2010

# Formal Models of Virtual Enterprise Architecture: Motivations and Approaches

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# FORMAL MODELS OF VIRTUAL ENTERPRISE ARCHITECTURE: MOTIVATIONS AND APPROACHES

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## Abstract

*Enterprise Architecture deals with the structure of an enterprise, relationships and interactions of its units. It provides a holistic approach to reconcile IT and Business concerns in an enterprise. Virtual Enterprises are collaborative ad-hoc alliances of multiple enterprises for a specific business opportunity. First we discuss both paradigms and then the Enterprise Architecture viewpoint of Virtual Enterprise and provide a definition of Virtual Enterprise, Enterprise Architecture and Virtual Enterprise Architecture. This paper surveys research into formal models of Virtual Enterprise Architecture (modelling languages, reference models, architecture frameworks) and identifies current gaps in this research.*

*Keywords: Enterprise Architecture, Virtual Enterprise, Formal Models, Virtual Enterprise Architecture, Virtual Enterprise Modelling, Virtual Enterprise Architecture Modelling.*

# 1 INTRODUCTION

Business enterprises, government and non-government organizations have grown in complexity and their dependency on information systems and information technology has grown significantly. The advent of Internet technologies has led to the evolution of different forms of business such as e-commerce, e-business, supply chains and virtual enterprises. The complexity and challenges for businesses has only been compounded by such evolution as they struggle to align IT with their strategic intent. Thus there is a need to approach this ever increasing complexity in a holistic manner.

Formal models have been used in other fields such as software engineering and business process management. Various formal methods such as Automata and Logics (Propositional, Predicate and Modal Logics), Temporal Logic (CTL, LTL, ATL) (Baier and Katoen 2008; Clarke 1999; Clarke et al. 2008), Petri Nets, Communicating Sequential Processes (CSP), and Hierarchical State Machines have been developed and used in various fields. Formal models provide precise specifications and allow for easier analysis and simulation. Formal models can also be verified for various properties and correctness, and such verification can be automated.

In model checking, the formal models represent the semantics of the system under study using labelled graphs representing the states of a system and the transitions between those states. Kripke Structure is one example of such labelled graphs. The properties of system are specified using Temporal Logic. Model checking algorithm then checks whether specification holds true for the given future state of the system (Baier and Katoen 2008; Clarke 1999; Clarke et al. 2008).

Formal models and model checking can also be applied to holistic approaches for virtual enterprises. In this paper, we look at the concepts of Enterprise Architecture (EA) and Virtual Enterprise (VE) in section 2 and 3 and introduce a definition of Virtual Enterprise while comparing it with other paradigms. In section 4 we define Enterprise Architecture (EA) and Virtual Enterprise Architecture (VEA) and provide results from our study of different approaches for formal models of VEA (modelling languages, reference models, architecture frameworks). Then we focus on the motivation for our research which centres on formal models for VEA and the analysis, simulation, and visualization thereof.

# 2 ENTERPRISE ARCHITECTURE

EA originated from different knowledge areas such as Enterprise Modelling, Enterprise Integration, Concurrent Engineering, and mainly from the architectural thinking in Software Engineering and Information Technology. IEEE 1471 standard (ISO/IEC 42010:2007) for Architectural Description of Software Intensive Systems, defines the term architecture as ``the fundamental organization of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution" [page 3](ISO/IEC/(IEEE) 2007). Building upon this definition by IEEE, TOGAF 9 describes EA as a formal description of the enterprise, which is a detailed plan at the component level to guide its implementation. The plan consists of structure of the components[1], their inter-relationships, and the principles and guidelines governing their design and evolution over time [page 9](The Open Group 2009).

Lankhorst et al. define EA as ``a coherent whole of principles, methods, and models that are used in the design and realization of an enterprise's organizational structure, business processes, information systems, and infrastructure" [page 9](Lankhorst 2005). Similar views have been echoed by different practitioners and researchers in EA (Bernard 2005; Bernus et al. 2003; Camarinha-Matos and Afsarmanesh 2008b; Zachman 1997).

[1] The use of the term `component' here is not elaborated by TOGAF. We consider the usage of term in the broader sense of (Szyperski 2002), to represent the self contained elements or units with well defined interfaces or contracts.

We conclude from these definitions that EA is considered a holistic expression of the enterprise in terms of key strategies. These keys strategies usually evolve from different domains of business architecture, information architecture and technology architectures. Business architecture addresses business strategy, processes, business services, policies and governance. Technology architecture addresses infrastructure, security, applications, technology services and middleware. Information architecture addresses ontology, taxonomy, meta-data, master data, transaction data, information flows and other forms of data and information assets. Some of these concerns are in fact cross-cutting across Business, Information and Technology Architectures. EA aims to bring a coherent structure into these key strategies and align them together. Thus, we define Enterprise Architecture (EA) as follows:

**Definition 1: 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. Enterprise Architecture* centres on modelling, predicting and managing key properties *such as profits, costs, risks, changes and innovation from an architectural perspective and in a holistic way.*

Growing interest in the field of EA over the last two decades has resulted in the creation of several frameworks, models and methods. We categorize the most important ones among them as follows:

- *EA frameworks and reference models*[2] such as Zachman from the Zachman Institute of Architecture (Sowa and Zachman 1992; Zachman 1987; Zachman 1999), TOGAF from The Open Group (The Open Group 2009), DoDAF from the US Department of Defence (Department of Defense 2007), MoDAF from the UK Ministry of Defence (Ministry of Defence, UK 2008), EA Cube from Scott Bernard (Bernard 2005), TEAF from the US Department of Commerce (Department of the Treasury Chief Information Officer Council 2000), FEAF from the US Federal Government (CIO Council 1999), RM-ODP (ISO/IEC 10746) (Putman 2000), CIMOSA from the AMICE Consortium (Kosanke et al. 1999), GRAI/GIM from GARI Labs (Doumeingts et al. 1998), PERA (Williams 1998) from the Purdue Consortium, GERAM (ISO 15704: 2000) (Bernus 1999) from IFIP/IFAC, ARIS (Scheer and Schneider 2005) from IDS Scheer.
- *EA methodologies* such as TOGAF ADM (The Open Group 2009), EAP (Spewak and Hill 1992), EA Cube Method (Bernard 2005) and SEAM (Filipe et al. 2003). Each of US Government Frameworks included a methodology (DODAF, FEAF, TEAF).
- *EA modeling techniques and notations*[3] such as ArchiMate, UEML, SysML, BPMN, ERD and IDEF.
- *EA tools* such as Abacus from Avolution, Enterprise Architect from Sparx, System Architect from IBM, BizzDesigner from Bizzdesign, ARIS Process from IDS Scheer and Altova Enterprise from Altova.

EA brings multiple benefits such as architectural alignment of Business and IT (Filipe et al. 2003; Steen et al. 2005), coherence between strategy and execution (Lankhorst 2005), and collaboration among planning, operations and infrastructure.

# 3 VIRTUAL ENTERPRISE

Generally the term `virtual' has the connotation of 'one that is not real', imaginary or simulated as in virtual reality, virtual prototyping, virtual disk or virtual memory. However, the VE does not fit in this category. Hence this section clarifies the meaning of the term Virtual Enterprise.

[2] We are excluding TAFIM and C4ISR since they are not in use any more and replaced by new ones.
[3] We are not mentioning the Rational Unified Process (RUP), IEEE 1471, SSAD here because they are meant for Software Development and Architecture and not for Enterprise Architecture.

Goranson defines VE as ``a temporary aggregation of core competencies and associated resources collaborating to address a specific situation, presumed to be a business opportunity" [page 66](Goranson 1999).

Camarinha-Matos and Afsarmanesh define VE as “a temporary alliance of enterprises that come together to share skills and resources in order to better respond to business opportunities and whose cooperation is supported by computer networks” [page 4](Camarinha-Matos and Afsarmanesh 1999).

Putnik defines VE as “an optimized enterprise synthesized over universal set of resources with the real-time substitutable physical structure. The design (synthesis) and control of the system is performed in an abstract, or virtual, environment.”[page 86](Putnik 2001).

However Camarinha-Matos and Afsarmanesh argue that the common definition of VE is still not agreed by community (Afsarmanesh and Camarinha-Matos 2008a). From a review of the literature, we discovered that essential characteristics of VE are:

- *Purpose*: A VE is formed to leverage core competencies, resources and skills of multiple enterprises to each provide benefit to the other for a specific set of business opportunities (Barnett et al. 1994). Each participant enterprise may gain its own benefits that it would not have otherwise. Further, the coalition may gain benefits which individual participants may not gain if acting independently.
- *Life Time*: A VE is ad-hoc in nature which gets dissolved as soon as the specific opportunity passes or the explicit goal is achieved (Barnett et al. 1994; Camarinha-Matos et al. 1998; Westphal et al. 2007). Although there is no limit of time, there is an explicit consideration that VE is not formed for a perpetual purpose.
- *Organizational Structure*: The VE itself owns no inventoried resources, assets, plants, factories or warehouses. These are owned by its participating enterprises. The VE owns only a small Headquarter of staff to handle administration (Barnett et al. 1994). There is no dominant partner and members can leave or join any time (Pires et al. 2001).
- *Legal Status*: VE in itself has no separate legal existence. All the participating entities are independent legal entities that are bound by contracts only (Westphal et al. 2007).
- Customer Interface: The participating enterprises appear as one single enterprise (The VE) to the consumer (Pires et al. 2001).

The following captures the essence of the VE in a single and concise definition:

**Definition 2: A Virtual Enterprise** (VE) *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 specific situation could be a business opportunity such as “manufacture promotion material for Australian Football League (AFL) tournament” or crisis situation such as “fight bushfire and save lives in Regional Australia”.

Often this collaborative network is supported by information technology elements at different levels such as computer networks, business process/work-flow management systems and service oriented architectures etc. Examples of VE are large government projects, distributed manufacturing enterprises such as ship-building or airplane manufacturing conglomerates, managed health-care and emergency services.

Cunha and Putnik provide a detailed comparison of VE with Traditional Enterprise (Cunha and Putnik 2006; Putnik and Cunha 2005). The literature survey shows different usage of related terminology, but we consider VE analogous to VC (Virtual Company), VO (Virtual Organization) and NO/CNO (Networked Organization) for the purpose of this paper. We do not attempt to debate whether VE is a special case or a subset of Traditional Enterprise or vice-versa (Putnik and Sousa 2006). The meaning

of the term collaborative is also interpreted differently. Collaborative could mean ``sequential process", ``any to any connection of processes" or ``a hybrid of peer to peer and sequential" (Putnik and Sousa 2006). We assume any of the above 3 depending on context and requirement. We also assume concurrency is permitted in VEs.

### 3.1 VEs and Other Organizational Paradigms

The concept of VE has emerged from the organizational paradigms of Extended Enterprise, Virtual Community, Supply Chain and e-Business. However, a VE is different from these paradigms as explained in subsections below and summarised in Table 1.

#### *3.1.1 Virtual Community and VE*

A Virtual Community (VC) is a network of people utilizing information technology to create a web of relationships (Rhelngold 1998). A VC is created for professional (linkedin), social (myspace, facebook), friendship (orkut) or several other purposes. A VC engages people in various ways, supported by technology, to achieve different goals such as chat, discussions, relationship chains, private spaces and group messaging. In contrast, a VE is an ad-hoc network of enterprises whereas a VC is a somewhat continued network of people or enterprises. The purpose of a VE is to serve a unified goal of exploiting a specific business opportunity whereas the purpose of a VC is to create and support a web of relationships.

#### *3.1.2 Extended Enterprise and VE*

An Extended Enterprise (EE) refers to a single enterprise extending its boundaries to include its suppliers, consumers and partners into collaborative networks for its own benefit (Browne and Zhang 1999; Filos 2005). The difference between EE and VE is that the EE is controlled by the main participating enterprise whereas a VE is controlled by a common goal or manifesto, and the participant can join or drop out of the VE at any time. Thus VE is a more democratic structure with peer-to-peer cooperation among participant enterprises (Filos 2005).

#### *3.1.3 Supply Chain and VE*

A Supply Chain (SC) refers to a network of suppliers, producers, distributors and consumers of particular products and services. These come together to form a virtual demand chain in order to gain benefits, optimize, reduce costs and provide value addition (Pires et al. 2001). Pires et al. also argue that SC and VE differ from each other in terms of purpose, organizational structure, duration and participation. The main purpose of SC is to increase competitiveness whereas the purpose of VE is to exploit specific business opportunity. SC is stable and extends over a longer period of time, whereas VE is dynamic, ad-hoc and temporary and exists only for the lifetime of a specific business opportunity. In the case of SC, an enterprise could be exclusively participating in just one SC depending on contracts, whereas in VE, the participant enterprise participates in multiple VEs (Pires et al. 2001).

#### *3.1.4 eBusiness and VE*

eBusiness refers to extending business to leverage the electronic and specially the Internet media for different purposes such as connecting to customers (B2C), conducting business transactions (B2B) and inter-office or inter-branch communications. In fact all of the business transactions are possible to be executed virtually from the Internet except for storing goods the business still needs a physical warehouse. eBusiness refers to one single legal entity, and VE has no legal existence except the contracts between the participating enterprises. VE is a natural extension of e-Business.

Camarinha-Matos and Afsarmanesh provide a detailed discussion and definitions of various different collaboration forms including VEs (Camarinha-Matos and Afsarmanesh 2008a).

| | Virtual Enterprise | Virtual Community | Extended Enterprise | Supply Chain | E-Business |
|---|---|---|---|---|---|
| **Purpose** | exploit a specific business opportunity | create web of relationships | seamlessly integrate external entities (partners) | increase competitive-ness | extending reach to customers, businesses or employees |
| **Organization-al Structure** | Controlled by common goal and manifesto | Networks of people | Controlled by main participating enterprise | Virtual demand chain | No special organizational setup |
| **Life Time** | Ad-Hoc and Temporary | Long Term and Somewhat stable | Long Term and Stable | Long Term and Stable | Long Term and Stable |
| **Participation** | Participants may join or drop any time, and may involve in multiple VEs at same time | Participants may join or drop any time, and may join multiple VCs at same time | Participants may join EE exclusively | Participants may join SC exclusively | Single Enterprise |
| **Reconfig-urability** | Very High | High | Low | Low | Low |
| **Partner Dependency** | Low | Low | Moderate | High | NA |

*Table 1. Summary of different characteristics of VE and Other Paradigms*

# 4 VIRTUAL ENTERPRISE ARCHITECTURE

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. Looking at VE as a single Enterprise, the same paradigm could also be applied to VE. Hence we use the term Virtual Enterprise Architecture (VEA) to represent the EA based models or abstractions of VE. We define VEA as follows:

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

EA enables enterprises to meet the three core challenges of the information age: **integration**, **agility** and **change** (Hoogervorst 2004). Interestingly, it has been identified that VE also faces similar challenges: rapid **integration** of business processes of participating companies (Barnett et al. 1994; Putnik and Cunha 2005), and **agility** in dynamic reconfiguration of systems and business (Wu and Su 2005) due to **change** introduced by various factors such as joining/dropping of partners and changes in market/context.

Thus, we see that the notions of VE and EA face the critical challenges of integration, agility and change and EA as a solution to these challenges.

## 4.1 Formal Models of VEA

VEA Formal models describe the structure and behaviour of VE. Formal models have mathematical underpinnings. They allow detection and removal of ambiguity, inconsistency and incompleteness in

VEA. They make it easier to analyze and simulate the VEA for helping in decision making. Formal modelling includes the following:

- *VEA Model Specifications*: Behavioral models of VEA can be specified using Transition Systems such as Automata, Petri Nets, State Machines or Communicating Sequential Processes (CSP). Formal specifications are precise definitions of behavior.
- *VEA Properties*: The properties of such VEA models can be expressed using formulae in Logic. Use of modal and temporal logics has been proposed for modeling temporal aspects of behavior and processes (Camarinha-Matos and Afsarmanesh 2004; Camarinha-Matos and Afsarmanesh 2006; Camarinha-Matos and Afsarmanesh 2007). For example, using Alternating-time Temporal Logic (ATL) (Alur et al. 1997) we could define the following properties for Emergency Services Virtual Enterprise.
  - Property: "Emergency VE Participants would ensure that no human casualty happens during emergency operations"
    Formula: $\langle\langle EmVE - Partners\rangle\rangle\Box\neg Human - Casualty$
  - Property: "Water Units shall ensure continued supply of water into affected areas"
    Formula: $\langle\langle Water - Units\rangle\rangle\Diamond Water - Supply$
- *VEA Model Verification*: Also known as model-checking, automated technique can be applied to check whether the VEA properties in temporal logic hold for given behavioral model of VEA using transition systems (Baier and Katoen 2008; Clarke 1999; Clarke et al. 2008). Model Checkers such as Mocha, SPIN or PRISM could be used for this purpose.

### 4.2 VEA Modelling Approaches

We studied different approaches to provide modelling of Virtual Enterprise Architecture for Virtual Enterprises. 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 approaches by various researchers and practitioners. However, only those approaches were selected which were specifically devised or customized for Virtual Enterprises, listed below:

- NEML (Networked Enterprise Modeling Language). (Steen et al. 2002)
- CAML (CNO Architecture Modeling Language). (Kim 2007)
- AVERM (Agile Virtual Enterprise Reference Model). (Goranson 1999)
- VERAM (Virtual Enterprise Reference Architecture and Methodology). (Zwegers et al. 2003)
- BM_VEARM (Virtual Enterprise Architecture Reference Model). (Putnik 2001)
- ARCON (A Reference model for Collaborative Networks). (Afsarmanesh and Camarinha-Matos 2008b)

Figure 1 gives a timeline of the VEA modelling approaches and Table 2 provides a summary of the main characteristic features across all of them.

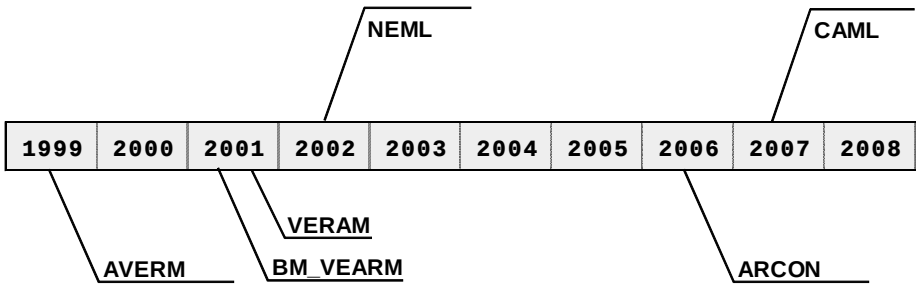


*Figure 1. Timeline of Virtual Enterprise Architecture modelling approaches*

| | 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 et al. 2006 |
| **Continent (Country) of Author(s)** | Europe (Netherlands) | Asia (Korea) | North America (US) | Europe (Netherands, Denmark), Australia | Europe (Portugal) | Europe (Portugal, Netherlands) |
| **Inspired from** | Zachman | Zachman and OMG-MDA | -- | GERAM, (CIMOSA, GRAI/GIM, PERA) | Hierarchical multilevel systems theory | -- |
| **Type** | Modelling language | Architecture Modelling Language | Reference model | Reference architecture and methodology | Reference model | Reference model |
| **Modelling Target** | Networked Enterprises | Collaborative Networked Organizations | Agile Virtual Enterprises | Production or manufacturing VEs | {Agile, Distributed, Integrated, Virtual} Enterprise | Collaborative Networked Organizations |
| **Modelling Dimensions** | Three Dimensional Matrix | Three Dimensional Matrix | Two Dimensional Matrix | Multi-dimensional Matrix mixed with Layered Approach | Layered Approach | Multidimensional Matrix mixed with Layered Approach |
| **Modelling Scope** | Structure and behaviour in Business and ICT dimensions | Five views ad six focus areas as in Zachman, six levels as in OMG-MDA | Five lifecycle stage, six applications areas in an enterprise | Four modelling views across eight life cycle stages, generic/partial models, network/VE/product entities | Inter enterprise process and resources | Five lifecycle 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 setup 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-modelling levels | Formal model is provided in terms of matrix of cells containing decision points and principles | Entity life cycle concept and modelling 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 |

*Table 2. Comparison of six VEA modelling approaches*

### 4.3 Motivation and Related Work

Apart from the notable approaches to VEA modelling mentioned in above sections, various researchers have applied different techniques to formal models of Enterprise Architecture. Johnson et al. proposed Architecture Theory Diagrams (ATD) for formal analysis of EA models and applied it for modifiability analysis and information security (Johnson et al. 2006). Iacob et al. added quantified attributes for formal performance analysis of ArchiMate EA models (Iacob and Jonkers 2005).

Møller et al. created VEA for logistics service based on an advanced simulation model which mediates information between stages of the systems lifecycle represented using GERAM framework (Møller et al. 2008). Møller et al. used VEA for effective design of a new complex service for Changi Airport, Singapore.

Bremer created a VE reference model based on ARIS, having the business process model with data, functional and organizational views linked by the Control View (Bremer and Eversheim 2000). Bremer used the reference model for a group of nine manufacturing and technology based small and medium enterprises in Brazil. Katzy et al. provided a summarized study of different virtual organization patterns (Katzy et al. 2005).

The research in holistic representation of VE in terms of EA, i.e. Virtual Enterprise Architecture (VEA) is relatively new (Goel et al. 2009), and research in Formal Models of VEA is at a very nascent stage (Camarinha-Matos 2004; Camarinha-Matos and Afsarmanesh 2004; Kaisler et al. 2005; Langenberg and Wegmann 2004). Lack of formal underpinnings of Virtual Enterprise models in terms of formal methods leaves a huge gap in planning and architecture of Virtual Enterprises. The lack of formal methods of VEA has also been identified as a serious obstacle to effectiveness and efficiency of development and application of VE (Putnik and Sousa 2006). Recent studies also identified lack of published research in Formal Models of VEA (Goel et al. 2009).

In the absence of formal models of Virtual Enterprises, there is no mechanism to provide strong analysis of future states and available alternatives. Hence it becomes difficult for high level stakeholders (CxO) to choose future state architecture from various available alternates. In recent surveys it was found that key concerns which CxO level stakeholders wish to be addressed by VEA included cost and risk (Lindström et al. 2006). Similar studies have also concluded that existing VEA Frameworks and Models do not address these concerns of CxO level stakeholders (Johnson et al. 2004; Lindström et al. 2006; Raadt et al. 2008), which are usually the key concerns of strategic level decision making. Therefore the motivation for research stems from these identified gaps.

## 5 CONCLUSION AND FUTURE WORK

In this paper, we discussed the concepts of Enterprise Architecture, Virtual Enterprise and Virtual Enterprise Architecture. We have also defined EA, VE and VEA. In summary we can say that VEA is a holistic approach for thinking strategically about VE and solving the challenges of integration, agility and change. We also discussed different approaches in terms of modelling languages, reference models and modelling frameworks for formal models of VEA. We identified a major gap in research in analysis, simulation and visualization of formal VEA models accessible to CxO level stakeholders.

Currently the research community is working on finding adequate formal models of VEA which address key concerns of CxO level stakeholders. Our continuing work is attempting to formalize the modelling of structural and behavioural aspects by applying concepts from Petri Nets (Reisig 1985), Temporal Logic and Economic Modelling Theories. The focus of our work is on identifying adequate formal models for modelling capabilities and resources in a VE for purpose of providing support for analysis, simulation and visualization for such formal models. Our work also includes using model checking for virtual enterprise architecture. Model checking has been used in different fields for planning, verification and decision making.

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