information and to use the information that have been exchanged". In fact, interoperability is about establishing a relationship, sharing information, and services between application software even though having different hardware platforms. In other words, interoperability is described as two software units that are created by different methods and tools, but able to work with each other. One of the most significant challenges of interoperability is establishing and improving the interoperability within the systems and enterprises. Systems and enterprises to interoperate with each other, and share their required information, or improve their interoperability rate, ought to use an identified model. So far, several models have been offered for improving interoperability in which each of them provides a certain viewpoint of structure for interoperability. Therefore, choosing an appropriate model as a reference model of the existing models is considered as the main challenge of this study. For this purpose, the interoperability models are introduced, reviewed, analysed and compared in this paper. The objective of the paper is to review the existing interoperability models.

II. Interoperability Types

According to [3-10], there are four types of interoperability. The interoperability types are organizational, conceptual, operational, and technical interoperability. **Organizational Interoperability:** this interoperability type concerns with the definition of authority and responsibility with the intention that interoperability could happen under good conditions [11, 12]. **Conceptual Interoperability:** this interoperability type refers to the semantic and syntactic differences of information to be exchanged [4]. Syntactic interoperability is defined as the ability to exchange data, and Semantic interoperability is defined as the ability to operate on that data according to agreed-upon semantics [13]. **Operational Interoperability:** The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together [3, 6, 7, 10, 14]. **Technical Interoperability:** the technical interoperability is achieved among communications-electronics systems or items of communications-electronics equipment when services or information could be exchanged directly and satisfactorily between them and their users. In referring to specific cases, the interoperability degree must be defined [15].

III. Interoperability Models

This section reviews on the interoperability models. Interoperability models are levels of information systems interoperability, The System of Systems Interoperability Model, and E-health interoperability model.

A. *Levels of Information Systems Interoperability*

With the objective of identifying the required interoperability degree, The US Department of Defense

C4ISR Working Group has developed the Levels of Information Systems Interoperability (LISI) model to evaluate the capabilities and implementation of the information systems [16]. LISI is one of the most widely referenced interoperability models since 1998. LISI predicts the potential of systems, interoperability by combining the basic reference model with mechanisms to develop an Interoperability Profile and metrics for a particular system, and to compare the specific system profiles. LISI model focuses on enhancing interoperability levels of complexity within the systems [16, 17]. The five interoperability levels (0-4) are Isolated, Connected, Functional, Domain and Enterprise in which each interoperability level exists in a specific environment. Five LISI interoperability levels are illustrated in rows, and four columns, show the attributes of the LISI Reference Model that contain Procedures, Applications, Infrastructure, and Data (PAID). **Procedures** attributes include numerous forms of operational controls and documented guidance that influence all aspects of system integration, development, and operational functionality. The procedure attributes address the architecture guidance and standards, policies and procedures, and doctrine that enable information exchanges between systems. **Applications** attributes include the system mission which is the fundamental purpose of system building and functional requirements of the system. These attributes indicate applications that permit processing, exchange, and manipulation. **Infrastructure** attributes in which the establishment and use of a connection between applications or systems is supported. These attributes include the environments enabling the interaction such as system services, networks, hardware and etc. **Data** attributes focus on information processes of the system, and contain both data format (syntax) and its content or meaning (semantics). These data attributes of interoperability include protocols and formats enabling information and data interchanges. The LISI Reference Model is illustrated in Figure 1. The defined interoperability levels are illustrated in the first three columns, and each attribute of PAID is presented in the next four columns providing a broad representation of the types of Procedures, Applications, Infrastructure, and Data that is required in the relevant level of interaction.

Description	Computing Environment	Level	P	A	I	D
Enterprise	Universal	4	Enterprise Level	Interactive	Multi-Dimensional Topologies	Enterprise Model
Domain	Integrated	3	Domain Level	Groupware	World-wide Networks	Domain Model
Functional	Distributed	2	Program Level	Desktop Automatior	Local Networks	Program Model
Connected	Peer-to-Peer	1	Local/Site Level	Standard System Drivers	Simple Connection	Local
Isolated	Manual	0	Access Control	N/A	Independen:	Private

Figure 1. Levels of Information Systems Interoperability [16]

B. *The System of Systems Interoperability Model*

The Software Engineering Institute of Carnegie Mellon University [6] developed the system of systems interoperability model in order to facilitate system of systems interoperability. As illustrated in Figure 2, in the system of systems interoperability model, three types of activities are required to achieve interoperability. These three types of activities are Program Management, System Construction and Operational System [18].

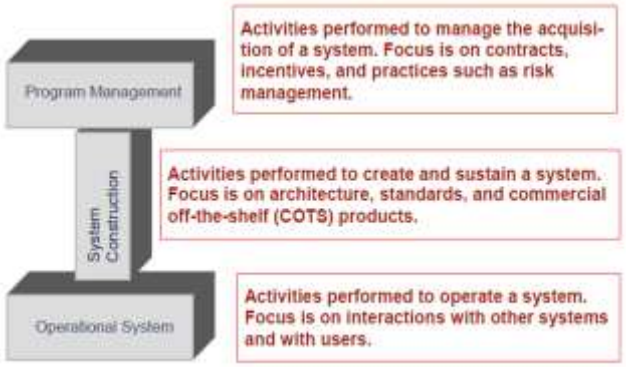

Figure 2. System of Systems Interoperability Model [6]

The set of activities managing the system acquisition is defined as Program Management. The activities done to develop or evolve a system are defined as System Construction. The activities in and between the executing system and its environment, as well as the interoperation with other systems are defined as operating system. In addition, the end user is considered as part of the operational system. The activities in a single acquisition organization are represented in Figure 2. Three types of interoperability are defined in the system of systems interoperability model [19]: **Programmatic Interoperability:** In programmatic interoperability, interoperability contains between different program offices. Programmatic interoperability includes the cooperation that must be achieved by programs building interoperating systems. **Constructive Interoperability:** In constructive interoperability, interoperability is presented between the organizations responsible for the systems construction and maintenance. Constructive interoperability relates to the specific technical agreements, standards and engineering processes that must be considered to achieve interoperability. **Operational Interoperability:** Operational interoperability relays on interoperability between the systems. The interpreting system's ability to contribute to achieving a superior human goal in the operating environment is referred to as the operational interoperability.

C. *E-health Interoperability Framework*

National E-Health Transition Authority (NEHTA) of Australia developed the E-health Interoperability Framework [21]. The NEHTA Interoperability Framework

is considered as a common reference model in Australia that offers guidelines for IT and business experts to deliver interoperable e-health systems. The NEHTA Interoperability Framework contains three separate interoperability perspectives that relate to each other. As illustrated in Figure 3, the NEHTA Interoperability Framework consists of the technical perspective, the information perspective and the organizational perspective [22].

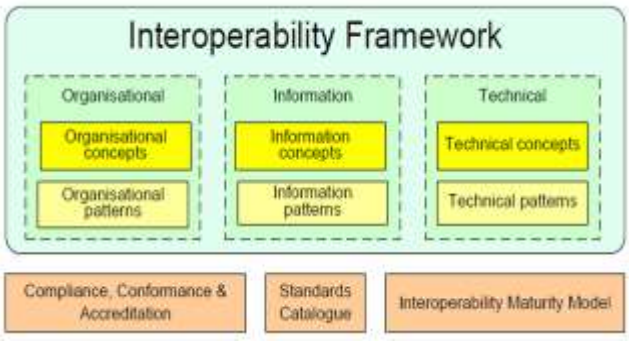

Figure 3. NEHTA Interoperability Framework and related components [23]

The Organizational Perspective is related to the understanding of healthcare, regulatory, legislative and enterprise environment where IT systems are required to be deployed to enable improved healthcare delivery. For this purpose, it is required to agree on key organizational concepts, for instance, processes, policies and roles, as well as capture the relevant organizational patterns, for instance change management, governance and legislative compliance [22].

The Information Perspective is related to the way that the clinical, statistical or administrative information could be represented and interpreted. According to ISO/IEC 10746-2, any kind of exchangeable knowledge among users, about concepts and facts in a universe of discourse is defined as information. For this purpose, it is required to agree on a core set of information concepts, for instance, information components and relationships between them, as well as capturing the relevant information patterns, for instance, information quality, information rights and application scope [22].

The Technical Perspective is related to the understanding of technical functionality to deliver e-health systems. For this purpose, it is required to agree on a core set of technical concepts, for instance, technical components, interface, technical service and interactions, as well as capturing the relevant technical patterns, for instance, technical architecture styles and component interaction styles [22]. Some related components are shown in Figure 3 such as the compliance, conformance and accreditation (CCA), the interoperability maturity model and standard catalogue.

IV. Discussion

In this section, the existing interoperability models are summarized, and different interoperability aspects are discussed and compared, and their strengths and weaknesses are described. Table I illustrates each of the introduced interoperability models with the types of systems covering them.

TABLE I. Categories of System

Interoperability Model	System Category
Levels of Information Systems Interoperability Model	Information Systems
The System of Systems Interoperability Model	System of Systems
E-health interoperability framework	E-Health Systems

The required amount of interoperability types that each interoperability model covers are shown in Table II. Reviewing Table II demonstrates that currently there is no interoperability model supporting all types of interoperability.

TABLE II. Types of Interoperability

Interoperability Model	Interoperability Type			
	Technical	*Organizational*	*Conceptual*	*Operational*
Levels of Information Systems Interoperability Model	√			√
The System of Systems Interoperability Model	√	√		√
E-health interoperability framework	√	√	√	

Table III presents the interoperability attributes that are defined in each of the interoperability models, and the structure offered for them.

TABLE III. Interoperability Attributes

Model	Interoperability Attribute
Levels of Information Systems Interoperability Model	Procedures, Applications, Infrastructure, and Data
The System of Systems Interoperability Model	Requirements, Technology, Communication, Data Models, Architecture
E-health interoperability framework	Organizational, Information, Technical

Table IV present mapping of interoperability attributes to interoperability types. As illustrated in Table IV, most of the interoperability models cover the relevant attributes of the technical and organizational interoperability, and a few of them support the relevant attributes of operational and conceptual interoperability. However, a complete reference model defining and addressing all the relevant attributes to different types of technical, organizational, conceptual and operational interoperability does not exist yet.

TABLE IV. Mapping of Interoperability Attributes to Interoperability Types

Interoperability Model	Interoperability Attributes	Interoperability Type			
		Technical	*Organizational*	*Conceptual*	*Operational*
Levels of Information Systems Interoperability Model	Procedures	√			√
	Applications	√			√
	Infrastructure	√			√
	Data	√			√
The System of Systems Interoperability Model	Requirements		√		
	Motivation, Incentives, and Processes		√		
	Technology	√			
	Communication	√			
	Data Models	√			
	Architecture	√			
	Operational				√
E-health interoperability framework	Organizational		√		
	Information			√	
	Technical	√			

From the researcher perspective, generally the strengths of the existing interoperability models could be classified as follows: All of the existing interoperability models cover the technical interoperability type. Most of the existing interoperability models include the organizational interoperability type. Also, in general, the weaknesses of the existing interoperability models could be described as follows: Few of the existing interoperability models contain the conceptual interoperability type. Form the existing interoperability models, only the LISI and the system of systems interoperability model support the operational interoperability type. Currently, there is not any model covering all types of interoperability. In each of the existing interoperability models, different set of interoperability attributes has been defined. There is no unique set of interoperability attributes defined in the existing interoperability models.

V. Conclusions

This paper presents an overview on the development of interoperability models. In order to improve interoperability, a number of attempts have been made to develop interoperability models. In general, there is not yet a standard model available to improve systems interoperability, since each of the existing interoperability models is defined only for improving a specific type of systems. Considering the best condition, most of the existing interoperability models only cover three types of the required interoperability. However, four interoperability types are needed for a comprehensive and complete coverage. As stated in the previous part (see Table IV), each of the existing interoperability models cover a specific attribute of interoperability. Therefore, concluding from the notes pointed out, this research could not select any of the existing interoperability models as a comprehensive model. The main reason of this fact is that the existing interoperability models do not contain the appropriate maturity level to achieve a comprehensive interoperability. Lessons learnt from the researches on interoperability models can be summarized as follows: Structuring interoperability models into one single comprehensive and complete interoperability model is necessary in order to ensure consistency and avoid redundancy. In addition, we need to identify metrics and properties to allow better development of interoperability between systems. Interoperability models should have addressed more on how to align the business strategy to technology for implementation. In order to offer the structure of interoperability, the interoperability model must consider the existing standards for implementing interoperability. It is important that a model is simple and easy to understand, because in this situation the developers could understand and use it easily. For the future research and development, the interoperability model must be defined based on the standard concepts and definitions of interoperability. The existing technology of the interoperability should be taken into account as well. In addition, taking into consideration that today, there is more emphasis on semantic interoperability in creating a common understanding between systems, thus the interoperability model must focus on the semantics interoperability.

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