HADMÉRNÖK
VÉDELEMINFORMATIKA
17. évfolyam (2022) 1. szám 171–191.
DOI: 10.32567/hm.2022.1.11

Sándor Munk[1]

Are Traditional IT System Interoperability Solutions Sufficient and Efficient? Thoughts on Novel Solutions

In our globalised world the interoperability of organisational IT systems has become an indispensable condition for the cooperation of organisations, so IT interoperability is now a priority demand of all application. In practice, we can essentially only find solutions based on standardised intermediary representations, but these have a number of limitations, the analysis of which is not covered in the literature. Novel interoperability solutions have also emerged in connection with the development of information technology, but little is said about the general requirements for innovative solutions. This publication seeks to contribute to these tasks.

Keywords: **IT interoperability, limitations of traditional solutions, interoperability infrastructure, interoperability services**

1. Introduction

The role and significance of IT interoperability nowadays do not require any special justification in any field of application. For actors in a specific field of application – e.g. in the case of military application, the forces performing the operations, in the case of administrative application, the bodies performing administrative tasks – their effective cooperation is almost impossible without the seamless cooperation and interoperability of their IT systems and services.

The related visions and requirements are defined by each application area in interoperability policies and frameworks at the national, allied or EU level, and for

[1] Professor emeritus, University of Public Service, Faculty of Military Science and Officer Training, e-mail: munk.sandor@uni-nke.hu

the implementation of which they operate interoperability programs.[2] The interoperability solutions that ensure the implementation of the requirements are fundamentally similar from the beginning. In addition to these solutions, which can be called traditional, novel approaches and solutions have also emerged, which, however, are not yet widespread.

The scientific and professional literature basically deals with the presentation of the individual solutions, the possibilities of their implementation, and analyses of their limitations and the reasons for the emergence of novel solutions to a lesser extent. Many people believe that today's interoperability solutions are appropriate, interoperability is not really a problem as there is massive availability of standard formats, application programming interfaces (APIs), widespread cloud-based solutions, and these can solve the interoperability of systems. In reality, however, interoperability is not primarily a technical concept, but a concept related to cooperation between organisations and organisational processes, and its quality must also be measured at this level.[3]

However, experiences on the subject, including my personal experience, suggests that traditional interoperability solutions have limitations that cannot be overcome, so that, under given circumstances, effective interoperability requires novel solutions. Knowledge of the limitations can provide an opportunity to define the requirements for innovative solutions and to examine the compliance of each innovative solution with these requirements.

Based on the above, the aim of the present publication is to explore the limitations of traditional IT interoperability solutions, to define the requirements for novel solutions, and to analyse their key features. To do this, in the following:

- I briefly summarise the basic concepts of IT interoperability and present the content and main features of traditional solutions
- I explore the most important limitations of traditional solutions and, based on them, determine the requirements for novel solutions
- finally, I analyse the characteristics of two novel solutions, the situation of their practical implementation and their limitations

2. Interoperability of IT systems, traditional solutions

Analysing today's IT interoperability solutions, I must first state what I mean by interoperability, interoperability between IT systems and their traditional solutions in the present publication, as we can find many different interpretations in the literature and in different application areas, although these are similar in their essential

[2] *C-M(2005)0016 NATO Policy for Interoperability* (North Atlantic Council, 2005); *COM(2010) 744, Towards interoperability for European public services* (Brussels: European Commission, 2010); *COM(2017) 134, European Interoperability Framework – Implementation Strategy* (Brussels: European Parliament, Council, Economic and Social Committee, Committee of Regions, 2017); *e-Government Interoperability Framework Version 6.1* (Cabinet Office UK, 2005).

[3] Leo Liu et al., 'A framework to evaluate the interoperability of information systems – Measuring the maturity of the business process alignment', *International Journal of Information Management* 54 (2020).

components. The interpretations presented below are based on my own previous research,[4] which is essentially in line with generally accepted ones.

2.1. Basics of IT systems interoperability

The first term related to interoperability was interoperable, meaning "capable of being used or operated reciprocally",[5] which appeared in the form of "interoperable weapon systems" between 1965–1970. Nowadays, interoperability has become a prominent concept in the field of information technology, many of the partly different definitions of which can be found in both military and civilian applications.[6]

In the definitions there are two common elements. The first is that it can be interpreted between two or more objects, and the second is that it is connected with collaboration. Accordingly, in the present publication, I mean interoperability: a relation between/among objects, a mutual capability necessary to ensure successful and efficient interoperation, supporting cooperation.

This general definition is only a starting point for the different types of interoperability, which can be identified by different adjectives. These cover different concepts, of which I would highlight the operational and technical interoperability. The subjects of the former are consciously acting, organised groups of people, and the latter are purposeful, purpose-built technical systems. Of the two, the former has priority, the latter plays a subordinate role compared to this, supporting its implementation.

The basis of effective and efficient cooperation is the continuous coordination of goals and situational awareness, the coordinated planning and coordinated implementation of joint activities, which requires regular exchange of information (communication). Thus, the concept of information interoperability, which is the mutual ability of different actors necessary to ensure exchange and common understanding of information needed for their successful cooperation, plays a key role.

There are three distinct levels of information exchange based on a common understanding, and on each level the interoperability should be implemented. These are:

- technical [level information] interoperability is a mutual ability to exchange material representations of information needed for cooperation (with possible transformations)
- syntactic [level information] interoperability is a mutual ability to exchange information representations needed for cooperation (with possible transformations) independent of their meaning

4 Sándor Munk, 'An Analysis of Basic Interoperability Related Terms, System of Interoperability Types', *AARMS* 1, no 1 (2002), 117–132; Sándor Munk, *Katonai informatikai rendszerek interoperabilitásának aktuális hadtudományi kérdései,* MTA doktori értekezés (Budapest: Magyar Tudományos Akadémia, 2007); Sándor Munk, 'Interoperability Services Supporting Information Exchange Between Cybersecurity Organisations', *AARMS* 17, no 3 (2018), 131–148.

5 *Webster's Encyclopedic Unabridged Dictionary of the English Language.*

6 *AAP-06, NATO Glossary of Terms and Definitions* (Brussels: NATO Standardization Office, 2020); *COM(2017) 134, European Interoperability Framework,* 4–5; *ISO/IEC 2382, Information Technology – Vocabulary* (ISO/IEC, 2015).

- semantic [level information] interoperability is a mutual ability to exchange information representations (with possible transformations) in a meaning-preserving way

Nowadays, the exchange of information without human intervention, based on the direct exchange of data between the IT systems of the cooperating actors, is an increasingly important part of the exchange of information. This necessitated the introduction of the concept of IT [devices, systems] interoperability, which is the mutual ability to exchange data managed by IT devices and systems preserving their intended meaning and interpretation (through possible transformations).

In the definition, I would like to draw attention to the requirement to preserve the "intended" meaning. In the absence of this, the exchange of data between IT systems does not ensure the conditions for information interoperability. As the meaning and the interpretation of the data are subjective, the meaning assigned to the managed data is determined by the agreed intentions, needs and interpretation of the primary group of users.

The issue of interoperability always arises only in situations that are characterised by differences and heterogeneity in some way. This is true for all three levels of information interoperability. There is no need to talk about semantic interoperability among professionals of a given specialisation who use the same terms, the same conceptual framework; to mention syntactic interoperability for those using the same message formats, or to examine the interoperability of IT systems between systems of the same type.

Today, in information technology the heterogeneity at the technical and syntactic level has decreased and is expected to decline further. In the field of physical transmission methods and message formats, some standard solutions become prevalent, individual, manufacturer- or task-specific solutions have been marginalised due to two reasons. One of the reasons is the constantly growing integration of the information environment into a globally interconnected system. This can be done effectively and reliably by adapting to the most commonly used solutions. The second reason is the increase in capabilities provided by the rapidly evolving information technology, which in many cases makes certain previously important aspects redundant (e.g. the character or bit-oriented nature, length, or structural complexity of messages). As a result, interoperability between the cooperating parties at the lower two levels is now relatively easy to achieve.[7]

However, it is a much bigger task to ensure the same interpretation of the data transmitted by the messages or stored and accessible in databases, as well as the functions provided by the systems, i.e. semantic interoperability. As the range of participants in the cooperation expands and the possibilities of information exchange extend, it may become more and more common that the conditions for a common level of common interpretation have not been established in advance, there is a semantic heterogeneity when "there is disagreement regarding the interpretation and intended

[7] For example, using standard OSI physical layer solutions, TCP/IP protocol, or XML or JSON message formats.

use of related information, or when the same phenomenon in a Universe of Discourse (UoD) is modeled different ways in two systems".[8]

Today, interoperability solutions designed to eliminate interoperability problems can be divided into two major groups of different importance. The essence of the first solution is the elimination of the existing differences, heterogeneity, the application of the same tools and procedures selected or developed in an agreed manner, i.e. the commonality, or the transition to it. In practice, this is only a very limited possibility, even in the case of central management, as different application areas usually have different requirements, and it is very rare to be able to introduce a new version at the same time everywhere. In reality, the state-of-the-art systems usually coexist, often for long periods of time, with the systems of earlier periods. However, it is possible to reduce the differences, especially at the technical and syntactic level, as they are mostly not application area-specific; therefore, they can be interchanged without affecting the services of the systems.

The second interoperability solution type, which is the most commonly used today, is the use of common mediation representations created by prior consultation. These include the various message format standards and information [exchange] data models, which are based on the acceptance of the autonomy of the cooperating actors, and of the heterogeneity of their IT systems in the scope, content and format of the information they manage. Accordingly, the essence of the solution is to define a common intermediary language, representation used in the exchange of information, and transfer the responsibility for carrying out the necessary transformations between the inner representations and the intermediary representation to the actors involved.

In addition to the interoperability solutions mentioned above, novel solutions have emerged that would take the task of resolving differences off the shoulders of cooperating IT systems. These solutions would allow the affected systems to exchange data with their cooperating partners using their own existing information exchange capabilities (protocols, data formats) and the possible heterogeneities are eliminated through interoperability solutions outside them, implementing the transformations necessary to the meaning-preserving exchange of data. This requires that each system provide adequate descriptions of the protocols, data formats and meanings associated with the data. The new solutions are referred to in the literature under different names: interoperability infrastructure, mediators, interoperability services, interoperability as a service. I will address these in more detail later in this publication.

2.2. Traditional solutions of IT systems interoperability

Nowadays, the interoperability solutions of IT systems, the exchange of data managed by these systems, preserving their meaning defined by the primary group of users, are almost exclusively based on the application of shared, agreed, standardised

[8] Paul Johannesson and M Hasan Jamil, 'Semantic Interoperability Context, Issues, and Research Directions', *Proceedings of the Second International Conference on Cooperative Information Systems* (Toronto, 1994), 180–191.

intermediary representations. The essence of this solution is that "everyone use a common language". In the following, from the perspective of my research goal, I briefly summarise the basic issues, and main tasks of development and application of interoperability solutions based on intermediary representations.

Intermediary representation is an information representation used in the exchange of data between IT systems to satisfy user information exchange needs, which is a set of different level representations built on each other. These include the physical representations used on the data carrier, or data transmission medium during the data exchange, as well as the data and message formats used. The meaning preserving exchange of data between cooperating systems is only possible if they use pre-agreed representation(s). It is the 'common language' that cooperating IT systems 'know', 'use' and 'interpret' in the same way.

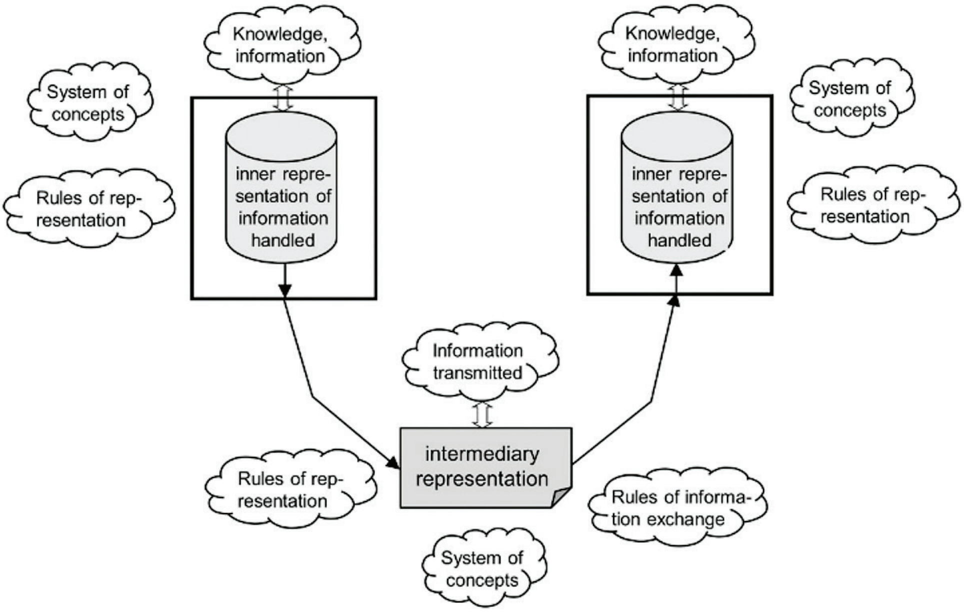

Figure 1: Traditional interoperability solution based on intermediary representation
Source: Compiled by the author.

Intermediary representation is always linked to a group of cooperating actors (communities of interest) and their IT systems. It is designed and applied because the stakeholders are interested in the cooperation, in the information exchange necessary for the cooperation, and consequently in the creation of the conditions for the interoperability of their IT systems and the meaning preserving exchange of their data.

Cooperating communities have shared goals and activities that can change over time. These communities can be narrower and wider, separated and overlapping, and may be built on each other. The existence and members of cooperating communities can also change over time, and an actor may be a member of one or more cooperating communities at the same time.

To *create an intermediary representation* means to select or create of the representations that make it up. This is based on the information exchange requirements of the cooperating community: the established representation must ensure the representation of the information and messages to be exchanged, including all elementary information, complex information and sets of information. The intermediary representation can be created without precedents, or it can be a modification of an existing intermediary representation. The reason for the modification may be a change in information exchange requirements or changes in the IT environment and available solutions, options. Existing representations or some of their components can also be used during creation.

The intermediary representation should be developed from the top down. First, at the semantic (conceptual) level, the things, properties and relationships described by the information involved in the information exchange must be defined, and a uniformly interpreted system of concepts accepted by all actors must be created. In doing so, it is necessary to harmonise the concepts used by the cooperating parties and their interpretation, existing concepts can be used, and the aim is to develop a universally accepted interpretation that is in line with the objectives of cooperation. This task is not related to IT systems, it is equally necessary for the exchange of information only by traditional methods.

The definition of the agreed conceptual system is followed at the syntactic level by the definition of the data model representing the conceptual system, the type, format and relationships of the elementary data and data structures carrying information about things, their properties and relationships. The same properties (e.g. geographical position) can be represented by different types of data, with different accuracies, interpreted in different contexts, and the same relationships (e.g. subordination) with different data structures. At the syntactic level, there can be several superimposed representations, the lowest level of which is the bit sequence, or bit stream representation, on which a string representation can be built, and an XML format representation can be built on the latter. Finally, at the physical level, the data transmission method and data transmission format used must be specified.

The *role, and importance of the different level components of the intermediary representation* and the possibilities of defining them are not the same. Of these, the semantic (conceptual) level representation plays a key role. Physical representations, as well as intermediate and lower-level syntactic representations, do not affect the content of the information of the information exchange requirements, their possible modification or replacement with a different variant does not affect the content of the information exchange.

The implementation of data exchange between IT systems at the physical level is the task of telecommunications and data transmission. Their technological solutions and applied formats are available to the syntactic level as an infrastructure service. In this field IP-based data exchange plays a key role, with the exception of some special application areas it has become predominant. One of the goals of the Future Internet research started in the early 2010s, “Everything on IP, IP on Everything”, seems to be coming true. Consequently, interoperability solutions based on intermediary representation practically do not deal with the physical level representations, for transmitting bit sequence messages they consider an available IP infrastructure, and a TCP or UDP capability built on it.[9]

Similar unification tendencies can be observed at the syntactic level. In contrast to individual bit-oriented message formats that meet special application needs, character-oriented message formats are dominated by the general-purpose XML format, which can be extended to meet specific information exchange requirements, the SOAP message format, and its transport protocol message formats (e.g. HTTP or RPC). Consequently, interoperability solutions based on intermediary representation at the syntactic level usually choose an existing solution (e.g. SOAP + XML), consider its messaging implementation an infrastructure service, and only define the format of the specific messages and message exchange procedures related to the solution to be implemented.

The definition of the semantic level representation is always application-specific, in the course of which only sub-elements, concepts related to general things, properties (e.g. geographical location, date, quantitative characteristics), relationships (e.g. higher unit – subordinate unit, supporting–supported, adjacent) can be used from other solutions. In these cases, however, it is advisable to use terms already used in other solutions instead of defining new ones in order to facilitate a wider exchange of information in the future.

The ability to use an intermediary representation means that the cooperating IT systems are able to convert the data involved in the data exchange from their own representation to the shared intermediary representation in a meaning preserving way, and to convert back from the intermediary representation to their own representation. The scale and difficulty of this task depends on the differences between the IT system's own representation and the shared intermediary representation. This difference may exist at all three levels of representation, but resolving it is a major challenge primarily at the semantic level.

The development of an interoperability capability based on an intermediary representation is a different task in case of the development of a new IT system, and development of an existing system. In the case of the development of a new system, when creating one's own internal representation used in the software and database it is possible to take into account the content of the intermediary representation as much as possible. If the user requirements allow, the intermediary representation can be used in its entirety, which makes the transformation unnecessary, but its minor modification, 'customisation' also means a simpler transformation task. In case of the development of an existing system, this advantage is no longer present.

In an IT system, two types of own representations of a given set of information can be distinguished. The first is the own 'internal' representation used in the software and database: the own data model, and the conceptual framework behind it. In case of a distributed system, the second is the own 'external' representation used to exchange data between system components. In case of such an 'external' representation, the

[9] Internet Protocol (IP), Transmission Control Protocol (TCP), User Datagram Protocol (UDP).

ability to use an intermediary representation can be realised without modifying the components of the system by creating a gateway subsystem for the purpose to do necessary meaning preserving transformations between the own messages and the intermediary representation.

3. Limitations of traditional interoperability solutions, requirements for novel solution

One of the aims of my publication is to prove the hypothesis that traditional solutions are neither sufficient nor the most effective for solving interoperability problems; to this end, novel solutions are needed. Therefore, in the following, I identify the most important limitations of traditional solutions and the circumstances in which these limitations play a significant role, and then formulate and systematise the requirements for new solutions, which can be deduced from user needs and interests.

3.1. Limitations of traditional solutions

I examine the limitations of traditional interoperability solutions, which I consider to be the most important, divided into three groups. In addition to these, there would obviously be additional groups and other limitations within the groups. In the following, I first define the difficulties, problems and limitations associated with the information exchange requirements, then to the formation of the intermediary representation, and finally those related to the implementation of the ability to use this intermediary representation.

The first factor that limits the effectiveness of traditional solutions is the *dependence on the affected community,* the homogeneity of their information exchange requirements, and the characteristics of their cooperation. In case of close and permanent cooperation, and actors with substantially identical or similar functions, and consequently well-defined and similar information needs, it is relatively easy to determine an intermediary representation according to the needs and interests of all parties, as under these conditions, a common conceptual framework for the information exchanged and a common interpretation to the extent necessary for cooperation have already been established and consolidated.

If the cooperation is not close and permanent, there will be more differences between the information exchange requirements of the parties involved, in the content and interpretation of the information contained therein. This makes it difficult to establish a common intermediary representation suitable for all, and the level of compliance with the real needs of each party decreases as the differences between the parties increase. If an actor joins a cooperating community later, or if different communities with their own intermediary representation are involved in a higher level of cooperation, the different information exchange requirements cannot be realised without modifying the intermediary representation(s), without having to go through the conciliation process again.

The emergence of interoperability needs is clearly characterised by the ever-expanding range of actors involved. In general, and in case of military application after the narrower, functional area level cooperating communities, the need for interoperability at the service level and then between the services emerges. According to another dimension, interoperability needs extend from national military IT systems to alliance systems and then to the IT systems of other nation's armed forces units, governmental, or non-governmental organisations involved in joint operations. Traditional interoperability solutions are becoming less and less suitable to meet these interoperability needs.

The above is also supported by the case of interoperability of military map symbols. There is a fundamental need for cooperating military organisations to be able to share map-based situational awareness data managed in their IT systems in a meaningful manner. This also requires a meaningful exchange of map symbols describing the situation, which has been addressed by military symbol standards (NATO AAP-6 or U.S. military MIL-STD-2525 standards), the fourth version (D) of which is currently in place.[10]

The military map symbol standards clearly show the dependence on the user community, they include symbols that are important for some actors and not interesting for other actors (e.g. U.S. national security and law enforcement agencies). There is no complete, one-to-one correspondence between the symbols of the different versions of the standards, and there is a loss of information when switching between the standards.

Thus, it can be seen that the differences between the information needs and applied solutions of the cooperating actors cannot be eliminated even with elaborated standards, they must be resolved by the parties concerned.

The second limitation is the difficulty of and time required for prior consultation associated with the formation of an intermediary representation. In essence, this process is a standardisation process in which such an intermediary representation must be developed that differs as little as possible from the representations previously used by the cooperating parties. If the parties have previously exchanged information, but not through their IT systems, the intermediary representation is the optimal compromise based on the individual representations.

The more the information managed by the parties differ in their interpretation, content and format, the more difficult is to form an intermediary representation. As I have emphasised in several places earlier, the most difficult is to develop a solution that fits different interpretations and contents, especially in the case of cooperation consisting of a wide range and therefore more heterogeneous actors.

A standardisation process requires complex procedures, and organisational background, working groups, review and decision-making bodies, and a decision-making body, as well as a series of review–discussion–decision-making cycles. This process

[10] *APP-6 NATO Joint Military Symbology. Edition D Version 1* (Brussels: NATO Standardization Office, 2017); *MIL-STD-2525D Department of Defense Interface Standard Joint Military Symbology* (Defense Information Systems Agency, 2014).

requires a significant amount of time, typically on an annual scale, and additional development cycles that ensure adequate quality and continuous updating.

An example is the Multinational Interoperability Program, the successive baselines of which have been published at several-year intervals (2003, 2004, 2009), and the new version[11] has been under development since 2012. The evolution of the Friendly Force Tracking standard message formats shows a similar picture over time (2006, 2016). But similar data can be seen for the message formats used by LINK-16 and the Air Command and Control System (J-series messages, AWCIES), or the VMF K-series messages. All this proves that the development of a standard intermediary representation is a process of one or a few years.

A third major problem in case of traditional solutions is the difficulty of development required to use the intermediary representation and the low cost-effectiveness of these developments. The interoperability solution based on intermediary representation is essentially a meaning preserving transformation and re-transformation between the internal representation of the information exchanged in the given IT system and the intermediary representation.

In existing IT systems, the possibility of modifying the internal representation is limited, as this would affect the components of the system that handle (produces, or consumes) the given information, and would require their modification. Thus, in most cases, the actual option is to supplement the system with transformation components that form an interface between the system and the outside world. This needs a new development that can be most effectively met by the original developer of the system, if it still exists, and if it undertakes the development task. In many cases, however, this condition is not met, the system in question is a so-called legacy system, that has survived from an earlier period, is often obsolete, or is becoming obsolete for various reasons, and cannot be further developed.

In addition to the difficulties or even impossibility of development, a significant economic issue is that during the fitting of different systems to the same intermediary representation, the same transformation functions become necessary, and thus are implemented several times. The reason for this is that in several systems there may be overlaps between internal representations, which thus require the same transformation. Multiple implementations are obviously an unnecessary expense, but can even lead to discrepancies that pose interoperability problems.

3.2. Requirements for novel solutions

A number of requirements can help to exceed the limits mentioned in the previous point. These are based on more general approaches, and even without their specific formulation they played a role in the appearance of various novel interoperability directions and solutions. In the following, I would like to highlight three requirements related to transformations between cooperating IT systems. These are the following:

- implementation of transformations as a separate functional unit

[11] MIP4 Information Exchange Specification.

- implementation of transformations as a service
- feasibility of conversions without prior consultation

The first requirement is to decouple the transformations between internal and intermediary representations from the systems involved, which aims to overcome the limitations of development difficulties and economic disadvantages. Its implementation is justified by the fact that there are many widely used transformation functions in traditional interoperability solutions that do not become 'public benefit', because they are 'buried' in a system and cannot be reused.

These problems can be solved by component-based software development, which allows the organisation of the transformation functions into a system-independent but tightly connected functional unit or into an interoperability infrastructure that meets the needs of multiple systems. The decoupling of the transformation functions appears in several conventional solutions in the form of separate gateways, however, this is only software separation, they remain part of the system, and their implemented functions are not available to other systems.

In addition to the lack of reusability, adapting to new or changing information exchange needs, further development the interoperable transformation functions implemented in each system is also uneconomical, because it requires further development of the given system without actually affecting the basic system functions.

The decoupling and reusability of interoperability solutions was also one of the objectives of the European Union's ISA² interoperability program, as exploration, creation and operation of interoperability solutions to support the implementation of EU policies and activities, facilitating the re-use of such solutions by European administrations.[12] However, according to the 2019 report,[13] evaluating the implementation of the program, the objective of reusability was only achieved to a certain extent.

The business interests of software companies make it rather difficult to meet the requirement for reusability of interoperability solutions. It is more profitable for companies to sell their interoperability solutions embedded in comprehensive products than to facilitate the activities of other software vendors by publishing or selling it.

The decoupling of interoperable transformations from the affected systems makes it possible to *decouple the implementation and operation of the transformations from the development and operation of the systems* using them, which can also be considered a response to the development difficulties and economical disadvantages. Instead of developing own development and interoperability infrastructure, it is possible to use the required capabilities as an interoperability service.

The separation of reusable functions and their implementation by external service providers makes it possible to centralise the expertise required for their development;

[12] *Decision (EU) 2015/2240 of the European Parliament and of the Council,* 1. (d).

[13] *Evaluation Study supporting the interim evaluation of the programme on interoperability solutions for European public administrations, businesses and citizens (ISA²). Final Report* (European Commission, Directorate General for Informatics, 2019).

to increase the quality of software development, to improve its productivity; and more economical use of resources allocated to interoperability services.

Because interoperability is inherently a mutual capability between cooperating IT systems interconnected by a network (whether it is the open Internet or a restricted access network of an application area), interoperability services can emerge as value-added services on that network.

In contrast to the sharing of interoperability solutions, there may already be/ is an economic interest in the provision of interoperability services, which has been reinforced by the emergence and rapid spread of cloud-based solutions. I will deal with interoperability services in more detail in the next section.

The third, most demanding requirement – the *possibility of implementing transformations without prior consultation* – aims to reduce the time required to implement interoperability solutions, and it is already foreseeable that to meet this requirement may encounter the greatest difficulties. In contrast to the previous two requirements, this is not related to traditional solutions based on a common intermediary representation, its aim is not only a more efficient and economical implementation, but to dynamically implement transformations between representations used by different systems or intermediary representations used by different user groups even in different ways per connection.

A key condition of such an implementation is the formal description of the representations used by the individual systems, or user groups. With the help of these descriptions the transformations can be realised in a shorter time, possibly using previously implemented transformations. These descriptions are relatively easy to produce in the lower two (technical and syntactic) of the three levels of interoperability mentioned in the introduction. However, this is not true for the semantic level that carries the meaning of information representations, where currently even standardised intermediary representations contain only a textual description of the meaning and references to certain source documents.

A ‘dynamic’ interoperability solution that differs from link to link, based on a formal description of the representations, would be particularly useful for systems with similar representations, but for lack of a better one using general intermediary representations of a wide community of users.

Ontologies, as formal descriptions of knowledge as a set of concepts, are an essential tool for semantic-level interoperable transformations without prior consultation. These have been at the forefront of IT research for a few decades, but their practical applications have appeared in only a few areas. A 2020 literature review[14] examines their potential applications in the field of product lifecycle management. The authors state that 93% of the publications are theoretical proposals, more than 50% describe a model or framework.

14 Alvaro Luis Fraga et al., ‘Ontology-based solutions for interoperability among product lifecycle management systems: A systematic literature review’, *Journal of Industrial Information Integration* 20 (2020).

4. Thoughts on novel solutions

Among the novel, non-traditional interoperability solutions in the literature, the interoperability infrastructure and the closely related interoperability as a service occupy a prominent place. These have appeared partly in response to the limitations of traditional solutions and partly in connection with popular directions of information technology development, but they have not yet gained significant application in practice. In the following, I will formulate some thoughts on these two issues without claiming completeness.

4.1. Interoperability infrastructures

According to Google NGram Viewer, the term 'interoperability infrastructure', appeared in the literature after 1990, however, there is still no uniformly accepted definition of its content. The term is most commonly found in the areas of public administration and healthcare, which are characterised at national and EU level by actors who need to work closely together, but operate heterogeneous IT systems.

In the following, I first summarise the basic features of two related research projects. The EU-funded 2004–2006 *ARTEMIS project*[15] aimed to improve the data exchange capabilities of medical IT systems. The objective of the project was to enhance the data exchange capabilities of medical information systems. The rationale was that most of the information systems that are in use in health care institutions are not able to communicate among each other, "they are proprietary and often only serve one specific department within a healthcare institute. A number of standardization efforts are progressing to address this interoperability problem such as EHRcom[16], openEHR[17] and HL7 Version 3[18]. Yet, it is not realistic to expect all the healthcare institutes to conform to a single standard. Furthermore, different versions of the same standard […] and even the different implementations of the same standard, […] do not interoperate".[19]

The objective of ARTEMIS was to develop "a semantic web service based P2P interoperability infrastructure for healthcare information systems".[20] The proposed solution was "to provide the exchange of meaningful clinical information among healthcare institutes through semantic mediation".[21] The heterogeneities among the standards was handled at the semantic level using ontologies, ontology mapping and semantic mediation. The two basic parts of the Artemis Message Exchange Framework was the message schema mapping, and the message instance transformation.

15 A Semantic Web Service-based P2P Infrastructure for the Interoperability of Medical Information Systems.
16 *ISO 13606 Health informatics – Electronic health record communication* (ISO, 2019).
17 A technology for e-health consisting of open platform specifications, clinical models and software.
18 Health Level Seven Version 3 (V3) Normative Edition.
19 Veli Bicer et al., 'Artemis Message Exchange Framework: Semantic Interoperability of Exchanged Messages in the Healthcare Domain', *ACM SIGMOD Record* 34, no 3 (2005), 71.
20 Mike Boniface and Paul Wilken, 'ARTEMIS: Towards a Secure Interoperability Infrastructure for Healthcare Information Systems', *Studies in Health Technology and Informatics* 112 (2005), 181–189.
21 Bicer et al., 'Artemis Message', 71.

Message schemas were translated to OWL ontologies, and then mapped pairwise to each other, creating a mapping definition. The messages were transformed to OWL instances, then these instances transformed to the target format using the mapping definition, and finally converted back to message formats.

The also EU-funded 2006–2008 *SEEMP project*[22] aimed to allow existing national/local job market places and data warehouses to be interoperable at pan-European level. The essential phases of the job market process are: describing the requirements of the job position, publishing the job posting, receiving of applications and final decision-making. The starting point was that the public employment services, who are information intermediaries between job seekers and employers, differ substantially in the way they describe positioning regarding to geographical areas, specific industries or occupation groups, and the format and content of CVs of the applicants are diverse, too.[23] The objective of the project was to develop a federated architecture and interoperability middleware as well as applicative plug-in services.

The proposed solution of the project is – like ARTEMIS – web service based. It is composed of a reference part, which reflects the 'minimal shared commitment', and the connectors toward the various local actors. The reference part is made up of a central abstract machine, and a set of common services supporting the execution. The abstract machine does not perform directly any operation, but offers abstract services that are made concrete by delegation. When the abstract service is invoked, its execution is delegated to the appropriate employment service to invoke the correspondent concrete services. A core component of the solution is a reference ontology, that is built on commonly used standards. This contains those interpretations which are shared by cooperating parties on high-level aspects, allowing for collaboration among them, while disagreeing on minor details that differentiate one party from the others.[24]

The professional-scientific results of the two research projects are common in that:

- do not include a definition of interoperability infrastructure
- they assume that the cooperating systems exchange data in the form of XML or EDI format messages
- their proposed solutions are based on web services and the use of ontologies
- there is no literature information on their practical results for more than ten years since the closure of the projects

As the *definition of interoperability infrastructure* is not included in the literature, in the following I will formulate a proposed interpretation, which can be based on the general content of the concept of infrastructure and its purpose in support of interoperability. Since the essence of IT interoperability is the exchange of data between IT systems, which preserves the intended meaning, the basic foundation for this is the existence of a network infrastructure enabling the data exchange. However,

[22] Single European Employment Market-Place.

[23] *The SEEMP project. Single European Employment Market-Place. An e-government case study* (OASIS).

[24] Emanuele Della Valle et al., 'SEEMP: An Interoperability Infrastructure for e-Government Services in the Employment Sector', in *The Semantic Web: Research and Applications, 4th European Semantic Web Conference, ESWC 2007,* ed. by Enrico Franconi, Michael Kifer and Wolfgang May (Berlin–Heidelberg: Springer, 2007), 220–234.

communication networks do not provide interoperability transformations, so the interoperability infrastructure can be implemented as a value-adding layer based on these networks.

Based on the above, the interoperability infrastructure is a set of tools, methods, procedures and operating personnel, the purpose of which is to implement and support the conditions of interoperable data exchange for a specific group of IT systems. In addition to the ability to exchange raw data, the interoperability infrastructure performs widely used meaning-preserving transformations, taking over this task from the systems concerned. Based on the levels of interoperability, the interoperability infrastructure can also be divided into levels, or layers, the lower layer of which provides syntactic transformations, while the upper layer contains functions implementing semantic transformations.

The *results of the research programs* of the early 2000s did not appear in practice. In the literature we cannot find the presentation of an existing IT interoperability infrastructure, nor has a major research program been launched in the last ten years to establish it. Although the use of web services, which is the basis of these solutions, is constantly expanding, ontology-based solutions for semantic interoperability have encountered significant limitations. The reasons for this were partly the difficulty of creating formal domain ontological descriptions (in fact, due to the shortcomings in the clarity of field concepts) and partly the difficulty of transformations between different conceptual systems.

Another reason for the lack of interoperability infrastructures is practical. The implementation and maintenance of a global, regional, national or organisational infrastructure requires significant expenses and resources, which at present, in my opinion, the actors involved are unable or unwilling to provide. The costs of implementation and, consequently, usage of a market-based infrastructure service are high.

A recent review article emphasises that the interoperability frameworks (the bases of interoperability infrastructures) "are mainly concerned with the structuring of the interoperability concepts, and not on the actual implementation of software prototypes to support these specifications".[25]

4.2. Interoperability services

The concept of 'interoperability services' is strongly connected to the concept of interoperability infrastructure discussed in the previous point, as all infrastructures, whether organisational, national, regional or global, provide services to their customers. We must look for the place and role of the examined concept among these infrastructural services. As in the case of interoperability infrastructure, in the literature the term interoperability as a service is used in various forms, mostly without a precise definition.

[25] Claudia-Melania Chituc, 'Interoperability Frameworks for Networked Information Systems: A Comparative Analysis and Discussion', *International Journal of Cooperative Information Systems* 28, no 1 (2019).

In the following I highlight two literature occurrences of the interoperability service. The *Interoperability Service Utility* is one of the basic concepts of a 2008–2011 EU project (Collaboration & Interoperability for Networked Enterprises, COIN). The term has already been used in the roadmap of enterprise interoperability research project. The starting point of the project was to meet their business objectives, enterprises need to collaborate with other enterprises. The report states, that "questions remain about the impact and significance of […] vendor-based solutions. Specifically, a single, monolithic solution for Enterprise Interoperability rested on proprietary protocols and captive markets is untenable in a climate of change, unworkable in real businesses, and strategically undesirable for promoting innovation and growth".[26] The conclusion is, that "interoperability as a utility-like capability needs to be supported by an enabling system of services for delivering basic interoperability to enterprises, independent of particular IT deployment. We use the term Interoperability Service Utility (ISU) to denote this overall system. […] Value-added functionalities, for which customers would be willing to pay a premium, would flow above the ISU. Conceptually, the ISU constitutes the next "layer" of open cyberspace, sitting atop the Internet and the Web. The implicit proposition is that interoperability as a technical functionality is a public good – the ISU is available for all to use, exploit and build upon".[27]

In a later document the economic and implementation questions were analysed. How can enterprise interoperability be sold as a utility, rather than as an adjunct to a commercial offering? Who would (should) own and/or operate the ISU? The hypothesis is that "interoperability […] realised as a commoditised technical functionality, delivered as services, and independent of particular IT deployment – is key to the infrastructure of a new generation of software-based services and applications".[28]

The report defines the ISU as a utility infrastructure which comprises utility services. A service is a software component which provides functionality that can be activated and called on demand remotely from another software system. The term refers to:

- the functionality provided by the utility and exposed using service interfaces (utility service)
- any third party service available over the utility (value added service)[29]

The interoperability services term also appears in the title of the *Content Management Interoperability Services* standard of OASIS[30] published in 2010 and modified in 2015. The purpose of the standard is to support information sharing between content management repositories/systems made available by different service providers, by specifying web services and interfaces.[31] The standard "defines a domain model and Web Services, […] bindings that can be used by applications to work with one

[26] Man-Sze Li et al. (eds), *Enterprise Interoperability. Research Roadmap. Final Version (Version 4.0)* (Luxembourg: Publications Office of the European Union, 2006), 1.

[27] Ibid. 2.

[28] Man-Sze Li, *D6.2.1a – Integrated EI Value Proposition – M24 issue* (COIN Consortium, 2010), 6.

[29] Ibid. 14–15.

[30] Organization for the Advancement of Structured Information Standards.

[31] Florian Müller and Ken Baclawski (eds), *Content Management Interoperability Services (CMIS) Version 1.1 Plus Errata 01* (OASIS, 2015).

or more Content Management repositories/systems. The CMIS interface is designed to be layered on top of existing Content Management systems and their existing programmatic interfaces". In fact, the standard – despite its name – is nothing more than traditional interoperability solutions: a standard intermediary representation and the interface that handles it.

The *concept of interoperability service* in relation to IT interoperability can be defined as a service by which the service provider supports interoperability (meaning preserving data exchange) between service consumers' (users') IT systems, devices and applications. The service can provide the conditions of interoperability in whole or in part, its basic task is to support and implement transformations between different information representations. The technical implementation of interoperability services can be middleware, web service and cloud-based (which partially overlap one another).

Among the interoperability services 'interoperability as a service' plays a key role, and its interpretation fits into the conceptual framework of cloud-based solutions. The essence of this is "enabling network access to a scalable and elastic pool of shareable physical or virtual resources with self-service provisioning and administration on-demand".[32]

The range of cloud-based services is expanding nowadays, with new 'as a service' type concepts emerging one after the other, of which a research material already collected 68 in 2015.[33] The concept of 'Everything/Anything-as-a-Service' (XaaS) has also appeared in the literature to summarise them.[34] Definition of interoperability as a service is not included, but it is relatively easy to interpret it in this context: a cloud-based software service that performs on-demand transformation of, and mediation between data exchange mechanisms, protocols or data to support interoperability.

The situation of the *practical application of interoperability services* is similar to that of the interoperability infrastructure closely related to it. The user demand for these services is significant in many application areas, of which health informatics and the Internet of Things stand out in the literature. The reasons for the current lack of implementation are also similar to those stated in the case of interoperability infrastructure: the difficulties of services at the semantic level and the economic aspects of the market emergence of interoperability service providers.

Despite the above situation, syntactic transformations between character sets, number representations, or different message formats (XML, JSON), or semantic transformations between classifications, units of measure, coordinate, or calendar systems could be widely used.

The concept of interoperability services is strongly connected to clouds, but – as an article[35] shows – "the cloud providers and clients have opposite motivations for cloud interoperability. The providers prefer vendor lock-in situations to keep the clients and ensure higher profits enabling more and more cloud features. On contrary,

[32] *ISO/IEC 17788 Information technology – Cloud computing – Overview and vocabulary* (ISO/IEC, 2014), 3.25.

[33] Sugam Sharma, 'Evolution of as-a-Service Era in Cloud', *ArXiv,* abs/1507.00939 (2015).

[34] Yucong Duan et al., 'Everything as a Service(XaaS) on the Cloud:Origins, Current and Future Trends', *2015 IEEE 8th International Conference on Cloud Computing,* 2015, 621–628.

[35] Magdalena Kostoska et al., 'An Overview of Cloud Interoperability'. *Proceedings of the Federated Conference on Computer Science and Information Systems* 8 (2016), 873.

the clients would like freedom, and the ability to choose the provider that offers the highest quality of services they want. Therefore, the need for cloud interoperability is more initiated by the clients than the providers". As a conclusion, the author states that "cloud interoperability on IaaS and PaaS levels has been addressed and several partial solutions exist, while the cloud interoperability on the SaaS level is still in an infant development".[36]

5. Summary, conclusion

The starting point of my publication is the traditional solution of IT interoperability, the essence of which is to use a standard intermediary representation. The development of this 'common language' is based on the information exchange needs of a cooperating community and is created as a result of a prior consultation process and then modified as necessary as information exchange needs change. The meaning preserving transformation between the representation used in the IT systems of the individual actors and the intermediary representation is the responsibility and task of the given actors.

Practice clearly shows that traditional interoperability solutions are in many cases not sufficient, nor the most effective, to solve interoperability problems. The first contribution of the publication is to explore and systematise the limitations of traditional solutions. These include dependence on the community concerned, the homogeneity of their information exchange needs and the closeness of their cooperation. This self-evident dependence implies the difficulty of achieving interoperability between actors who do not cooperate closely and on a lasting basis. The second limitation is the time required for prior consultation, which makes it difficult to establish the IT interoperability required for cooperation in a timely manner in case of new cooperation environments, such as new coalition operations. Finally, the third limitation is the difficulty of adaptation to the intermediary representation for existing systems and the low cost-effectiveness of development due to the multiple implementation of the same transformation functions.

The second contribution of the publication is the definition of general requirements for novel solutions, which can be deduced from the limitations of conventional solutions. These are: decoupling the transformation between internal and intermediary representations from the systems involved, decouple the implementation and operation of the transformations from the development and operation of the systems using them and the possibility of implementing transformations without prior consultation.

Finally the most characteristic research results of two novel solutions – interoperability infrastructures and interoperability services – and the state of their practical implementation are presented. The third contribution of the publication is the exploration that these novel solutions are still in the research phase, there are no examples of their practical application, and the reasons for this lie primarily in

[36] Ibid. 876.

the difficulties of semantic interoperability and the economic conditions of IT interoperability infrastructure operation and service provision.

References

AAP-06, NATO Glossary of Terms and Definitions. Brussels: NATO Standardization Office, 2020.

APP-6 NATO Joint Military Symbology. Edition D Version 1. Brussels: NATO Standardization Office, 2017.

Bicer, Veli, Gokse B Laleci, Asuman Dogac and Yildiray Kabak, 'Artemis Message Exchange Framework: Semantic Interoperability of Exchanged Messages in the Healthcare Domain'. *ACM SIGMOD Record* 34, no 3 (2005), 71–76. Online: https://doi.org/10.1145/1084805.1084819

Boniface, Mike and Paul Wilken, 'ARTEMIS: Towards a Secure Interoperability Infrastructure for Healthcare Information Systems'. *Studies in Health Technology and Informatics* 112 (2005), 181–189.

Chituc, Claudia-Melania, 'Interoperability Frameworks for Networked Information Systems: A Comparative Analysis and Discussion'. *International Journal of Cooperative Information Systems* 28, no 1 (2019). Online: https://doi.org/10.1142/S0218843019500023

C-M(2005)0016 NATO Policy for Interoperability. North Atlantic Council, 2005.

COM(2010) 744, Towards interoperability for European public services. Brussels: European Commission, 2010.

COM(2017) 134, European Interoperability Framework – Implementation Strategy. Brussels: European Parliament, Council, Economic and Social Committee, Committee of Regions, 2017.

Decision (EU) 2015/2240 of the European Parliament and of the Council.

Della Valle, Emanuele, Dario Cerizza, Irene Celino, Jacky Estublier, Germán Vega, Mick Kerrigan, Jaime Ramirez, Boris M Villazon, Pascal Guarrera, Gang Zhao and Gabriella Monteleone, 'SEEMP: An Interoperability Infrastructure for e-Government Services in the Employment Sector', in *The Semantic Web: Research and Applications, 4th European Semantic Web Conference, ESWC 2007,* ed. by Enrico Franconi, Michael Kifer and Wolfgang May. Berlin–Heidelberg: Springer, 2007, 220–234. Online: https://doi.org/10.1007/978-3-540-72667-8_17

Duan, Yucong, Guohua Fu, Nianjun Zhou, Xiaobing Sun, Nanjagund C Narendra and Bo Hu, 'Everything as a Service (XaaS) on the Cloud: Origins, Current and Future Trends'. *2015 IEEE 8th International Conference on Cloud Computing,* 2015, 621–628. Online: https://doi.org/10.1109/CLOUD.2015.88

e-Government Interoperability Framework Version 6.1. Cabinet Office UK, 2005.

European Interoperability Framework – Implementation Strategy. Brussels: European Commission, 2017, 4–5.

Evaluation Study supporting the interim evaluation of the programme on interoperability solutions for European public administrations, businesses and citizens (ISA²). Final Report. European Commission, Directorate General for Informatics, 2019.

Fraga, Alvaro Luis, Marcella Vegetti and Horacio Pascual Leone, 'Ontology-based solutions for interoperability among product lifecycle management systems: A systematic literature review'. *Journal of Industrial Information Integration* 20 (2020). Online: https://doi.org/10.1016/j.jii.2020.100176

ISO 13606 Health informatics – Electronic health record communication. ISO, 2019.

ISO/IEC 2382, Information Technology – Vocabulary. ISO/IEC, 2015.

ISO/IEC 17788 Information technology – Cloud computing – Overview and vocabulary. ISO/IEC, 2014.

Johannesson, Paul and M Hasan Jamil, 'Semantic Interoperability Context, Issues, and Research Directions'. *Proceedings of the Second International Conference on Cooperative Information Systems,* Toronto, 1994, 180–191.

Kostoska, Magdalena, Marjan Gusev and Sasko Ristov, 'An Overview of Cloud Interoperability'. *Proceedings of the Federated Conference on Computer Science and Information Systems* 8 (2016), 873–876. Online: https://doi.org/10.15439/2016F463

Li, Man-Sze, *D6.2.1a – Integrated EI Value Proposition – M24 issue.* COIN Consortium, 2010.

Li, Man-Sze, Ricardo Cabral, Guy Doumeingts and Keith Popplewell (eds), *Enterprise Interoperability. Research Roadmap. Final Version (Version 4.0).* Luxembourg: Publications Office of the European Union, 2006.

Liu, Leo, Weizi Li, Naif R Aljohani, Miltiadis D Lytras, Saeed-Ul Hassan and Raheel Nawaz, 'A framework to evaluate the interoperability of information systems – Measuring the maturity of the business process alignment'. *International Journal of Information Management* 54 (2020). Online: https://doi.org/10.1016/j.ijinfomgt.2020.102153

MIL-STD-2525D Department of Defense Interface Standard Joint Military Symbology. Defense Information Systems Agency, 2014.

Munk, Sándor, 'An Analysis of Basic Interoperability Related Terms, System of Interoperability Types'. *AARMS* 1, no 1 (2002), 117–132.

Munk, Sándor, *Katonai informatikai rendszerek interoperabilitásának aktuális hadtudományi kérdései,* MTA doktori értekezés. Budapest: Magyar Tudományos Akadémia, 2007.

Munk, Sándor, 'Interoperability Services Supporting Information Exchange Between Cybersecurity Organisations'. *AARMS* 17, no 3 (2018), 131–148. Online: https://doi.org/10.32565/aarms.2018.3.9

Müller, Florian and Ken Baclawski (eds), *Content Management Interoperability Services (CMIS) Version 1.1 Plus Errata 01.* OASIS, 2015.

Sharma, Sugam, 'Evolution of as-a-Service Era in Cloud'. *ArXiv,* abs/1507.00939 (2015).

The SEEMP project. Single European Employment Market-Place. An e-government case study. OASIS.

Webster's Encyclopedic Unabridged Dictionary of the English Language.