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A Proposal of Unified Reference Model for Smart Manufacturing

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Abstract—**This paper examines "Unified Reference Model - Map & Methodology (URM-MM)" as a development guideline for open-ecosystem, which support users to integrate individual components developed by diversified vendors in order to address complicated challenges, which is not easy to solve by a single vendor. The first contribution of this paper is finding insufficiency of not only functionality but also a process for building open-ecosystems through a survey on existing reference models/architecture. The second contribution is to shape URM-MM as a unified model, a development guideline for boosting discussions towards the realization of smart manufacturing.**

I. Introduction

In various domains, it has held active discussions on leveraging not only information and communication technologies, but also field data and open data to promote innovations for expanding business opportunities. Besides, in the industrial domain, which Germany is leading Industrie4.0, it needs to address emerging challenges for delivering new added values such as mass-customization and shorter product lifecycle. For this purpose, it leads to require realization of smart manufacturing by integrating various components flexibly.

Major Standards Developing Organizations (SDOs) such as ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission) are working on standardization for smart manufacturing, which is a derived concept of Industrie4.0, and a main topic of the discussion has been shifting to a unified model development currently.

Because diversified reference models/architecture have been developed at various organizations to fulfill diversified specific requirements so far, it needs a unified model allowing to guide developments of diversified production systems as open-ecosystems, which allow users to integrate various components from diversified vendors, by presenting related international standards for easing complicated system integrations.

Mathias Uslar, et al. studied an visualization technique of use-cases in terms of manufacturing system using a layered model based on RAMI4.0[1]. Their approach is to visualize use-cases by drawing related objects on individual layers of RAMI4.0, and connecting lines for representing their relationships among those objects. When it would map related international standards on use-cases drawn by this approach, it seems that an visibility of international standards would become a potential challenge due to limited view area of a single perspective.

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By following the overview of standardization activities about smart manufacturing at SDOs, we give a basic idea for considering a unified reference model in Section II. We follow by analyses on existing reference models and architecture in Section III. Then, in Section IV, we discuss our proposal about a unified model. we relate analyses on reference models and architecture to other works in Section V. Finally we conclude the discussions in Section VI.

II. Unified Model for Smart Manufacturing

For beginning to consider a unified model, we think it would be important to take into not only a consideration for merging those models and architecture into a single model by eliminating overlaps and clarifying their core part, but also a consideration for combination of those models and architecture, because they have specialized characteristics respectively for particular domains to fulfill diversified expectations at different levels.

A. Motivation for a Proposal:

The following descriptions are the motivation for proposing a unified model for smart manufacturing:

- Industrial major SDOs have requested to promote merging existing reference models/architectures into a unified model by eliminating overlaps and clarifying their core contents.
- Reference models/architecture have already been developed for diversified scales/granularity with various domains/life-cycles at various organizations.
- Although outcomes delivered through international standardization activities for smart manufacturing should make user benefits a central value, it seems that such discussion is not enough yet.

B. Purpose of Proposing Unified Model

The main purpose for proposing a unified model is :

- To support open-ecosystem developments, which allow users to integrate various components from diversified vendors, by presenting related international standards delivering interoperability and interchangeability for easing complicated system integrations..

Therefore the unified model, which is going to be considered and developed, should have capabilities to draw various use-cases of smart manufacturing, describe their functional requirements, and show related international standards.

III. Analyses on Reference Models

Because many SDOs have been developing various reference models and reference architecture, we conduct a survey first on them in order to find most relevant ones as citable references for considering the unified model, which can fulfill requirements for smart manufacturing, to take clear shape.

A. Survey on Models and Architecture

Table I shows existing reference models and architecture, which are subjects for finding most relevant models, related to smart manufacturing.

TABLE I. MODELS RELATED TO SMART MANUFACTURING

#	Organization	Name
1	Industrie4.0	Reference Architecture Model Industire 4.0
2	NIST	Smart Manufacturing Ecosystem
3	Industrial Internet Consortium	Industrial Internet Reference Architecture
4	National Intelligent Manufacturing Standardization Administration Group of China	Intelligent Manufacturing System Architecture
5	ISO/IEC JTC1/WG10	Reference Architecture
6	IEEE P2413	Reference Model
7	ITU-T SG20	IoT Reference Model
8	oneM2M	Architecture Reference Model
9	ISO TC184	Big Picture 3D diagram
10	Alliance Industrie du Futur	Framework for the smart manufacturing standards landscape
11	Industrial Value Chain Initiative	Industrial Value Chain Reference Architecture

To clarify characteristics of individual models and architecture, we conducted an analysis on them in terms of capability of representation.

The remaining section of this section provides outlines of some major reference models.

Fig.1 shows RAMI4.0, which was developed for delivering common understanding of Industire4.0. It has three dimensional axes: Right horizontal axis represents functionalities within a facility, Left horizontal axis represents life cycle of facilities or products, and Vertical axis represents different perspectives in manufacturing systems.[1][3][4][5]

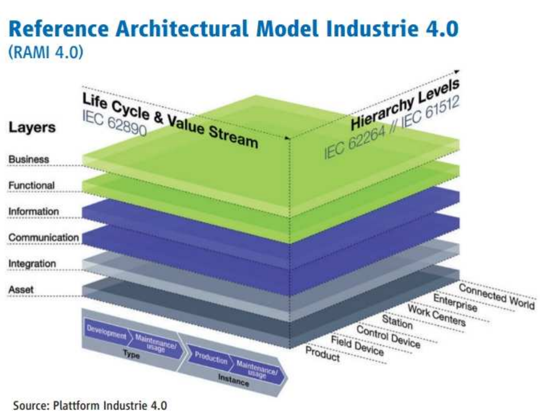

Figure 1. Industrie4.0: Reference Architectural Model Industrie 4.0 [1]

RAMI4.0 is based on the Smart Grid Architecture Model (SGAM) developed before by CEN & CENELEC.

Fig.2 shows Smart Manufacturing Ecosystem developed at NIST.

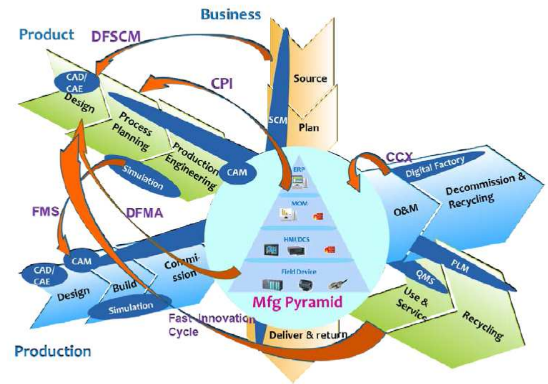

Figure 2. NIST: Smart Manufacturing Ecosystem [6]

NIST model (Smart Manufacturing Ecosystem) has a broad scope of manufacturing systems including business, production, management, design, and engineering functions. Fig.2 shows three dimensions of concern that are manifest in Smart Manufacturing Systems. Each dimension (i.e. product, production system, and business) represents individual lifecycle.[6]

Fig.3 shows summary of reference models defined at IEEE P2413.

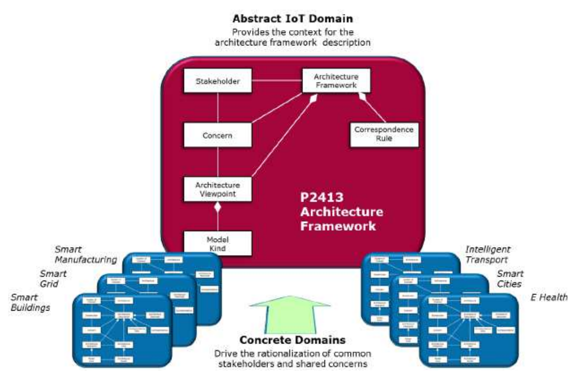

Figure 3. IEEE P2413: Reference Framework [12]

This Reference Model aims to leverage different architectural views (in different embodiments) in order to produce the same system quality. It uses the notations developed as ISO/IEC/IEEE 42010, because is widely used and has a broad supportive base among standardization organizations. In P2413, relationships among reference model, reference architecture, and concrete architecture are defined. Fig.3 shows relationships among reference models: Physical Entity Model, Domain Model, Communication Model, Functional Model, Information Model, Integrity Model.[12]

Fig.4 shows a reference architecture, which is developed at Industrial Value Chain Initiative as loosely defined standard.

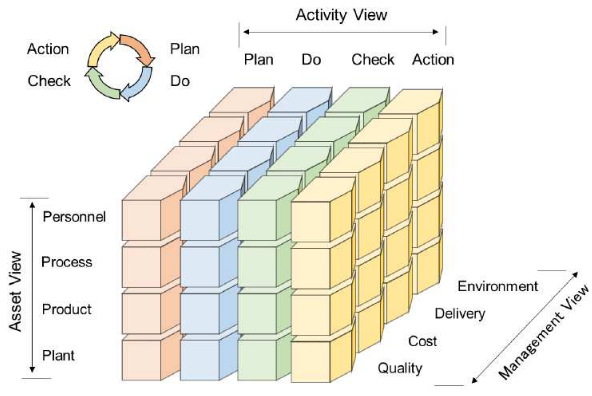

Figure 4. IVI: Three Views of Smart Manufacturing Unit [18]

Industrial Value Chain Initiative (IVI) aims Connecting technology from bottom up approach (needs-oriented from manufacturing industries). Industrial Value Chain Reference Architecture (IVRA) delivers two novel concepts. One is Smart Manufacturing Unit (SMU), which presents an autonomous unit of smart manufacturing. SMU is a system of systems that faces diversity and individuality of industrial needs, drastically improving its productivity and efficiency through mutual communication and connection of autonomous units of manufacturing organizations. And individual SMU is composed of three axes, Asset, Activity, and Management views. Another one is General Function Blocks, which is utilized to be modeled a whole smart manufacturing with three axes, engineering flow, demand and supply flow, and organizational hierarchy level.[18]

Table II shows description capabilities, which are supported by individual models, as results of the analysis. These capabilities are categorized into Logical aspect, Physical aspect, Lifecycle aspect, and Comprehensive aspect.

B. Important Findings through the Survey

Through the survey, to fulfill the purpose based on the motivation described in Section II, we have perceived that a main challenge addressed in this paper is an insufficiency of not only functionality but also a process for building open-ecosystems.

Besides, we have perceived the following appearances. Firstly, it seems that RAMI4.0 and IVRA provide a capability as "Connected World" to represent connections between different enterprises (e.g. between a factory and an energy management provider, between a factory and a truckload carrier). However it seems that standards related to "Connected World" in RAMI4.0 are under development.

Secondly, Both RAMI4.0 and NIST model provide capabilities as "Product" and "Product Development Lifecycle" to represent themselves manufactured by a factory. In that sense, there is no significant difference in terms of referred standards in RAMI4.0 and NIST model.

On the other hand, although reference modes/architecture, which are subjects of the analysis this time, have quite diversified description capabilities focusing different scales and granularity for representing use-cases as shown at Table II, we have noticed that it could be possible to categorize them into some typical groups.

IV. Proposal of Unified Reference Model

To address the main challenge perceived through the survey, we propose "Unified Reference Model" as a guideline for open-ecosystem development in order to support users to conduct system developments with complicated integrations by presenting To support open-ecosystem developments by presenting related international standards delivering interoperability and interchangeability for easing complicated integrations. Therefore, this section explains our proposal of Unified Reference Model for smart manufacturing.

A. Properties for Open-Ecosystem Development

Because development scale is getting bigger, development complexity is also getting higher rapidly, and stakeholders are diversified even in the industrial domain, an open ecosystem development, which integrates with appropriate components developed by various providers, is a promising solution to address the situation.

TABLE II. Result of the Analysis for Existing Reference Models and Architecture

Aspect	Description Capability	I4.0	IIC	Made in China2025	NIST	JTC1/WG10	IEEE P2413	oneM2M	ITU-T	ISO TC184	AIF	IVI
Logical	Usage		X									
	Business	X	X	X					X	X	X	X
	Information	X	X	X				X		X	X	X
	Communication	X	X	X				X	X	X	X	
	Integration	X	X			X	X	X	X	X	X	X
	Asset	X	X	X						X	X	X
	System model representation	X	X	X					X		X	X
Physical	Interaction among enterprises					X	X					X
	Production system hierarchy	X		X							X	X
	Product	X		X	X					X	X	
Lifecycle	Meta-lifecycle	X								X	X	
	Product lifecycle	X	X	X							X	
	Supply chain/ Value chain	X			X					X	X	
	Service lifecycle	X			X					X	X	X
Comprehensive	Security/Safety/Privacy	X			X					X	X	X
	Regulation	X										X

Therefore Unified Reference Model contains the following properties for supporting open-ecosystem developments:

- Classification of typical development processes for representing each use-case at appropriate scales and granularity.
- Support of selection for appropriate existing reference models/architecture for representing each use-case at individual classified development processes to fulfill their aim.
- List of relevant international standards corresponding to each use-case drawn on the selected reference models/architecture.

B. Unified Reference Model - Map & Methodology

To represent each use-case utilizing existing reference models/architecture, Unified Reference Model - Map & Methodology (URM-MM) defines the following classification as four different views, “Canvas”, “Use-case”, “Function”, and “Data”. And it provides a guideline to describe individual use-case to utilize appropriate existing reference models/architecture categorized into “Canvas”, “Use-case”, “Function”, and “Data” for presenting related international standards.

“Canvas” provides a space as “Focus Area” having appropriate aspects such as domain, hierarchy, and life-cycle in order to draw a physical structure of an implementing use-cases, which is composed from field equipments to Manufacturing Execution System (MES). At “Canvas”, we suppose that those drawings present related international standards and de-facto products such as industrial ethernet (e.g. Profibus, EtherNet/IP), communication protocols (e.g. AMQP, MQTT, CoAP), and Web service interfaces (e.g. RESTful, SOAP). Fig.5 shows an example of a notation of “Canvas”.

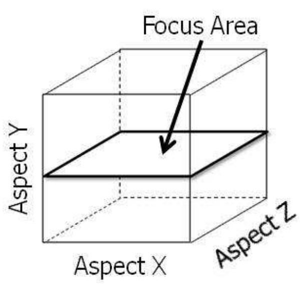

Figure 5. Example of “Canvas”

“Use-case” provides a space for drawing behavior diagrams of whole use-cases in order to define main actions, which are performed by subjects, and express interactions with external actors as stakeholders. At “Use-case”, we suppose that those drawings present international standards related to system-wide issues such as system architectures (e.g. IEC62264, IEC61512), security / safety / privacy (e.g. IEC62443, ISO/IEC27000), and (inter-)national regulations (e.g. trade restrictions, international procurement). Typical use-cases related to smart manufacturing have been discussed at some initiatives such as Platform Industrie4.0[5], IIC, and IVI. Fig.6 shows an example of a notation of “Use-case”.

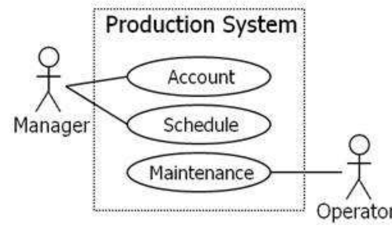

Figure 6. Example of “Use-case”

“Function” provides a space for drawing logical functional blocks, which implement necessary and characterizing features of each use-case, and visualized relationships among those functional blocks. At “Function”, we suppose that those drawings present related international standards, de-facto products, and de-facto Open Source Software (OSS) such as virtualization software (e.g. Docker, KVM, Vmware), database (e.g. PostgreSQL, MongoDB), data processing infrastructures (e.g. Hadoop, Spark). Fig.7 shows an example of a notation of “Function”.

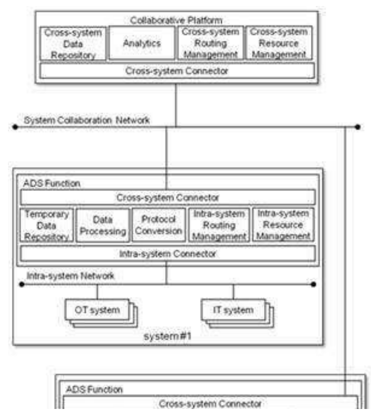

Figure 7. Example of “Function”

“Data” provides a space for drawing data models, which are defined and utilized in each use-case. At “Data”, we suppose that those drawings present related international standards such as business indexes (e.g. ISO22400), engineering data (e.g. IEC62714, IEC61131), dictionary data (e.g. IEC61360, ecl@ss). Fig.8 shows an example of a notation of “Data”.

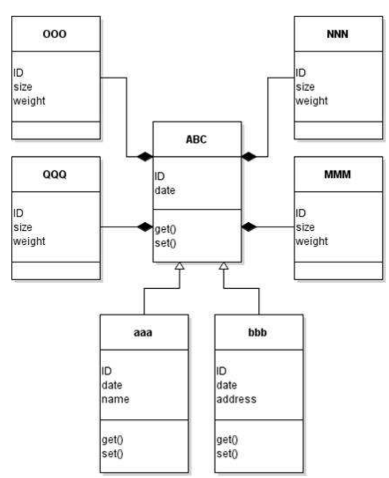

Figure 8. Example of “Data”

The upper half of Fig.9 shows dependency among four views as development processes. At “Canvas”, a selected model provides a capability to describe a whole of a use-case from appropriate aspects for satisfying all expectations of stakeholders. At “Use-case”, a selected model provides a capability to draw a use-case at a specific focus area selected at the “Canvas”. At “Function”, a selected model provides a capability to describe all or part of functional components and their relationship of drawn at “Use-case”. At “Data”, a selected model provides a capability to describe all or part of data structures and their relationship of data, which is utilized at “Function”.

C. Taxonomy of Reference Models/Architecture

Besides, URM-MM provides a table listing existing reference models/architecture categorized according to the classification of four development processes for supporting of selection for appropriate existing reference models/architecture for representing each use-case.

The lower half of Fig.9 shows an example of the table of the classification. As presented at Fig.9, RAMI4.0[2] of Industrie4.0, IIRA[9] of IIC, Intelligent Manufacturing System Architecture of Made in China2025[10], Smart Manufacturing Ecosystem of NIST[6], IoT Reference Model of ITU-T SG20[13], Big Picture 3D diagram of ISO TC184[15], and Industrial Value Chain Reference Architecture of IVI[18] are categorized into “Canvas”. Reference Architecture of JTC1/WG10[11] and Reference Model of IEEE P2413[12] are categorized into “Function”. Architecture Reference Model of oneM2M[14] is categorized into both “Function” and “Data”. Unified Modeling Language of OMG is categorized into all of “Use-case”, “Function”, and “Data”. Framework for the smart manufacturing standards landscape of Alliance Industrie du Futur (AIF) introduces a guideline[17] to describe use-cases onto “Canvas” type of models, such RAMI4.0.

D. Usage

By walking through development processes defined in URM-MM, users can make open-ecosystem development easier, guided with relevant international standards for each development process. Iterative operations of the following three steps at four development processes, from “Canvas” through “Data”, is typical usage of URM-MM:

Step.1: Select an appropriate reference model/architecture for describing a use-case by reference to a table summarizing features of individual reference models/architecture such as Fig.9.

Step.2: Draw the use-case visually leveraging the selected model at appropriate scales and granularity to have common understandings among diversified stakeholders having interests from various aspects..

Step.3: Map relevant international standards delivering interoperability and interchangeability onto the drawn use-case precisely for supporting open-ecosystem developments allowing complicated system integrations.

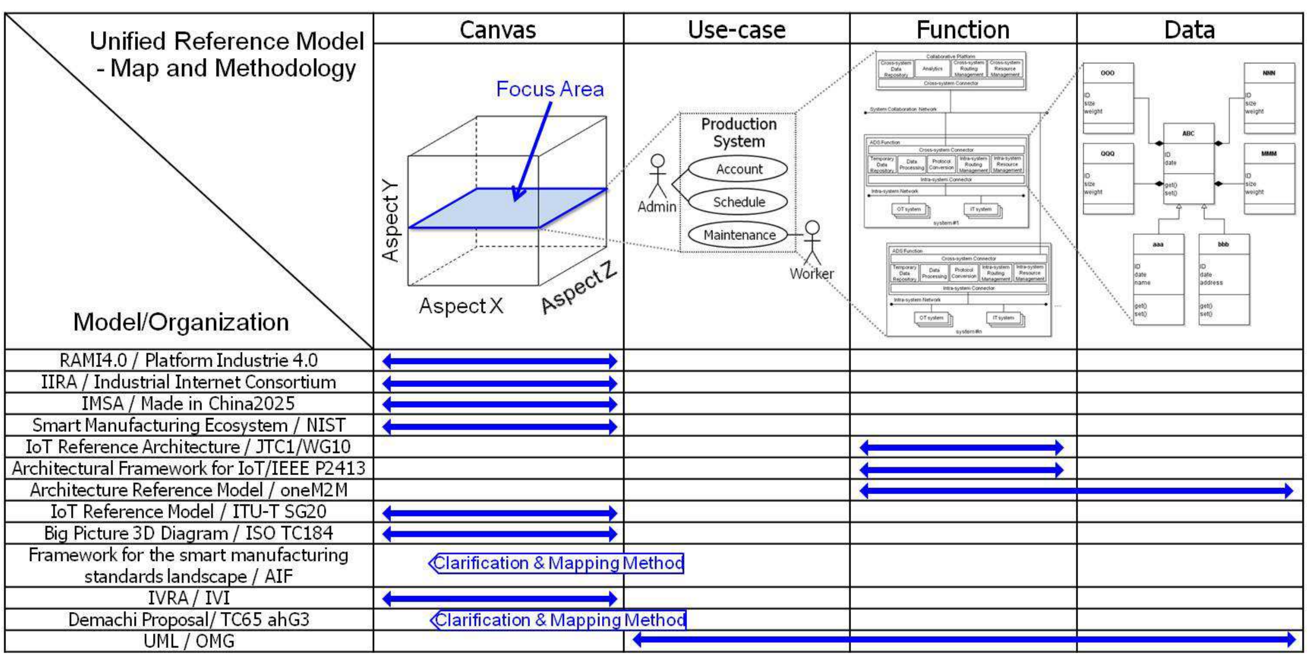

Figure 9. Classification of Existing Reference Models/Architecture for each view

V. Related Work

Microsoft provides Application Architecture Guide (AAG), which intends to support software developers and solution architects for building high-quality applications based on .NET Framework by leveraging reliable architecture, designs, and patterns. And it focuses on delivering references of general principles and overviews of practical and useful information about solution architecture and designs for Microsoft platform and .NET Framework. Therefore it provides general overviews of fundamental principles and patterns for good architecture and designs, although it does not provide practical and formal solution architecture for specific scenarios.[19]

Even though Microsoft AAG is guidance with patterns as best practices from business layer to physical layer for Microsoft platform and .NET Framework, it applies appropriate pattern based on a single reference model for addressing various use-cases. In contrast, URM-MM proposes a guideline to support not only a easy selection of appropriate reference models/architecture for applying to various use-cases for presenting related international standards, but also to refer practical cases, which are applying URM-MM.

The Open Group provides the Open Group's Architecture Framework (TOGAF) for defining Enterprise Architecture (EA) to build IT systems according to a business strategy [20]. The Architecture Development Method is a core part of TOGAF to build a specific EA of an organization by defining required processes for planning, designing, implementing, and maintaining such EA utilizing existing techniques such as UML and BPMN.

Although both TOGAF and URM-MM leverage existing resources for modeling targeting systems, URM-MM focuses on not only development process but also scale and granularity for modeling.

VI. Conclusion

Through the survey and the discussions on a unified model for smart manufacturing, we have proposed "Unified Reference Model - Map & Methodology (URM-MM)", a guideline, which supports users to develop their production systems as open-ecosystems by presenting related international standards.

Our proposal needs to be examined continuously in more detail to become more beneficial for users. In particular, the table shown at Fig.9 should be sophisticated for supporting appropriate reference models/architecture selection. And also sufficient practical guides for utilizing URM-MM should be ready for ease of use.

Therefore, as a future plan, we are going to promote a development of the table shown at Fig.9 in order to support selection of relevant existing reference models for presenting related international standards at “Canvas”, “Use-case”, “Function”, and “Data” respectively. Besides, we are also going to develop quantitative index for easing selection of relevant models for “Canvas”, “Use-case”, “Function”, and “Data”, because the current selection scheme of models highly depends on the subjectivity of users.

On the other hand, Platform Industrie4.0 (PI4.0), Robot Revolution Initiative (RRI), and Standardization Council Industrie4.0 have co-published a common strategy paper for international standardization through Japan-Germany Cooperation on IoT/Industrie4.0[21]. In the paper, URM-MM has been recognized and assessed as a beneficial development guideline, and it has been agreed to evaluate coverage of international standards and extract requirements by promoting analysis with URM-MM for concrete and practical use-cases such as ones described in [5].

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