Adaptive Enterprise Architecture for Digital Transformation

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Abstract. The Internet of Things, Enterprise Social Networks, Adaptive Case Management, Mobility systems, Analytics for Big Data, and Cloud services environments are emerging to support smart connected products and services and the digital transformation. Biological metaphors of living and adaptable ecosystems provide the logical foundation for self-optimizing and resilient run-time environments for intelligent business services and related distributed information systems with service-oriented enterprise architectures. We are investigating mechanisms for flexible adaptation and evolution for the next digital enterprise architecture systems in the context of the digital transformation. Our aim is to support flexibility and agile transformation for both business and related enterprise systems through adaptation and dynamical evolution of digital enterprise architectures. The present research paper investigates digital transformations of business and IT and integrates fundamental mappings between adaptable digital enterprise architectures and service-oriented information systems. We are putting a spotlight with the example domain – Internet of Things.

Keywords: Digital transformation · Internet of Things · Digital enterprise architecture · Architectural integration method · Adaptable services and systems

1 Introduction

Smart connected products and services expand physical components from their traditional core by adding information and connectivity services using the Internet. Smart products and services amplify the basic value and capabilities and offer exponentially expanding opportunities [1]. Smart connected products combine three fundamental elements: physical components, smart components, and connectivity components. A challenging example of digital transformation for smart products results from capabilities of the Internet of Things [2].

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Information, data and knowledge are fundamental concepts of our everyday activities. Social networks, smart portable devices, and intelligent cars, represent only a few instances of a pervasive, information-driven vision [1] for the next wave of the digital economy and the digital transformation. The digital transformation of our society changes the way we live, work, learn, communicate, and collaborate. This disruptive change interacts with all information processes and systems that are important business enablers for the digital transformation since years.

Major trends for the digital enterprise transformation are investigated by [3]: (i) digitization of products and services: products and services are enriched with value-added services or are completely digitized, (ii) context-sensitive value creation: though popularity of mobile devices location contexts are used more frequently and enable on demand customized solutions, (iii) consumerization of IT: one of the challenges is the safe integration of mobile devices into a managed enterprise architecture for both business and IT, (iv) digitization of work: today it is much easier to work together over large distances, which allows often an uncomplicated outsourcing of business tasks, and (v) digitization of business models: businesses need to adapt and have to rethink their business models to develop innovative business models according to employees' current skills and competencies.

Enterprise Architecture Management [4] for Services Computing is the approach of choice to organize, build and utilize distributed capabilities for Digital Transformation [5]. They provide flexibility and agility in business and IT systems. The development of such applications integrates the Internet of Things, Web and REST Services, Cloud Computing and Big Data management, among other frameworks and methods, like architectural semantic support. Today's information systems span a broad range of domains including: intelligent mobility systems and services, intelligent energy support systems, smart personal health-care systems and services, intelligent transportation and logistics services, smart environmental systems and services, intelligent systems and software engineering, intelligent engineering and manufacturing.

The Internet of Things enables a large number of physical devices to connect each other to perform wireless data communication and interaction using the Internet as a global communication environment. Information and data are central components of our everyday activities. Social networks, smart portable devices, and intelligent cars, represent a few instances of a pervasive, information-driven vision of current enterprise systems with IoT and service-oriented enterprise architectures. Social graph analysis and management, big data, and cloud data management, ontological modeling, smart devices, personal information systems, hard non-functional requirements, such as location-independent response times and privacy, are challenging aspects of the above software architecture [6].

Novel technologies demand an increased permeability between "inside" and "outside" of the borders of the classic enterprise system with traditional Enterprise Architecture Management. In this paper we are concentrating on following research questions to support the digital transformation by flexible architectural environments:

RQ1: What are novel architectural elements, compositions, and constraints usable for digitization?

RQ2: What is the blueprint for an extended Enterprise Reference Architecture, which is able to host even new and small types of architectural descriptions, e.g. for the Internet of Things?

RQ3: How can we integrate a dynamically growing number of architectural elements for digitized products and services into an evolutionary architecture?

In our current research we are extending our first version of the Enterprise Services Architecture Reference Cube (ESARC) [4, 7, 8] by mechanisms for architectural integration and evolution to support adaptable information systems and architectural transformations for changing business models. ESARC is an extendable classification framework, which sets a conceptual baseline for digital architectural models. ESARC makes it possible to verify, define and track the improvement path of different business and IT changes considering alternative business operating models, business functions and business processes, enterprise services and systems, their architectures and related technologies. The novelty in our current research about digital enterprise architectures comprises new aspects for architectural evolution and integration methods as an instrument to guide digital transformation endeavors.

The following Sect. 2 sets the architectural context for Digital Transformation with the Internet of Things. Section 3 describes our research platform for Digital Enterprise Architecture, which is a starting point of our mapping approach and scope for agile and adaptable information systems. Section 4 revisits and extends our Architecture Metamodel Integration Method and covers the seeding research for agile adaptable and transformable enterprise architectures and systems. Finally, we summarize in Sect. 5 our research findings and sketch our future research plans.

2 Digital Transformation with the Internet of Things

The Internet of Things maps and integrates real world objects into the virtual world, and extends the interaction with mobility systems, collaboration support systems, and systems and services for big data and cloud environments. Sensors, actuators, devices as well as humans and software agents interact and communicate data to implement specific tasks or more sophisticated business or technical processes. Therefore, smart products as well as their production are supported by the Internet of Things and can help enterprises to create more customer-oriented products. Furthermore, the Internet of Things is an important influence factor of the potential use of Industry 4.0 [9].

In the context of current fast changing markets [2] the Internet of Things (IoT) fundamentally revolutionizes today's digital strategies with disruptive business operating models [10] and holistic governance models for business and IT [Ro06]. Reasons for strategic changes by the Internet of Things [2] are: (i) information of everything – enables information about what customers really demand, (ii) shift from the thing to the composition – the power of the IoT results form the unique composition of things in an always-on always-connected environment, (iii) convergence – integrates people, things, places, and information, and (iv) next-level business – the Internet of Things is changing existing business capabilities by providing a way to interact, measure, operate, and analyze business. With the huge diversity of Internet of Things technologies and products organizations have to leverage and extend previous enterprise architecture efforts to enable business value by integrating the Internet of Things into their classic business and computational environments.

The Internet of Things supports many connected physical devices over the Internet as a global communication platform. The Internet of Things is the result of a convergence of visions [11] like, a Things-oriented vision, an Internet-oriented vision, and a Semantic-oriented vision. A cloud centric vision for architectural thinking of a ubiquitous sensing environment is provided by [12]. The typical configuration of the Internet of Things includes besides many communicating devices a cloud-based server architecture, which is required to interact and perform remote data management and calculations.

A main question of current and further research is, how the Internet of Things architecture fits in a context of a services-based enterprise-computing environment? A service-oriented integration approach for the Internet of Things was elaborated in [13]. The core idea for millions of cooperating devices is, how they can be flexibly connected to form useful advanced collaborations within the business processes of an enterprise. The research in [13] proposes the SOCRADES architecture for an effective integration of Internet of Things in enterprise services. The architecture from [13] abstracts the heterogeneity of embedded systems, their hardware devices, software, data formats and communication protocols. A layered architecture structures following bottom-up functionalities and prepares these layers for integration within an Internet of Things focused enterprise architecture: Devices Layer, Platform Abstraction Layer, Security Layer, Device Management Layer with Monitoring and Inventory Services, and Service Lifecycle Management, Service Management Layer, and the Application Interface Layer.

Today, the Internet of Things includes a multitude of technologies and specific application scenarios of ubiquitous computing [11], like wireless and Bluetooth sensors, Internet-connected wearable systems, low power embedded systems, RFID tracking, smartphones, which are connected with real world interaction devices, smart homes and cars, and other SmartLife scenarios. To integrate all aspects and requirements of the Internet of Things is difficult, because no single architecture can support today the dynamics of adding and extracting these capabilities. A first Reference Architecture (RA) for the Internet of Things is proposed by [14] and can be mapped to a set of open source products. This Reference Architecture covers aspects like: cloud server-side architecture, monitoring and management of Internet of Things devices and services, a specific lightweight RESTful communication system, and agent and code on often-small low power devices, having probably only intermittent connections.

The Internet of Thing architecture has to support a set of generic as well as some specific requirements [14, 15]. Generic requirements result from the inherent connection of a magnitude of devices via the Internet, often having to cross firewalls and other obstacles. Having to consider so many and a dynamic growing number of devices we need an architecture for scalability. Because these devices should be active in a 24 × 7 timeframe we need a high-availability approach [16], with deployment and auto-switching across cooperating datacenters in case of disasters and high scalable processing demands. Additionally an Internet of Thing architecture has to support automatic managed updates and remotely managed devices. Often connected devices collect and analyze personal or security relevant data. Therefore it is mandatory to support identity management, access control and security management on different levels: from the connected devices through the holistic controlled environment.

Specific architectural requirements [11, 14] result from key categories, such as connectivity and communications, device management, data collection and analysis, computational scalability, and security. Connectivity and communications groups existing protocols like HTTP, which could be an issue on small devices, due to the limited memory sizes and because of power requirements. A simple, small and binary protocol can be combined with HTTP-APIs, and has the ability to cross firewalls. Typical devices of the Internet of Things are currently not or not well managed by device management functions of the current Enterprise Architecture Management.

Desirable requirements of device management [14] include the ability to locate or disconnect a stolen device, update the software on a device, update security credentials or wiping security data from a stolen device. Internet of Things systems can collect data streams from many devices, store data, analyze data, and act. These actions may happen in near real time, which leads to real-time data analytics approaches. Server infrastructures and platforms should be high scalable to support elastic scaling up to millions of connected devices, supporting alternatively as well smaller deployments. Security is a challenging aspect of this high-distributed typical small environment of Internet of Things. Sensors are able to collect personalized data and can bring these data to the Internet.

3 Digital Enterprise Architecture

Our contribution is an extended approach about the systematic composition and integration of architectural data, models, metamodels, and ontologies using adaptable service-oriented enterprise architecture frameworks by means of different integrated service types and architecture capabilities. ESARC - Enterprise Services Architecture Reference Cube, [4, 7, 17] is an integral service-oriented enterprise architecture categorization framework, which sets a classification scheme for main enterprise architecture models, as a guiding instrument for concrete decisions in architectural engineering viewpoints. We are currently integrating metamodels for EAM and the Internet of Things.

The ESARC – Enterprise Services Architecture Reference Cube [4, 7] (see Fig. 1) completes existing architectural standards and frameworks in the context of EAM – Enterprise Architecture Management [18–21] and extends these architecture standards for services and cloud computing in a more specific practical way. ESARC is an original architecture reference model, which provides a holistic classification model with eight integral architectural domains. ESARC abstracts from a concrete business scenario or technologies, but is applicable for concrete architectural instantiations.

Metamodels and their architectural data are the core part of the Enterprise Architecture. Enterprise architecture metamodels [21, 22] should support decision support [23] and the strategic [8] and IT/Business [20] alignment. Three quality perspectives are important for an adequate IT/Business alignment and are differentiated as: (i) IT system

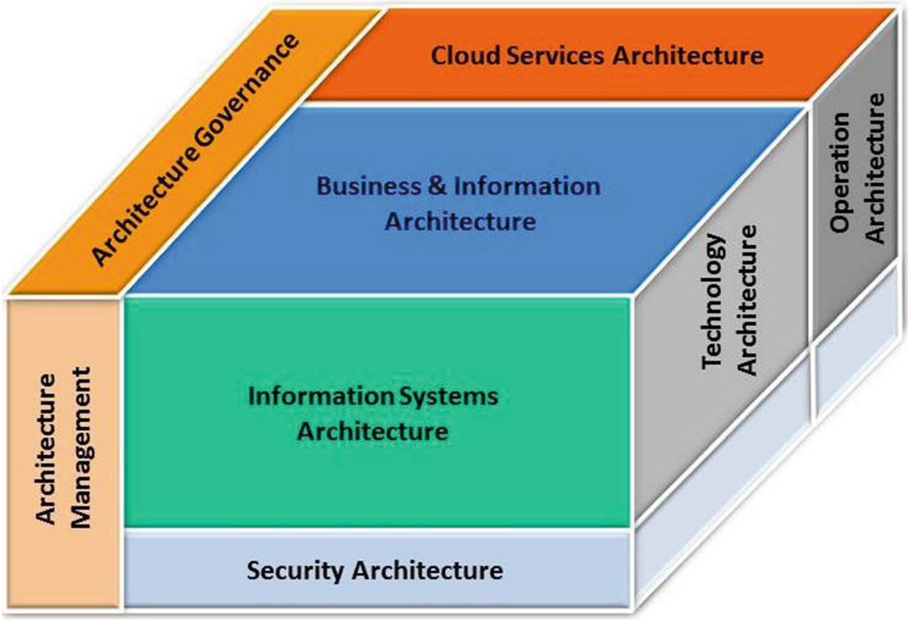

Fig. 1. Enterprise Services Architecture Reference Cube [Zi11], [Zi13b], [Zi14]

qualities: performance, interoperability, availability, usability, accuracy, maintainability, and suitability; (ii) business qualities: flexibility, efficiency, effectiveness, integration and coordination, decision support, control and follow up, and organizational culture; and finally (iii) governance qualities: plan and organize, acquire and implement deliver and support, monitor and evaluate.

Architecture Governance, as in [10] sets the governance frame for well aligned management practices within the enterprise by specifying management activities: plan, define, enable, measure, and control. The second aim of governance is to set rules for architectural compliance respecting internal and external standards. Architecture Governance has to set rules for the empowerment of people, defining the structures and procedures of an Architecture Governance Board, and setting rules for communication.

A layered Reference Architecture for the Internet of Things is proposed in [14] and (Fig. 2). Layers can be instantiated by suitable technologies for the Internet of Things. A current holistic approach for the development for the Internet of Things environments is presented in [15]. This research has a close link to our work about leveraging the integration of the Internet of Things into a framework of digital enterprise architectures. The main contribution from [15] considers a role-specific development methodology, and a development framework for the Internet of Things. The development framework contains a set of modeling languages for a vocabulary language to describe domain-specific features of an IoT application, an architecture language for describing application-specific functionality, and a deployment language for deployment features.

Associated with this language set are suitable automation techniques for code generation, and linking to reduce the effort for developing and operating device-specific code.

The metamodel for Internet of Things applications from [15] defines elements of an Internet of Things architectural reference model like, IoT resources of type: sensor, actuator, storage, and user interface. Internet of Thing resources and their associated physical devices are differentiated in the context of locations and regions. A device provides the capability to interact with users or with other devices. The base functionality of Internet of Things resources is provided by software components, which are handled in a service-oriented way by using computational services.

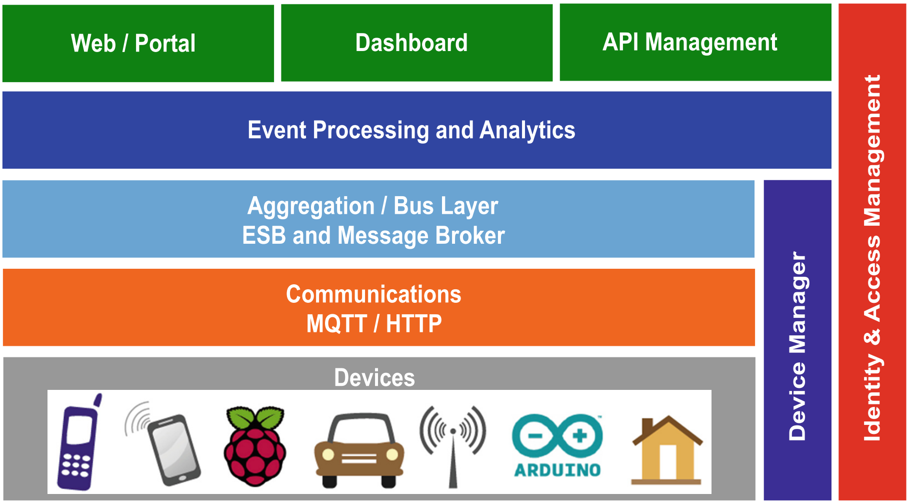

Fig. 2. Internet of Things Reference Architecture [14]

4 Architectural Integration and Adaptation

We have developed the architectural evolution approach to integrate and adapt valuable parts of existing EA frameworks and metamodels from theory and practice [24]. Additionally to a new building mechanism for dynamically extending core metamodels we see a chance to integrate small-decentralized mini-metamodels, models and data of architectural descriptions coming from small devices and new decentralized architectural element, which traditionally are not covert by enterprise architecture environments.

Our focused model integration approach is based on special correlation matrixes (Fig. 3) to identify similarities between analyzed model elements from different provenience and integrate them according their most valuable contribution for an integrated model. According to [25] we are building the conceptualization of EA in 4 steps – from stakeholders' needs, to the concerns of stakeholders, then the extraction of stakeholder relevant concepts, and last but not least the definition of relationships for new tailored architectural metamodels.

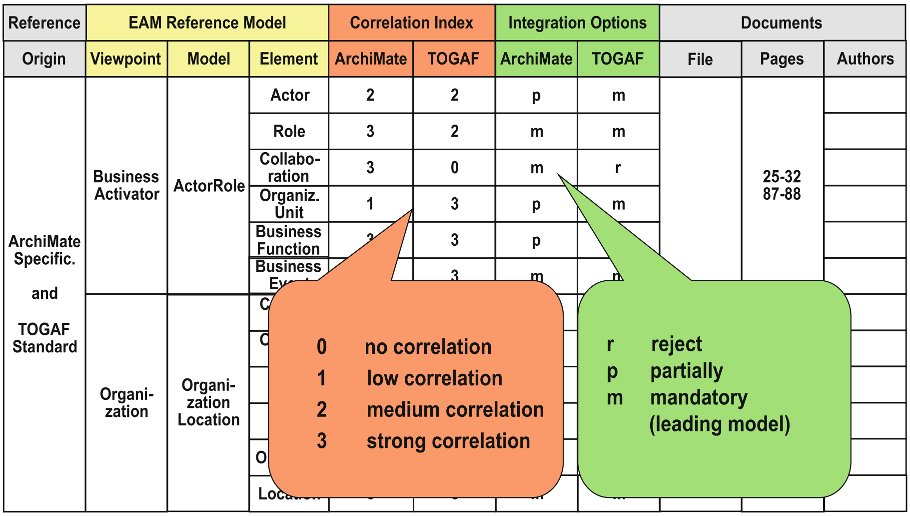

Fig. 3. Correlation analysis and integration matrix

First we analyze and transform given architecture resources with concept maps and extract their coarse-grained aspects in a standard way [24] by delimiting architecture viewpoints [20, 26], architecture models [27, 28] their elements, and illustrating these models by a typical example. Architecture viewpoints are representing and grouping conceptual business and technology functions regardless of their implementation resources like people, processes, information, systems, or technologies. They extend these information by additional aspects like quality criteria, service levels, KPI, costs, risks, compliance criteria a. o. We have adopted modeling concepts from ISO/IEC 42010 [26, 29] like Architecture Description, Viewpoint, View, and Model. Architectural metamodels are composed of their elements and relationships, and are represented by architecture diagrams.

To integrate a huge amount of dynamically growing Internet of Things architectural descriptions into a consistent enterprise architecture is a considerable challenge. Currently we are working on the idea of integrating small EA descriptions (Fig. 4) for each relevant IoT object. EA-IoT-Mini-Descriptions consists of partial EA-IoT-Data, partial EA-IoT-Models, and partial EA-IoT-Metamodels associated with main IoT objects like IoT-Resource, IoT-Device, and IoT-Software-Component [14, 15]. Our research in progress main question asks, how we can federate these EA-IoT-Mini-Descriptions to a global EA model and information base by promoting a mixed automatic and collaborative decision process [30, 31]. For the automatic part we currently extend model federation and transformation approaches [32–34] by introducing semantic-supported architectural representations, e.g. by using partial and federated ontologies [35] and associated mapping rules - as universal enterprise architectural knowledge representation, which are combined with special inference mechanisms.

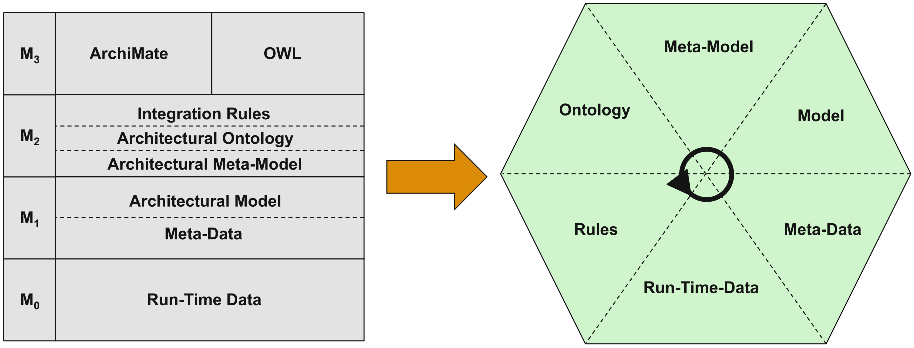

Fig. 4. Structure of EA-IoT-Mini-Description

We are extending architecture metamodels as an abstraction for architectural elements and relate them to architectural ontologies [24, 36]. Ontologies are a base for semantic modeling of digital enterprise architectures in a most flexible way. As mentioned in this section, integration of enterprise architectural elements is a complex task, which is today mainly supported by human effort and integration methodologies, and only additionally by some challenging federated approaches [33, 34] for automated Enterprise Architecture model maintenance. We believe that a part of this manual integration can be automated or additionally supported by human decisions using architectural cockpits, if we better understand the analysis approaches [28] and collaborative architectural decision mechanisms [19, 23, 30, 37] for adaptable digital enterprise architectures as a base for the digital business transformation.

We have adopted an agile manageable spectrum of multi-attribute analysis metamodels and related architectural viewpoints from [20, 23] to support adaptable enterprise architectures. We have extracted the idea of digital ecosystems from [38] and linked this with main strategic drivers for system development and their evolution. Core concepts of ecosystem's enterprise architectures are based in our approach on specific microarchitectures, which are placed in the context of Internet systems. The preferred mechanisms for modularization rely on decoupling and on interface standardization. Architecture governance models show the way to achieve adaptable ecosystems and to orchestrate the platform evolution.

Adaptation drives the survival [38] of enterprise architectures, platforms and application ecosystems. Adapting rapidly to new technology and market contexts improves the fitness of adaptive ecosystems. Volatile technologies and markets typically drive the evolution of ecosystems. Also we have to consider internal factors. Most important for supporting the evolution of ecosystems is the systematic architecture-governance alignment. Both are critical factors, which affect the ecosystem-wide motivation and the ability to innovate ecosystem structures and change processes. The alignment of Architecture-Governance shapes resiliency, scalability and composability of components and services for distributed information systems.

5 Conclusion

From our research in progress work on integrating Internet of Things architectures into Enterprise Architecture Management results some interesting theoretical and practical implications. By considering the context of service-oriented enterprise architecture, we have set the foundation for integrating metamodels and related ontologies for orthogonal architecture domains within our Enterprise Architecture Management approach for the Internet of Things. Architectural decisions for Internet of Things objects (see RQ1), like IoT-Resource, Device, and Software Component, are closely linked with code implementations. Therefore, researchers can use our approach for integrating and evaluating Internet of Things in the field of enterprise architecture management. Our results can help practical users to understand the integration of EAM and Internet of Things as well as can support architectural decision making in this area. Limitations can be found e.g. in the field of practical multi-level evaluation of our approach as well as domain-specific adoptions.

In this paper, we have introduced a new perspective for adaptable digital enterprise architectures (see RQ2), which is model-based and extends main standards, technologies and agile business models. We have developed a metamodel-based EA model extraction and integration approach for enterprise architecture viewpoints, models, standards, frameworks and tools for EAM towards consistent semantic-supported service-oriented reference enterprise architectures in cloud environments.

The presented architectural classification and integration approach (see RQ3) supports new architectural integration aspects for the Internet of Things and other small or mobile environments as well. Our goal is to be able to better support architecture development, assessments, architecture diagnostics, monitoring with decision support, and optimization of the business, information systems, and technologies. We intend to provide a unified and consistent ontology-based EAM-methodology for the architecture management models of relevant information resources, especially for service-oriented and cloud computing systems. Today we additionally observe companies adopting a three level architecture: On the basic level the classic systems of records, on a further level the systems of differentiation, and at the third level new IT opportunities for the systems of innovation. Expanding the classical EAM agenda thru ontology support with business rules and metamodel updating we see the chance for future work and research.

We contribute to the current IS literature by introducing this new perspective for adaptable digital enterprise architectures. EA managers can benefit from new knowledge about adaptable enterprise architectures and can use it for decision support and can reduce operational risks. Some limitations (e.g. use and adoption in different sectors) must be considered. Future research can adopt and evaluate our results for EAM and can take a look at the use in different industry sectors.

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