Rethinking of Framework and Constructs of Enterprise Architecture and Enterprise Modelling Standardized by ISO 15704, 19439 and 19440

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Abstract. Enterprise Architecture (EA) and Enterprise Modelling (EM) are systems engineering tools to understand, design, develop, implement and integrate complex enterprise and information systems. ISO 15704, 19439 and 19440 define fundamental concepts and principles of EAs and EMs, which are emphasized as the top standards of smart manufacturing by NIST's smart manufacturing ecosystem and relative standardization roadmap. Since the three international standards will soon be subject to revision, this paper rethinks the basic principles of EAs and EMs, and presents a General Enterprise Modelling (GEM) framework and a relative EA (GEM-EA). GEM-EA provides tools and methodology of model-based systems engineering (MBSE) to enterprise and automation systems integration. GEM involves a set of models and methods to describes different aspects of a system and covers its lifecycle. GEM and GEM-EA can greatly facilitate the process of enterprise diagnosis, business process reengineering and information system implementation.

Keywords: Enterprise Architecture · Enterprise Modelling · Framework Construct

1 Introduction

Enterprise Architecture (EA) and Enterprise Modelling (EM) are effective ways to analyse the system integration issues of information and communication technology (ICT) systems, especially in the face of increasingly complex industrial automation systems. In the past forty years, experts from different professional domains committed themselves in the study of EAs, and produced a set of significant works, including Zachman Framework, CIM-OSA (computer integrated manufacturing open system architecture), PERA (Purdue enterprise reference architecture), ARIS (architecture of integrated information system), GERAM (generalised enterprise reference architecture and methodology), FEAF (federal enterprise architecture framework), DoDAF (department of defence architecture framework), TOGAF (the open group architecture framework), etc. At the meanwhile, international standards such as ISO 15704 [1], 19439 [2] and 19440 [3] were published to underpin the identification of requirements

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for enterprise reference models, the establishment of enterprise modelling framework and the formation of enterprise modelling methodology respectively. It is worth noting that the National Institute of Standards and Technology(NIST) stated that the three standards are the cornerstones of its proposed smart manufacturing eco-system, implying that those standards are of importance in the revolution of smart manufacturing [4].

In additional to enterprise architecture, enterprise modelling methods and languages have undergone rapid evolutions in order to satisfy the demanding analysis requirements for complex systems. Enterprise modelling languages such as IDEF (integration definition) series modelling languages (including IDEF0, IDEF1x, IDEF3, IDEF5, et al.), UML (unified modelling language, which includes multiple views and diagrams), DFD (data flow diagram), ERD (entity relationship diagram), EPC (event process chain), BPMN (business process modelling notation), BPEL (business process execution language), Petri net and the newly developed SysML are gaining increasing popularity in the field of enterprise modelling.

Emerging technologies, including mobile internet, cloud computing, internet of things (IoT), big data, CPS (cyber-physical system) and artificial intelligence (AI), have posed great challenges to both areas of enterprise infrastructure and operation. In response to the substantial technological changes within the global industries, many countries have initiated some domain-specified architectures for the sake of the high-level understanding of enterprise integration amid the new technology era. For example, Germany has proposed a Reference Architecture Model for industry 4.0 [5]; NIST has presented a Smart Manufacturing Eco-system to identify smart-manufacturing-related standards [4]; Industrial Internet Consortium (IIC) has published an Industrial Internet Reference Model to guide to development of industrial internet systems [6]; The framework of IoT and the framework of CPS are also developed [7–9]. On the whole, EAs are widely used to solve systems engineering issues of complex ICT-based industrial systems.

Since ISO 15704, 19439, 19440 have been published for more than 10 years, they will be subject to revision based on the new development of EAs, EMs, as well as emerging technologies. This paper rethinks the basic principles of existing EAs and its corresponding modelling methods at first, and then proposes the General Enterprise Modelling (GEM) framework and the GEM Enterprise Architecture (GEM-EA) based on the result of the discussion.

2 Enterprise Architecture and Enterprise Modelling Review

An EA is a set of models and methods describing different aspects of the system and covering its whole lifecycle of an enterprise-integration project from its initial concept through definition, functional design or specification, detailed design, physical implementation or construction, operation to decommission or obsolescence [1].

Based on systematic literature review of existing enterprise architectures, a set of basic elements of architecture are identified as follows:

- Division of views: it simplifies an enterprise/system into various aspects to help stakeholders review an enterprise or an integrated system from different perspectives.
- Relationship among views: it describes the relationship of different views and finally realizes the synthetic description and analysis of an enterprise or a system.
- Components of integrated system: hardware, software, human resources units/elements and so forth that form a real system.
- Lifecycle: it defines the phases and succession of system development and integration. It also provides a project management baseline for each phase.
- Guidance or methodology: it gives a structured approach for the integrated system design, implementation and operation.
- Mechanism of models reusing: it provides how to form reference models and create the enterprise knowledge based on models.

In accordance to ISO 15704 [1] and ISO 19439 [2], the minimal set of enterprise models is identified as function view, organization view, resource view and information (Data) view, along with additional view including decision view and economic view. ARIS [11] instead specifies function view, organization view, data view, product/service view and process view as the pillars of its architecture. Although different architectures adopt different methods of view divisions, it is commonly accepted that organization, function, resource and information aspects of an enterprise should be considered during the implementation of enterprise/system integration. The relationships among views in these architectures remained different as well. Usually there are three types of relationships as follows:

- Views are independent from each other and they have equal status. Each view can be described and analysed separately and need not be closely related to each other. However, because of the emphasis on independent analysis of each view, the relationship and convergence between views are weak.
- Views are ordered according to modelling sequence. This kind of relationship provides a guideline to develop synthetically enterprise models, but it does not show how to converge information between views.
- The relationships among views are both associated and combined. This kind of relationship simplifies the content of every view and realizes a synthetic analysis through combined analysis among different views.

The lifecycle presented by an architecture not only reflects the phase division of enterprise engineering or system integration project management, but also provides stage division after the project implementation phase, such as operation, maintenance and re-configuration stage.

The comparison of some widely used EAs is shown in Table 1.

Enterprise modelling is the abstract representation, description and definition of the structure, processes, information and resources of an enterprise [2]. While an enterprise architecture is primarily used to define key concepts, identify views and their relationships on an organization, enterprise modelling offers an explicit representation of

Table 1. Comparison of EAs

EAs	Comparison
CIM-OSA	Views: organization, resource, function, information
	Relationships between views: start from function view, then generate organization and resource view, and finally get the information View of the enterprise
	Lifecycle: requirements definition→design specification→implementation description
	Methodology: generic building block→partial building block→particular building block
PERA	Lifecycle: enterprise definition→conceptual engineering → preliminary engineering → detailed engineering → construction → operations → decommissioning → enterprise dissolution
	Methodology: tasks and focuses in the process of system construction
	System components: facilities, people, control and information systems
IMPACS	Views: resource, information, function, decision
	Relationships between views: start from function view, then generate decision and physical view, and finally get the information view
	Lifecycle: analysis→design→technical design→development
	Methodology: conceptual(analysis→design) → structural (design → technical design) → realization (technical design→development)
	System components: Information Techniques, Manufacturing Techniques, Organization
ARIS	Views: organization, data, function, output, process/control
	Relationships between views: the control/process view combines organization, data, function and output views together
	Lifecycle: requirements definition→design specification→implementation description
Zachman	Views: data, function, network, people, time, motivation
	Lifecycle: business goal/scope→enterprise model→system model→technique model→detailed description→enterprise operation
GERAM	Views: function, information, organization, resource
	Lifecycle: identification→concept→requirements→preliminary design → detailed design→implementation→operation→decommission
	Methodology: generic building block→partial building block→particular building block
	System components: customer service, management and control, software, hardware, machine, human
FEAF	Sub architectures: business, data, application, technology
	Viewpoints: planner/scope (contextual) → owner/business model (conceptual) → designer/system model (logical) → builder/technology model (physical) → sub-contractor/detailed representations (out of context)
DoDAF	Views: operational, systems, technical standards
TOGAF	Sub-architectures: business, applications, data, technology
	Lifecycle: preliminary → architecture vision → business architecture → information systems architecture → technology architecture → opportunities and solutions → migration planning → implementation governance → architecture change management
UAF	Grid style frame work with blocks for views, artifacts, and sequence

different views on an enterprise with the use of semantics or diagrams. In response to the increasing complexity of enterprise organizations, a set of enterprise modelling methods or languages, aiming at depicting different aspects of enterprises, have been developed by industry and academia.

Enterprise modelling methods enable the understanding of the structure, behaviour and performance aspects of an enterprise, and they can also be categorized into views of EAs. The comparison of widely used enterprise modelling methods is presented in Table 2.

Table 2. Comparison of EMs

Methods	Description	Types		
		Structure	Behaviour	Performance
DFD	Function model of data transformation	x		
IDEF0	Function model		x	
ER	Data model	x		
IDEF1x	Data model	x		
IDEF3	Process model and object transformation model		x	
IDEF5	Ontology capture method	x		
EPC	Event-driven process model		x	
GRAI grid and net	Decision model	x	x	
UML class diagram	Static view of the system	x		
UML use case diagram	Function model	x		
UML activity diagram	Process model		x	
UML sequence diagram	Process model		x	
UML state machine diagram	Process model		x	
AHP (analytic hierarchy process)/ANP (analytic network process)	Decision model/evaluation model			x
System dynamics	Evaluation model			x
SysML	Structure, behavior, Requirements, parametric models	x	x	x
ArchiMate	Structure and behavior models with some extension	x	x	

Based on the above discussion, the basic methodology of an architecture is to describe a complicated system separately and respectively through different views. Since each view only provides particular information on certain aspect of the system, the recognition of the whole system can be acquired through synthesizing descriptions of various views from different angles and all views in EAs are related to certain kind of enterprise modelling methods.

3 General Enterprise Modelling Framework and Constructs

Based on the discussion from the previous section, a General Enterprise Modelling (GEM) framework is proposed, as shown in Fig. 1. The GEM framework is organized into three layers, from top to down that is, system evaluation and economic analysing

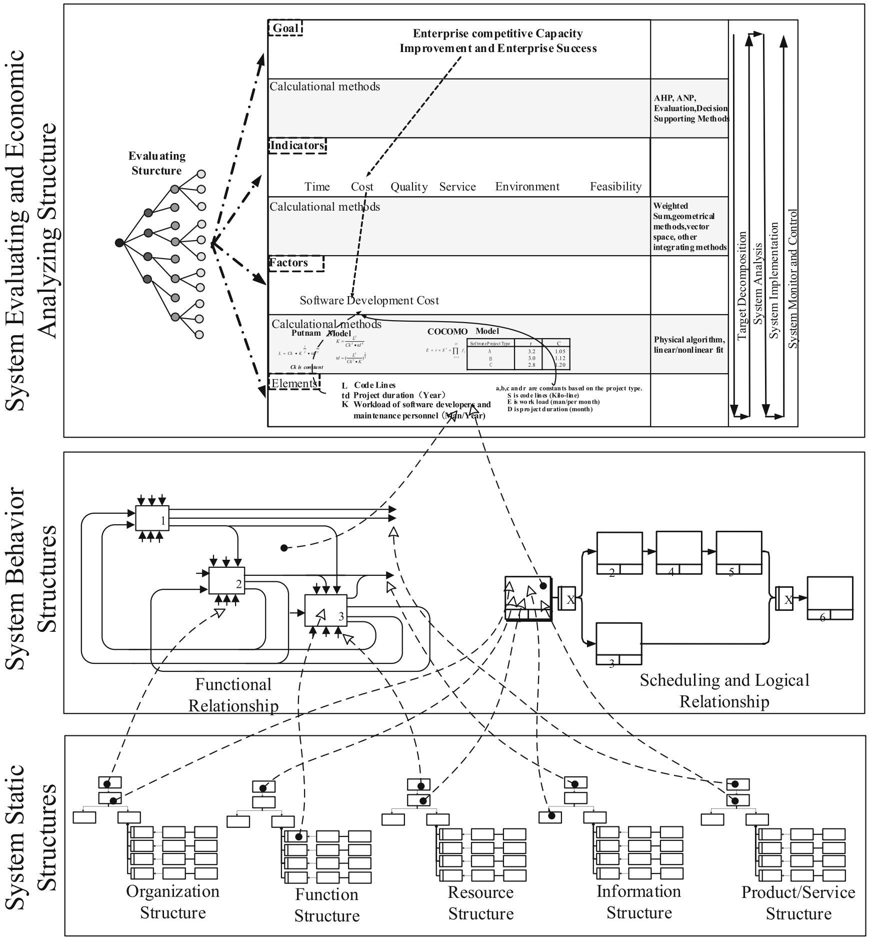

Fig. 1. General enterprise modelling framework

structure layer, system behaviour/dynamic structure layer and system static structure layer. Models at each layer reflect a particular aspect of an enterprise, and the description of each layer of the framework is given as follows:

- System static structure layer: models at which define the static structures of an enterprise including the organizational structure, resource structure, data/information structure, product/service structure and function structure, which define the existence of an enterprise and answer the question of what is the system.
- System behaviour/dynamic structure layer: models at which describe logical, sequential and correlative characteristics of the whole system and combine elements defined at the static structure layer together and define the operation mechanism of the enterprise.
- System performance structure layer: model at which define the target of the system, the related performance indicators and measurement methods.

Models at system static and behaviour layer describe the system structures and operation mechanism subject to the constraint of the system objective, forming the basis for economic/performance analysis. Built on the foundation of system structure and behaviour layer, system performance structure layer provides a modelling formalism to the economic/performance aspect of the integrated system, draws upon the existing model content and establishes analytical methods to inform decision makers. Since performance evaluation is critical for decision makes and stakeholders in the early stage of a system integration project, performance-related modelling becomes one of the key divisions in the field of enterprise modelling. For instance, ISO 22400 is developed for Automation systems and integration – Key performance indicators (KPIs) for manufacturing operations management [10]; ISO/IEC 42030 is developed for Systems and Software Engineering – Architecture Evaluation. Evaluation modelling and analysis can point out the optimization direction of enterprise development [1]. In ISO 15704 Amd 2005, AHP/ANP (Analytical Hierarchy/Network Process) method and Activity Based Costing (ABC) are proposed to facilitate the decision-making process on the multiple criteria's aspect of system integration justification.

In fact, various structures have mutual correlation, therefore, structured units at every aspect of architecture can all be used as the focus to associate with other units, reflecting that views are the embodiment of a certain aspect of the enterprise system. For instance, the product structure cannot reflect the panorama of the product without the description of the producing process; the organizational structure cannot reflect well the operation of enterprise without the constraint of operating mechanism in the organization; the resource structure only reflects existence and quantity, but it is the dynamic resource configuration and utilization that really influences the enterprise operation.

With the guidance of enterprise strategy and performance evaluation mechanism, the reticular description with structure components comes into being according to mutual correlation (input, output, control, mechanism) or sequential and logical relationship; and the functional relationship diagram and process network diagram can both describe operation mechanism.

4 General Enterprise Modelling - Enterprise Architecture

Based on the enterprise modelling framework derived from the previous section, a new enterprise architecture titled GEM-EA is constructed, as shown in Fig. 2. GEM-EA includes three axes: view, lifecycle and realization.

- View: According to the above discussion, GEM includes seven views: Function View, Organization View, Resource View, Information View, Product View, Process View and Economic/Performance Evaluation View.
- Lifecycle: Project lifecycle starts from project definition and ends up with implementation. The sole difference between lifecycle of GEM-EA and project lifecycle is that the lifecycle of GEM includes operation and maintenance of the system. That is because architecture can also benefit the operation of an integrated system about tremendous track, modification and optimization, and the modelling methods of architecture are equally important for system operation.
- Realization: This axis reflects the major methodology of the architecture, namely, how to accomplish system analysis, design, operation and maintenance by means of modelling methods. Firstly, according to the division of views, the description of current system is formed with the methods of describing views, and then other enterprise modelling methods are introduced to mutually form AS-IS models with coherence based on the description of views. Secondly, the AS-IS models shall be analysed to find the problems and contradictions. Next, the problems are arranged in terms of their significance and then resolved step by step. Afterwards TO-BE models are developed, providing a solution on the principle and abstract layer to meet the requirement, which is the content of preliminary design (or in the beginning of detailed design). Thirdly, in the phase of detailed design, according to the verified requirement embodied by various models (or views), the requirement is transferred into design specification in three concrete domains (or called subsystems) by constructing tools and then the real system is built. What should be emphasized is that there is "multi-to-multi" mapping between the design specification and the description of models (or views). At present, many developing tools or tool sets can benefit the mapping such as CASE tool, Workflow Management Technique, etc.

One of the important ideas of this architecture is that the system recognition and construction are evolved step by step. In the phase of conceptual definition, it is necessary to define the strategic goal of the enterprise and then confirm the target of the integrated system. Sequentially according to these purposes, we can describe the actuality of an enterprise from the aspects of organization, resource, information, product, function and operating process and then infrastructure and operation mechanism. Under constraints of these descriptions, the system can be analysed with suitable modelling and analysis methods to find its problems and then improve it. Then the target system is constructed and its various views can be formed. This is a specifying and optimizing process. When describing the target system, we can apply other modelling methods besides the method of view description to characterize the system comprehensively. When model-based design is accomplished, it will be translated into

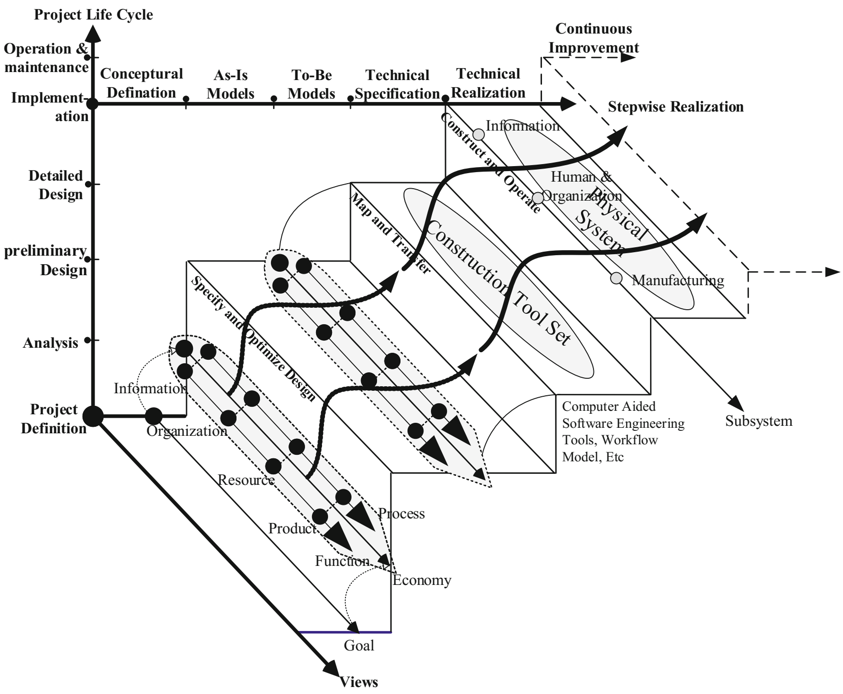

Fig. 2. GEM Enterprise Architecture

technique instruction for constructing system with the help of constructing tool sets and then a real system will be formed. Because the description of the system will still work on while the system operation, it can be used as the operating reference of the real system and then modifies and optimizes the real system.

5 Summary and Conclusion

This paper attempts to point out the revising direction for ISO 15704, 19439 and 19440 based on literature reviews and systematic comparisons of both existing EAs and EMs. Moreover, the GEM framework and GEM-EA are proposed to condense the key concepts and ideas gleaned from our previous research of enterprise architecture and modelling. In summary, some recommendations for the refinement of ISO 15704, 19439 and 19440 are listed as follows:

- The division and relationships of views: GEM framework includes three layers and seven views, which presents a new consideration to the organization of enterprise model views.
- Performance evaluation view: performance evaluation view identifies the development and optimization direction of enterprise/system integration, and its corresponding modelling and analysing methods support enterprise re-engineering and continuous improvement.

- Model-based systems engineering (MBSE): continuous system evolvement from the As-Is model to the To-Be model is the key methodology of GEM-EA, which is an important MBSE approach for system integration.

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