# Article

## A Survey of Approaches to Virtual Enterprise Architecture: Modeling Languages, Reference Models, and Architecture Frameworks

*By Amit Goel, Sumit Kumar Jha, Ivan Garibay, Heinz Schmidt, and David Gilbert*

### Abstract

*As the theory and practice of enterprise architecture became mature, researchers and practitioners have started applying similar concepts and approaches to virtual enterprises. The virtual enterprise is a temporary coalition of enterprises joining hands to exploit a particular opportunity. Virtual Enterprise Architecture addresses a Virtual Enterprise holistically at a strategic level. This article provides a definition of Enterprise Architecture, Virtual Enterprise, and Virtual Enterprise Architecture and presents results from a study of six approaches to virtual enterprise architecture for virtual enterprises (NEML, CAML, AVERM, VERAM, BM VEARM, and ARCON). Interestingly, all of these approaches attempt to provide a holistic coverage of Virtual Enterprises, but have significant difference in the way they approach it. This article is aimed as an aid for researchers and practitioners to study different approaches for strategic planning of enterprise architecture.*

### Keywords

Virtual Enterprise Architecture, VERAM, VEARM, AVERM, NEML, CAML, ARCON, Enterprise Architecture Frameworks, Enterprise Architecture Modeling Language, Enterprise Architecture Reference Models

### INTRODUCTION

Globalization, increasing complexity, and continuous change are some of the drivers that keep businesses and organizations always trying to reinvent themselves. At the same time, a trend towards being distributed and agile is being seen. The distributed organization brings its own share of concurrency problems and integration is seen as another challenge for such organizations.

Over the last decade, a new organizational paradigm of the Virtual Enterprise (VE) has become popular. During the same time, the theory and practice of Enterprise Architecture (EA) has made progress in tackling the challenge of complexity, integration, and agility. Virtual Enterprise Architecture (VEA) is an attempt to bring these two disciplines together to solve the challenges mentioned above and to provide a holistic view of the VE at a strategic level.

We studied six approaches to VEA for VEs. Not surprisingly, all of them were published in the last decade by several researchers and practitioners. They were classified as modeling languages, reference models, and architecture frameworks for collaborative networks, virtual enterprises, or agile enterprises. This article reports the results of our findings. In the remaining part of this section, we introduce the concepts of VE and VEA and related terminology. In the following section, we describe the six VEA modeling approaches. We then provide a comparison table and a discussion. We end by providing a conclusion and future directions for our work. References are provided for the reader interested in studying these modeling approaches in detail.

### VIRTUAL ENTERPRISE

A Virtual Enterprise (VE) is characterized by properties as identified by scholars and researchers in the last decade. The characteristics are presented below for the purpose of giving background to the reader:

- Purpose: Enterprises form the VE in order to combine core competencies, skills, and resources for a specific opportunity, resulting in benefit to each other (Barnett et al, 1994).
- Life Time: The VE only lives as long as the opportunity for which it was created exists, and terminates when the explicit goal is achieved (Barnett et al, 1994; Camarinha-Matos et al, 1998; Westphal et al, 2007).
- Organizational Structure: The VE does not possess any inventories, plants, or warehouses. The participating enterprises have the ownership of such assets and the VE possesses only a small staff at headquarters for handling the administrative tasks (Barnett et al, 1994). The members of a VE have freedom to join and leave at any point in time during its existence, subject to the agreements and contracts and none of the enterprises acts as a central authority (Pires et al, 2001).

- Legal Status: The VE does not exist as a separate legal entity. The participating enterprises are independent legal entities joined by binding agreements and contracts (Westphal et al, 2007).
- Customer Interface: The VE appears as one single enterprise to the customer despite the fact that there are multiple enterprises behind the scenes (Pires et al, 2001).

We summarized these characteristics in a concise definition in one of our earlier papers as follows (Goel et al, 2010):

**Definition 1***: A Virtual Enterprise is an ad hoc coalition of independent enterprises and organizations, collaborating to achieve an explicit and specific goal of responding to a specific situation, by leveraging resources, skills, and competences of the members of the coalition. A Virtual Enterprise has no dominant partner, legal existence, or physical ownership of resource inventories. Members can join or leave the coalition at any time, but within contractual limits. A Virtual Enterprise is dissolved as soon as its explicit goal is achieved.*

The general examples of explicit goal are: business opportunities such as "create five million iRobots to meet peak demand of Christmas" or crisis situations such as "save lives and restore normalcy in the aftermath of a hurricane". The VE manifests itself in various real-life examples such as large government projects, distributed manufacturing enterprises as in ship-building or airplane manufacturing conglomerates, managed health-care, and emergency services.

## VIRTUAL EA

EA models describe complex and large but single enterprises in a holistic manner. EA traditionally has been created and consumed within an enterprise for its internal purpose. The paradigm of EA can be applied to VEs considering it as a single enterprise. Hence, we use the term Virtual Enterprise Architecture (VEA) to represent the EA-based models or abstractions of VE. In our previous work, we presented the definitions of EA and VEA as follows (Goel et al, 2009, 2010):

Definition 2**:** *Enterprise Architecture (EA) is the expression of key strategies around architectural decisions, variations, generic families, patterns, and building blocks for architecting complex enterprises and systems that are subject to dynamic change. EA centers on modeling, predicting, and managing key properties such as profits, costs, risks, changes, and innovation from an architectural perspective and in a holistic way.*

Definition 3: *Virtual Enterprise Architecture (VEA) is a description of the VE in terms of its components and their relationship to each other using elements of EA. The components in a VE are member enterprises, skills, competences, and resources. The structural modeling of VEA includes the representation of skills, resources, and competencies that are brought into the VE by the members. Behavioral modeling of VEA includes the continuous allocation, re-allocation, and distribution of resources and distributed business processes during the life-cycle of the VE.*

## VEA TERMINOLOGY

Instead of debating terminology, we would like to define the terms we used in this article, so that the meaning and expression of our text is clear to the reader:

- A *model* is an abstract representation of the real or virtual world or system. Different stakeholders may need models at different levels of detail and from different points of view. Hence, models can be created at different levels of abstraction and may represent different views of a system from different viewpoints.
- *Reference model* is a generally accepted but "abstract, conceptual**,** and generic" model used for various purposes such as: to derive more specific models for different target systems, to understand significant concepts, entities**,** and relationships of the domain being modeled.
- *Architecture framework* and ***r****eference architecture* are analogous to reference model. Both are "generally accepted generic architecture" and have generic templates and generic building blocks that could be used to define concrete architecture.
- *Modeling language* is a collection of symbols, syntax, and semantics which facilitates the creation and depiction of the models. Modeling language may contain graphical elements to depict the models visually. The modeling languages sometimes define more aspects such that they overlap with reference models or architecture frameworks.

## APPROACHES TO VIRTUAL EA

We studied different approaches for modeling of VEA for VEs. For the purpose of this study, we considered Virtual Enterprise, Virtual Organization, Collaborative Networked Organizations, and other related paradigms as similar. Initial literature review and search revealed that there are many architectural frameworks, reference models, and reference architecture-based approaches by various researchers and practitioners. However, only those approaches were selected for the current article that were specifically devised or customized for VEs. Approaches that originated for other purposes such as supply chain (SCOR), grids (EGA), integration

(CIMOSA), and EA for single enterprises (Zachman, EA Cube, FEAF, TEAF, DoDAF, GERAM) were not considered. Some projects had applied these approaches (Zachman, SCOR, CIMOSA) directly to VEs with adaptations. However, they did not make those adaptations generic enough to be released as a reference model or architectural framework for VEs. Analysis and impact of such approaches is left for another study and is not covered in this article. The approaches for VEA which we studied are described below:

***NEML (Networked Enterprise Modeling Language)***

NEML (Steen et al, 2002) is one of the earliest languages for modeling networked enterprises. NEML consists of viewpoints across three dimensions for structuring the domain of networked enterprises. Along the first dimension are: business viewpoint concerned with organization and business processes, information and communication technology (ICT) viewpoint concerned with systems, networks and applications implementing these processes. Along the second dimension are: functional viewpoint concerned with overall "black-box" structure of the enterprise and operational viewpoint concerned with concrete implementation of this structure and behavior. Along the third dimension are the viewpoints of structure, behavior, and artifacts corresponding to who/where, how/when, what columns, respectively, from the Zachman Framework.

NEML defines key concepts to instantiate each cell (Table 1). These key concepts have attributes that link them together for creating a cohesive model of the networked enterprise. NEML re-uses the modeling formalisms provided in some of the existing methods such as workflow, business processes, and enterprise modeling. The notation is graphical and also provides for extensible attributes for recording extra information. The NEML language is sufficiently formalized for analysis and simulation at operational level, according to its authors.

**Table 1: Key Concepts in Different Domains in NEML, based on Steen et al (2002)**

| | Business | | | ICT | | |
|---|---|---|---|---|---|---|
| | **Structure** | **Behvior** | **Artifacts** | **Structure** | **Behavior** | **Artifacts** |
| **Functional** | Role | Function | Flow | System | Service | Message |
| **Operational** | Actor | Action | Item | Compon-ent | Protocol | Data |

***CAML (CNO Architecture Modeling Language)***

CAML (Kim, 2007) is an EA modeling language (EAML) for Collaborative Networks. CAML supports multi-level and multi-focused modeling (Table 2) and is characterized by six levels and six focuses. Six levels (meta-meta model, meta-model, business model, system model, technology model, and detailed representation) are based on the OMG MDA for expressiveness and easy implementation. Six focuses (data, process, link, participant, event, and goals) are based on the Zachman Framework for completeness of modeling.

CAML facilitates sharing and transformation of models in very abstract form using meta-modeling levels. CAML was developed considering three key requirements of EA modeling languages: completeness of framework, expressive power of language, and ease of implementation. Although CAML contains rich modeling constructs, there is no formal definition of these modeling constructs in CAML.

**Table 2: CAML Modeling Levels and Concepts, based on Kim (2007)**

| | Level | Concept |
|---|---|---|
| L0 | Meta-meta model | Entity, Relationships, Property |
| L1 | Meta-model | Meta-entity; e.g., data Meta-relationship; e.g., composition |
| L2 | Business model | Entity; e.g., project, contract Relationship; e.g., is-a, use |
| L3 | System model | E.g., class, attribute, operation |
| L4 | Technology model | E.g., server configuration, network protocol |
| L5 | Detailed representations | N/A |

***AVERM (Agile Virtual Enterprise Reference Model)***

AVERM (Goranson, 1999) consists of a matrix which has decisions associated with all life-cycle processes of a VE (Opportunity Identification, Partner Selection, VE Formation, VE Operation, and Reconfiguration/ Dissolution) along the horizontal side, and areas of applications within the enterprise (Social/Cultural, Legal/Explicit, and Physical) on the vertical side, aptly termed infrastructures (Table 3). This reference model gives a structure for analysis of VE. In this model, each cell deals with a discrete decision and involves a discrete set of principles. The reference model decomposes the enterprise on the basis of value-added processes and capabilities instead of functions and resources.

AVERM does not suggest how to utilize the cells for behavior analysis with respect to future transformations in VEA. It appears as a very high-level framework for classifying VE processes, and for utilizing this matrix for further analysis.

**Table 3: AVERM, based on Goranson (1999)**

| Infrastructures → | Social/ Cultural | | | Legal/ Explicit | | | Physical | | |
|---|---|---|---|---|---|---|---|---|---|
| Life Cycle Process ↓ | Human Dynamics | Community Cultures | Business Culture | Business Processes | Contracts/Regulations | Workflow | Logistics / Warehousing | Equipment | Laws of Physics |
| Opportunity Identification | | | | | | | | | |
| Partner Selection | | | | | | | | | |
| VE Formation | | | | | | | | | |
| VE Operation | | | | | | | | | |
| Reconfig/ Dissolution | | | | | | | | | |

***VERAM (Virtual Enterprise Reference Architecture and Methodology)***

VERAM (Zwegers et al, 2003) focuses on VE formation and operation, and positions elements to support modeling, set-up, management, and ICT needs of the VE. VERAM is based on GERAM (Bernus, 1999), and provides a framework for capturing EA knowledge of virtual enterprises (Figure 1). VERAM consists of three layers named VE Concept, VE Reference Architecture, and VERAM Components (Karvonen et al, 2003; Tolle and Vesterager, 2003; Vesterager et al, 2003; Zwegers et al, 2003).

The bottom layer (VE Concept) introduces the Enterprise Network and VE. The middle layer (VERA) organizes the VE-related generic concepts into a generic framework based on the entity life-cycle concept and modeling architecture of GERAM. The top layer (VERAM Components) consists of components used during application of the architectural framework in practice such as guidelines, modeling languages/tools, configuration tools, infrastructure modules, roles, standards, technologies, etc.

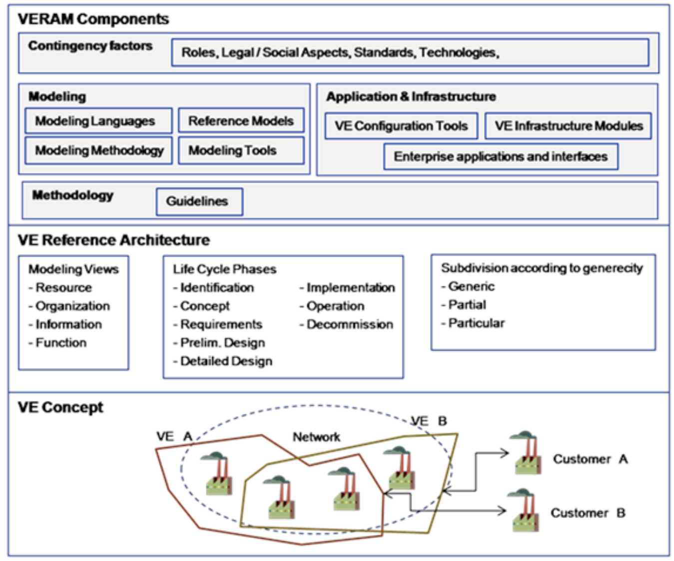



**Figure 1: VERAM, based on Zwegers et al (2001)**

***BM_VEARM (Virtual Enterprise Architecture Reference Model)***

BM_VEARM (Putnik, 2001) is a reference model for “integrated(I), distributed(D), agile(A), and virtual(V)” enterprise based on the hierarchical multi-level model of the manufacturing system control. BM_VEARM is synthesized over elementary structures of VEA that provides I, D, A, V as design parameters. Each elementary structure has a resource management (broker) level linked to two control levels via integration mechanism. These elementary structures are used to build the instances of VE.

Virtuality and agility are achieved by using the resource management level as a broker between two consecutive levels of process control. The context-free attributed grammar can be used to generate both canonical and non-canonical kinds of BM_VE structures for a VE instance (Putnik and Sousa, 2006; Sousa and Putnik, 2005). Non-canonical structures can be transformed into canonical structures using the grammar. A non-canonical structure is one where two control blocks are directly connected without a broker or resource management block in between them.

***ARCON (A Reference Model for Collaborative Networks)***

ARCON (Afsarmanesh and Camarinha-Matos, 2008) is developed as a generic abstract representation for understanding entities involved in VEs, and relationships among them (Camarinha-Matos and Afsarmanesh, 2006, 2007). It is used for deriving specific models of VE. At the highest abstraction level, ARCON is structured like a 3-D cube, having three perspectives of life-cycle, modeling intent, and environment characteristics. Life-cycle perspective captures the evolution of CNOs during five stages named creation, operation, evolution, metamorphosis, and dissolution. Environment characteristic perspective captures two subspaces of internal and external viewpoints named endogenous elements and exogenous interactions. Modeling intent perspective captures three modeling levels or layers named general representations, specific models, and detailed specifications of implementation architecture.

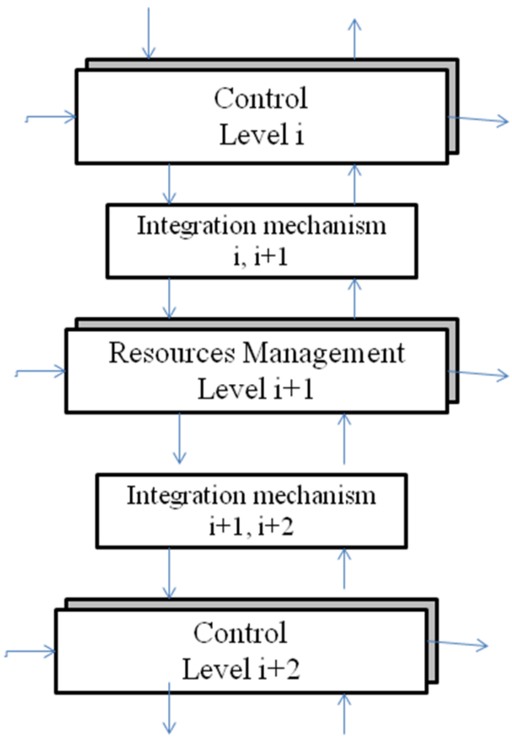



**Figure 2a: BM_VEARM Elementary Structure, based on Putnik (2001)**

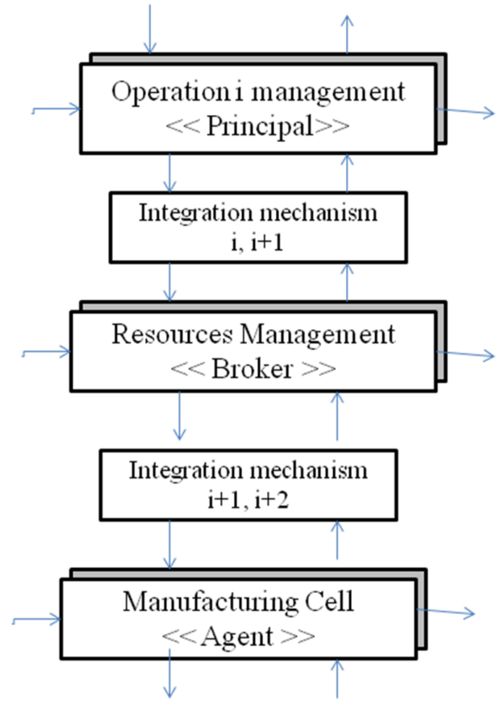
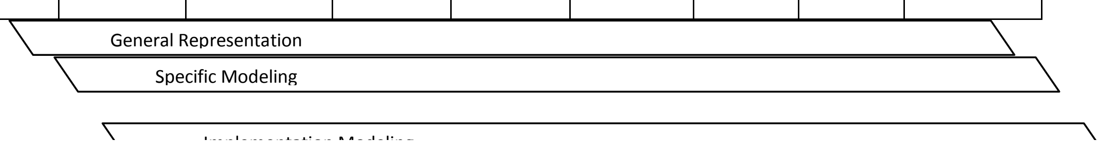



**Figure 2b: VE Demonstrator based on BM_VEARM. based on Putnik (2001)**

Each of the environment characteristic subspaces (endo-e, exo-i) has four dimensions because of a diverse set of aspects. Endo-e has structural, componential, functional, and behavioral dimensions. Exo-i has market, support, societal, and constituency dimensions. Classification of various modeling methods and tools along these dimensions can be found in (Camarinha-Matos and Afsarmanesh, 2008a, 2008b).

| | **Endo-E Abstraction** | | | | **Exo-I Abstractions** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Structural** | **Componential** | **Functional** | **Behavioral** | **Market** | **Support** | **Societal** | **Constituency** |
| **Dissolution** | | | | | | | | |
| **Metamorphosis** | | | | | | | | |
| **Evolution** | | | | | | | | |
| **Operation** | | | | | | | | |
| **Creation** | | | | | | | | |



## DISCUSSION OF VEA APPROACHES

The six approaches that were shortlisted for our study had varied differences and similarities. This section provides an interesting discussion of such aspects. A summary of the discussion can be found in Table 4.

### *Origins and Roots of Approaches*

Almost all the approaches we considered in this article appeared in the last decade, with first being published in 1999 and the latest in 2007 (Figure 3). The Zachman Framework for Enterprise Architecture has inspired NEML and CAML, whereas AVERM and ARCON have been developed from the ground up. VERAM has its roots in frameworks from Enterprise Integration and Enterprise Architecture in manufacturing space such as GERAM, CIMOSA, PERA, and GRAI/GIM. BM_VEARM is inspired from hierarchical multi-level control theories. It is also interesting to note that four out of six major approaches were developed in Europe (Figure 3, 4), which probably indicates the future trend towards global industrial coalitions in European Industry and Communities.

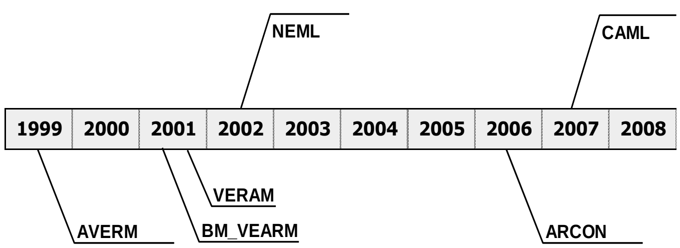



**Figure 3: Timeline of VEA Modeling Approaches**

**Figure 4: Countries of Author(s) for VEA Modeling Approaches Publications (indicated in red)**

### *Modeling Target*

The modeling target of all the approaches was envisaged to be Collaborative Network Enterprises or Virtual Enterprises and similar organizational set-ups, with the exception of VERAM which was specifically developed for Production or Manufacturing VEs. Although the authors of VERAM claim that concepts could be applied to other VEs as well.

### *Modeling Dimensions and Scope*

The modeling scope of ARCON seems to be vast, followed by VERAM. These approaches are so huge that their application and implementation seems like a burden for the VE that is not perpetual in nature and gets dissolved at the end of the opportunity. One of the promising features of the CAML approach is sharing of models by using meta-meta-model and meta-model levels across multiple enterprises or even domains. NEML seems to be the most simplistic and promising in achieving a solution to the perennial problem of Business-IT alignment because of its focus on Business and ICT dimensions. Further, VERAM and ARCON seem to be the most complex having multiple dimensions, whereas NEML and CAML are only a three-dimensional matrix. AVERM seems to be the most simple of the six, having a two-dimensional matrix of enterprise decisions and processes. Surprisingly, the second simplest approach BM_VEARM also deals with process management and control primarily.

### *Usage*

NEML is used for modeling business functions along with information and value flows. CAML is used for creating meta-models and models of CNOs. AVERM models provide structure for further analysis. Using AVERM, the VE can formulate strategies by populating and then choosing appropriate cells in combinations. BM_VEARM is mainly used for Integration, Resource Management, and Process Control. ARCON has been created for deriving specific models of CNOs such as breeding environments, virtual enterprises, and virtual communities. Another usage of ARCON is to understand the entities, their relationships, and interaction, in collaborative networks. A similar use for VERAM has also been proposed: that it structures a body of knowledge for a manufacturing VE that would foster re-use of information and standardization across VE instances. VERAM is also used for supporting set-up and operation of VEs.

### *Formalizations*

The extent of formalizations provided by each approach differs significantly. While ARCON claims to embrace multiple modeling constructs in its exo-i and endo-e sub-spaces of environment characteristics, CAML does not provide any formalization except meta-modeling levels. NEML has been formalized at operational level. In AVERM, formalization is provided in terms of a matrix of cells containing decision points and principles. VERAM provides formalizations using the entity life-cycle and modeling architecture of GERAM. BM_VEARM provides context-free attributed grammar-based constructs to generate the structural elements of a VE instance from the generic reference model.

### *Similarities and Overlaps*

First, let us look at the levels of modeling supported by each of the approaches. Generally there are three levels of models: Generic Modeling Level, Specific Modeling Level, and Detailed/Implementation Modeling Level. VERAM and ARCON have provision for all three levels. CAML also provisions the levels, albeit it provides three more levels, thus having a total of six modeling levels, from L0 to L5. NEML has only two levels, the Functional level being at a higher level of abstraction and the Operational level being the more detailed one providing detailed modeling of its internal operations. AVERM seems to provide these levels in the form of its matrix under Social/Cultural, Explicit/Legal, and Physical dimensions.

Second, let us look at the support of modeling during the life time of a VE. AVERM, VERAM, and ARCON explicitly mention the different life-cycle dimensions or views. BM_VEARM majorly focuses on process control and integration; hence it does not explicitly or separately model any life-cycle views or dimensions. CAML has process and event focuses which could be used for life-cycle modeling views. NEML does not specify anything related to life-cycle.

## CONCLUSION AND FUTURE WORK

Our study of VEA modeling approaches has shown that there has been a significant interdisciplinary interest in Collaborative Networks, Virtual Enterprises, Agile Manufacturing, Enterprise Integration, Enterprise Modeling, and Enterprise Architecture communities. We also found that there is a lack of research in holistic representation of VE in terms of EA (Goel et al, 2009), and formal models of VEA are at a nascent stage (Camarinha-Matos, 2003; Camarinha-Matos and Afsarmanesh, 2004; Kaisler et al, 2005; Langenberg and Wegmann, 2004). The absence of formal methods is a barrier to efficiency of application and development of VE (Putnik and Sousa, 2006). Our recent work also identified lack of published research in Formal Models of VEA (Goel et al, 2009). In the absence of formal underpinnings, the process of choosing future state architecture from various available alternates is difficult for high-level stakeholders (CxO).

However, the research community is geared towards finding adequate formal models of VEA that address top concerns of CxO-level stakeholders. Our continuing work is attempting to formalize the modeling of structural and behavioral aspects by applying concepts from Petri Nets (Reisig, 1985), Temporal Logic (Clarke et al, 2005), and Economic Modeling Theories. The focus of our work is the identification of adequate formal models for modeling capabilities and resources in a VE.

**Table 4: Six VEA Modeling Approaches**

| | NEML | CAML | AVERM | VERAM | BM_VEARM | ARCON |
|---|---|---|---|---|---|---|
| **First Published in Year** | 2002 | 2007 | 1999 | 2001 | 2001 | 2006 |
| **Reference of Original Publication(s)** | Steen et al (2002) | Kim (2007_ | Goranson (1999) | Zwegers et al (2001) | Putnik (2001) | Camarinha-Matos and Afsramanesh (2006, 2007, 2008) |
| **Continent (Country) of Author(s)** | Europe (Netherlands) | Asia (Korea) | North America (US) | Europe, Australia (Netherands, Denmark, Australia) | Europe (Portugal) | Europe (Portugal, Netherlands) |
| **Inspired from** | Zachman | Zachman and OMG-MDA | — | GERAM, (CIMOSA, GRAI/GIM, PERA) | Hierarchical Multi-level Systems Theory | — |

| | NEML | CAML | AVERM | VERAM | BM_VEARM | ARCON |
|---|---|---|---|---|---|---|
| **Type** | Modeling Language | Architecture Modeling Language | Reference Model | Reference Architecture and Methodology | Reference Model | Reference Model |
| **Modeling Target** | Networked Enterprises | Collaborative Networked Organizations | Agile Virtual Enterprises | Production or Manufacturing VEs | (Agile, Distributed, Integrated, Virtual) Enterprise | Collaborative Networked Organizations |
| **Modeling Dimensions** | Three-dimensional Matrix | Three-dimensional Matrix | Two-dimensional Matrix | Multi-dimensional Matrix mixed with Layered Approach | Layered Approach | Multi-dimensional Matrix mixed with Layered Approach |
| **Modeling Scope** | Structure and behavior in business and ICT dimensions | Five views and six focus areas as in Zachman; six levels as in OMG-MDA | Five life-cycle stage, six application areas in an enterprise | Four modeling views across eight life-cycle stages, generic/partial models, network/VE/ product entities | Inter-enterprise process and resources | Five life-cycle stages, two viewpoints (internal and external), three layers or levels of models (general models, specific models, detailed specifications) |
| **Usage** | Model business functions, model information and value flows | Sharing and transformation of models at very abstract level | Model provides a structure for further analysis; strategies can be formed by populating and choosing cells | Support set-up and operation of VE; structure a body of knowledge for VE fostering standardization and re-use | Resource and process, management, integration | Understanding entities involved in CNO, deriving specific models of CNO |
| **Formalizations** | Formalized at operational level | Meta-modeling levels | Formal model is provided in terms of matrix of cells containing decision points and principles | Entity life-cycle concept and modeling architecture of GERAM | Context-free attributed grammar to generate structural elements of a VE instance from BM_VEARM | Supports various formalizations for different internal dimensions |

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## REFERENCES

Afsarmanesh, H., and Camarinha-Matos, L.M.: The ARCON Modeling Framework, in Collaborative Networks: Reference Modeling, New York, USA: Springer, pp67-82 (2008).

Barnett, W., Presley, A., Johnson, M., and Liles, D.H.: An Architecture for the Virtual Enterprise, in Proceedings of IEEE International Conference on Systems, Man, and Cybernetics, IEEE, pp506-511 (1994).

Bernus, P.: GERAM: Generalized Enterprise Reference Architecture and Methodology (1999).

Camarinha-Matos, L.M.: New Collaborative Organizations and their Research Needs, in Processes and Foundations for Virtual Organizations: IFIP TC5/WG5.5, Fourth Working Conference on Virtual Enterprises (PRO-VE'03), Lugano, Switzerland, L.M. Camarinha-Matos and H. Afsarmanesh (Eds.), Springer, pp3 (October 29-31, 2003).

Camarinha-Matos, L.M., and Afsarmanesh, H.: Formal Modeling Methods for Collaborative Networks, in Collaborative Networked Organizations: A Research Agenda for Emerging Business Models, L.M. Camarinha-Matos and H. Afsarmanesh (Eds.), New York, USA: Springer, pp237-244 (2004).

Camarinha-Matos, L.M., and Afsarmanesh, H.: Towards a Reference Model for Collaborative Networked Organizations, in Information technology for Balanced Manufacturing Systems: IFIP TC5, WG 5.5 Seventh International Conference on Information Technology for Balanced Automation Systems in Manufacturing and Services, Niagara Falls, Ontario, Canada, W. Shen (Ed.), New York, USA: Springer, pp193-202 (September 4-6, 2006).

Camarinha-Matos, L.M., and Afsarmanesh, H.: A Comprehensive Modeling Framework for Collaborative Networked Organizations, Journal of Intelligent Manufacturing, (18:5) Springer, pp529-542 (2007).

Camarinha-Matos, L.M., and Afsarmanesh, H.: A Survey of Soft Modeling Approaches for Collaborative Networks, in Collaborative Networks: Reference Modeling, New York, USA: Springer, pp165-190 (2008a).

Camarinha-Matos, L.M., and Afsarmanesh, H.: A Survey of Modeling Methods and Tools, in Collaborative Networks: Reference Modeling, New York, USA: Springer, pp139-164 (2008b).

Camarinha-Matos, L.M., Afsarmanesh, H., Garita, C., and Lima, C.: Towards an Architecture for Virtual Enterprises, Journal of Intelligent Manufacturing (9:2) Springer, pp189-199 (1998).

Clarke, E., Fehnker, A., Jha, S.K., and Veith, H.: Temporal Logic Model Checking, in Handbook of Networked and Embedded Control System, D. Hristu-Varsakelis and W. S. Levine (Eds.), Boston, MA: Birkhäuser Boston, pp539-558 (2005).

Goel, A., Schmidt, H., and Gilbert, D.: Towards Formalizing Virtual Enterprise Architecture, in Enterprise Distributed Object Computing Conference Workshops, EDOCW 2009, 13th, pp238-242 (2009).

Goel, A., Schmidt, H., and Gilbert, D.: Formal Models of Virtual Enterprise Architecture: Motivations and Approaches, in Proceedings of 14th Pacific Asia Conference on Information Systems (PACIS), Association for Information Systems (2010).

Goranson, H.T.: The Agile Virtual Enterprise: Cases, Metrics, Tools, Westport, CT, USA: Quorum Books (1999).

Kaisler, S.H., Armour, F., and Valivullah, M.: Enterprise Architecting: Critical Problems, Proceedings of the 38th Annual Hawaii International Conference on System Sciences, (00:C) Ieee, pp224b-224b (2005).

Karvonen, I., den Berg, R., Bernus, P., Fukuda, Y., and Hannus, M.: Global Engineering and Manufacturing in Enterprise Networks, Global Engineering and Manufacturing in Enterprise Networks, (I. Karvonen, R. den Berg, P. Bernus, Y. Fukuda, and M. Hannus, Eds.) (2003).

Kim, D.H.: Towards an Architecture Modeling Language for Networked Organizations, in Establishing the Foundation of Collaborative Networks: IFIP TC 5 Working Group 5.5 Eighth IFIP Working Conference on Virtual Enterprises, Guimarães, Portugal, L.M. Camarinha-Matos, H. Afsarmanesh, P. Novais, and C. Analide (Eds.), (Vol. 243) Springer Boston, pp309-316 (September 10-12, 2007).

Langenberg, K., and Wegmann, A.: Enterprise Architecture: What Aspects is Current Research Targeting? (2004).

Pires, S.R.I., Bremer, C.F., De Santa Eulalia, L.A., and Goulart, C.P.: Supply Chain and Virtual Enterprises: Comparisons, Migration, and a Case Study, International Journal of Logistics, (4:3) Taylor and Francis Ltd., pp297-311 (2001).

Putnik, G.D.: BM Virtual Enterprise Architecture Reference Model, in Agile Manufacturing: the 21st Century Competitive Strategy, A. Gunasekaran (Ed.), Elsevier, pp73-93 (2001).

Putnik, G., and Sousa, R.: On Formal Theories – and Formalisms for Virtual Enterprises, in Information Technology for Balanced Manufacturing Systems (Vol. 220) Boston: Springer, pp223-232 (2006).

Reisig, W.: Petri Nets: An Introduction, New York, NY, USA: Springer-Verlag New York, Inc. (1985).

Sousa, R., and Putnik, G.: A Formal Theory of bm Virtual Enterprise Structures, in IFIP International Federation for Information Processing: Emerging Solutions for Future Manufacturing Systems (IFP TC 5/WG 5.5 Sixth IFIP International Conference on Information Technology for Balanced Automation Systems in Manufacturing and Services 27, (Vol. 159), pp315-322 (2005).

Steen, M.W.A., Lankhorst, M.M., and van de Wetering, R.G.: Modelling Networked Enterprises, in Proceedings of Sixth International Enterprise Distributed Object Computing Conference (EDOC), pp109-119 (2002).

Tolle, M., and Vesterager, J.: VEM: Virtual Enterprise Methodology, in Global Engineering and Manufacturing in Enterprise Networks, I. Karvonen, R. den Berg, P. Bernus, Y. Fukuda, and M. Hannus (Eds.), (Vol. 224), pp53-70 (2003).

Vesterager, J., Tolle, M., and Bernus, P.: VERA: Virtual Enterprise Reference Architecture, in Global Engineering and Manufacturing in Enterprise Networks, I. Karvonen, R. den Berg, P. Bernus, Y. Fukuda, and M. Hannus (Eds.), (Vol. 224), pp39-52 (2003).

Westphal, I., Thoben, K.D., and Seifert, M.: Measuring Collaboration Performance in Virtual Organizations, Establishing the Foundation of Collaborative Networks: IFIP TC 5/WG 5. 5 Eighth IFIP Working Conference on Virtual Enterprises, Guimaraes, Portugal, Springer Verlag, pp33-42 (September 10-12, 2007).

Zwegers, A., Tolle, M., and Vesterager, J.: VERAM: Virtual Enterprise Reference Architecture and Methodology, in Global Engineering and Manufacturing in Enterprise Networks, I. Karvonen, R. den Berg, P. Bernus, Y. Fukuda, and M. Hannus (Eds.), (Vol. 224), pp17-38 (2003).