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Characterization of process related models for enterprise engineering

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Abstract

One of the main concerns in enterprise engineering is the development of techniques and tools for organizational design, encompassing structure, information flow and process coordination. For this, the development of models and their application are core issues. Models for enterprise engineering and integration found in the literature deal with different aspects of organizational design - architectures, frameworks, methods and techniques. As these models abound, there is a need for their organization, enabling their application. This work addresses this problem by analyzing and characterizing the main process related models for enterprise engineering. Firstly, a review of these models is conducted including works from the late 1980s to the late 1990s, focusing on the development of enterprise-wide models and architectures, and from the late 1990s to today, focusing on the further development of models, architectures and their interoperability. Secondly, these models are characterized based on a set of six variables - primary literature reference, origin, tool support, application domain, concerns addressed and evaluation results. This characterization is then used to propose further research topics in the area, including the development of enterprise engineering methods incorporating an improvement and evolutionary perspective and a governance concern, the search for enterprise models for specific areas, the integration and application of interoperability frameworks and the need for proper enterprise engineering project management.

Keywords: enterprise engineering; process models; model characterization.

1 Introduction

Enterprise engineering is a broad field of study. Its main concern is the development of tools and techniques to be applied for business design, encompassing areas such as organizational structure, information flow and process coordination. It combines elements from different fields such as organizational sciences and information systems in order to unify and integrate these areas in a seamless manner, so that an enterprise can operate and mobilize its resources towards its goals. Enterprise engineering has developed significantly in the last decade (Hoogervorst, 2009).

Given this definition, enterprise integration and interoperability aspects can be considered to play a vital role in any enterprise engineering endeavor. Both of these themes have received an increasing amount of attention in the last decade. Nevertheless, some open issues still exist. Panetto and Molina (2008) describe five grand challenges to enterprise integration and interoperability in enterprise engineering: (1) collaborative networked organizations; (2) enterprise modeling and reference models; (3) enterprise and process models interoperability; (4) validation, verification, qualification and accreditation of enterprise models; and (5) model reuse and repositories. More recently, Hvolby and Trienekens (2010) present another challenge: the application of existing frameworks to the development of business applications which support the operation of an enterprise. Vernadat (2010) argues that although enterprise integration and interoperability are mature areas in the technical domain, they are still areas under development in the organizational and semantic domains.

One can conclude from these challenges that processes and their models, definition and application are one of the core points in enterprise engineering. Process modeling, implementation and coordination are

the basis for driving any enterprise engineering effort towards interoperability and integration. Process related models that support interoperability and integration can be found in the literature for different elements of an enterprise such as architectures, frameworks, methods and techniques (Chalmeta et al, 2001; Mertins and Jochem, 2005; Chen et al, 2008). There are also standards that formally describe some of these models and their application (Chen and Vernadat, 2004; Kosanke and Nell, 1999).

As these models abound, there is a clear need for their organization and characterization in order for them to be correctly applied. Some of the questions that arise when the application of a model is considered are: (i) in what level and context can it be applied; (ii) what is necessary for its application; and (iii) what is the basis for its correct application. This work tries to address these questions by analyzing the main process related models used for enterprise engineering, integration and interoperability. Firstly, a review of the main models for these areas is presented. Secondly, the models are characterized according to a set of elements. Finally, conclusions and perspectives for future works are drawn.

2 Review of main process related models

Models presented here were found based on a literature research in reference databases such as the ACM Digital Library, Emerald Insight, IEEE Xplore, Science Direct and Wiley Online Library, as well as conference proceedings from IFAC (International Federation for Automatic Control). Only process related models based on an enterprise engineering approach were considered, that is, the scope of the work had to be related to process modeling, structuring, implementation or execution in an organizational context.

Broadly speaking, the works studied may be categorized in two main phases. The first phase goes from the late 1980s until the late 1990s and is mainly concerned with the development of enterprise-wide models and architectures which can describe, in detail, how an enterprise should be organized and operate. Phase two starts in the late 1990s and has two main concerns: (i) the further development of the models and architectures by means of new modeling constructs, languages and methods; and (ii) the interoperability of enterprise models. The following discussion will be started with some of the main models in the first phase: GIM, TOVE, CIMOSA, PERA, and GERAM.

One of the first attempts in the creation of enterprise-wide models with a certain level of formalism was named GIM, the GRAI Integrated Methodology (Doumeingts et al, 1993). GIM focused on computer integrated manufacturing systems and established three sets of components: (i) a global model, describing the invariant parts of the system; (ii) a modeling framework that used formalisms to represent the physical and functional aspects of a system; and (iii) a structured approach to guide the application of the methodology. Although trying to be general, it was mainly of academic interest and addressed only the analysis and design phases of a system life cycle.

Fox (1992) described both a framework and a software tool to support the process of gathering organizational knowledge and representing it for further reference. His framework was based on the definition of a simple ontology, structured from the functional level of an organization downwards. Its aim was to help describe organizational elements, including processes and their interactions. The software tool was mainly used to model and visualize the ontology, applying it to a specific organizational context, not to implement and coordinate the execution of the necessary processes for each functional level. This work was later extended and the resulting extension called TOVE – TOronto Virtual Enterprise (Fox et al, 1994). TOVE included a methodology and a set of meta-ontologies used to model enterprises. This set of meta-ontologies was later specialized, so that it could model particular areas such as quality management systems (Kim and Fox, 2002), aiding enterprise models to achieve conformance to regulatory standards (Kim et al, 2007). TOVE also defined a common language for the representation and interchange of process specifications, enabling them to be reused in the modeling of different contexts.

Sarkis et al (1995) presented a structured methodology for the strategic management of technology in an integrated manufacturing context, covering organizational, cultural, process and technological issues. It was based on four main elements: a shared corporate vision, an enterprise reference architecture, a set of

tools for analysis and design and a methodology. The following processes defined the methodology: (i) develop vision and strategy; (ii) change culture; (iii) integrate and improve the enterprise; and (iv) develop technological solutions. The focus of such an approach relies on a strategy breakdown, being the integration of the enterprise another activity to be performed. This activity was further detailed to be composed of four sequential processes, but there were no feedback loops to reinforce the fact that the system could evolve over time.

Extending the above mentioned methodology, Liles and Presley (1996) presented an enterprise modeling framework for enterprise engineering based on an approach with five views. They advocated that, as well as following the processes defined before, only through the use of these views is that an enterprise could be completely modeled. These views were the information view, the activity view, the business process view, the resource view and the organization view. These set of views were inspired in some of the general models discussed here and are also influential to future works in the area.

Perhaps the best-known initiative in enterprise modeling is CIMOSA – Computer Integrated Manufacturing Open Systems Architecture (ESPRIT Consortium AMICE, 1993; Zelm et al, 1995, Kosanke et al, 1999; Kosanke and Zelm, 1999). In the beginning of the 1990s, a consortium named AMICE (reverse for European CIM Architecture) was formed to develop the necessary infrastructure to facilitate the implementation of CIM – Computer-Integrated Manufacturing systems. As well as an integrating infrastructure that supported the execution of a particular model, the consortium developed a generic modeling framework in order to generate these models, with three main dimensions. The views dimension is composed of the organization, resource, information and function elements. The generic dimension is composed of the generic, partial and particular elements. The life-cycle dimension is composed of the requirements definition, design specification and implementation description stages. The results of the consortium were later detailed in a series of publications, some already mentioned, and other being Abdmouleh et al (2004), Berio and Vernadat (1999), Dickerhof et al (1999) and Kosanke (1995).

Also in the early 1990s, the Purdue Enterprise Reference Architecture – PERA was proposed (Williams, 1994). PERA used the concepts of enterprise elements (facilities, people and control and information systems) and enterprise phases (enterprise definition, conceptual, preliminary and detailed engineering, construction, operations, decommissioning and dissolution). PERA understands that anything in an enterprise, at a given time, can be described by the combination of elements in a given phase. The scope of PERA is to define an enterprise reference architecture that describes the elements in each one of the phases. Although PERA is supposed to be generic, that is, applicable to organizations of any domain, it was developed with industrial organizations in mind.

In the late 1990s, an IFIP/IFAC task force on architectures for enterprise integration dedicated itself to the development of a Generic Enterprise Reference Architecture and Methodology, the acronym for GERAM (Bernus and Nemes, 1996). The aim was to create a meta-model for enterprise reference architectures and methodologies described by an ontology that stated the main elements that had to be defined. This ontology covered eight main elements: (1) the GERA – Generic Enterprise Reference Architecture, which described the elements to be considered and applied in the process of generating the enterprise model; (2) the GEEM – Generic Enterprise Engineering Methodology, describing how to proceed in the application of the reference architecture and reference models; (3) the GEML – Generic Enterprise Modeling Language, describing what language and notation should be applied; (4) the GEMT – Generic Enterprise Modeling Tools, describing the tools which could be used to construct enterprise models; (5) the OT – Ontological Theories, describing the basic properties and axioms used in modeling; (6) the GEMs – Generic Enterprise Models, describing models of particular aspects that could be reused in modeling; (7) the GMs – Generic Modules, describing technologies which could be readily applied in the implementation of the constructed model; and (8) the EMs – Enterprise Models, which described how the enterprise would operate. Some mappings of the previous enterprise models into GERAM were later developed, one example being that developed by Chen et al (1998), which mapped GIM into GERAM.

As a final model for this first phase, in the late 1990s, an ISA – International Society for Automation - workgroup started work in a standard to bridge the gap between enterprise and manufacturing control systems in what would become IEC standard 62264. This standard defines three sets of models to be used for specifying the integration between enterprise and control systems: (i) a functional model, representing what are the main functions to be addressed by these models; (ii) an object model, defining what objects are relevant; and (iv) activity models of manufacturing operations. These models are to be used as references for the instantiation of specific systems and should help in their development. For instance, the functional models are specified as dataflow diagrams, the object models as UML class diagrams and the activity models as UML activity diagrams.

Although extremely comprehensive in nature, all of these works defined, actually, ontologies for generating models for an enterprise through the application of a set of predefined elements. With some exceptions, such as GERAM and GIM, they do not define how one should implement the defined ontology or their elements. Even GERAM and GIM, however, do not present the details in which the implementation should be carried out. Some initiatives tried to be more specific in the way they treated models and the specificities of their implementation, marking the start of the second phase in enterprise engineering efforts.

The ARDIN project was one of these initiatives (Chalmeta et al, 2001). ARDIN is an organized set of steps, reference models and tools to be applied to enterprises. ARDIN uses most of the concepts developed by GERAM. Based on a discussion about methodology and modeling requirements for a complete enterprise architecture, it defines five dimensions for enterprise engineering: (i) support tools; (ii) an integration model; (iii) enterprise structures; (iv) a development methodology; and (v) a change management approach. It is perhaps the first project in the area to address change management concerns, although not already in a continuous improvement cycle.

Another such initiative was IMEE – Integrated Methodology for Enterprise Engineering (Kim et al, 2001). IMEE defines a set of models to be constructed in order for networks of enterprises to be modeled in three dimensions: function, information and behavior. For the modeling of each dimension, IMEE defines a set of straightforward steps and artifacts to be constructed. IMEE is mapped onto the CIMOSA framework, so that each CIMOSA construct has an equivalent IMEE construct.

The Zachmann Framework, originally proposed by Zachman (1987) and later extended by Sowa and Zachman (1992) is a form of classification of architectural elements used for modeling the architecture of an enterprise. The framework is built in the form of a six by six matrix, the rows representing the different architectural views and the columns representing the different architectural perspectives in each view. The views, from top to bottom are the scope or planner's view, the business model or owner's view, the information systems model or designer's view, the technology model or builder's view, the detailed specifications or subcontractor's view and the functioning enterprise. The perspectives, from left to right are the data description (what), the function description (how), the network description (where), the people description (who), the time description (when) and the motivation description (why).

In the last couple of years, the area of enterprise interoperability has drawn attention and seen the development of frameworks for its development in the enterprise architecture domain. Interoperability frameworks were created as a means to conciliate the different views of diverse areas such as software engineering, computer science and industrial engineering (Vernadat, 2010). The four main interoperability frameworks are TOGAF – The Open Group Architecture Framework, the Levels of Information Systems Interoperability Reference Model, the ATHENA Interoperability framework and the EIF – European Interoperability Framework. All of these frameworks deal with the components and infrastructure necessary for different functions in an enterprise to interoperate, as well as for the interoperation of enterprises. For a more in-depth discussion on enterprise interoperability and these frameworks, one can consult Kim et al (2006), Vernadat (2007) and Paneto and Molina (2008).

Another focus of research has been on the development of modeling languages which could be used for modeling and depict the main characteristics of enterprises. There are many modeling languages that can

be used to express different views of an organization – for instance, its structure, behavior and interfaces – and it is difficult to find a language that can bridge existing gaps among all of these views (Anaya et al, 2010). Thus, other modeling languages were proposed to address these problems, such as UEML – Unified Enterprise Modeling Language, a specialization of the Unified Modeling Language - UML. UEML and other proposals have in common the fact that they define a set of constructs that can help integrate different models for different views of an enterprise, constructing, thus, an unified understanding of it.

Ros et al (2009) argue that most of the models and their application methodologies use a classical straightforward approach to designing and implementing enterprise entities. This approach, however, does not fit well into a continuous improvement effort, which organizations must pursue given a their competitors. Thus, they propose that a cyclic reengineering approach should be used. For that, they build on the work of Berrah et al (2001), who defined seven phases for the reengineering project, naming it the cyclic reengineering method: (i) identification of the necessity within a given domain; (ii) strategic analysis of the given business entities; (iii) analysis of the organization of relevant business entities (as-is analysis); (iv) reengineering decision and planning of the to-be phase; (v) organization redesign (to-be analysis); (vi) implementation of the new organization; and (vii) closing the project. The proposed methodology by Ros, Fuente and Ortiz, named ERE-GIO is based on two phases. Phase one is the reverse engineering phase, which consists of three steps: (i) identification of the business entity, (ii) conceptualization of the business entity; and (iii) process analysis (identification of the system, system description, as-is model specification and specification of the to-be model). Phase two is the forward engineering phase, which consists of seven steps: (i) action plan for change; (ii) process definition; (iii) process design; (iv) system implementation description; (v) system construction; (vi) system startup; and (vii) system dismantling. This approach was applied in a metal-mechanic industry, mainly for the reengineering of its supply chain processes (Fuente et al, 2008).

3 Analysis and characterization of process related models

The usual approach for classifying models, architectures and methodologies is to categorize them either in the levels where they are applied (strategic or corporate level, management level, control level or shop-floor level) or in the set of elements or views they describe (structure, behavior, interfaces or others). The approach used in this work is different - it seeks not to categorize but to characterize the reviewed models in their main aspects so that their main characteristics become apparent.

The approach used here will be adapted from the one used by Fettke et al (2005) for business process management models. Their approach was to survey the literature for reference models and characterize them according to three sets of information, each set containing a number of variables. The sets and their variables are: (i) general characterization set – name, primary reference, origin, responsibility for modeling, access and tool support; (ii) construction set – domain, modeling language, modeling framework, size, construction method and evaluation; and (iii) application set – application method, reuse/customization and use case. The characterization of this work will maintain some of these variables, exclude or adapt others and include a new one.

Name and primary reference will be maintained so that the model can be referred to and further information for it can be consulted. Origin will be maintained so that it is known if the model is derived from a scientific or a practical approach. Responsibility for modeling and access will be excluded, as only open and public models will be considered. Tool support will be maintained so that it is known if there is computational support for its use. Domain will be adapted into application domain, so that it is known what is the domain area for which the model can be applied (strategy, manufacturing, logistics and others). Modeling language and modeling framework will be excluded, as both of these variables will be treated in a new variable named concerns. Size will be excluded because our interest rests on the characterization, not quantification of the models. The whole application set will be excluded, as the main information of this set is treated in the application domain variable. Finally, one new variable will be added: concerns, which will be explained next.

The concerns variable represents the main issues that the model addresses. Regarding this assertion, a model can be classified as a reference model, an architecture/framework, a method or a technique. It is a reference model if it establishes a set of elements to be considered in the modeling effort. It is an architecture/framework if it defines how the basic elements of the system are to be combined, integrated or interfaced. It is a method or defines a method if it describes the set of steps through which a process issue, like modeling, is to be resolved. Finally, it is a technique if it defines a technology to be used or categorizes technologies. Table 1 summarizes the classification applied to the reviewed models of the previous session.

Table 1: Characterization of process related models for enterprise engineering.

Name/Primary Literature	Origin/Concerns	Tool support	Application domain	Evaluation
GIM/Doumeingts et al (1993)	Scientific/Method	None	Computer Integrated Manufacturing (CIM)	Example projects conducted by the authors
TOVE/Fox (1992)	Scientific/Method	Proprietary tool developed by the author and his group	General, with applications to quality management and activity-based costing	Models developed for quality management and activity-based costing
Sarkey, Presley and Liles approach to enterprise engineering/Liles and Presley (1996)	Scientific/Method	Proprietary tool developed by the author and his group	General	None
CIMOSA/ESPRIT Consortium AMICE (1993)	Scientific/Reference model	Proprietary and open source tools	Computer-Integrated Manufacturing	Used for the instantiation of other models
PERA/Williams (1994)	Scientific/Reference model	Proprietary systems developed for each application	Industrial (manufacturing and process control)	Application to industrial domain problems
GERAM/Bernus and Nemes (1996)	Scientific/Method and architecture	None	General	Through mapping of other frameworks
ARDIN/Chalmeta, Campos and Rangel, 2001	Scientific/Reference model, method and technique	None	General	Application to an industrial case by the authors
IMEE/ Kim, Weston and Woo, 2001	Scientific/Method and technique	Tools used to develop and construct prescribed models	General, networks of enterprises	Application to an industrial case by the authors
IEC 62264 and ISA 95/ ISO/IEC 62264 and ISA 95 standards	Scientific and practical/Reference model	Some tools to support modeling of prescribed models	Enterprise and control systems integration	Applied to a variety of cases in the industrial domain
Zachman Framework/ Sowa and Zachman (1992)	Practical/Technique	Several tools to model each of its constructs	Information systems and enterprise architecture	Several cases of application
TOGAF and other architecture frameworks/ Proprietary specifications of each framework	Practical/Architecture	Some proprietary tools	Enterprise architecture	Several cases of application

Name/Primary Literature	Origin/Concerns	Tool support	Application domain	Evaluation
UEML/ Anaya et al (2010)	Scientific/ Technique	Open-source tool	Enterprise models in general	Examples and case studies
Cyclic reegineering method/Berrah et al (2001)	Scientific/Method	None	General	Unkown
ERE-GIO/Ros, Fuente and Ortiz (2009)	Scientific/Method	None	General	Applied in a metal-mechanic industry

4 Conclusions

To conclude this work, some of its limitations will be addressed, observations about the characterization will be made and further developments of the work will be discussed.

The work is limited to the models presented here. Although general, this analysis is not comprehensive. More models could be added by either searching other databases for models that are both process related and aimed at an enterprise engineering context and by the analysis of proprietary models. Analyzing proprietary models, nonetheless, would require access to them, what may not be possible in some cases. These models also have limited applicability, as they would not be available to the general public, significantly hindering the interest in the results.

Another limitation of this work is the classification used. The main objective was the characterization of models, not their categorization into groups. However, the relationship between model characterization and model categorization could be better explored, so that a better characterization through the use of categorization could be reached.

A final limitation is that business process management models were deliberately excluded from the analysis. This is because these models and business process management life cycles, such as those described by Houy et al (2010) do not explicitly deal with an enterprise engineering context, but focus in the process context. One could understand this type of life cycles as being part of the way some of the models that were characterized could be implemented.

In respect to further developments which could be spun off from this work, there are four main areas to be noted: (i) the development of enterprise engineering methods which incorporate an improvement and evolutionary perspective and a governance concern; (ii) the search for enterprise models for specific areas; (iii) the integration and application of interoperability frameworks; and (iv) the need for proper enterprise engineering project management.

Regarding the development of enterprise engineering methods, it is noted that since the early 2000s, there has not been much discussion about this matter. Most of the works trying to address this issue did it by applying a straightforward set of steps. An exception is the work of Ros et al (2009), which integrates an improvement dimension in the process of enterprise engineering itself. This can be greatly enhanced, however, with novel contributions to the area, if a business process management life-cycle, such as those described by Houy et al (2010), is to be incorporated and adapted in the enterprise engineering method. Such a method should also support the ever-changing nature of enterprises and promote model evolution, reuse and its governance.

In later years, one has seen an increased interest in the application of enterprise engineering concepts to different areas, specially those related to some kind of standardization such as quality management (Kim and Fox, 2002) and sustainability and the environment (Brand et al, 2007; Ranky, 2010). Other traditional areas strongly influenced by process development also have seen increased interest, such as strategy and performance measurement (Pun, 2004; Pinheiro de Lima et al, 2009; Costa et al, 2010). The main issue here is the creation of ontologies that can help in modeling and implementing enterprises that have

activities in such areas or drive standardization efforts in them. This is also related to an increasing interest in knowledge representation of models and their reuse (Whitman and Huffman, 2009).

Interoperability frameworks, as quoted by Vernadat (2010), lie on the convergence vortex of three major areas: software engineering, computer science and industrial engineering. Computer scientists primarily deal with the technology necessary to implement such frameworks. Software engineers occupy themselves with the correct application of such constructs. Industrial engineers deal with the integration aspects of these frameworks so that they are used to improve business goals. The technology behind this must be developed and validated by computer scientists and software engineers. Nevertheless, there are still open issues to be worked out when considering the application of the developed frameworks in enterprises – mainly their validation and practical implementation aspects (Kim et al, 2006; Vernadat, 2007; Paneto and Molina, 2008).

The management of enterprise engineering projects is another issue identified as a gap in the literature. Although many authors occupy themselves with the development of models and issues related to interoperability and the necessary technology and infrastructure, little attention has been dedicated to their practical implementation aspects. Given an enterprise engineering project, there are many possibilities for its realization - there is a great scope variance in such projects and the scope breakdown in activities and resources allocation will, consequently, also vary greatly. In addition to this, different architectures and techniques that adequately treat the necessities of each of such processes will have to be employed.

As a final remark, if one considers the Cambridge process approach (Platts, 1993) and its characteristics (Platts, 1994) – procedure, participation, project management and point of entry - it can be argued that many of the issues previously presented could be addressed by it. Two issues that become clear in this analysis are the procedure and project management characteristics. The latter is clear from the analysis in the previous paragraph. Procedure, on the other hand, emerges when one considers that the different existing methods for enterprise engineering are still in early development stages, not yet properly tackling the problem and all of its complexities.

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