A Benchmarking of Reference Models for Digital Manufacturing Platforms

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Abstract This paper presents a benchmarking of different reference models for Industry 4.0 solutions, using available alignment reports as a tool for benchmarking, a qualitative indicator to assess the appropriateness of the use of the different reference models, and an assessment using existing implementations and proposals as an initial starting point for future benchmark use cases. The main objective of the benchmark is to facilitate the adoption of reference models for the architectural definition of new digital manufacturing platforms. With this purpose, the benchmark first identifies the main synergies and complementarities of the different reference models under analysis and later performs a qualitative analysis of the relevance of the definitions they contain in the context of concrete implementations and proposals. In early stages of the definition of a new digital manufacturing platform, this is a useful start to position the proposal in the problem space spanned by the reference models and understand which aspects are really needed. The benchmarking can also be useful for the definition of new reference models for specific application domains or meta-models of reference models that aim to map features of different reference models in a common framework.

Keywords Cloud manufacturing · Methods and tools for interoperability · Enterprise application integration · Reference ontologies and standardization

1 Introduction

Industrial Internet of Things (IIoT) [1] integrates different technologies to collect product or process data originated in production environments, store these data, and gain insights through advance analytics, accurate predictions using machine learning or simulation capabilities implementing the digital twin pattern. IIoT is a fundamental part of digital manufacturing platforms [2], which leverage such services to support manufacturing in a broad sense, from product or process design to manufacturing

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B. Archimède et al. (eds.), *Enterprise Interoperability IX*, Proceedings of the I-ESA Conferences 10, https://doi.org/10.1007/978-3-030-90387-9_9

Table 1 Reference model foundations

Model	Provided by	Based on
RAMI 4.0	Industrie 4.0 consortium	CIMOSA [8], SGAM [9], ISA-95 [10], IEC 62264 [11], IEC 62890 [12], OPC UA [13], AutomationML [14], AASX [15]
SMS	National institute of standards and technologies	SCOR [16], ISA-95 [10], CAM-I [17], CIMOSA [8], ATHENA [18], MTConnect [19], HTTP [20]
IIRA	Industrial internet consortium	ISO 42010 [21], BMM [22]
IMSA	Ministry of industry and information technology of China	CIMOSA [8]

operations. There is a great interest in the adoption of these services in the manufacturing industry. As a consequence, there is a growing number of digital manufacturing platforms and use cases that have emerged in recent years. The rapid advancement of related technologies (e.g., fields like big data, machine-to-machine communications, or data analytics) is another important factor that drives the appearance and evolution of digital manufacturing platforms.

Reference models provide a framework for the definition of complex systems and their related use cases. This common framework facilitates the architectural definition of the system and encourages standardization and interoperability. As described in [3], there are different reference models specifically designed for Industrial IoT systems and digital manufacturing platforms. The most prominent ones are the Reference Model for Industrie 4.0 (RAMI 4.0) [4], the Smart Manufacturing Standardization (SMS) Reference Model [5], the Intelligent Manufacturing Standardization Reference Model (IMSA) [6], and the Industrial Internet Reference Model (IIRA) [7]. Table 1 summarizes the main foundational models and standards in which the different reference models are based on.

The table highlights that although they all have similar objectives and there are synergies between them, they are different in scope, are based on different sets of standards, and provide somewhat overlapping definitions. These facts underpin the main objectives of this research paper: (a) map the different reference models against each other and conform a space where concrete implementations can be placed to better understand what aspects are relevant and (b) assess the relevance of the definitions in this space in the context of existing implementations and outstanding proposals to provide a useful starting point for new platform-related projects.

2 Benchmarking Methodology

The first step of the methodology is to align the definitions in the different reference models so that they can be evaluated in a meaningful way. The alignment used in this research paper is based on existing alignment reports in [4, 23, 24]. Based on these results, it is possible to use the four architectural viewpoints defined in IIRA, the business viewpoint, the usage viewpoint, the functional viewpoint, and the implementation viewpoint as four base dimensions for the alignment. This way, the RAMI 4.0 life cycle dimension and the RAMI 4.0 value streams can be mapped to the usage dimension, the IMSA life cycle, and NIST perspectives fit in the usage dimension. Likewise, the RAMI 4.0 layers and hierarchical levels, NIST 300-5 layers and ISA-95 levels, and IMSA layers and hierarchical functions fit in the functional dimension. Finally, the RAMI 4.0 administration shell and connectivity, the NIST AMS 300-2 (manufacturing data), AMS 300-4 (wireless), and AMS 300-6 (blockchain) fit into the implementation viewpoint (Fig. 1).

Based on this alignment, it is possible to perform an independent qualitative assessment to analyze and compare the different (alternative) definitions and determine to which extent they are relevant in the context of a concrete proposal and its related use cases. In this paper, six commercial platforms and research projects in digital manufacturing have been selected for the assessment. The benchmark indicator is a qualitative measure of the relevance of each definition for each implementation or proposal. To obtain this measure, first, a group of experts rated the relevance of each definition in each reference model in a scale from 1 to 10. Then, the average score is calculated, and the benchmark indicator is expressed as one of the following categories: ✓—relevant (10–7 score), (✓)—relevant to some extent (7–4 score), and ✘—out of scope (4–1 score). The following section shows the percentage of definitions that fall into each category based on the alignment results.

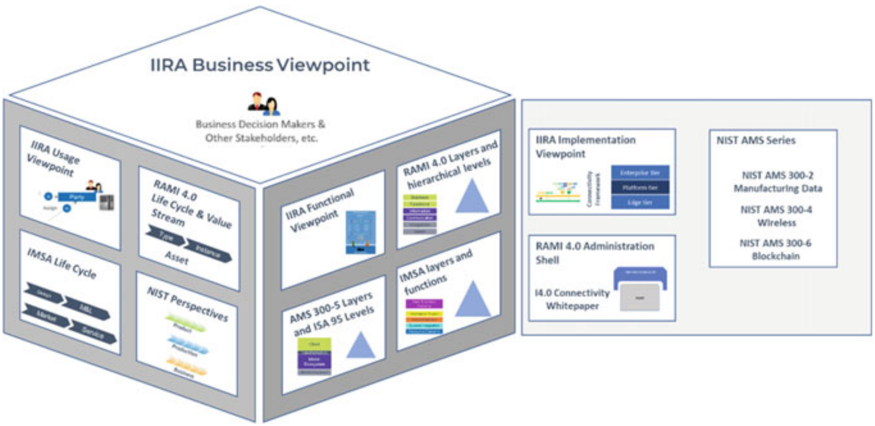

Fig. 1 Reference model alignment results

Table 2 Commercial platforms

Commercial platform	Platform provider	References
Mindsphere	Siemens	[25]
Thingworks	PTC	[26]
Predix	GE	[27]
IBM Cloud	IBM	[28]
Azure IoT Suite	Microsoft	[29]
Adamos	Software AG	[30]

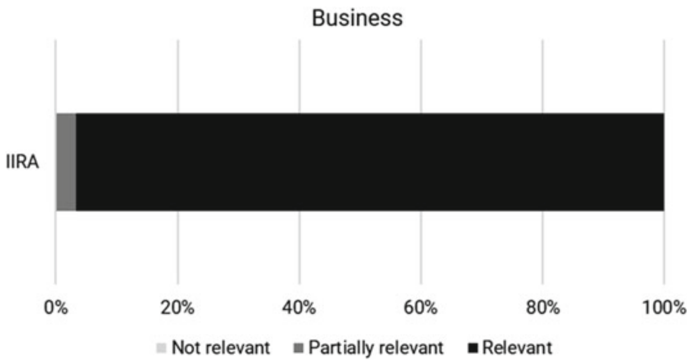

Fig. 2 Commercial platform benchmarking: Business viewpoint

3 Benchmarking Results

3.1 Commercial Platforms

Table 2 lists the different commercial platforms selected for the benchmarking (Figs. 2, 3, 4, and 5).

3.2 Research Projects

Table 3 lists the different research projects in digital manufacturing platforms selected for the benchmarking (Figs. 6, 7, 8 and 9).

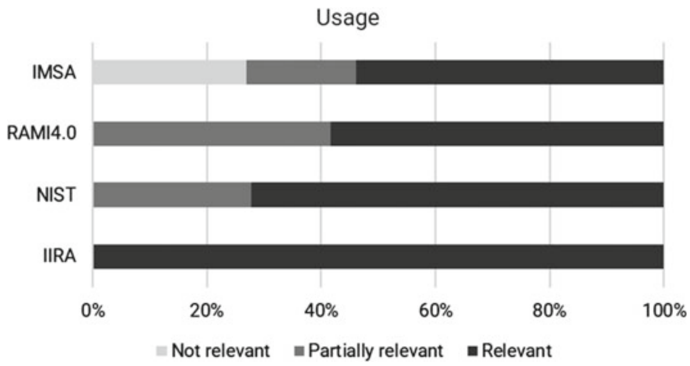

Fig. 3 Commercial platform benchmarking: Usage viewpoint

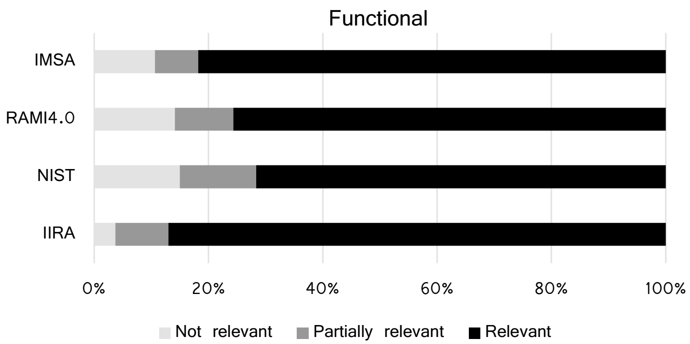

Fig. 4 Commercial platform benchmarking: Functional viewpoint

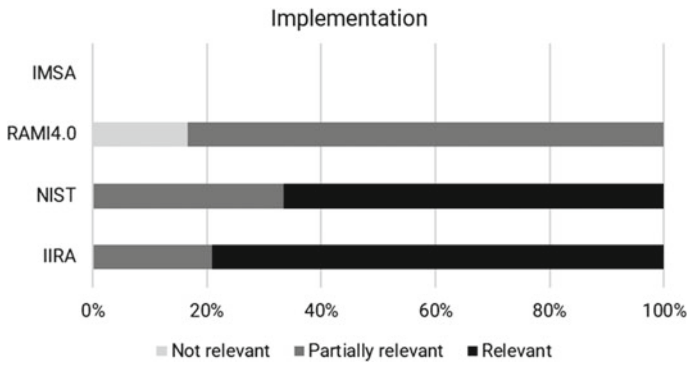

Fig. 5 Commercial platform benchmarking: Implementation viewpoint

Table 3 Research projects platforms

Research project	Title	References
ZDMP	Zero Defects Manufacturing Platform	[31, 32]
vf-OS	Virtual Factory Open Operating System	[33, 34]
CREMA	Cloud-Based Rapid Elastic Manufacturing	[35, 36]
C2NET	Cloud Collaborative Manufacturing Networks	[37, 38]
FIWARE	Future Internet Core Platform	[39, 40]
QU4LITY	Certifiable and Highly Standardized, SME-Friendly, and Transformative Shared Data-Driven ZDM Product and Service Model for Factory 4.0	[41, 42]

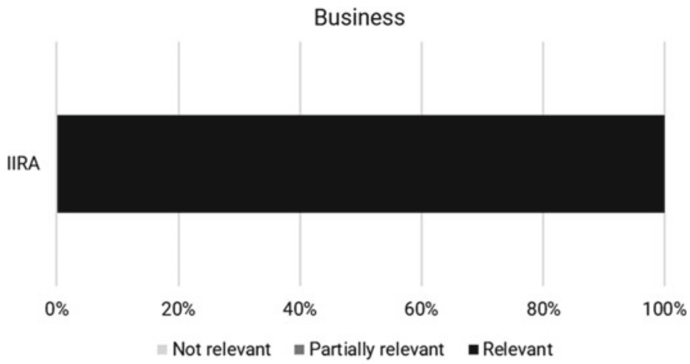

Fig. 6 Research project benchmarking: Business viewpoint

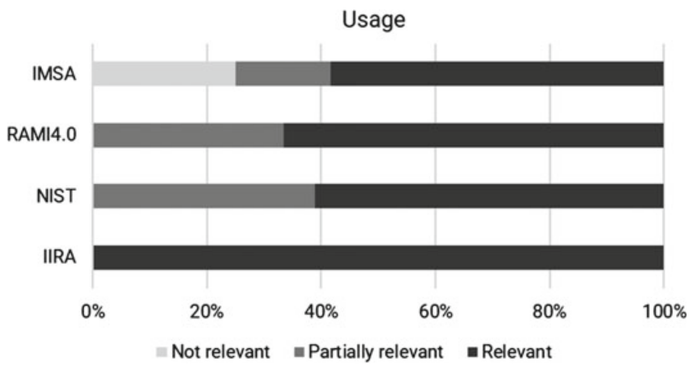

Fig. 7 Research project benchmarking: Usage viewpoint

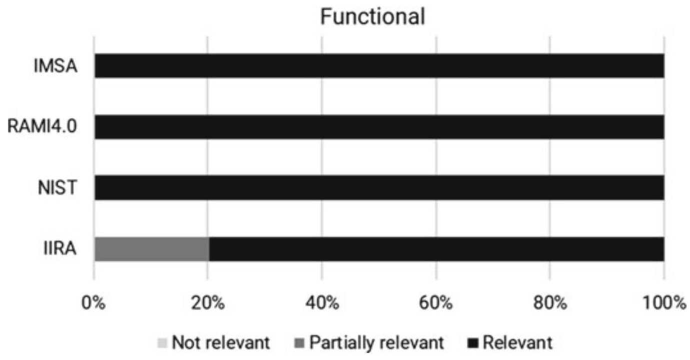

Fig. 8 Research project benchmarking: Functional viewpoint

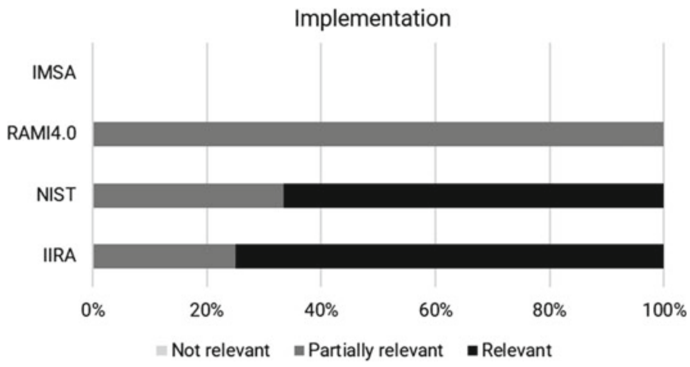

Fig. 9 Research project benchmarking: Implementation viewpoint

4 Conclusion

The assessment shown in this paper provides researchers and practitioners with a good starting point about the coverage of each reference model using existing implementations and proposals as an example. This will support them in the decision-making process about which reference model fits better for their specific project.

The main improvements that can be introduced in future research works are related to the number of reference models covered. Other reference models could be incorporated into the framework, first aligning them to the reference model alignment and then conducting the computing the qualitative measure of relevance with a group of experts. The incorporation of new reference models could also result in the definition of additional dimensions gathering for instance sustainability aspects, so as to define additional perspectives to assess the relevance of the reference models.

Finally, the assessment conducted has not been validated nor analyzed in detailed. The objective is to serve as example for other proposals, and due to the limitations in length, the results have not been discussed properly. In lines of this, future research should consider an in-depth analysis and validation of the assessment results, possibly conducted through an independent panel of experts.

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