Advancing Data Exchange Standards for Interoperable Enterprise Networks

Nenad Ivezic[1], Elena Jelisic[1,2], Marija Jankovic[3], Boonserm Kulvatunyou[1], Dionysios Kehagias[3], and Zoran Marjanovic[2]

[1] *National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD 20899, USA*
[2] *Faculty of organizational sciences, Jove Ilica 154, Belgrade, 11000, Serbia*
[3] *Centre for Research and Technology Hellas, 6th km Charilaou-Thermi Rd, Thessaloniki, 57001, Greece*

Abstract

Recently, our interoperability research strategy delivered significant results by (1) adopting the ISO-approved Core Components Technical Specification (CCTS) meta-model as a basis for a new data exchange modeling framework and (2) developing Score, which is an innovative open-source, CCTS-based, data exchange standards modeling and life-cycle management tool. This strategy has been arguably very promising, as evidenced both by industry uptake of our research results. Moreover, there are additional possible capabilities that can contribute to even greater interoperability of enterprise systems. However, for the CCTS- or a similar meta-model-based modeling framework, and a newly enabled tool to have a full impact, new challenges need to be addressed. The paper discusses these challenges for the data exchange standards-based systems integrations, identifying the current state-of-the-art solutions and limitations. The paper also proposes future research directions and strategies to enable advanced capabilities by building on both the already successful and accepted technologies as well as new and emerging ones.

Keywords

Data exchange standards, meta-model, modeling framework, agility, robustness, interoperability, networked enterprises.

1. Introduction

This paper focuses on the subset of systems integration problems typically found in the inter-enterprise or business-to-business (B2B) integrations involving enterprise systems, supply chain management systems, and, increasingly, analytical systems [1, 2]. These integration problems often involve both (1) a large number and a large variety of enterprise information exchanges, and (2) a large number of participants (such as in industrial supply chains). For that reason, they are very often, if not always, addressed by developing a data exchange standard (DES) specification for the industrial community and their networked ecosystem. In these integration problems, the information that is exchanged is mostly well understood by the participating parties. However, because of the differences between the implementations of the systems exchanging the data, there may be both significant as well as subtle differences in data exchange standard interpretations and integration solutions that may hinder valid data exchanges in the networks of participants.

Because of the significant heterogeneity of the exchanged data, the size of the network of the participants, and large variations in systems implementations, the total cost of a manual effort to develop, use, and manage traditional standards-based integration solutions is typically very large, if at

Proceedings of the Workshop of I-ESA'22, March 23–24, 2022, Valencia, Spain
EMAIL: nenad.ivezic@nist.gov (N. Ivezic); elena.jelisic@nist.gov (E. Jelisic); jankovicm@iti.gr (M. Jankovic); boonserm.kulvatunyou@nist.gov (B. Kulvatunyou); diok@iti.gr (D. Kehagias); zoran.marjanovic@fon.bg.ac.rs (Z. Marjanovic)
ORCID: 0000-0003-1863-4370 (N. Ivezic); 0000-0002-4294-8313 (E. Jelisic); 0000-0002-7429-473X (B. Kulvatunyou); 0000-0002-6912-3493 (D. Kehagias); 0000-0002-0929-686X (Z. Marjanovic)

all feasible [3]. Past research efforts have tried to devise novel architectures to overcome the issues of costly, inefficient traditional standards that rely on rudimentary development, use, and management support. However, these strategies have been slow and ineffective, and proved to be infeasible in terms of actual solution sustainment and engagement by industry [4]. In the past couple of years, new research results have been delivered with a significant advancement in the state of art and practice in data exchange standards life-cycle management [5]. The overall approach taken was to strengthen the foundation of data exchange standards by including new concepts and methods to support new capabilities. In other words, the general data modeling frameworks used in the traditional standards for data exchange life-cycle management, such as the general XML modeling framework, have been substituted with a more focused one that trades off the generality for important new capabilities.

The researchers propose a CCTS meta-model as a basis for a novel modeling framework [6]. The meta-model introduces a new abstract data model with three essential new concepts. First, shared data types are introduced to address both the need for conceptual, application domain-independent data types, and the need for logical, application domain-specific data types [7]. Second, common data structures are introduced that follow object-oriented view of the world, which aligns well with the software applications' view of the world, and also provides the needed expressiveness to deal with proprietary data structures while doing away with constructs that are not relevant to typical information exchange tasks. Third, a uniform method to classify business semantics is adopted, allowing application domain - and integration situation-specific usage details of the standard to be uniformly expressed from the lowest, basic data type level to the highest, composite data type level (i.e., message or document type).

Using the latest CCTS modeling framework as the new foundation, the researchers created a new development platform and tooling with new capabilities [8]. Score is an innovative open-source, CCTS-based, data exchange standards modeling and life-cycle management tool developed to support industry in adopting and using the latest advancements of the CCTS-based standards [9]. It has been developed collaboratively between NIST and the OAGi business consortium and standards-development organization. Score initially focused to address two key challenges in traditional data exchange standards life cycle management: (1) the need for multiple expressions of data exchange standard and capturing its usage specification; and (2) the need for efficient management of standards documents for usage specification [10]. Next, we discuss the achieved and the new potential capabilities, the enabling technologies, as well as the challenges we observe to achieve the capabilities.

2. Novel capabilities, enabling technologies, and challenges

New capabilities and life-cycle management methods for advanced data exchange standards require new enabling technologies. Figure 1 shows the relationship between enabling technologies (left) and new capabilities (right).

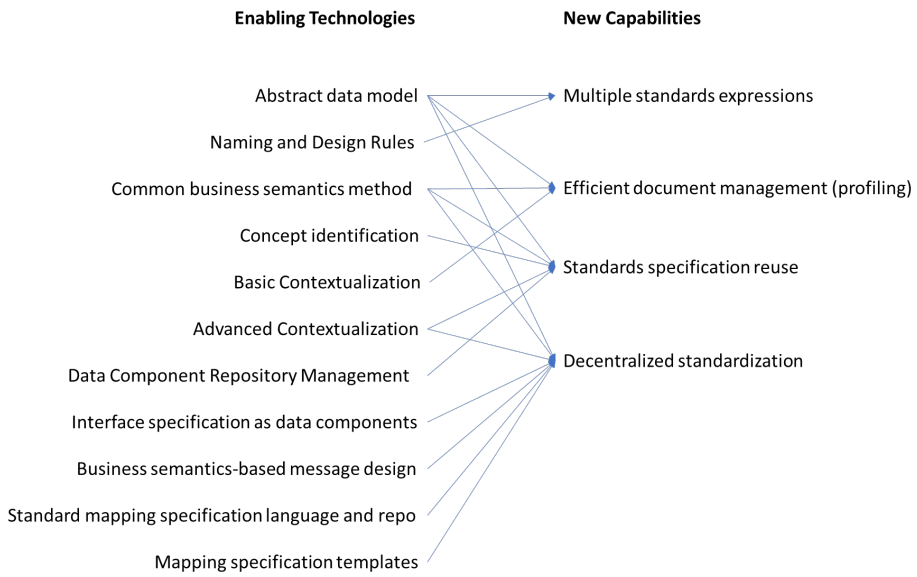

Figure 1: Enabling Technologies and New Capabilities

Multiple standards expressions of both data exchange standards and their usage specifications were needed as mobile and IoT devices required new data exchange syntactical formats, bringing the JSON, OpenAPI Specification (OAS), and other representation schemas as new industrial requirements [11]. Attempts to manage this multiple representation requirement by direct mappings from one implementation technology, like XML, to others, like JSON and OAS, have been difficult. One issue is that the standards and usage specifications expressed in one implementation-level standard need to be in sync with other implementation-level standards, each of which may change at any time, requiring such change to propagate to each syntactical expression. Instead, the new CCTS-based Abstract Data model-based specification of data exchange standards and their usage together with the Naming and Design Rules (NDR) for a specific expression language, provided for an easier and more manageable path to automated generation of a new standard expression and its usage specification for that particular language by providing a single abstract reference model [12]. A major challenge was to transform a living data exchange standard into a novel CCTS-based data exchange standard while continually supporting industry needs in the transition. This challenge has been resolved by developing the Score tool that allowed transition by working closely with the OAGi industry consortium and standards development organization [9].

Efficient standards contextualized document/message profiling (subsetting) has been needed for many years. Standard messages or documents have grown tremendously in size, reflecting the accumulated requirements for data exchange coming from an increasing number of participating enterprise systems and cross-industry usage. Traditionally, the management of the large size of these message or document standards has been dealt with in a completely manual and informal manner. This is anything but feasible on a realistic scale, making the standards management inefficient and costly. Instead, the new CCTS modeling framework enabled abstract class-based specification of data exchange standards to be 'assembled' into a hierarchical, easy-to-review, select-from, and profile (i.e., subset) standards specification. The Common business semantics method and Basic Contextualization allowed ad-hoc management of profiles, increasing the manageability of the standards and their usage specification [13]. A major challenge was to provide a means for developers to utilize the technologies in an efficient manner. This challenge has been resolved by developing the Score tool that allowed meaningful and usable user interface by working with the OAGi industry consortium and their member industry companies.

Standards specification reuse has been another long-term need that continues to grow in importance as the standards continue to increase in size and complexity. Once enabled and optimized, the reuse capability would help in achieving ease and efficiency of standards development and usage, and also achieving higher-quality interoperability solutions. Traditional approaches could not address this need as they typically only enable ad-hoc, locally defined standards specification store and reuse,

which lacked any ability to register and search for reusable specifications while providing assurance of the quality of the reuse candidate. To enable reuse, the new CCTS approach envisions several additional new technologies, including Concept Identification, Advanced Contextualization, Data Components Specification Repository Management, Interface Specification as Data Components Specification, and Business Semantics-based Message Design [14]. A major challenge is two-part: (1) Development, use, maintenance, and validation of uniform, shareable application domain semantics to enable computer-supported Advanced Contextualization; and (2) Development, use, maintenance, and validation of formal conceptual model/ontology to enable computer-supported Concept Identification. To resolve the challenge, we envision an experimental assessment of conceptual models / ontologies / taxonomies in collaboration with Industrial Ontologies Foundry (IOF), OAGi, and industry partners [15,16].

Decentralized standardization is a potential new capability that has presented itself as a radically different way of managing standardization in the future. As Industry 4.0 seeks agile and resilient processes, this puts growing pressure on the traditional, centralized life-cycle management (LCM) processes that develop and maintain these standards in a centralized and inefficient fashion. With advances in technology and data modeling, it is possible to reconsider these long-standing practices. A CCTS meta-model-based approach could lead toward a decentralized standardization process where the data exchange requirements for the participating parties are captured precisely and completely by using a new method and an innovative architecture. With the new standardization process, the time and cost needed to reach a broad consensus among many companies on the design of each DES document schema is significantly reduced. The new approach envisions additional new technologies, including Standard Mapping Interchange Language, Contextualized Semantic Mapping Repository, and Mapping Specification Templates. A major challenge is two-part: (1) Development, use, maintenance, and validation of uniform mapping interchange language that builds on the CCTS meta-model, shareable with middleware platforms; and (2) Development, use, maintenance, and validation of the Mapping Specification Templates that can provide efficient computer-based support to the software developer. To resolve the challenge, we develop a prototype mapping interchange language specification for its validation by industry and to be submitted to a standards development organization. With such a language in place, we then plan to perform an experimental assessment of the Mapping Specification Template solutions on a representative number of industrial use cases.

3. Conclusion

The paper has described existing and potential new capabilities obtained through (1) adopting the ISO-approved Core Components Technical Specification (CCTS) meta-model as a basis for a new data exchange modeling framework and (2) developing Score, which is an innovative open-source, CCTS-based, data exchange standards modeling and life-cycle management tool. The technology that exists today provides a foundation on which new technologies and capabilities can be reliably built and tested. Ultimately, to assure industry engagement, leadership, and adoption of the technologies, we expect such new technology development to need such a reliable foundation on which, in a sound engineering way, the industry, standards development, and research organizations can consistently be developing new capabilities through iterative propose-assess-adapt-deploy R&D advances.

4. Disclaimer

Any mention of commercial products is for information only; it does not imply recommendation or endorsement by NIST.

5. Acknowledgements

Work reported in this paper has received funding from the European Union Horizon 2020 research and innovation programme under grant agreement No. 952684 (project: IoTAC).

6. References

[1] H. A. H. Awad, M. O. Nassar, A broader view of the supply chain integration challenges, International Journal of Innovation, Management and Technology 1 (2010) 51-55. doi: 10.7763/IJIMT.2010.V1.11.

[2] K. Bala, Supply chain management: Some issues and challenges-A Review, International Journal of Current Engineering and Technology 4 (2014) 946-953.

[3] A. Wasala, J. Buckley, R. Schäler, C. Exton, An empirical framework for evaluating interoperability of data exchange standards based on their actual usage: A case study on XLIFF, Computer Standards & Interfaces 42 (2015) 157–170. doi: 10.1016/j.csi.2015.05.006.

[4] D. Tchoffa, N. Figay, P. Ghodous, H. Panetto, A. El Mhamedi, Alignment of the product lifecycle management federated interoperability framework with internet of things and virtual manufacturing, Computers in Industry 130 (2021) 103466. doi: 10.1016/j.compind.2021.103466.

[5] B. (Serm) Kulvatunyou, H. Oh, N. Ivezic, S. T. Nieman, Standards-based semantic integration of manufacturing information: Past, present, and future, Journal of Manufacturing Systems 52 (2019) 184–197. doi: 10.1016/j.jmsy.2019.07.003.

[6] UNECE, Core Components Technical Specification CCTS, version 3.0, 2009. URL: https://unece.org/DAM/cefact/codesfortrade/CCTS/CCTS-Version3.pdf.

[7] STUDYLIB, UN/CEFACT Unified Context Methodology Technical Specification, 2010. https://studylib.net/doc/7241720/un-cefact-unified-context-methodology-technical.

[8] D. Novakovic, C. Huemer, Business Context Sensitive Business Documents: Business Context Aware Core Components Modeling Using the E-UCM Model, in: Proceedings of the 11th International Conference on Industrial Informatics (INDIN), IEEE, Bochum, Germany, 2013, pp. 523-528. doi: 10.1109/INDIN.2013.6622939.

[9] NIST, Score: Standards Life Cycle Management Tool, 2019. URL: https://www.nist.gov/services-resources/software/score-standards-life-cycle-management-tool.

[10] N. Ivezic, B. Kulvatunyou, E. Jelisic, H. Oh, S. Frechette, V. Srinivasan, A Novel Data Standards Platform Using the ISO Core Components Technical Specification, in: ASME 2021 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, 2021. doi: 10.1115/DETC2021-68067.

[11] D. Novakovic, C. Huemer, Contextualizing Business Documents, in: Proceedings of the 10th International Conference on e-Business Engineering (ICEBE), IEEE, New York, 2013, pp. 236-243. doi: 10.1109/ICEBE.2013.36.

[12] D. Novakovic, Business Context Aware Core Components Modeling Vienna, 2014. URL: https://publik.tuwien.ac.at/files/PubDat_234005.pdf.

[13] UNSTATS, International Standard Industrial Classification of All Economic Activities, 2008. URL: https://unstats.un.org/unsd/classifications/Econ/Download/In%20Text/ISIC_Rev_4_publication_English.pdf.

[14] N. Ivezic, E. Jelisic, B. Kulvatunyou, S. Nieman, H. Oh, Z. Marjanovic, Towards Inter-Operable Enterprise Systems – Graph-Based Validation of a Context-Driven Approach for Message Profiling, in: APMS 2020. IFIP Advances in Information and Communication Technology, vol 591, Springer, Cham, 2020. doi: https://doi.org/10.1007/978-3-030-57993-7_23.

[15] IOF, Welcome to the IOF, 2021. URL: http://www.industrialontologies.org.

[16] Open Applications Group (OAGi), OAGIs covers these business areas and more, 2021. URL: https://oagi.org/.