

Towards a smart connector for dynamic interoperability in agile enterprises

Farouk Belkadi, Jean Vieille, Bernard Tanous

▶ **To cite this version:**

Farouk Belkadi, Jean Vieille, Bernard Tanous. Towards a smart connector for dynamic interoperability in agile enterprises. 10th IFAC Conference on Manufacturing Modelling, Management and Control (MIM 2022), Jul 2022, Nantes, France. pp.2342-2347, ⟨10.1016/j.ifacol.2022.10.058⟩. ⟨hal-03835349⟩

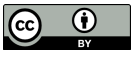
HAL Id: hal-03835349

https://hal.science/hal-03835349v1

Submitted on 15 Jul 2026

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons CC BY 4.0 - Attribution - International License

Available online at www.sciencedirect.com

ScienceDirect

IFAC Papers Online CONFERENCE PAPER ARCHIVE

IFAC PapersOnLine 55-10 (2022) 2342–2347

Towards a smart connector for dynamic interoperability in agile enterprises

F. Belkadi*, J. Vieille, B. Tanous****

**Nantes Université – Centrale Nantes – LS2N*

(e-mail: firstname.lastname@ls2n.fr)

***agHaren France*

(e-mail: firstname.lastname@agharen.fr)

Abstract: The "industry 4.0" transition requires a digital chain capable of self-adapting face to evolving and increasingly complex organizational, informational and technological contexts. For this need, this paper discusses the incentive to develop new kind of connectors, intelligent and pragmatic, as a unique and universal interface to support interoperability between different types of technological and software systems in various collaborative processes in the enterprise of the future.

Copyright © 2022 The Authors. This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/)

Keywords: Industry 4.0; interoperability, smart connector, artificial inteligence.

1. INTRODUCTION

Within the paradigms of smart enterprise and industry 4.0, many developments and changes have taken place in recent years, at both technological and organizational aspects. These developments can be summarized in the following points:

(a) Proliferation and variety of information systems to ensure the digital continuity throughout the whole value chain at both individual companies and collaborative networks. These information system can be: standards offers from specialized editors with proprietary licenses, open source offers, company-dedicated solutions, SAS, etc. ; **(b)** Emergence of new technologies such as: cyber-physical systems, sensors and the Internet of Things, the cloud, and augmented reality. In addition, new tools are dedicated for managing big data and supporting human decision by using AI and knowledge engineering techniques; **(c)** Permanent (re)structuring of company processes to adapt to new business opportunities and competitive constraints via innovative product and/or service offers. This leads to a growth of collaboration and partnership actions between companies in a complementary way, while keeping an autonomy and a flexibility of functioning; **(d)** Strong constraints of security and data sharing of useful information in correct time, without loss or redundancy, and with anticipation of user needs.

These elements are leading to a complexification of interoperability issues at different levels: semantic (to map data models), organizational (to synchronize processes) and technical (to connect software components). Although it is not new, the question of interoperability is still becoming a very important challenge and a success factor of any digitalization process within "Industry X.0" perspective.

Technologically, Interoperability between information systems is ensured by computer modules called connectors or interfaces. Hundreds, even thousands, of connectors are regularly developed to link heterogeneous information systems. However, these initiatives are often domain-specific and designed to support unique business functions, generally in B2B configurations.

The integration costs might increase exponentially with the number of applications and/or processes to be linked with the dataflow types, endpoints and interaction occurrences. Generally, it is needed to create new connector for every new application to connect. In addition, regular updates are required to integrate new technological constraints or collaboration needs. This will impact not only the development costs, but can also cause a lack of productivity and flexibility for the company.

For all these reasons, it is important to shift from "static connectors" to more dynamic platforms that tend to be universal, flexible, and auto-adaptive to cope with different interoperability situations within Industry 4.0. The aim of this paper is to discuss this challenge and to propose the main foundations to build such a platform. Section 2 will introduce the problem statement as a synthesis of literature survey. Section 3 will explain the theoretical foundations and the conceptual architecture of the so-called "smart-connector".

2. PROBLEM STATEMENT

2.1. Literature survey

In a recent publication, Longo et al. (2020) have made a synthesis of the different technologies that contributed to the emergence of the fourth industrial revolution and provide potential benefits for the fifth industrial revolution. All these technologies tend to be integrated in a complete digital chain, at different managerial, operational and technical levels of the factory. Consequently, the structure and consistency of this digital chain is evolving and becoming more complex.

For example, CAD/CAM (Computer Aided Design/ Engineering) tools dedicated to product representation are connected to virtual factory tools for manufacturability studies and process simulation. PLM (Product Lifecycle Management) systems have evolved in their structure and functionality to be able to manage the consistency between all these business tools (Stark, 2015).

In addition, new Internet of Things technologies have significantly improved the communication and monitoring capabilities of cyber-physical systems in connection with

2405-8963 Copyright © 2022 The Authors. This is an open access article under the CC BY-NC-ND license.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2022.10.058

legacy enterprise information systems (Greer et al., 2019). The large amount of data harvested in this way is exploited in digital twin software that provides real-time simulation for the control and diagnosis of production systems by taking into account the state of resources (Liu et al., 2019). Furthermore, a connection with MES (Manufacturing Execution systems) and ERP (Enterprise Resource Planning) type of information systems is expected to couple diagnostic and analysis functions with planning and execution functions to close the control loop (Negri et al., 2020). Similarly, the interoperability issue has been incorporated as a priority in the development of robust digital twins (Lu and Xu, 2018). This observation is also true for virtual/augmented reality technologies that require advanced models to assist operators in some operational tasks (Lee, 2019).

This need for integration of heterogeneous tools has not only revolutionized the role and operating modes of enterprise information systems but also challenged the conventional view of the concept of interoperability. This challenge is not only leaded by technological evolutions but also by organizational and productivity constraints.

Indeed, competitiveness is pushing companies to establish privileged collaborations along the development project in order to better leverage the wealth of internal and external resources (Denicol et al., 2021). These collaborations can be permanent or temporary in virtual organizations or extended enterprises. But in both cases, the main issue remains the integration of each partner (or supplier) in the main project, and consequently the degree of information sharing and access. This requires agile operational structures that rely on automation and flexibility of business processes. It leads to a fundamental requirement for a dynamic interoperability strategy that connect data sharing with integration strategy at the managerial level (Belkadi et al., 2017).

In a convention way, three categories of methods are used to support the interoperability of different information systems:

- Ontology and semantic web technologies, mainly dedicated to semantic interoperability, perform mappings between heterogeneous data models at the meta-level. Several studies have adopted this axis like the ONTO-PLM framework (Panetto et al., 2012) for interoperability between product data (encapsulated in PLM) and other enterprise applications (i.e. ERP, MES). The Industrial ontology foundry (IOF) is used to support interoperability in digital manufacturing and related fields (Ameri et al., 2022). The VFDM ontology uses, the Industry Foundation Classes (IFC) standard and written in the ifcOWL format in turn allows to support the interoperability of heterogeneous information systems involved in the manufacturing phase (Pauwels and Terkaj 2016).

- APIs (Application Programming Interface) and web services ensure communication between software. Web Service is a service rendered through the web by a server for a client according to a predefined information exchange contract such as Java Message Service messaging (a solution particularly suited to asynchronous, scheduled actions/requests needs). The "OMG PLM Enablers" for example are web technologies based on middleware technologies and "PLM Services" to support the communication between PLM systems and other CAX applications (Wang et al., 2009). Finally, we find the open standard CMIS, the Simple Object Access Protocol (SOAP) and the Representational State Transfer (REST). They were designed to facilitate data exchanges between applications and cloud services that are distant from each other. In addition, the technical languages Business Process Execution Language (BPEL) and Automation Markup Language are also used to automatically execute interoperability actions in web-services oriented software connectors (Alexopoulos et al., 2011).

- Other "specific" connectors are currently created according to different standards (such as ISO15926 or IEC62264, ...) and are mainly designed for the software of the dominant players (SAP, Microsoft, ...). Most publishers offer specific connectors or APIs in addition to their software solutions, from large accounts to start-ups (SAP, Sage, Praxedo French start-up, Domo American start-up...). To respond to the multiplication of communication exchanges via the increase in the number of partners, specialized connectors are being deployed today, such as the E-connector from Vaison@, a universal e-commerce gateway.

2.2. Synthesis and Challenges

Despite the richness and robustness of the existing interoperability mechanisms, they still require regular updates to take into account the evolution and variety of current information systems. During these updates, there is already a risk of work disruption in the company.

On the other hand, the different interfaces are limited in their "vocabulary" to include all the diversity of information, especially with the emergent technologies. Thus, losses of information can be observed during interoperability process (examples: Exchanging 3d model from CAD to a CAE files, aggregated feedback information from operational processes to managerial board, etc.). The huge number and variety of connectors is making the problem of data consistency more challenging because every editor generally has its own semantic repository and communication mechanisms. The need to connect new communication technologies, as required by the I4.0 paradigm, makes the current semantic repositories limited to cover all the associated concepts. Finally, the interfacing modes must respect a predefined exchange contracts between heterogeneous companies, which is not easy in the fact. Mutual constraints propagation between organizations coming from different disciplines could generate several misunderstandings.

So, for an efficient management of software and process interfaces, more and more startups are specializing in the development and deployment of new API based platforms. However, the basic problem of interface adaptability has not yet been correctly solved. In fact, according to a recent study published by Axway in 2021 resulting from the interview of around 800 IT managers, the increasing complexity of APIs is seen as a major bottleneck stopping the deployment of digital chain in the enterprises. Among the main causes, the

less reusability of API was cited by 23% of managers. It is often the case to start the development from scratch … Also, efficient secure strategy should incorporate several technologies, which are highly costing to develop, to integrate, and to maintain along the time.

The key challenge is therefore to develop smart mechanisms that transcend local representations (correct semantic understanding), while allowing the right contextual interpretation at the global level for correct concepts translation and pragmatic data exchange. In this paper, it is proposed to combine Artificial Intelligence and knowledge engineering modules in order to allow instantaneous interactions between processes, applications, equipment and companies. The next section will setup the main foundations at the conceptual level to develop such solution.

3. FRAMEWORK FOUNDATIONS

3.1. The Smart Pragmatic Enterprise Approach

The Smart Pragmatic Enterprise (SPE®) approach draws from the "organism/process" theory of Albert North Whitehead (Whitehead 1929-1978; Mesle 2008), the "semiotics/pragmatism" of Charles Sander Peirce (Plowright, 2016), and the Fractal Brain Theory (Tsang 2017). It is summarized in the following assumptions (Figure 1):

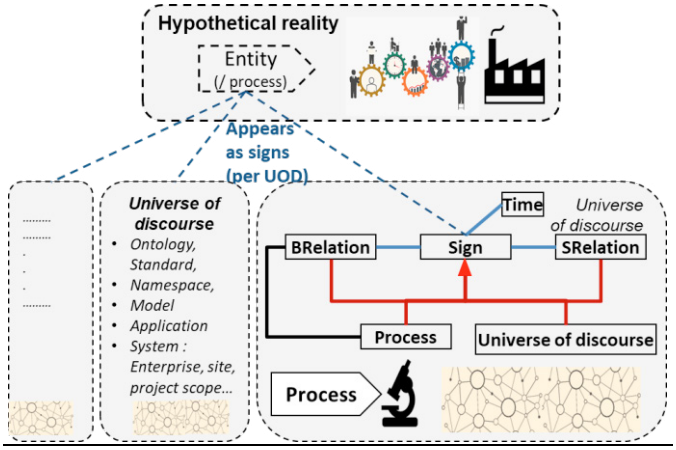


Figure 1. Global Picture of semiotic theory

(a) Any activity can cooperate with any other activity. If software must rigidly orchestrate some invariant workflows, it should not prevent autonomous and opportunist collaborations to take place; **(b)** By definition, models of a system address individual "points of views" according to the needs of an observer. Hence, multiple models at different granularity levels can coexist rightfully, even if they seem to be conflictual; **(c)** The real nature and state of a system cannot be directly and fully known. This knowledge is built from "signs" (a sensor measurement, a chemical transformation, an invoice…) that are intended and displayed by the observed system, perceived and interpreted by the observing system. The matching accuracy between intention and interpretation results of a semiotic learning process; **(d)** Each representation domain is in its own universe of discourse, which is ontologically disjoint from others, but potentially exposed to the same reality; **(e)** Space and time are human concepts to grasp signs and events, which refer to somethings to be observed, imagined, or reasoned. Functions and entities, (i.e. process, product, and resource) are all coupled with "signs" and time as a marker.

3.2. The Knowledge management method

In the proposed vision, the interoperability method is defined as knowledge based Framework relying on the Neuromorphic Reference Ontology® (NRO). NRO is a neuronal, meta-upper ontology that is intended to support these processual/semiotic assumptions. The timestamped signs are statically linked by structural relations that can implement any practical ontology, and dynamically linked by behavioral relations in emergent processes.

The structure of such ontological repository is aligned with organizational agility perspective. Agility refers to the ability to cope with business, technology, and environment changes. It makes IT system sticking to the actual business, rather than driving it. To do so, it relies on the concept of process as a snapshot of a life situation of collaborating entities. Process can be spontaneous or predefined (procedure, …).

According to the NRO modelling framework, "processes" are characterized by their context, resources, inputs, and outputs, as collaborating entities. These processes can be individual or collective operating entities, regardless the global context. By definition, operational processes (elementary activities) are uniquely defined by their performers. They are autonomous, supervised agents with smart reasoning capabilities. At run-time, they self-assemble to build a network within an extended collaboration. Agility is then achieved through real time auto-adaptation function. Figure 2 shows how the same entity signs are involved in different processes with different roles, representing their past, current and future linkages in a global, possibly infinite neuronal network or quantum mechanics interrelated facts.

Processes at the higher level are kind of "observation processes", supervising the operational processes through similarity analysis of the various gathered entities. All independent modelling views are allowed for observation processes. This establishes the preconditions for auto-organization taking into consideration all possible complexification in a systemic and smart way.

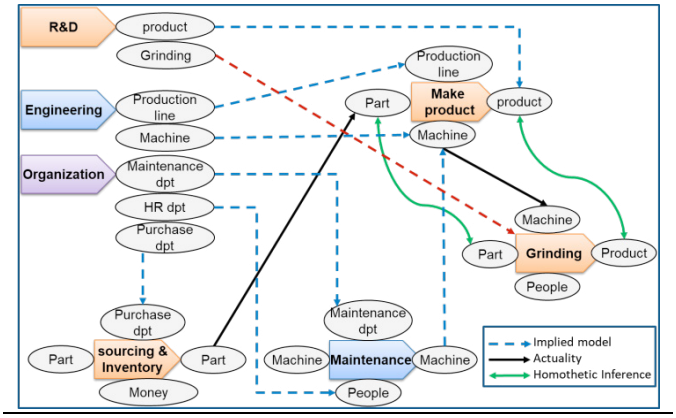


Figure 2. Independent processes and their potential relationships

4. THE SPE CONNECTING STRATEGY

4.1. Connecting process within the SPE® approach

The customary way at handling interoperability somewhat follows this sequence: **(1)** Identify the information exchange situations to provide a catalogue of transactions involving the considered applications to be connected; **(2)** For each transaction, describe the sequence and content of the messages that are involved; **(3)** For each message, map the data structures of both concerned applications, either: by transforming the sending application data structure into the receiving application language; or by specifying and mapping the exchanged messages in a chosen common ontology ; **(4)** Determine the events that will trigger the transaction. They can be issued by sending or receiving applications, or by an external mediating application (a BPM or an advanced middleware); **(5)** Provide the infrastructure for connecting applications through predefined APIs, respecting the above defined connection strategy; **(6)** Finally, implement the functionalities that will handle the data flows.

Conversely, the proposed SPE® approach tends to follow a backward simple process, sequenced as follow: **(1)** Provide each application with an intelligent routing functionality that standardizes the collaborative setting process for all involved applications. This can be done by plug in the router in the application itself, or by using an external process integrator; **(2)** Define the basic network infrastructure enabling physical connections between applications and/or the process integrators coupled with a virtual marketplace; **(3)** Feed the router with the NRO model of the system processes that are driven by the application; **(4)** Wrap the inner functioning of the application in the NRO processes; **(5)** Register the application to allow its services to be exchanged in the marketplace; **(6)** When needed, address semantic translation by the mediation of a repository and semantic mapper, automated by a semiotic mapper.

SPE® takes interoperability as a generic collaboration scheme rather than a set of ad hoc predefined transactions between software applications. New applications, services, organizational units can readily join and collaborate within an SPE® ecosystem after updating or implementing the intelligent router and registering their knowledge in the common ontology.

Since information flows between applications always occurs between collaborative functions (and business processes as well), SPE® establishes emergent, dynamic collaborations as services required by one party and fulfilled by another. Accordantly, instead of defining messages according to specific origins, destinations and context, only the subject of potential collaborations is defined regardless their future occurrences. The SPE® connector / process integrator wraps an application's functionalities in ready to collaborate, application independent SPE® processes which are autonomous agents.

At run time, processes spontaneously trigger and collaborate with other processes by posting, listening to and negotiating service requests on a virtual marketplace. The requests are analyzed semantically regardless the global context : the technical infrastructure is fully neutral, only handling the negotiation protocol and real-time communication, the operational capabilities are embedded / hard-coded in processes independently and the organization, actual business processes is emergent from the IT view-point: the full extent of a process is the result of the opportunistic self-acquaintance of multiple autonomous sub-processes gathered to achieve a final objective. The applications are faithful slaves of the business reality, sticking on business actual operations, organization and strategy.

4.2. Semantic and semiotic based interoperability

The agility constraints supposes that the SPE® connector will be able to work on different situations, from simple one (linking Mature applications like ERP are sharing some common vocabulary and data structures definition rules) to more complex one (applications from different locations, enterprises from various fields, etc.). Three interoperability levels are expected in terms of complexity (Figure 3).

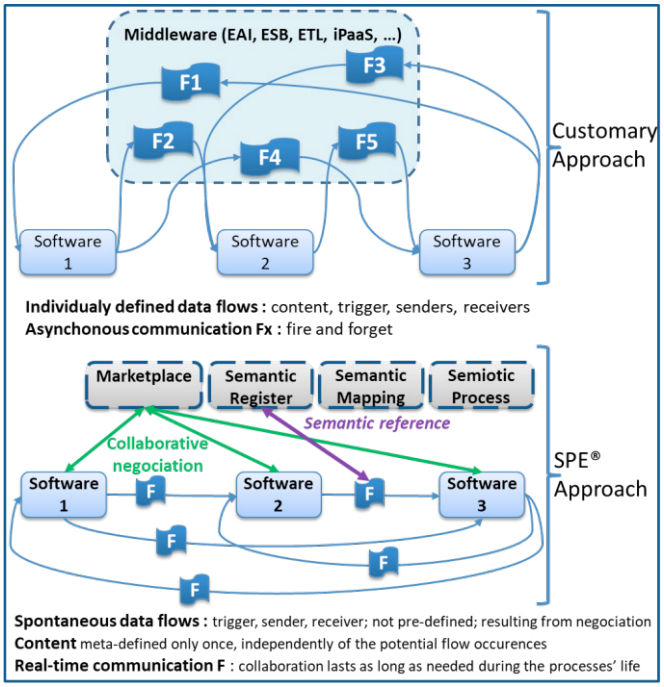


Figure 3. From semantic to semiotic interoperability

At the first level, named common semantic interoperability, the shared concepts and corresponding data structures express the meaning of connecting entities in the standardized format understood by all applications. The semantic mapping is done one time for all, regardless the future unknown goals.

When the collaboration scope expands to other departments or external companies, semantic mapping becomes necessary to make any process understanding the requested or candidate features of other processes in different universes of discourse.

At the second level of complexity, named multi-semantic interoperability, each type of sign from different universe of discourse (UOD) that can be subject of exchange process is published into a central register, where correspondences between equivalent signs are identified. This allows

instantaneous and real time translation of signs during collaboration. The ISO11179 is an example of such register.

The third complexity level seeks a semiotic-based interoperability. It relies on the ability to automatically translate signs from different UODs. The semiosis process of understanding is an iterative process to reach a common understanding of the same concept/entity. This automatic concepts translation will be achievable by preprocessing the concerned ontologies using symbolic AI learning capabilities and expanding the reach to emergent concepts using connectionist AI learning capabilities.

4.3. Towards a generic smart connector

Based on the above approach, the practical SPE® implementation is represented in Figure 4. The SPE® core platform provides the marketplace that handles service requests notifications, semantic registry, mapping and contracting, AI capabilities for semiotic mapping, multilevel process inference and route optimization. SPE® applications are designed to co-operate in the SPE ecosystem. "Non-SPE" applications become part of this ecosystem through SPE® generic connectors, which relies on the SPE® core platform. The NRO model of the system is configured in one or several SPE® connectors that realize the wrapping of this model for one or several applications.

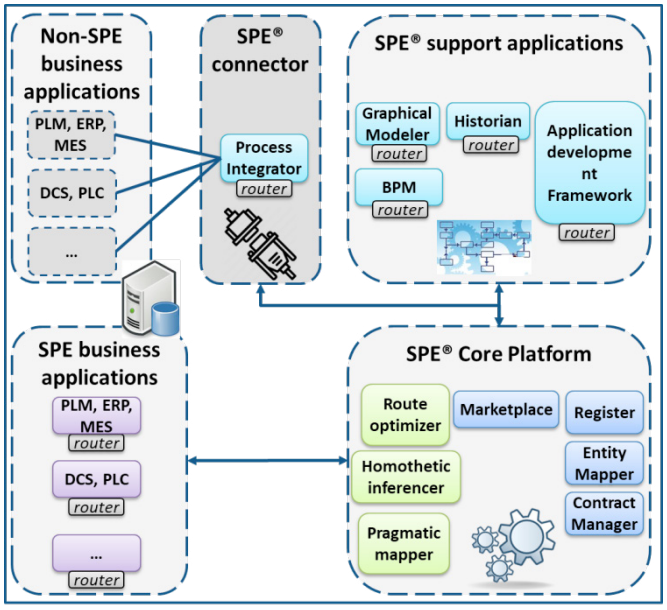


Figure 4. Global architecture of the SPE connector

Conceptually, the smart connection platform will be implemented following a "three-layer" architecture, as shown in Figure 5. This kind of architectures respect the principle of context-aware system (Fadzillah et al., 2013), which gives the capacity to analyze the current environment and classify it in the right classes of situations to generate the adequate decision (in this case, the configuration of the suitable connector for a given collaborative process).

Following this architecture, the first layer implements the generic interfaces defined by the "intelligent router", which is situated in the second layer. This last module is a distributed multi-agent system (Ferber 1999) using AI to handle dynamic collaborations and real-time inference regardless the software involved. It relies on a global knowledge repository as a kernel element that aim to store and manage all knowledge necessary for the configuration of connector parameters. Located at the last layer, it is featuring the NRO ontology capable of implementing the different meta-models and domain standards, as well as the concept matching rules. It also contains a library of software resources that can be (re-) used (fully or partially) to build a given contextual interface.

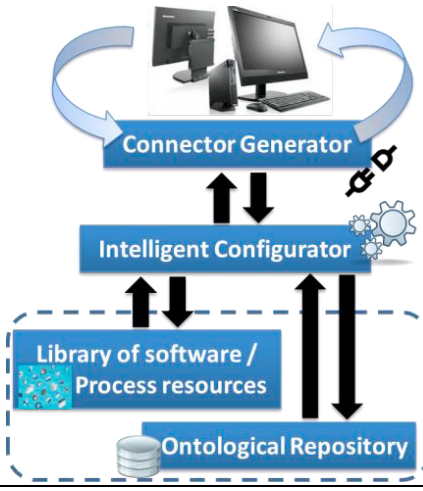


Figure 5. Implementation strategy of the smart connector

To support the intelligent routing process, the semiotic approach is used to recognize the diversity of ontological models proper to each IT systems and map them within a common repository. From a philosophical point of view, the semiotic approach could be seen as an extension of the semantic approach where different signs and symbols coming from the environment are used to understand better the message. So, in case of interoperability between IT systems, this understanding will be implemented as the interpretation of all operational, organizational, and technological features, characterizing the operating context of a given IS.

5. CONCLUSION

This paper focuses only on the conceptual Framework. The technical developments are an ongoing step and will be presented in future communications. The proposed approach opens the road to a paradigm change of existing interoperability solutions and strategies. The smart connector redraws software modularity and enslaves IT to business reality, breaking a critical constraint to agility. Interoperability is no longer tied to the inner functioning of the system nor at its organization. Several aspects of AI are leveraged: process routing optimization, multi-level process linkage, semiotic matching. Finally, the neuronal nature, formal contextualization and limitless complexity of NRO provide actionable data for easy decisional processing, full traceability and unleashes systemic intelligence.

The expected platform should allow responding to new interoperability situations, including new communication technologies of the Industry 4.0 and Intelligent Enterprise paradigms. It is also a platform that builds on existing

knowledge and resources to maximize communication performance and compatibility with existing systems.

Thus, the methodological and software modules will make possible to solve the scientific and technological obstacles mentioned in the introduction. This solution is:

- **Generic**, which can be applied to all types of IT solutions used in Industry 4.0 and the intelligent enterprise.
- **Complete**, by covering all dimensions of interoperability: semantic, organizational, and technical (Vernadat, 2010).
- **Universal**: through the application of the same strategy to various collaborative and interoperability situations.

The expected benefits of this intelligent platform are: **(a)** Streamline data exchanges, with minimum loss of information and better prediction and anticipation of communication needs; **(b)** Extend the conventional connectors to cover all types of ICT systems. This will enable a better integration of the components of the digital chain, without significant disruption of current systems; **(c)** Reduce considerably the costs of digital chain continuity since it will be matter of managing a single connector, rather than multiple, for any type of ICT and every collaborative context; **(d)** Ensure the durability of the solutions with less maintenance effort because the updates will be made and propagated automatically through an intelligent learning, in regard to technological and organizational evolutions; **(e)** Support process agility by allowing instant collaboration to achieve any objective, through rapid reconfiguration of the connector, face to changes in IT capabilities or partnership.

By means, companies will be able to dynamically change the levels of integration of suppliers (or other partners) in their development projects, since they will have a robust "device" to dynamically manage the connection/disconnection of heterogeneous applications and business processes.

REFERENCES

Alexopoulos K., Makris S., Xanthakis V., Chryssolouris G. (2011) A web-services oriented workflow management system for integrated digital production engineering. CIRP Journal of Manufacturing Science and Technology, 04: 290–295.

Ameri F., Sormaz D., Psarommatis F., Kiritsis D. (2022). Industrial ontologies for interoperability in agile and resilient manufacturing. International Journal of Production Research, 60(2), 420-441.

Belkadi, F., Messaadia, M., Bernard, A., Baudry, D. (2017) Collaboration management framework for OEM–suppliers relationships: a trust-based conceptual approach. Enterprise Information Systems. 11(7): 1018-1042.

Denicol J., Davies A., Pryke S. (2021) The organizational architecture of megaprojects. International Journal of Project Management, 39(4): 339-350.

Fadzillah A., Azlina N., Omar N., Abidin Z., Zaleha S. (2013) Context awareness monitoring model for smart office environment. 3rd Int. Conf. Advanced Collaborative Networks, Systems and Applications, 81-87.

Ferber J. (1999) Multi-agent Systems An Introduction to Distributed Artificial Intelligence.

Greer C., Burns M., Wollman D., Griffor E. (2019) Cyber-physical systems and internet of things. Special Publication du National Institute of Standards and Technology (NIST SP) – Report N° 1900-202.

Lee H. (2019) Real-time manufacturing modeling and simulation framework using augmented reality and stochastic network analysis. Virtual Reality, 23(1): 85-99.

Liu J., Zhou H., Tian G., Liu X., Jing X. (2019) Digital twin-based process reuse and evaluation approach for smart process planning. International Journal of Advanced Manufacturing Technology, 100(5–8): 1619–34.

Longo, F., Padovano, A., & Umbrello, S. (2020). Value-oriented and ethical technology engineering in industry 5.0: a human-centric perspective for the design of the factory of the future. Applied Sciences, 10(12): 4182.

Lu Y., Xu X. (2018) A Digital Twin Reference Model For Smart Manufacturing. CIE48 Proceedings, Auckland University, 2-5 december.

Mesle, C. R. (2008). Process-relational philosophy: an introduction to Alfred North Whitehead. Templeton Foundation Press.

Negri E., Berardi S., Fumagalli L., Macchi M. (2020) MES-integrated digital twin frameworks. Journal of Manufacturing Systems, 56: 58–71.

Panetto H., Dassisti M., Tursi A. (2012) ONTO-PLM: Product-driven ONTOlogy for Product Data Management interoperability within manufacturing process environment. Adv. Engineering Informatics 26: 334–348.

Pauwels P., Terkaj W. (2016) EXPRESS to OWL for construction industry: Towards a recommendable and usable ifcOWL ontology. Automation in Construction, 63: 100-133.

Paviot T., Cheutet V., Lamouri S. (2011) A PLCS framework for PLM/ERP interoperability. International Journal of Product Lifecycle Management, 5(2/3/4): 295 – 313.

Plowright, D. (2016). Charles Sanders Peirce: Pragmatism and education. Springer Netherlands.

Stark J. (2015) Product lifecycle management. Product Lifecycle Management, Vol. 01: 1-29, Springer.

Tsang, W. (2017). The Fractal Brain Theory. Lulu. com.

Vernadat F. (2010) Technical, semantic and organizational issues of enterprise interoperability and networking. Annual Reviews in Control, Vol. 34(01): 139–144.

Wang Y., Ge J., Shao J., Han, S. (2009) Research on Web Service-based Interoperability of Heterogeneous PLM Systems. Inter. Conf. on Measuring Technology and Mechatronic Automation. Hunan, China, April, 11-12.

Whitehead A.N., (1929-1978) Process and Reality: An Essay in Cosmology', New York: Macmillan, 1929; corrected .edition: D.R. Griffin and D.W. Sherburne, New York: Free Press, 1978.