VERAM: Virtual Enterprise Reference Architecture and Methodology

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Abstract

Nowadays, enterprises cooperate more extensively with other enterprises during the entire product life cycle. Temporary alliances between various enterprises emerge such as those in Virtual Enterprises. However, many enterprises experience difficulties in the formation and operation of virtual enterprises, for instance concerning integration issues. This chapter lays down an architectural framework, called VERAM, which aims to support the set up and operation of virtual enterprises. The framework aims to offer handles that contribute to solving the problems that enterprises face when they want to cooperate in a Virtual Enterprise. Supported by the framework, individual enterprises might operate and set up a virtual enterprise from a dynamic, inter-enterprise network. Furthermore, this chapter shows how other chapters of this book fit into the VERAM architectural framework.

1. Introduction

One of the trends in the global market is the fact that enterprises cooperate more extensively with other enterprises during the entire product life cycle. This is related to business drivers, such as the need for cost reduction, flexibility, focus on core competencies, and so on. The result is anything from a rather stable alliance between partners as in a supply chain to a more transitory cooperation as in a Virtual Enterprise (VE) [1].

The objective of this paper is to lay down a foundation for future applications to support the set up and operation of VEs. It is a result of research performed on the definition of an architectural framework for virtual enterprise engineering, as part of IMS project GLOBEMEN [2]. The project focuses on one-of-a-kind-production (OKP) and aims to organise knowledge about the formation and operation of virtual enterprises. The framework that organises all this knowledge is called VERAM – Virtual Enterprise Reference Architecture and Methodology and is a VE specialisation of GERAM (ISO15704: 2000) [3].

This chapter is organised as follows. The next section explains the need for an architectural framework for VE engineering. In section 3, the VERAM architectural framework is presented. Each of the components in the framework is subsequently presented in more detail. If applicable, references are made to other chapters of this book that fill in the VERAM components. A discussion concludes this chapter.

2. Rationale

Several problems frequently occur during the set up, operation, and reconfiguration of virtual enterprises. Different levels of integration have to be considered. A number of viewpoints must be taken into account; not only the technical view, but also – for instance – the economic, organisational, and legal points of view have to be taken into consideration. Generally, virtual enterprises are quite complex, and their set up and operation is often quite expensive and risky. The information systems, business processes, and procedures of existing companies – i.e. the members of the virtual enterprise – have to be considered in the VE design process, so that the members can interact in a proper way. The activities performed during each phase of the VE life cycle are essentially derived from ad hoc procedures, so that the quality of the resultant VE will depend considerably upon the experience of the persons and companies involved. The problem is accentuated due to a low level of formalism with which those activities are usually carried out. This often leads to solutions that do not adequately address business requirements, lack of traceability of design decisions, low repeatability of successful results, and so on.

The purpose of the architectural framework is to structure a body of knowledge that supports future work in the area of global engineering and manufacturing in enterprise networks. The framework aims to offer handles that contribute to solving the problems mentioned above, and with which individual enterprises might operate and set up a virtual enterprise from a dynamic, inter-enterprise network. The aim is to organise knowledge about the formation and operation of virtual enterprises. A large part of the procedures, tools, and methods used is in fact similar and common every time a VE is set up or operated. This part could be formalised and re-used instead of figuring out every time what tools or methods to use, and developing some parts again from scratch. In addition to a more time and cost-effective operation of the VE, it is expected that the set up of the VE from an enterprise network would become faster and more efficient. Therefore, an architectural framework is needed that organises all this knowledge.

The above implies that the architectural framework contains tools, methods, applications, etcetera, on a *generalised level*, i.e. these tools, methods, and applications are not focused on one specific virtual enterprise or instance of a network. Rather, it focuses on generic knowledge, which is applicable in many, specific situations. Other companies outside the GLOBEMEN consortium might use these tools, models, and methods as well.

3. VERAM

3.1 Introduction

A Virtual Enterprise Reference Architecture and Methodology (VERAM) has been created in GLOBEMEN (see Figure 1). The architectural framework positions elements that support modelling, formation/set up, management and ICT support of VEs, such as reference models, and supporting tools and infrastructures. Interrelations among these elements are indicated. This framework is inspired by the GERAM framework [3], and focuses on virtual enterprise formation and operation. First versions of VERAM were previously published in [4, 5].

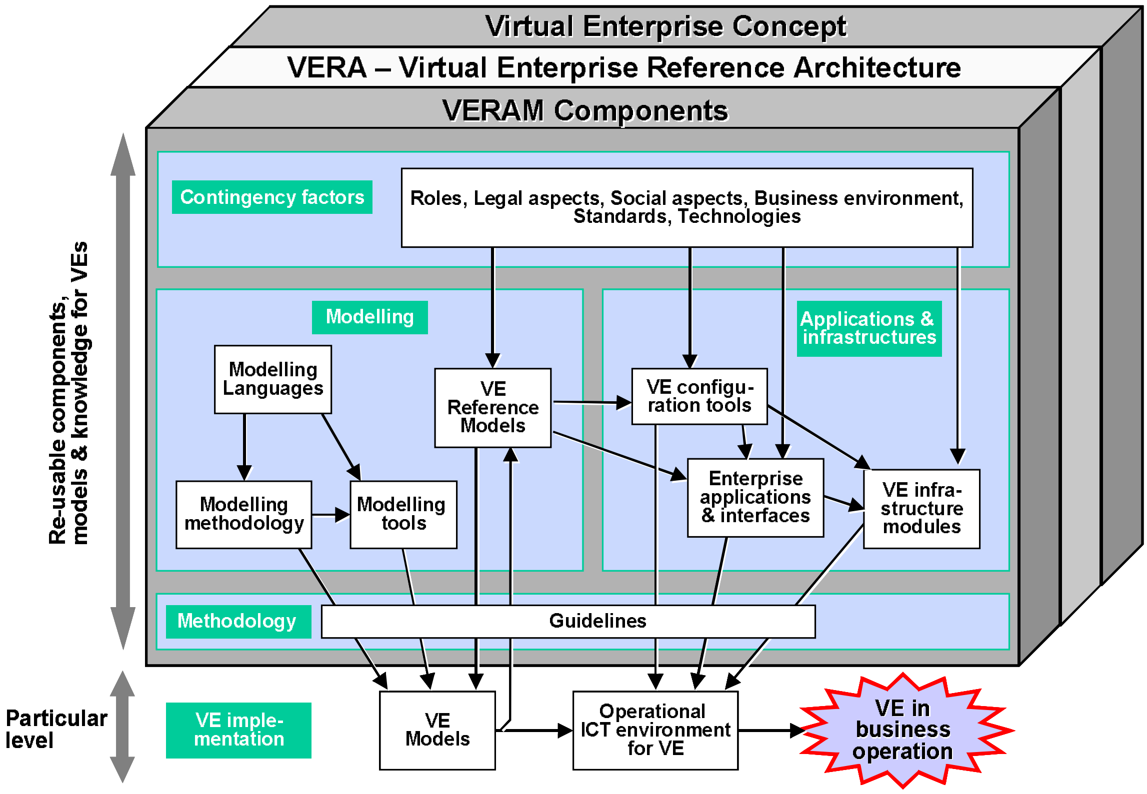

Figure 1 VERAM – Virtual Enterprise Reference Architecture and Methodology

Figure 1 shows that VERAM consists of three layers. A layer builds on its underlying layer, which at its turn builds on its underlying layer as well. Consequently, a layer explicitly uses the concepts of its underlying layer, and implicitly uses the concepts of all layers underneath its underlying layer. The rest of this chapter describes the three VERAM layers.

3.2 Virtual Enterprise concepts

The bottom layer shows the Virtual Enterprise concepts (see Figure 2). It introduces the concepts of the Virtual Enterprise (VE) and the Enterprise Network. The latter is a cooperative alliance of enterprises established to jointly exploit business opportunities through setting up virtual enterprises. The main purpose of a network is to prepare the life cycle of VEs and the products created by the VEs as well as to manage the life cycle of VEs. It establishes mutual agreements among its members on issues such as common standards, procedures, intellectual property rights, and ICT, so that these time-consuming preparations can be significantly shortened when a customer request arises, and a VE is put in place. The network should be seen as a potential from which different VEs can be established in order to satisfy diverse customer demands. The network will seek out and await customer demands, and when a specific customer demand is identified the business potential is realized by forming a VE. When the customers demand has been fulfilled, the virtual enterprise dissolves. Accordingly, compared to a virtual enterprise, a network can be perceived as a relatively long-term cooperation since it typically sets up multiple VEs. Conversely, the VEs have a more temporary nature.

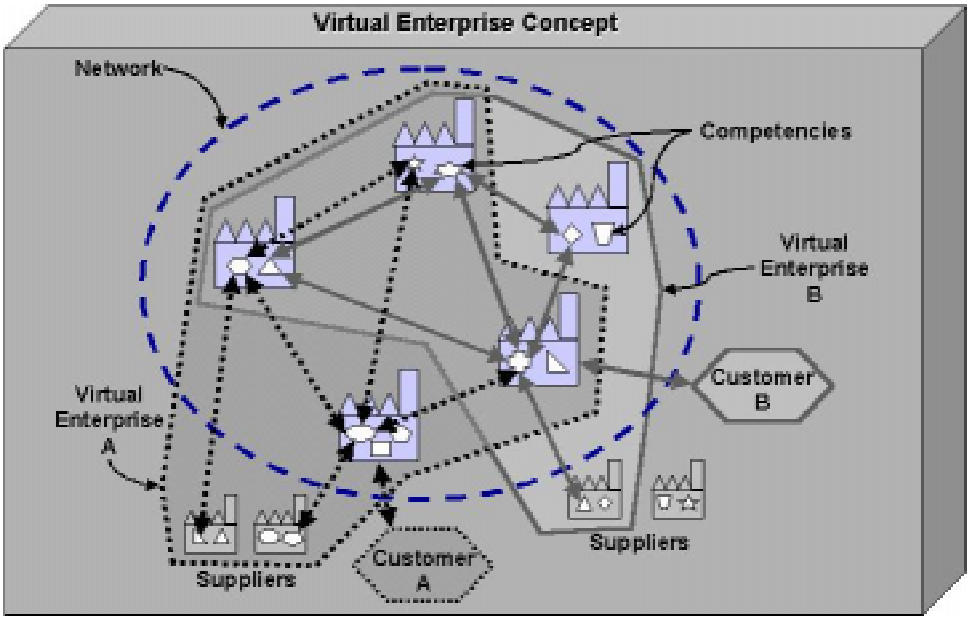

Figure 2 Enterprise Network and Virtual Enterprises

A Virtual Enterprise can be defined as a *"Customer solutions delivery system created by a temporary and reconfigurable ICT enabled aggregation of core competencies"* [2, 6]. Formation of the VE materializes through configuration of the core competencies and capabilities available in the network and possibly through inclusion of additional, required competencies provided by non-network participants, cf. Figure 2. Though being comprised by competencies from various partners, the VE performs as one, unified, and attuned enterprise. Hence its virtual nature. Accordingly, the business processes are not carried out by a single enterprise, but every enterprise is a node in the VE that adds some value to the product chain.

3.3 Virtual Enterprise Reference Architecture

The middle layer consists of the Virtual Enterprise Reference Architecture (VERA), which organises the virtual enterprise related generic concepts recommended for use in virtual enterprise engineering and integration projects (see Figure 3). It captures the essence of the GLOBEMEN view of virtual enterprises described in the bottom layer, and conceptualises it into a generic framework based on the entity life cycle concept and modelling architecture of GERAM [3]. VERA also organises other essential VERAM components, such as Reference Models, configuration tools, applications, and also some of the Contingency factors (standards and technologies).

In short, VERA illustrates the logical, recursive relationships between the network entity, the VE entity, and the product entity. Each of these three entities is represented by a life cycle describing possible phases an entity can be in throughout its life span from identification to decommission. VERA illustrates that the network can create VEs in its operational phase and, correspondingly, that a VE can create products and/or services in its operational phase. A central means for facilitating a fast and efficient set up and operation of VEs and hereunder a fast realisation of the product or service in the VE is through preparation. The generic and partial boxes in Figure 3 have been shaded indicating the location of general (thus reusable) parts such as e.g. reference models (RMs) in VERA. The remaining non-shaded boxes represent the particular entities containing instantiated RMs, commercial off-the-shelf components or self-developed components. Enterprises engaged in VE focused networks should determine which of the non-shaded boxes they would need and most importantly by what means (using available standards, RMs from other sources, and/or develop own RMs) [7]. The life cycle activities of the VE are prepared in the network phases up to and including implementation and set up in the operation phase of the network. The preparation in the network should address not only the set up but also the operation of the VE. This means that the network also should prepare the products or services created by the VE. Likewise the life cycle of the product or service can be further prepared (if needed) and subsequently created in the operation phase of a VE. Please note that a network can establish several VEs, just like a VE can produce several products.

Even though VERA implies a time progression from the identification phase to the decommission phase and from the network entity to the product entity, neither the individual life cycles nor the complete reference architecture express an explicit time dimension. Therefore, it does not describe the actual or planned life history of a virtual enterprise. Examples of life histories can be found in [8] and [9].

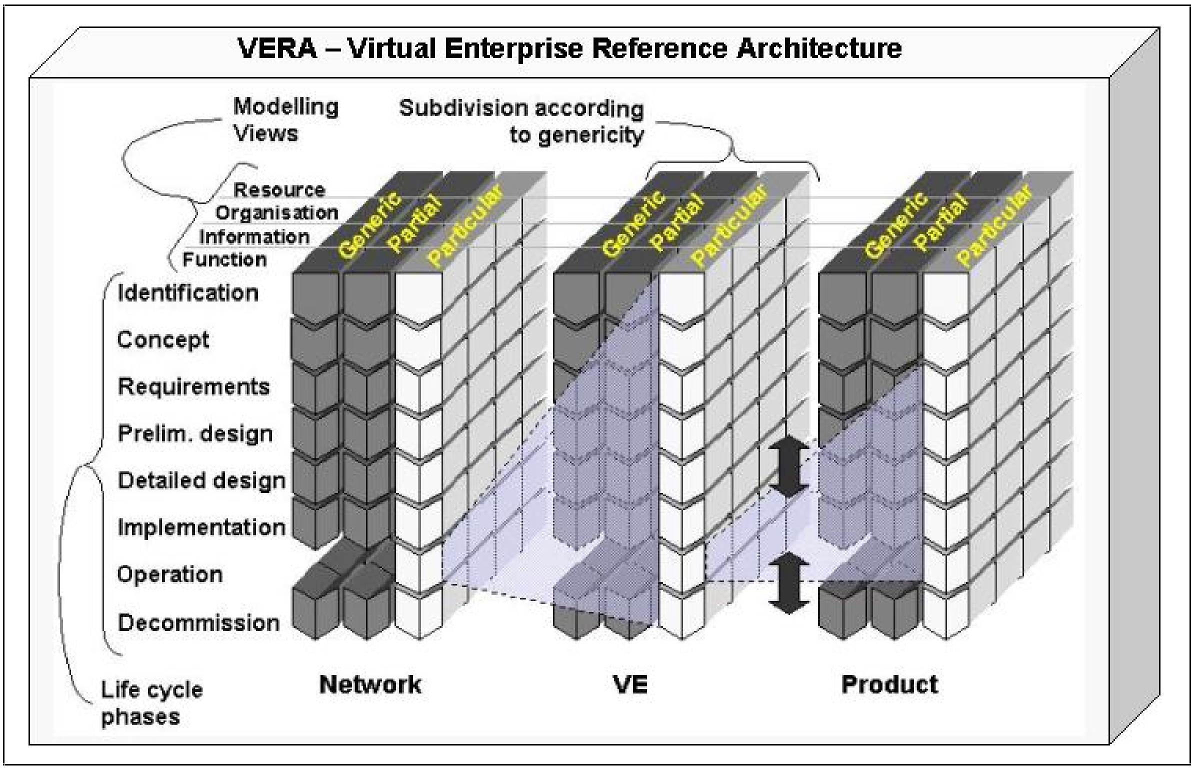

Figure 3 The Virtual Enterprise Reference Architecture

What is not shown in VERA is that the network is identified, set up as well as operated by enterprises. Each of the life cycle phases of the network is carried out by one or more enterprises, all of them being in their operational phase. Thus, all phases of the network are executed by 'real' enterprises, which are not shown in Figure 3. Likewise, when a network sets up and operates VEs, it is the 'real' enterprises participating in the network which set up and operate the VE which eventually creates the delivery to the customer.

For more information about VERA, please refer to [8]. Special cases of the Virtual Enterprise concept in VERA are the concepts of the 'Quotation Virtual Enterprise' and the 'Service Virtual Enterprise' [10]. Building upon the latter concept is another chapter in this book which describes an organizational and technical approach to how small and medium sized enterprises can improve and extend their future after-sales service business by setting up cooperation networks [11]. Within the scope of cooperations between one-of-a-kind producers, customers, service partners and suppliers, services can be offered in collaboration with local service partners or directly in interaction with the customer using tele-service and e-service applications.

3.4 VERAM components

3.4.1 Introduction

Finally, the top layer consists of the VERAM components that are used during the application of the architectural framework in practice. It consists of those tools, applications, models, and so on, that can be used during the formation and operation of VEs and enterprise networks. Please note that these components can be positioned in VERA as well, but they are shown in the top layer to indicate their mutual interrelations and their application in practice.

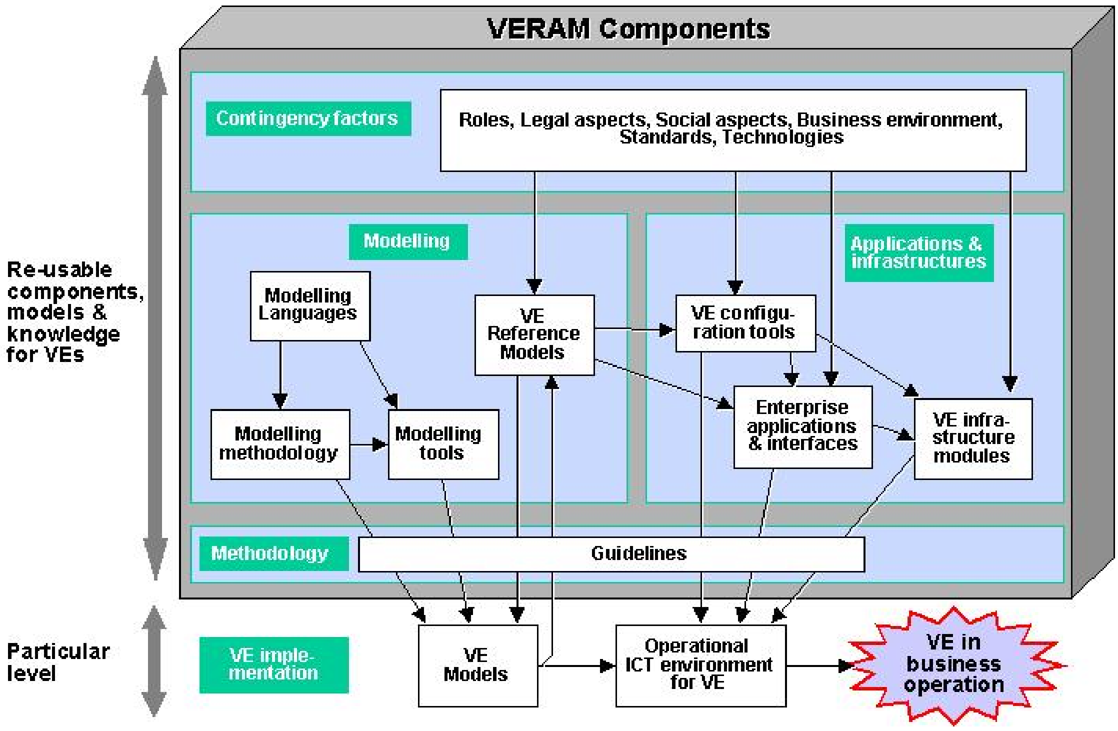

Figure 4 VERAM components

Perhaps the most important component in the top layer is the guidelines that indicate how the tools, applications, and models should be used in practice. Therefore, VERAM includes a methodology, which describes how an organisation should use the various components of the architectural framework during virtual enterprise engineering (see [9]). The guidelines should describe main procedures and considerations to apply for deciding how to get from the top layer VERAM components to the particular models and operational ICT environment for a specific VE, as a way to get to the actual business operation of the VE.

In the remainder of this section, the top layer VERAM components are described into detail.

3.4.2 Modelling

VERAM's modelling part allows enterprises to analyse, prepare and (re-)design the VE's business processes, partner roles, contracts, and so on. During the formation of a VE, but also during reconfiguration of an existing VE, enterprises may acquire knowledge of current business processes by means of modelling. This knowledge is needed in order to analyse the existing processes and communicate about them. Then, the models may be changed to take required modifications into account.

The definition of sound business processes, upon which the further design or selection of needed ICT tools and applications is based, is one of the keys to business process integration. Cooperation in virtual enterprises requires that a common understanding exists about shared business processes. Modelling languages are needed to make these business processes explicit. Main areas are modelling of data and modelling of processes.

Modelling Languages

(Enterprise) Modelling Languages define the generic modelling constructs for (enterprise) modelling adapted to the needs of people creating and using enterprise models. In particular, enterprise modelling languages provide constructs to describe and model human roles, operational processes and their functional contents [3].

Main classes of modelling languages are:

- Process modelling languages, such as SADT, OMT, Petri nets
- Data modelling languages, such as Entity-Relationship Modelling, Express
- Process and data modelling languages, such as IDEF, UML

Most enterprise modelling languages are generally applicable to inter-enterprise modelling as well but may require a specific modelling style in order to distinguish intra- and inter-enterprise issues.

Modelling Methodology

Modelling Methodologies support the modelling process by means of guidelines, which guide a user in making models. Modelling Methodologies are usually related to a specific Modelling Language and may be 'embedded' in a Modelling Tool.

Modelling Tools

Modelling Tools support the processes of enterprise engineering and integration by supporting modelling languages. Frequently, a kind of engineering methodology is implemented in a modelling tool as well. Modelling tools should provide for analysis, design and use of enterprise models.

Numerous modelling tools are available that support IDEF or UML modelling. In addition, well-known enterprise engineering tools exist, such as ARIS.

VE Reference Models

Reference Models (or Partial Models) capture characteristics that are common to many (virtual) enterprises within or across one or more industrial sectors. Thereby, these models capitalise on previous knowledge by allowing model libraries to be developed and reused in a 'plug-and-play' manner rather than developing the particular (VE) models from scratch. Reference models make the modelling process more efficient.

The scope of these models extends to all possible components of the enterprise such as models of human roles (skills and competencies of humans in enterprise operation and management), and operational processes (functionality and behaviour). Some authors consider models of technology components (service or manufacturing oriented), and infrastructure components (information technology, energy, services, etc.) to be part of reference models as well. However, in VERAM the latter two are positioned in Enterprise Applications and VE Infrastructure Modules respectively.

Reference models may cover the whole or a part of a typical (virtual) enterprise. They may concern various enterprise entities such as products, projects, companies, and may represent these from various points of view such as data models, process models, and organisation models. More information about reference models applicable for VEs can be found in [7].

The GLOBEMEN Reference Model focuses on the processes executed by an enterprise related to:

- participation in / management of an enterprise network,
- formation of a virtual enterprise, and
- operation in a virtual enterprise.

Figure 5 shows that the GLOBEMEN Reference Model consists of various types of models, ranging from $IDEF_0$ process models to UML implementation diagrams.

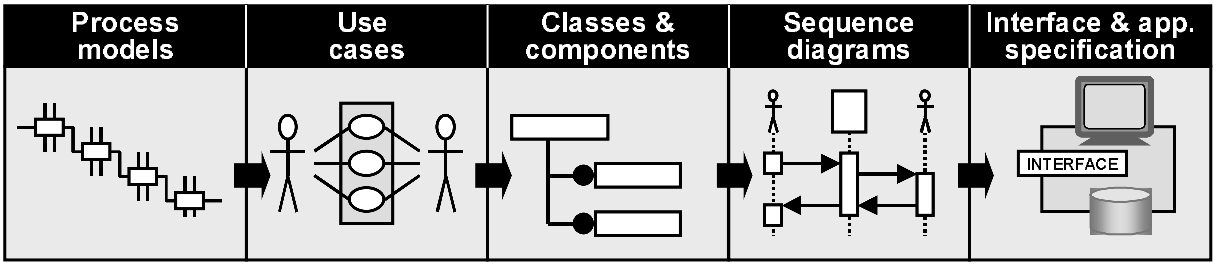

Figure 5 Types of models in the GLOBEMEN Reference Model

Other chapters in this book that deal with reference models are [12, 13, 14].

Bernus *et al.* propose a new approach based on intelligent agents to improve reference models for the management of virtual enterprises in general, and the GLOBEMEN reference model in particular [12].

In another chapter, Bernus *et al.* show the advantages of using tailorable reference models for virtual enterprise design and implementation [13]. They present a step-by-step methodology for designing virtual enterprises for after sales service. Their methodology includes the identification and concept development of the enterprise network as well as of its virtual enterprises. The management and service delivery processes are designed through customising the Globemen Reference Model.

Also in the after sales domain, Hartel *et al.* present a reference model for collaborative service and an industrial case study [14]. They introduces a model showing how future collaboration in after-sales services in the one-of-a-kind industry might look like. The proposed reference model is intended to provide a guideline to set up an inter-enterprise service enterprise based on the principles of the virtual enterprise.

3.4.3 Contingency Factors

The rationale behind having a set of contingency factors is that – like in many other fields – there are few, if any, simple and universal principles that explain virtual enterprises, and that there are few, if any, solutions that are applicable for all types of virtual enterprises. This does not mean that no valid general descriptions can be made, for instance about how to set up and operate a virtual enterprise. It does mean, however, that the VE concepts, tools, and guidelines must reflect situational or contingency conditions. That is, certain types of situations and environment speak for certain types of configurations and accompanying solutions such as applications and infrastructure.

The contingency factors distinguish between two types:

- **Situational factors**: conditions, which affect the set up of the VE-focused network, i.e. characteristics of the business environment, which is outside the control of the network and VE members.

- **Design parameters**: selected parameters, which describe different set ups for VE-focused networks, e.g. pre-qualification for the network, network management, etc. Thus design parameters are defined as the solution space in which the network can freely be decided.

For instance, the duration of the network could influence the level and type of preparation in the network – a longer duration implies a higher level of preparation. Similarly, the 'power balance' between the partners speaks for different types of design, e.g. a consortium with a dominant main contractor needs different role models and management structure than a more democratic partnership where the partners have a more similar size and power towards each other.

3.4.4 Applications and Infrastructure

The Applications and Infrastructure section contains the components that perform or support the business processes as described in the Modelling section. As such, they provide the (technological) realisation of these business processes. These Applications and Infrastructure Modules concentrate on the execution or support of the formation or operation of virtual enterprises and networks.

VE Configuration Tools

VE Configuration Tools are used to set up virtual enterprises. Different types of configuration tools may be identified such as platform configuration tools, project configuration tools, and contract configuration tools. These tools aim to set up a virtual enterprise quickly, based on proven business models, applications, and platforms. They use VE Reference Models, and define a configuration of Enterprise Applications and VE Infrastructure Modules.

Zwegers *et al.* propose an approach based on 'traditional' project management tools for the definition and management of relations in an enterprise network [15]. They introduce the concept of eXtended Relationship Management services. These services should be part of an integration infrastructure, and should be used for definition and management of inter-enterprise relationships.

Enterprise Applications

Enterprise Applications are either standard, commercial off-the-shelf systems or bespoke solutions, developed for a particular enterprise. In this context, we focus on the functionality provided by Enterprise Applications to join and/or set up a network, and to form and/or operate a virtual enterprise. Examples are applications for collaborative project management, distributed engineering, subcontracting, internal trade, certain knowledge management functions, and so on.

Enterprise Applications provide (parts of) the functionality that is outlined in the VE Reference Models. Therefore, mappings can be made between Enterprise Applications and VE Reference Models. In other words, the mappings indicate what business processes as defined in VE Reference Models are covered by what (standard, off-the-shelf, home-grown) Enterprise Applications.

Many other chapters in this book present examples of enterprise applications, showing the large diversity of prototypes developed within the GLOBEMEN project. These prototypes are shortly listed below.

Anastasiou and Tsagkas describe the AGORA prototype, which aims to support the management of information related to the pre-sales and marketing processes in an inter-enterprise environment [16]. It builds on the thesis that the efficient operation of a business network is based on the dissemination and exchange of partners' local knowledge and innovation, throughout the whole product life cycle, from marketing and implementation to operation and support.

Välikangas and Puttonen present a knowledge creation environment (KCE) and accompanying procedure [17]. They show the principles that can be applied in collecting, creating and using standardised information in power plant engineering. They conclude that the KCE is a promising concept to establish advanced support for information exchange between different parties in a VE. The KCE is seen as an enabler of VEs, where the major role is to harmonise data exchange between different parties in a VE.

An internet-based platform for distributed after-sales services building upon the concept of the 'Service Virtual Enterprise' is presented by Kauer *et al.* [11]. The E-Service Support System gives access to various main user groups in a service virtual enterprise (e.g. service centre staff, service technicians, service partners, and customers) via three communication channels (Internet Channel, a Point-to-Point Channel and an Intranet-Channel).

Fukuda *et al.* show an example of a novel type of application, namely a Web-based instruction system using a wearable computer [18]. That system uses web manuals and web applications as powerful tools for instructing complex work, for instance to be used in maintenance and repair activities.

Kamio *et al.* introduce a prototype of a remote maintenance system that was developed for a fertiliser plant in Indonesia [19]. They discuss an accompanying business model of collaborative after-sales services in the one-of-a-kind industry, and the advantages of utilising the proposed hosting services as well.

A method, tools and services to support the design for agile set up or agile renewal of manufacturing systems are shown by Mori [20]. He proposes Renewal Support Services based on a distributed object oriented model. These services provide good factory design support functions to reduce total lead-time of the re-design of shop floors in factories of global inter-enterprise networks.

Kimura *et al.* introduce an example of a manufacturing support system called 'ASSIST' – After-Sales Support Inter-enterprise collaboration System using information Technologies [21]. ASSIST does not only support maintenance services but also consulting services for manufacturing systems consisting of multi-vendor machine tools. In order to do this, the system enables inter-enterprise collaboration between engineering companies and machine tool vendors.

Various Manufacturing Execution System (MES) applications using the OpenMES framework are described by Okano *et al.* [22]. The OpenMES framework is an object-oriented application framework for MES in the assembly and machining industry. This framework is connected to a B2B framework which enables the realisation of – for instance – sharing production data within a supply chain.

Nishioka *et al.* introduce the SUPREME prototype that deals with dynamic supply chains for one-of-a-kind production environments [23]. It covers web-based virtual enterprise design and collaborative planning. The architecture contains an APS module, PSLX interfaces, and web-service client-server modules.

Van den Berg *et al.* launch a prototype for collaborative project management, called C-Project [24]. It allows main contractors to set up, manage, and control a virtual enterprise, and is based on the traditional project management tools described in [15] for the definition and management of relations in an enterprise network.

Finally, the GAIA-DEE (Global Advanced Information Application for Distributed Engineering Environment) prototype is described by Kawashima *et al* [25]. It is a Web-based application platform for integrating dynamic business activities and product life cycle information. GAIA-DEE offers a collaborative engineering solution for globally distributed companies.

VE Infrastructure Modules

VE Infrastructure Modules are used to enhance Enterprise Applications with VE specific functionality. An explicit distinction is made between an Enterprise Application and the enabling technology offered by an infrastructure upon which the Enterprise Application resides. If certain technologies are chosen for the Enterprise Applications to implement certain functions, some additional technology (i.e. its functionality is not defined in VE Reference Models) might be needed to enable a proper functioning of the first technologies. VE Infrastructure Modules thereby enable the execution of VE processes by Enterprise Applications.

Within GLOBEMEN, a seven layer architecture has been defined that covers the VE applications, VE infrastructure modules, and enterprise-specific applications [26]. In addition, an integration infrastructure has been defined that should be able to support the set up and operation of virtual enterprises [27].

Kazi and Hannus claim that information exchange (upload and download) in a VE setting should be done through links between enterprise systems and stored in a central repository which also supports specific VE services [28]. They identify three different inter-enterprise mechanisms for one-of-a-kind production, viz. file exchange, project servers, and links between enterprise systems.

Kazi *et al.* argue that relying on common standards is seen as a main instrument for information exchange between heterogeneous information sources and applications [29]. In industries such as construction where multiple partners share complementary competencies to deliver a unique product, information integration and exchange is being pioneered through the use of product data technology. Approaches are developed that rely on pre-populating product models with references to relevant best practices, and making the results available through multi-dimensional visual interfaces for use by different categories of end-users.

4. Discussion

The discussion focuses on two parts, namely on how the VERAM framework can be used for the integration of different enterprises into a virtual enterprise, and on the status of VERAM. Regarding the first part, a distinction is made between five levels of integration. Satisfactory integration at a lower level is necessary before integration at a higher level can be achieved. Over the years, the higher levels of the framework have become more relevant.

The lowest level of integration, physical integration, is needed to facilitate co-operating applications and enterprises. Relevant standards at this level of integration are TCP/IP and Ethernet. VERAM does not explicitly address these technology standards.

Application integration is concerned with the usage of ICT to provide interoperation between enterprise resources. Cooperation between humans, machines and software programs has to be established by the supply of information through inter- and intra-system communication. Application integration is split in two parts. Whereas semantic standards support integration at the level of 'meaning', syntactic standards are meant for integration at the level of 'form'. Syntactic standards enable sources and messages to have similar formats. Standards in this area are STEP Part 21, Java RMI, XML, Corba, and DCOM. Semantic application integration should result in a situation where the output of applications is meaningful to other applications. Examples of standards at this level are EDIFACT, STEP Application Protocols, RosettaNet, and BizTalk. Clearly, the Applications and Infrastructures part of VERAM deals with application integration.

Business process integration is related to the fact that integration in virtual enterprises requires a common understanding about shared business processes. Modelling languages are needed to make these business processes explicit. Examples of standards at this level are IDEF, Petri nets, UML, and so on. VERAM's Modelling part is concerned with business process integration. Even if cooperating enterprises speak the same language, they may not understand each other because their business processes may not be aligned. Modelling interactions between members in a virtual enterprise – for example by means of UML sequence diagrams – is a suitable tool to define and analyse aligned business processes. The internal processes do not have to be modelled; just the business processes 'at the interface'. Furthermore, the VE Reference Models are the appropriate means to get consensus among different partners in a VE about the business processes to be adopted, about the various roles of different partners, and so on.

The highest integration level, inter-enterprise coordination, is specific for supply chains and virtual enterprises, in short for all situations in which enterprises cooperate with other enterprises and coordination is needed beyond their boundaries. For this, dedicated guidelines for inter-enterprise coordination are needed, e.g. for partner selection, certification or inter-enterprise best practice definition, and so on. The guidelines within VERAM address these issues.

Regarding the status of VERAM at the end of the GLOBEMEN project, it is clear that some parts are more mature than others. The foundations, the bottom and middle layers, are relatively stable and mature, but the top layer might be elaborated upon as new insight becomes available. This is an ongoing process which should be continued beyond the GLOBEMEN project. The availability of reference models, suitable applications and infrastructures, and perhaps above all guidelines and methodologies are crucial to execute upon visions such as 'collaborative business'.

The VOSTER project continues the work started on VERAM [30]. Its four technical work packages address respectively concepts, modelling, technologies and standards, and infrastructures for Virtual Organisations. Although VOSTER does not explicitly consider an architectural framework, its activities are based on (earlier versions of) VERAM. VERAM will find an adequate successor for GLOBEMEN in VOSTER.

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