Interoperability Maturity Assessment of the Digital Innovation Hubs

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Abstract: In today's manufacturing companies need to be able to join the Industry 4.0 paradigm and technologies. Often companies, especially SMEs are not digitally ready. Digital Innovation Hubs (DIHs) are raising for overcoming this problem. DIHs support companies providing services and digital technologies. However, the critical challenge, for the development of the DIHs ecosystem is to assess the ability of the DIHs and partners to interoperate together. DIH4CPS (Fostering DIHs for Embedding Interoperability in Cyber-Physical Systems of European SMEs) is an Innovation Action (IA) receiving funding from the European Union's Horizon 2020 programme. DIH4CPS aims to create an embracing, interdisciplinary network of DIHs, and solutions providers, focused on cyber-physical and embedded systems, interweaving knowledge and technologies from different domains, and connecting regional clusters with the Pan-European expert pool of DIHs. The paper presents the concepts, the ontology, and the prototype developed for DIH4CPS project with the aim of assessing the Interoperability maturity of the DIHs and partner's network.

1 INTRODUCTION

Industry 4.0 (I4.0) is a new paradigm of production systems and it addresses transformable and networked factories, depending on several drivers such as modularity, virtualization, decentralization, interoperability etc. and digital technologies including big data analytics, autonomous robots and vehicles, additive manufacturing, simulation, augmented and virtual reality etc. (Kagermann et al., 2013). The potentialities of I4.0 paradigm are to ensure a better flexibility and scalability of manufacturing systems through the developments of new information technologies (Dassisti and De Nicolò, 2012), (Brettel et al., 2014).

The advances and the development of digital technologies are largely responsible for the popularity of the industry 4.0 paradigm and its potential use by companies. Often SMEs lack IT competences and the necessary technological and digital knowledge (Dassisti et al., 2017). To lower barriers, Digital Innovation Hubs (DIH) are arising. Digital Innovation Hubs are defined as: *one-stop-shops that help companies to become more competitive with regard to their business/production processes, products or services using digital technologies* (Smart Specialisation Platform, 2020). The role of Digital Innovation Hubs (DIHs) is to help and support companies, especially SMEs, in growing digital competences, technologies and in providing advanced training in digital technologies and skills. DIHs provide services for the digitization of the companies and, thereby, support the development of the innovation ecosystem. The critical factor/challenge, for the successful development of the DIHs ecosystem and for the implementation of Industry 4.0 technologies is to assess the ability of the DIHs and partners to interoperate together. Interoperability is the ability or the aptitude of two systems that have to understand one another and to function together (Chen et al., 2006). In the context

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of DIHs, assessing the DIHs and partners' ability to interoperate allow the identification and the definitions of interoperability problems and interoperability improvements (Panetto, 2007). The interoperability assessment approaches can determine DIHs' interoperability strengths and weaknesses defining actions for improving, avoiding or solving interoperability problems (Guédria et al., 2015).
The paper aims to use and adapt the maturity model developed in (Gabriel da Silva Serapiao Leal et al., 2019) for defining how to assess and improve the network interoperability between Digital Innovation Hubs (DIHs) and partners. The paper presents the basis for the Network Interoperability assessment and improvement. In section 2 a focus is made on the state of art of interoperability frameworks with the aim of defining the DIHs interoperability requirements, the DIHs interoperability barriers and DIHs interoperability concerns in section 3. The ontology of interoperability assessment is presented in section 4 while the interoperability assessment prototype in section 5. At the end, the conclusions are presented.

2 STATE-OF-ART

Many researchers have proposed frameworks for describing and assessing the Interoperability providing and representing concepts, issues and knowledge on Interoperability in a structured way (Chen et al., 2006). The main discussed interoperability frameworks are the European Interoperability Framework (EIF), the Framework for Enterprise Interoperability (FEI) and the Enterprise Interoperability conceptualization (Gabriel da Silva Serapião Leal et al., 2019).
The European Interoperability Framework (EIF) provides a model to be applicable to all digital public services. It is composed of four layers of interoperability: legal, organizational, semantic and technical (EIF, 2017). Legal interoperability refers to the way in which organizations operating under different legal conditions can work together. Organizational interoperability defines how public administrations align their business processes, and responsibilities. Semantic interoperability denotes the ability to exchange data and information between applications and partners assuring a precise and unambiguous meaning of the exchanged information. Technical interoperability covers and includes technical interoperability aspects and services infrastructures.
The Framework for Enterprise Interoperability (FEI) aims at structuring the concepts of the Enterprise Interoperability domain and it is composed by three dimensions: interoperability barriers, interoperability concerns, and interoperability approaches (Chen et al., 2006). The interoperability barriers refer to the mismatches between systems which can obstruct the sharing and exchanging of information. The interoperability concerns regard enterprise levels where interoperation can take place. Finally, the interoperability approaches refer to the ways for applying solutions and thus, removing interoperability barriers. The FEI defines three major interoperability barriers: Conceptual, Technological and Organizational, four main Interoperability concerns: Business, Process, Service and Data and three approaches: federated, unified, and integrated.
The Enterprise Interoperability conceptualization attempts to conceptualize the interoperability domain (Panetto, 2007) defining the Ontology of Interoperability (OoI) (Rosener et al., 2005), (Ruokolainen et al., 2007). In the following years, the OoI had been integrated with concepts from FEI (Chen et al., 2006) and Enterprise-as-a-System concepts proposing the Ontology of Enterprise Interoperability (OoEI) (Chen et al., 2006). The OoEI formally describes the system's concepts and their relations, regarding interoperability.

3 DIHs INTEROPERABILITY REQUIREMENTS

A definite number of Interoperability Requirements (IRs) for DIHs should be defined and satisfied (Daclin et al., 2016) to achieve a higher quality of interoperability (Guédria et al., 2015). To structure the DIHs interoperability requirements we follow and adapt the Maturity Model for Enterprise Interoperability (MMEI) presented in (Guédria et al., 2015). The MMEI is composed by the following six components: the interoperability concerns, the interoperability barriers, the interoperability area, the maturity levels, the interoperability criteria, and the best practices. Based on the FEI dimensions, the MMEI defines four interoperability concerns (Business, Process, Service, Data), three interoperability barriers (Conceptual, Technological, Organizational) and twelve interoperability area. Those areas represent the crossing between an interoperability barrier and an interoperability concern e.g., Business-Conceptual, Service-Technological etc. The MMEI defines five maturity levels: Maturity Level 0- Unprepared; Maturity Level 1-Defined; Maturity Level 2-Aligned; Maturity Level 3-Organized; Maturity Level 4-Adaptive. The MMEI present one criterion for each interoperability area for each maturity level, totalizing forty-eight interoperability criteria that can be rated using four

qualitative measurements: Not Achieved (NA), Partially Achieved (PA), Largely Achieved (LA) and Fully Achieved (FA). Furthermore, MMEI proposes 126 Best Practices that describe "what" should be done to improve the interoperability performances (Guédria et al., 2015).

In order to define the DIHs interoperability concerns, we explored the Data-Business-Ecosystem-Skills-Technology (D-BEST) reference model proposed in (Sassanelli et al., 2020). The D-BEST reference model configures and classify the DIHs services portfolios on five main macro-classes: Data, Business, Ecosystem, Skills and Technology. Each class is composed by several types of services, as shown in the Figure 1. The types of services represent the main categories of services provided by the DIH to its stakeholders in each of the five specific macro-classes.

Data macro-class is important for exploiting digital technologies potentialities. A DIH can provide five types of services: data acquisition and sensing, data processing and analysis, decision-making and data sharing, including also physical-human action and interaction.

Business macro-class intervenes in providing services for supporting companies in business training and education, project development, and in facilitating access to different funding sources and facilities.

Ecosystem macro-class is aimed at creating, nurturing, expanding, and creating a community around the DIHs that connects the members of the innovation ecosystem providing services for sharing best practices expertise.

Skills macro-class services allows to assess the skills maturity of the companies that want to digitalize the organization to set an adequate roadmap to empower it and also to support the skill empowerment.

Technology macro-class provides hardware and software services and solutions to technology providers and technology users supporting the whole lifecycle of digital technologies from conception and idea generation to commercialization.

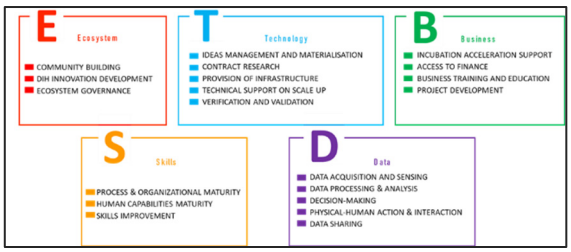

Figure 1: Services provided in the D-BEST reference model. Extracted from (Sassanelli et al., 2020).

The DIHs Interoperability Requirements are defined and organized according to the (ISO/IEC/IEEE 29148, 2011) recommendations for construction of a requirement, the MMEI and the D-BEST reference model. We integrate the European Interoperability Framework (EIF) with the Framework for Enterprise Interoperability (FEI) for defining the following DIHs interoperability barriers: Conceptual, Technological, Organizational and Legal. We adopt the D-BEST reference model for defining the DIHs interoperability concerns: Data, Business, Ecosystem, Skills and Technology.

Table 1 to Table 5 present the DIHs Interoperability requirements adapting also a set of interoperability requirements presented in (Gabriel da Silva Serapiao Leal et al., 2019), (Leal et al., 2020). Each table present the interoperability concerns on the rows and the interoperability barriers on the columns. The interoperability area is the cross-section between an Interoperability Barrier (Conceptual, Technological, Organizational and Legal) and an Interoperability Concern defined in D-BEST (Data, Business, Ecosystem, Skills, and Technology,) totalizing twenty interoperability areas *(Data-Conceptual, Data-Technological, Data-Organizational, Data-legal, Business-Conceptual, Business-Technological, Business-Organizational, Business-Legal, Ecosystem-Conceptual, Ecosystem-Technological, Ecosystem-Organizational, Ecosystem Legal, Skills-Conceptual, Skills -Technological, Skills-Organizational, Skills -Legal, Technology-Conceptual, Technology-Technological, Technology-Organizational, Technology-Legal)* and eighty interoperability criteria.

Each requirement in the tables has an ID, which it is composed of the first letter of the related Interoperability Concern, the second letter of the related Interoperability Barrier. These are followed by the letter "R", meaning that it is a requirement. The related maturity level follows it. For example, the ID "DCR1" represents the requirement related to the Data concern and the Conceptual barrier from the maturity level 1-Defined. The ID "BOR2" represents the requirement related to the Business concern and the Organizational barrier from the maturity level 2-Aligned.

Table 1: DIHs Interoperability Requirements for DATA Concern.

DATA							
ID	**Conceptual**	**ID**	**Technological**	**ID**	**Organizational**	**ID**	**Legal**
DCR1	Data models shall be defined and documented	DTR1	Data acquisition, sensing, storage and processing shall be in place	DOR1	Responsibilities and authorities shall be defined and in place	DLR1	Data protection and security shall be defined
DCR2	Standards shall be used for alignment with other data models	DTR2	Automated access to data based on standard protocols shall be in place	DOR2	Rules and methods for data management shall be in place	DLR2	Rules and methods for data security shall be in place
DCR3	Meta-modelling shall be done for multiple data model mappings	DTR3	Remote access to databases shall be possible for applications and shared data shall be available	DOR3	Personalized data management for different partners shall be in place	DLR3	Meta-modelling shall be done for data security
DCR4	Data models shall be adaptive	DTR4	Direct database exchanges capability and full data conversion tool(s) shall be in place	DOR4	Adaptive data management rules and methods shall be in place	DLR4	Adaptive data security rules and methods shall be in place

Table 2: Dihs Interoperability Requirements for BUSINESS Concern.

BUSINESS							
ID	**Conceptual**	**ID**	**Technological**	**ID**	**Organizational**	**ID**	**Legal**
BCR1	Business Models, Methods and Tools, Business Operations Modelling shall be defined and documented	BTR1	Basic IT infrastructure be in place shall	BOR1	Organization structure shall be defined and in place	BL1	Access to founding sources and financial issues shall be defined and documented
BCR2	Standards shall be used for alignment with other business models, Methods and Tools, Business Operations Modelling	BTR2	Standard and configurable IT infrastructures shall be used	BOR2	Standards shall be used for alignment with other partners	BL2	Standards shall be defined and used to provide legal and fiscal advices
BCR3	Business Model, Methods and Tools, Business Operations Modelling shall be designed for multi partnership and collaborative DIHs	BTR3	IT infrastructure shall be open	BOR3	Organization structure and collaboration shall be flexible	BL3	Technical and legal assistance should be provided to facilitation the access to different funding sources
BCR4	Business model, Methods and Tools, Business Operations Modelling shall be adaptive	BTR4	IT infrastructure adaptive shall be	BOR4	Organization -demand business shall be agile for	BL4	Legal services should be adaptative

Table 3: DIHs Interoperability Requirements for ECOSYSTEM Concern.

ECOSYSTEM							
ID	**Conceptual**	**ID**	**Technological**	**ID**	**Organizational**	**ID**	**Legal**
ECR1	Service provided to the ecosystem shall be defined and documented	ETR1	Applications/services shall be connectable and ad hoc information exchange shall be possible	EOR1	Ecosystem responsibilities and authorities shall be defined and put in place	ELR1	Ecosystem governance shall be defined and documented
ECR2	Standards shall be used for alignment with other partners and DIHs	ETR2	Standardize and configurable service architecture(s) and interface(s) shall be available	EOR2	Procedures for ecosystem interoperability shall be in place	ELR2	Procedures for ecosystem governance shall be defined and in place
ECR3	Meta-modelling shall be done for multiple service model mappings	ETR3	Automated services discovery and composition shall be possible and shared applications shall be in place	EOR3	Collaborative services and application management shall be in place	ELR3	Ecosystem collaboration shall be in place
ECR4	Service modelling shall be adaptive	ETR4	Dynamically composable services and networked applications shall be in place	EOR4	Dynamic service and application management rules and methods shall be in place	ELR4	Procedures for ecosystem governance shall adaptative

Table 4: DIHs Interoperability Requirements for SKILLS Concern.

SKILLS							
ID	**Conceptual**	**ID**	**Technological**	**ID**	**Organizational**	**ID**	**Legal**
SCR1	Skill and rules shall be defined and documented	STR1	Assessment of human skills maturity shall be defined and documented	SOR1	Responsibilities and authorities shall be defined and put in place	SLR1	Skills governance shall be defined and documented
SCR2	Standards shall be defined for assessing the company readiness for Industry 4.0	STR2	Standard process tools and platforms shall be available	SOR2	Procedures for skills exchange shall be in place	SLR2	Procedures for Skills governance and exchange shall be defined and in place
SCR3	Standard shall be defined based on the maturity model assessment	STR3	Platform(s) and tool(s) for collaborative training shall be available	SOR3	Organization of dedicated human up-skilling, re-skilling trainings and workshops shall be in place	SLR3	Intellectual properties shall be defined and in place
SCR4	Standard shall be defined for supporting the knowledge-transfer through internal channels, structure contacts and collaborations	STR4	Dynamic and adaptive tool(s) shall be available	SOR4	Support for knowledge-transfer through internal channels, structure contacts and collaborations shall be adaptative	SLR4	Procedures for Skills governance shall adaptative

Table 5: DIHs Interoperability Requirements for TECHNOLOGY Concern.

Technology							
ID	**Conceptual**	**ID**	**Technological**	**ID**	**Organizational**	**ID**	**Legal**
TCR1	Technologies shall be defined and documented	TTR1	IT devices shall support processes and ad hoc exchange of process information shall be possible	TOR1	Responsibilities and authorities shall be defined and put in place	TLR1	Technology governance shall be defined and documented
TCR2	Standards shall be used for alignment of new skills	TTR2	Standard process tools and platforms shall be available	TOR2	Procedures for technologies interoperability shall be in place	TLR2	Procedures for technology governance shall be defined and in place
TCR3	Meta-modelling shall be done for multiple process model mappings	TTR3	Platform(s) and tool(s) for collaborative execution of processes shall be available	TOR3	Cross-enterprise/DIHs collaborative processes management shall be in place	TLR3	Technologies intellectual properties shall be defined and in place
TCR4	Technologies modelling shall be done for dynamic re-engineering	TTR4	Dynamic and adaptive tool(s) and engines shall be available	TOR4	Real-time monitoring of processes, adaptive procedures shall be in place	TLR4	Procedures for technology governance shall adaptative

4 ONTOLOGY OF INTEROPERABILITY ASSESSMENT

To assess the interoperability degree between DIHs, we use and adapt the Ontology of Interoperability Assessment (OIA) presented in (Gabriel da Silva Serapiao Leal et al., 2019), (Leal et al., 2020). (Gabriel da Silva Serapiao Leal et al., 2019) propose a conceptual model for illustrating the concepts and relations of the OIA. This model serves as the basis for implementing the ontology using Protégé tool. The OIA presents an architecture containing three different layers: the Assessment Meta-model, the Interoperability Assessment Meta-model and the Implementation.

The Assessment Meta-model contains the general concepts of an assessment and defines a general representation of an assessment. The model is divided into two cores: the systemic core, which allows the design of systems to be assessed, and the assessment core that describes the concepts related to an assessment allowing the design of different kinds of assessment.

The Interoperability Assessment Meta-Model is an instantiation of the Assessment Meta-model, based on the interoperability assessment.

Finally, the Implementation is the instantiation of the real world, i.e., it represents the real assessed system and the applied assessment model.

We adapted the OIA to DIHs assessment populating the ontology with the fixed instances as shown in Figure 2. These instantiations include the following concepts:

- Requirement with the set of interoperability requirements defined in section 3 based on D-BEST reference model (Sassanelli et al., 2020) and the MMEI defined in (Guédria et al., 2015).
- Problem with the interoperability barriers described in the Framework for Enterprise Interoperability (FEI) (Chen et al., 2006) and in the European Interoperability Framework (EIF) (EIF, 2017).
- Solution with the 126 best practices defined in MMEI (Guédria et al., 2015), (ISO 11354-2, 2015) and the catalogue of DIHs competences.
- Quality Attribute with the sixteen interoperability areas (Data-Conceptual, Data-Technological, Data-Organisational, Data-legal, Business-Conceptual, etc) presented in section 3.
- Quality with the five maturity levels (Unprepared, Defined, Aligned, Organised and Adaptive) defined in MMEI (Guédria et al., 2015).

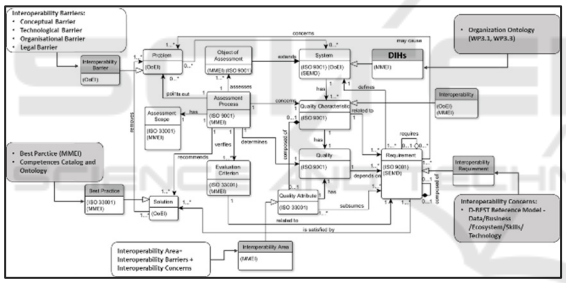

Figure 2: Ontology of Interoperability Assessment. Adapted from (Gabriel da Silva Serapiao Leal et al., 2019).

5 DIHs INTEROPERABILITY REQUIREMENTS

The prototype architecture, its functionalities, and the concerned users are developed based on the results discussed in section 3 and the ontology presented in section 4. The prototype has the objective to support the DIHs assessment process. An overview of the users, assessment process and prototype relations are illustrated in Figure 3. The assessment process is composed by the activities carried out by the Lead assessor and the Assessor. The Lead assessor manages the evaluation workflow and the system to structure and finalize the entire assessment. He oversees creating and editing the assessment. The assessors (in this context the DIHs and partners' network) are responsible for completing and editing their assigned assessment by entering their evaluations.

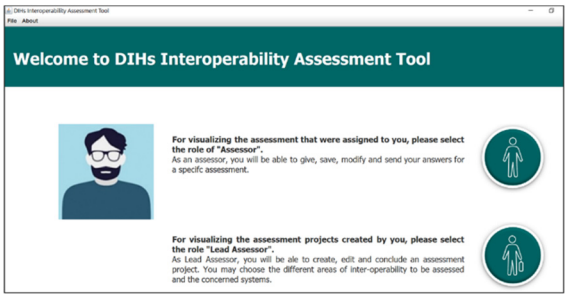

Figure 3: Screenshot of the DIHs Interoperability Assessment Tool.

When the lead assessor creates the assessment, he sends a notification to the concerned assessors (DIHs). The DIHs, then, can log in their accounts and complete the concerned interoperability assessment evaluating the interoperability concerns based on the interoperability layers (see Figure 4).

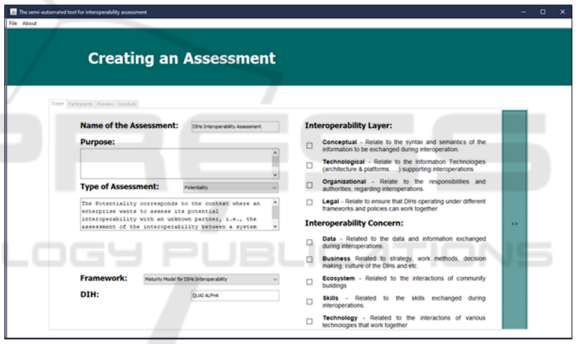

Figure 4: Screenshot of the DIHs assessment scope: Interoperability Barriers and Concerns.

The rating process is illustrated in Figure 5. The interoperability requirements presented in table 1-5 in section 3 are written in the form of questions to facilitate their evaluations. In this interface of the prototype, the assessors (DIHs) rate the requirements, related to the interoperability area: Conceptual barrier and Business concern, using the maturity levels: "Not Achieved (NA)", "Partially Achieved (PA)", "Largely Achieved (LA)" and "Fully Achieved (FA)". Comments and evidence (e.g., documents, images, etc.) can also be added.

Once the assessors complete their assessments, they send a notification to the lead assessor. The latter, then, aggregates the requirement ratings provided. Figure 6 illustrates the summary concerning the rates related to requirement from the Business-Concern. In the final step, the lead assessor launches the option "validate" to finalize the results.

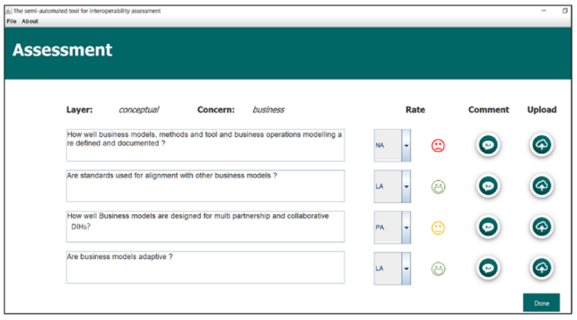

Figure 5: Screenshot of the DIHs assessment: Requirement rating.

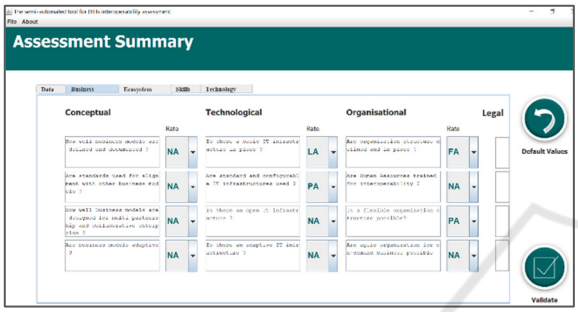

Figure 6: Screenshot of the DIHs assessment: Assessment Summary.

The prototype has the objective to assess the DIHs interoperability maturity. For example, if it assesses unprepared level (maturity level 0) means that the DIH does not have an appropriate environment for developing and maintaining interoperability. For achieving the next level (maturity level 1), the concerned DIH should focus on improving the conceptual/ technological/ organizational and legal requirements related to data/ business/ ecosystem/ skills/ technology concerns.

A list of best practices and competences based on the maturity level and criteria evaluation is automatically generated in the tool and presented in a report that contains the determined DIHs and partners' maturity level, the final rating of each evaluation criteria, the identified problems, and associated solutions (best practices and DIHs competences)

6 CONCLUSIONS

The paper aims at defining the DIHs interoperability requirements adapting the Ontology of Interoperability Assessment. In section 2 we have presented an overview of the state of art of interoperability assessment frameworks. First, we have explored the European Interoperability Framework (EIF), the Framework for Enterprise Interoperability (FEI) and the Enterprise Interoperability conceptualization. Second, we have reviewed the Interoperability exploring the Maturity Model for Enterprise Interoperability (MMEI), and the D-BEST reference to model to define the DIHs interoperability barriers and the DIHs interoperability concerns. The DIHs interoperability requirements have been presented and listed in section 3. In section 4 we have described the Ontology of Interoperability Assessment. The proposed architecture is composed by three layers: the Assessment Meta-model, the Interoperability Assessment Meta-model and the Implementation. Finally, in section 5 we have presented the interoperability assessment prototype developed from the ontology described in section 4. The prototype has the objective to ease the assessment process by providing automatic steps such as the requirement rate and the evaluation report generation.

This paper presents the first version of the interoperability maturity model prototype, which will have major additional improvements. These updates will concern mainly the integration of the maturity model and the prototype. Currently, the prototype is a stand-alone Java application linked to a MySQL database. As it is intended to be a feature/service of the DIH4CPS Portal, it should be easily transformed in a web-based feature available for all DIH4CPS partners but also the whole DIH4CPS network.

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