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Elements of a base VE infrastructure

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Abstract
The availability of a flexible and configurable base infrastructure is one of the main requirements for the practical implantation of agile virtual enterprises. An overview of current approaches and trends towards the establishment of such infrastructures is presented in this paper. Various example architectures from several international research projects are discussed. Also, the aspects of trust building and the formation of breeding environments, as an important basis for practical agile virtual organizations, are introduced. Finally a list of open challenges in terms of advanced infrastructures is included.

Keywords: virtual enterprise, virtual organization, breeding environment, infrastructure.

1. INTRODUCTION

A large number of research publications focus on the potential advantages brought in by virtual enterprises (VE) / virtual organizations (VO). Many recent proposals address more advanced dynamic, self-organizing cooperative networked organizations, suggesting the emergence of new business practices. The idea of highly dynamic organizations, that form themselves according to the needs and opportunities of the market, as well as remaining operational as long as these opportunities persist, put forward a number of benefits, among which the following can be emphasized:

- *Agility*: the ability to recognize, rapidly react and cope with the unpredictable changes in the environment in order to achieve better responses to opportunities, shorter time-to-market, and higher quality with less investment. The composition of a VE is determined by the need to associate the most suitable set of skills and resources contributed by a number of distinct individual organizations. When and if necessary, the VE can reorganize itself by adding / expelling some members or by dynamically re-assigning tasks or roles to its members.
- *Complementary roles*: enterprises seek for complementarities (creation of synergies) that allow them to participate in competitive business opportunities and new markets.
- *Achieving dimension*: especially in the case of small and medium enterprises (SMEs), being in partnerships with others allows them to achieve critical mass and to appear in the market with a larger “apparent” size.
- *Competitiveness*: achieving the cost effectiveness, by proper division of subtasks among cooperating organizations and timely response by rapidly gathering the necessary competencies and resources.
- *Resource optimization*: smaller organizations sharing infrastructures, knowledge, and business risks.
- *Innovation*: being in a network opens the opportunities for the exchange and confrontation of ideas, a basis for innovation.

The area of VE/VO is particularly active in Europe, not only in terms of research and development, but also in terms of the emergence of various forms of enterprise networking at regional level. This “movement” is consistent with the process of European integration, which represents a push towards a “culture of cooperation”, but also with the very nature of the European business landscape that is mostly based on small and medium size enterprises (SME) that have to join efforts in order to be competitive in open and turbulent market scenarios. But important activities can also be identified in other regions such as Australia, Brazil, Mexico, and Canada, in addition to the USA. Even Japan, whose cultural traditions privilege the long-term and trust-based relationships, is becoming more motivated to approach the challenges of the collaborative networks paradigm.

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However, in order to leverage the potential benefits of the agile VE/VO paradigm, there is a need for flexible and generic infrastructures to support the full life cycle of VE/VOs, namely the phases of creation, operation, and dissolution. Achieving such infrastructures is still a major challenge.

This paper tries to both summarize the state of the art and trends, and identify major challenges in the field from the technological point of view, based on the authors' experiences resulting from participation in various international projects. As such, aspects like the sociological and organizational implications of VE/VO are outside the scope of this paper.

The remaining of this paper is organized as follows. Section 2 addresses the traditional analysis and identification of the VE/VO requirements from the technological points of view. Section 3 presents evolution of two main support-infrastructure solutions for the identified requirements; namely the *layer-based framework approach* and the *agent-based framework approach*. Furthermore, both challenges and solutions in three specialized collaboration frameworks of: *Collaborative Engineering*, *Remote Supervision,* and *Virtual Laboratories,* are addressed. In Section 4 several new requirements are presented that have come up due to the implantation difficulties of VE/VO. This section introduces some recent solution approaches in form of breeding environments and *service federation frameworks*. Section 5 addresses the needs for further advances and concludes the paper.

2. THE NEED FOR A FLEXIBLE INFRASTRUCTURE

Although the advantages of the Virtual Enterprise are well known at the conceptual level (Goranson, 1999; Camarinha-Matos and Afsarmanesh, 1999), their practical implantation is still far from the expectations, except for the more stable, long-term networks applied to supply chains (e.g. automotive industry). Nevertheless, the potential agility of a VE in terms of fast reaction to business opportunities is certainly a very appealing feature in a scenario of fast changing market conditions. But the early phase of VE planning and creation, as well as several aspects of VE operation are still difficult and need to be properly adapted even by advanced and competitive enterprises. Some of the obstacles include the lack of common reference models and appropriate support tools, namely for: partners search and selection, VE contract bidding and negotiation, competencies and resources management, distributed task allocation, well-established distributed business process management practices, monitoring and coordination of task execution according to contracts, performance assessment, inter-operation and information integration protocols and mechanisms, etc. Further problems include the lack of common ontologies among the cooperating organizations, derivation of the information visibility regulations based on the contracts, the proper support for socio-organizational aspects e.g. lack of a culture of cooperation, the time required for trust building processes, the need for business process (BP) reengineering and training of people, etc. Support for VE dissolution is, so far, a subject almost absent from the large majority of research projects.

A large number of R&D projects tried to establish some technological foundations for the support of Virtual Enterprises /Virtual Organization (Camarinha-Matos and Afsarmanesh, 1999). Relevant examples can be found in the NIIIP program in US, the ESPRIT and IST programs in Europe (e.g. projects such as PRODNET II, VEGA, X-CITTIC, VIVE, etc.), or inter-regional cooperation programs such as the IMS (e.g. projects such as GLOBEMAN, GNOSIS, GLOBEMEN, etc.) and INCO (e.g. MASSYVE). A more extensive list, although not complete, of the VE/VO-related projects sponsored by the European Commission is shown in Fig. 1.

Many of these development efforts were concentrated on the design and development of infrastructures and basic VE/VO support functionalities. But only a few of these initiatives correspond to *horizontal developments*, aimed at establishing the base technology, tools and mechanisms, while most others correspond to vertical developments, addressing certain specific needs of specific sectors such as: cooperative design (collaborative engineering) in manufacturing, dynamic supply chain management in manufacturing and agribusiness, service federation in tourism, etc. Although it is natural that in the early phases of a new area, considerable effort is devoted to the design and development of the basic infrastructures, unfortunately this was not the case for the VEs. Furthermore, the lack of a common and widely accepted **reference model** and **infrastructure** is still forcing every vertical development project to design and implement its own mini-infrastructure, deviating some resources from its main focus, while generating something only applicable to that project. The ICT infrastructure is usually aimed at playing an *intermediary* role as an enabler of the interoperation among components. In this context, it is intended as the enabler for safe and coordinated interactions among the VE companies. Furthermore, and from another perspective, the integrating infrastructure should play the role of VE "operating system" or executor, hiding the details of the collaborative network "machinery".

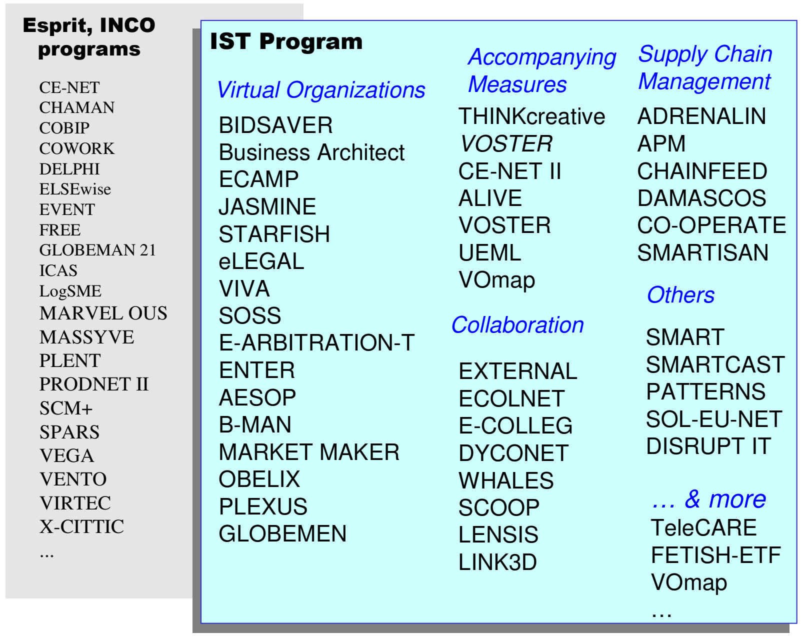

Figure 1 – Examples of European VE/VO projects

Emerging technologies: Are they enabling or inhibiting factors?

The emergence of a large and growing number of standards and technologies represent potential enabling factors, such as for instance:

- Open interoperable underlying network protocols (TCP/IP, CORBA-IIOP, HTTP, RMI, SOAP),
- Open distributed object oriented middleware services (J2EE Framework, CORBA Framework, ActiveX Framework),
- Information / object exchange mechanisms and tools (XML, ebXML, WSDL),
- Standardized modeling of business components, processes and objects (EJBs, OAG and OMGs Business Objects and Components),
- Business Process Modeling Tools and Languages (UML, UEML, WfMC XML-based Business Language, PSL),
- Open and standard business process automation and Workflow Management Systems (WfMC, OMG-JointFlow, XML-WfMC standards, many commercial products),
- Standard interfacing to federated multi-databases (ODBC, JDBC),
- Intelligent Mobile Agents (FIPA, OMG-MASIF, Mobile Objects),
- Open and standard distributed messaging middleware systems (JMS, MS-Message Server, MQSeries, FIPA-ACC),
- XML-Based E-Commerce Protocols (BizTalk, CBL, OASIS, ICE, RosettaNET, OBI, WIDL),
- Web Integration Technologies (Servlets, JSP, MS-ASP, XSL).

However, most of these technologies are in their infancy and under development, requiring considerable effort to implement and configure comprehensive VE/VO support infrastructures. In fact, even the most advanced infrastructures coming out of leading R&D projects still require complex configuration and customization processes, which are hardly manageable by SMEs. When infrastructures comprise components from different technologies and vendors, it is also difficult to determine which component (or tool provider) is responsible when something goes wrong with such complex systems. In general, there is a:

- Lack of effective approach to interoperability, regarding the software interoperation, and the information exchange / integration.
- Lack of standard definitions and mechanisms, and the fact that emerging solutions are all in preliminary stages, for instance in the areas of:
  - Definition of information / behavior semantics - Ontology of the concepts, Semantic/syntactic heterogeneity of legacy systems, Autonomy of organizations in their behavior and decisions making.
  - Workflow management and coordination of distributed business processes.

It is even the case that business functionalities for advanced cooperative organizations and related emerging behavior are not properly understood yet, which is also reflected in the lack of formal models and theories defining the VE/VO. As most R&D projects need to build their own infrastructure from scratch, limited resources in fact remain for the business functionalities definition!

In conclusion, setting up an infrastructure for VE/VO still requires a large engineering effort, which represents a major obstacle for the implantation of this new organizational paradigm. Furthermore, the fast evolution of the information technologies often presents a disturbing factor for non-IT companies. In order to leverage the potential benefits of the VE/VO paradigm, **flexible and generic infrastructures** need to be designed and implemented. *Flexibility*, usually understood as the capability of a system to rapidly adapt to different necessary processes, is a requirement to cope with the variety of emerging and evolving behaviors in collaborative organizations. *Generality* is another requirement to cope with the needs of different application domains. The infrastructure shall play the role of an enabler of the interoperation and integration among the various participants, which can be considered at various levels:

<u>Level 1</u> – Basic communications and information exchange, including safety, business transactions and technical information transactions.

<u>Level 2</u> – Application integration, supporting the interoperability among enterprise application tools running at different enterprises.

<u>Level 3</u> – Business integration, including support for distributed business process coordination.

<u>Level 4</u> – Teams integration, including facilities to support collaboration among professional teams composed of members from different enterprises / organizations.

It shall also be noted that new infrastructures induce new organizational forms, while emerging organizational forms will require new support infrastructures (a co-evolution principle).

3. TRENDS IN SUPPORT INFRASTRUCTURES

As a general requirement for an infrastructure to support a VE/VO, the involved organizations must be able to exchange, in a coordinated and safe way, a variety of information on-line, so that they can work as a single integrated unit pursuing some common goals, while preserving their independence and autonomy. It is also necessary to point out that legacy systems running at present enterprises were not designed with the idea of directly connecting to corresponding systems in other enterprises.

From the software engineering perspective, two of the main approaches that have been followed by the designers of new VE/VO infrastructures are the transaction-oriented layer-based and the agent-based infrastructures.

3.1 Transaction-oriented layer-based frameworks

This group includes infrastructure solutions that add a *cooperation layer* to the existing IT platforms of the enterprises. Inter-enterprise cooperation is then performed via the interaction (transaction-oriented) through these layers. Examples of this approach are early efforts in VE infrastructures, as represented by the NIIIP, PRODNET II (Camarinha-Matos and Afsarmanesh, 1999, Camarinha-Matos et al., 2001), or VEGA (Zarli and Poyet, 1999) projects, that aimed at designing open platforms to support the basic information exchange and coordination needs in industrial virtual enterprises. Most of these developments cover basically the integration levels 1 and 2.

In order to better understand the information exchange needs among enterprises, let us illustrate the some interactions between two nodes in a VE (Figure 2) by the following example in which Enterprise A needs to interact with a partner Enterprise B for the development of a specific product Part (Camarinha-Matos and Afsarmanesh, 1999).

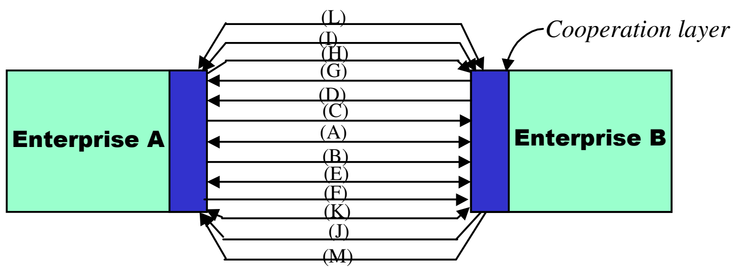

Figure 2 – Example of information exchange steps between two enterprises

For this example, let us consider a business process composed of the following steps:

1. Enterprise_A searches for a PART supplier;
2. Enterprise_A identifies Enterprise_B as a supplier;
3. Enterprise_A sends PART design to Enterprise_B; (C)
4. Enterprise_B and Enterprise_A interactively analyze the project, exchanging STEP models; (E)
5. Enterprise_A agrees with the design and sends a “design acceptance” to Enterprise_B; (F) 6. Enterprise_B sends proposal for the PART production; (G)
7. Enterprise_A evaluates the proposal and sends a “confirmation order” to Enterprise_B; (H)
8. Contract is signed and sporadic supply is planned; (A)
9. Enterprise_A generates an order entry and sends it to Enterprise_B; (B)
10. Enterprise_B sends an order-acceptance and project confirmation; (D)
11. Enterprise_A can request “production follow up bulletins” from Enterprise_B; (I)
12. Enterprise_B sends the product and releases documentation with product; (J) (K)
13. Enterprise_A receives and inspects the product;
14. Enterprise_A sends a “reception report” to Enterprise_B if any manufacturing problem is found in the product; (L)
15. Enterprise_A sends the invoice for payment. (M)

This example clearly shows the need to exchange business (EDIFACT) and technical (STEP) data. An adequate coordination functionality and interaction with the enterprise’s ERP/PPC and PDM systems are necessary in each enterprise in order to “guarantee” its proper participation in the VE-business process (the minimal functionality of level 2 integration).

On the other hand, safe communication is necessary to guarantee the privacy and authentication of the business interactions, and federated / distributed information management is necessary to support the information visibility rights and sharing of production status data. Considering more generic scenarios, other additional requirements listed below, can be identified.

As an example, the PRODNET infrastructure extends the functionalities of each VE member (represented by the enterprise applications such as ERP/PPC, PDM, CAD, etc.) with a ***Cooperation Layer*** responsible to handle all enterprises’ cooperation events. Central to this coordination kernel are a Distributed/Federated Information Management System (DIMS), a workflow-based Coordination Engine (LCM), and safe Communications Infrastructure (PCI). A library of support services (EDIFACT and STEP services) completes the Coordination Layer; see Figure 3.

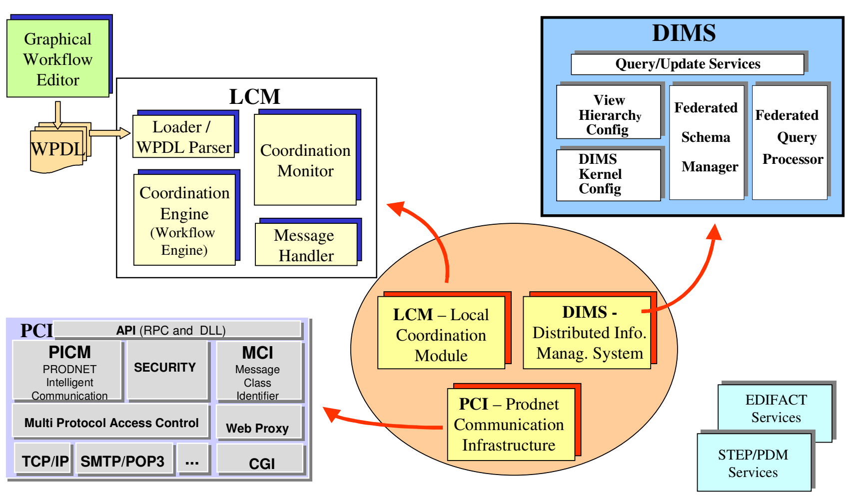

Figure 3 – Main components of the PRODNET infrastructure

Therefore, typical services for an industrial VE, as offered by the PRODNET platform, include:

- Exchange of commercial data via EDIFACT messages.
- Exchange of technical product data using STEP.
- Federated / distributed information management, supporting not only the administrative information about the VE, but also the information the enterprise shares individually with other VE members.

• Coordination module, handling all cooperation-related events (execution of a local activity flow plan).
• Configuration module, allowing the definition and parametrization of the VE and the behavior of each particular node.
• Safe communications, including cryptography services, digital signature, certificates, auditing mechanisms, etc.
• Monitoring of orders and production status.
• Quality related information exchange.
• Extended ERP/PPC system adapted to interact with a VE environment.

It shall be noticed that not all enterprises will be interested in all functionalities provided by the infrastructure. Therefore, PRODNET supports the capability that various functionalities can be enabled or disabled by an enterprise according to a set of configuration parameters. Thus, the behavior of the Cooperation Layer components either as single modules or as an integrated system can be configured to fit with the desired policies of the VE and each VE member. In fact, flexibility was identified in PRODNET II as one of the main design requirements when developing an infrastructure for VE in the SME context. The need for supporting the following factors can be pointed out as a justification for the flexible infrastructure requirement:

- Diversity of VE types and forms.
- Possible participation of a company in multiple VEs.
- Diversity of roles played by each enterprise in every VE.
- Diversity of internal management policies and socio-organizational structures found in each company.
- Proprietary information in enterprises / lack of trust requiring facilitation of access rights definition.
- Diversity of rights and duties associated to each VE member.
- Diversity of contract / subcontract forms and contents.
- Evolution of support technologies, safety mechanisms and the legal framework for electronic commerce.

This infrastructure was successfully tested with a comprehensive demonstrator system involving four enterprises, two in Europe and two in Brazil. The application area is the design and manufacturing of bicycles. The PRODNET infrastructure, and in particular its Cooperation Layer, was installed at each enterprise and the communications infrastructure was based on the Internet. In addition to the installation and configuration of the cooperation infrastructure, there was a need to integrate it with the enterprises' legacy systems, such as ERP / PPC and CAD / PDM. The developed infrastructure successfully proved to be flexible enough to support a number of collaboration scenarios and allowed the specification of different behaviors for different enterprise nodes, according to each enterprise's policies.

However, the large number of involved tools and technologies, each one requiring a specific configuration process, made the implantation process a non-trivial task in spite of the extensive configuration mechanisms provided with each module, and required the participation of experts with some level of knowledge about the multiple areas involved. In addition to the technological difficulties, there were other barriers coming from the socio-organizational side, which required a careful analysis and treatment of issues such as definition of new organizational structures, new roles and corresponding re-training of people, etc.

In terms of coordination of distributed business processes and specification of the local behavior of each node most of the early projects adopted a workflow-based model (in many cases following the WfMC reference architecture) (WfMC, 1994). Some developments have progressed further into the business integration level. For instance, in Klen et al. (1999) a prototype supervision system for distributed business processes (DBP) is described. The system includes some basic functionalities for:

- DBP monitoring: real-time information gathering from the BP executors (VE members).
- Conflict detection and identification of unexpected problems during processes execution.
- Reactive decision-making according to the conflict or conflicts detected.
- DBP control, offering a set of actions to be carried out in order to implement a selected decision.
- VE analyzer to provide an analysis of the VE operation and alternative solutions for BP distribution.
- Configuration, to define the rights and duties of the VE coordinator and VE members.

The developments around PSL (Process Specification Language) (Schlenoff et al., 2000), BMPL (Business Process Modeling Language) and ebXML (electronic business XML) (Busschbach et al., 2002) are expected to contribute to the needed common representation language for business processes. Nevertheless more research and standardization are needed in terms of representation (modeling), sharing, planning and execution of distributed business processes.

More recent developments have been evaluating diverse middleware technologies such as CORBA, RMI, EJB, Jini, etc. for the implementation of base infrastructures (Bernus et al. 2002; Beaune et al., 2002; Busschbach et al., 2002).

The concept of portal, sometimes incorrectly presented as the solution to all interaction problems in a VE, mostly corresponds to a web site that can in fact provide a limited solution for a particular need, namely for publicly available information sharing from a logically centralized repository.

3.2 Agent-based frameworks

This category includes those approaches that represent enterprises as *agents*, and the inter-enterprise cooperation as interactions in a distributed multi-agent system. Although at an abstract level there are similarities between agent-based and layer-based approaches, from the underlying technology / software development point of view they are quite different. We are assuming here an AI notion of **agent** as an encapsulated computational system, that is situated in some environment, and that is capable of flexible, autonomous behaviour in order to meet its design objective. There are nowadays a large number of development platforms for multi-agents systems (MAS), most of them based on Java. Some of these platforms, e.g. FIPA OS, JADE, ZEUS, follow the FIPA (Foundation for Intelligent Physical Agents) specifications and several of them are open-source.

There are a number of characteristics in the VE/VO domain that make it a suitable candidate for the application of multi-agent systems approaches (Camarinha-Matos and Afsarmanesh, 2001; Dignum and Dignum, 2002). Examples of such characteristics include:

- A VE is composed of distributed, heterogeneous and autonomous components, a situation easily mapped into MAS.
- Coordination and distributed problem solving also tackled by MAS are critical problems in VE management.
- Decision making with incomplete information, and involvement of network members as autonomous entities, that although willing to cooperate in order to reach a common goal might be competitors regarding other business goals, is another common point.
- The effective execution and supervision of distributed business processes requires quick reactions from enterprise members. Computer networks being the privileged media for communication, there is a need for each company having a “representative” in (or “listening” to) the network. Agents can support this need.
- Recent developments in VE are changing the focus from information modeling and exchange to role modeling, addressing aspects of distribution of responsibilities, capabilities and knowledge.
- The phase of VE formation in which it is necessary to select partners and distribute tasks, shows market characteristics and negotiation needs that have been research issues for years in the MAS community (coalition formation).
- A VE consortium is a dynamic organization that might require re-configurations – e.g. replacement of partners, changes in partners’ roles, etc., for which a flexible modeling paradigm is necessary.
- VE supporting functionalities need to interact with the “local” environment (legacy applications and humans). Interaction with the environment is one of the defining attributes of agents.
- The scalability property of MAS seems particularly adequate to support dynamic VEs in which different levels of cooperation with different sets of partners might be established at different phases. On the other hand, each enterprise might itself be seen as composed by a network of semi-autonomous entities (departments).
- More flexibility than in a client-server model is required to support dynamic change of roles of the VE members.
- Continuous evolution of business models, technologies, organizational paradigms, and market conditions require effective support for evolution and a high level of modularity of the infrastructures.
- New forms of teamwork, namely cooperative concurrent engineering or Virtual Communities of Practice (VCP), are emerging in the context of VEs. Agents can play an important role as “assistants” to the human actors in such environments.
- There is a need to handle the requirements of autonomy vs. cooperative behavior for which federated MAS approaches may provide a balanced solution.
- On the other hand, as agents are designed and developed independently, it is quite difficult to guarantee coordination unless common rules (“social laws” and standards) are adopted. Theoretical foundations on agents’ sociability can be combined with current developments of a legal framework for VE/VOs.

It shall be noted that in spite of these strong motivating elements, the application of MAS technology to VE/VO infrastructures is still limited to research projects.

Agents in VE creation. A growing number of research prototypes on the application of multi-agent systems and market-oriented negotiation mechanisms for the VE formation are being developed (Camarinha-Matos and Afsarmanesh, 2001). One such example can be found in Rocha and Oliveira (1999). This work assumes a *virtual market place* where enterprises, represented by agents that are geographically distributed and possibly not known in advance, can "meet each other" and cooperate in order to achieve a common business goal. A MAS-based architecture is proposed to model the electronic market to support the formation of the VE. In addition to the agents representing the enterprises, there is a market agent – coordinator or broker – that is created and introduced in the MAS community when a business opportunity is found. A multi-round contract-net protocol is followed: the market agent sends invitations to the electronic market corresponding to each of the VE sub-goals; receives bids and evaluates them; the most favorable ones are selected based on a multi-criteria mechanism and constraint-based negotiation. Examples of considered criteria are lower-cost, higher quality, higher availability, etc. Utility values are associated to each of these criteria and a linear combination of attribute values weighted by their utility values is used. Multiple negotiation rounds can take place. At the end of each round bidders receive indication whether their bids are wining or loosing and a rough qualitative justification, allowing them to change the parameters of their proposals.

A similar work is found in Li et al. (2000) where a more detailed analysis of the problem of goal decomposition, leading to a hierarchy of VE goals, is done. In addition to the enterprise agents and VE coordinator agent (broker), an information server agent is introduced to keep public information related to common organizational and operational rules, market environment, enterprises and products / services provided, etc. The need for a common ontology to support the communication among agents is explicitly introduced and a multi-attribute, constraint-based negotiation / selection process is implemented.

In Davidrajuh and Deng (2000) there is a proposal to use mobile agents that are sent to potential suppliers to check their competencies. These agents make an on-site broad selection (rough qualitative analysis), while a fine evaluation with the information brought back by them is then performed at the sender's place. As part of the selection process, an assessment of the partnership performance of the candidates, based on their history of cooperation, is also made. The work described in Shen and Norrie (1998) identifies the need for yellow pages agents that are responsible to accept messages for registering services (similar to the information agent server mentioned above). They also consider the concept of *Local Area*, a quasi-physical division of the network that can be controlled by a local area coordinator. This is a similar concept to the *Local Spreading center* first introduced by the HOLOS system (Rabelo and Camarinha-Matos, 1994).

These proposals are however limited by a number of factors which affect their practical implantation including:

- Lack of common standards and ontologies, a situation difficult to overcome in a general "open universe" of enterprises.
- None of these proposals takes into account more subjective facets like trust, commitment, successful cooperation history, etc.
- In general they pay little attention to the implantation aspects and the management of the yellow pages / market place.
- Security issues in the negotiation process are not addressed, a critical point as the agents (representing enterprises) are only partially cooperative (they might be self-interested, competitive, and even exhibit antagonistic behavior).
- The attempt to reach a fully automated decision-making process, although an interesting academic exercise, is quite unrealistic in this application domain.

Understanding the full VE/VO formation process, modeling it and developing support tools, are still open challenges. Initiatives such as UDDI or WSDL need to be considered in more practical MAS approaches.

A practical example of a MAS application to VE creation in the context of an industry cluster formed by twelve companies in the domain of moulds and die-casting can be found in Rabelo et al. (2000). The cluster is legally represented by a broker entity that supports a human expert responsible for getting and analyzing business opportunities. By means of a *broker agent* an opportunity is transformed into a distributed business process that is then distributed (through a contract-net protocol (Davis and Smith, 1983)) to the (potentially interested) enterprises within the cluster. In the end of the whole process, a set of possible teams of enterprises ("potential" VEs) that can carry out that business opportunity is formed and the most suitable team is proposed (but the ultimate decision is made by the human expert). Figure 4 illustrates the formation of a set of teams of enterprises within the cluster to attend a given distributed business process. In this example, there are three VEs capable of accomplishing the business process but VE1 was the selected team.

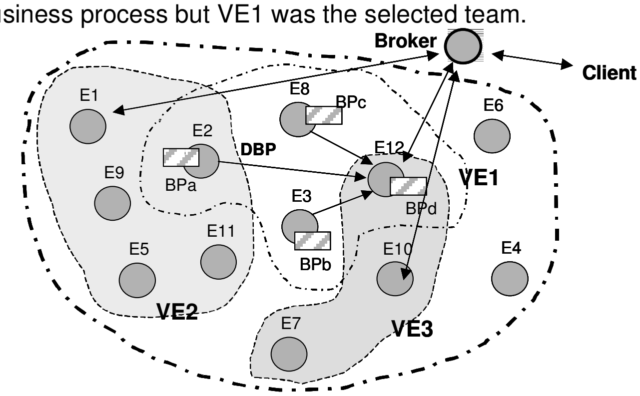

Figure 4 - Multiple VE hypothesis within a Cluster

One of the distinctive aspects of the MASSYVE approach is its hybrid / semi-automatic philosophy in which agents are used as human assistants. The fact that the MASSYVE approach is focused on clusters of enterprises, i.e., a controlled multi-agent universe, makes it a feasible solution from the implantation point of view, since a common modeling framework can be agreed upon and adopted by all members of the cluster.

Agents in VE operation. Early MAS applications to VE are mainly focused on the creation phase. In many cases it is assumed that simple mechanisms of inter-agent cooperation are sufficient to support the operation phase of VE. With deeper studies of VE application domains however this paradigm reveals many specific aspects that cannot be simply supported by basic MAS approaches. In the VE community interoperation / cooperation must be regulated by the following requirements:

- Cooperation agreements and contracts that establish a framework for the general operating conditions must be established.
- Distributed business process models and mechanisms that establish the allocation and sequence of tasks to be performed by the community must exist.
- Efficient data exchange and communication services, distributed service management functionalities, support for nodes autonomy / privacy, high level of service quality, auditability, and accountability, etc., have to be guaranteed.

A number of recent research works have addressed the issues of contract modeling and electronic contracting processes. For instance, in Angelof and Grefen (2002) a proposal for an **e-contracting** process model is presented. This process model covers both a function and communication perspectives and uses a set of rules to guarantee consistency of the e-contracting process. In Burgwinkel (2002) there is a proposal for XML-based contracts as a first step towards an IT-supported contracting process.

The decision-making in a VE is a complex process where it is important to combine human decision with some automatic functionalities. It is even likely that the level of automatic decision-making will evolve as the trust of humans in the systems increases. But independently of the ultimate decision making center, there is a need to provide mechanisms to support process coordination, supervision, and controlled information exchange and sharing.

As an example, MASSYVE (Rabelo and Camarinha-Matos, 1994; Rabelo et al., 1999), already mentioned, is focused on the support of agile scheduling functionalities for VE operation. The agent nodes represent either enterprises, when the scheduling problem is discussed at the VE level, or the internal manufacturing resources of the company when dealing with internal scheduling of tasks assigned within the company. The Contract-net Protocol coordination mechanism is used to support the task assignment among agents, and the Negotiation method is used to overcome conflicts taking place during planning or execution phases, both at intra-enterprise and inter-enterprise levels.

In the MASSYVE project an integration of MAS and federated information management is proposed. Each agent is enhanced with a Federated Information Management System (FIMS), through which it seamlessly interoperates and exchanges information with other agents. However, considering the autonomy of agents, the access to information is strongly controlled by the information visibility rights defined among them that in turn preserve their autonomy. Therefore, a MASSYVE agent is seen as a kind of tandem architecture composed of a “normal” agent and its FIMS. An essential concept introduced in this architecture is that the *data* elements are not sent from one agent to the other via a high-level protocol (e.g. ACL language), as in the traditional *push* strategy case, but rather through a *pull* strategy, via accessing to the respective agents' FIMSs. Thus, the high-level protocol is only used for the control/coordination purposes.

Figure 5 illustrates this approach. Consider an example case where a given agent (B) processes some information and generates some results (for example the "actual end of the production date for a part P and its termination status") that are needed to be accessed by another agent (A), according to some predefined *supervision clauses* specified in the VE's contract. Following the contract, then B sends a message to A (represented by "1" in this Figure), communicating that the data item on "part P's actual end of the production date" is at this enterprise. This control message sent from B to A informs A that now this data item is available and can be accessed by A (through its FIMS' *import schema*). Please notice that the access rights for the shared data among nodes are dynamically and bilaterally configured and preserved by their *import/export schemas* according to agents' roles in the collaboration and their needs.

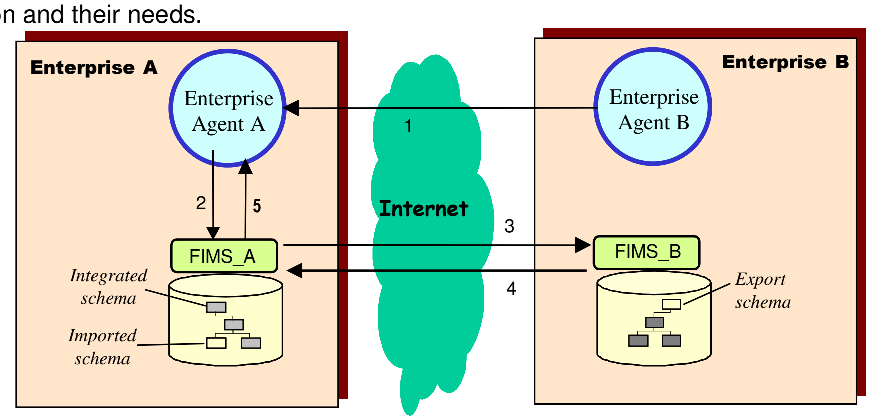

Figure 5 - Exchange of data in a *pull* strategy.

Once this notification message is received at A, whenever A wishes it can retrieve this updated information from B. In fact, this access goes as follows: Agent_A queries this information from its own integrated schema in FIMS (represented by "2") requesting for the actual end of production date and termination status regarding part P; an automatic access will occur from FIMS_A to FIMS_B (represented by "3") using the federated mechanisms for information access – that receives and returns this authorized information from B (represented by "4"). This information is in turn returned from FIMS_A to Agent_A for its internal processing (represented by "5").

Furthermore in the general case, the federated query mechanism of FIMSs allows agents, for instance Agent_A, to query information from their integrated schema that might initiate several queries to different other enterprises, transparently collecting partial contributions that are finally assembled into a global answer from the FIMS to the agent. The actual information exchange among VE nodes may resort to a safe and secure communications layer as the PCI module developed in PRODNET II (Camarinha-Matos et al., 2001). The main advantages of this approach follow:

- The inter-agent message's content becomes shorter and leaner;
- Agents will always access the necessary up-to-date data from their sources, at the exact time the data are needed;
- Transparent and controlled access to distributed data is provided over the agents' network in an integrated method. In this way, the agents can concentrate their tasks on the reasoning and processing of information instead of the management of information;
- Data and control is totally separated from each other in the multi-agent interaction environment;
- The information access rights and visibility levels among agents can be defined efficiently (at the desired granularity level) and evolve dynamically using the federated information management system functionalities;
- VE agents can only access authorized data with respect to their current access right definitions so that agents' desirable autonomy is preserved in terms of their data.

DAMASCOS is another project that developed a multi-agent based infrastructure for managing distributed business processes, including real-time monitoring and supervision activities (Rabelo et al., 2002).

In spite of the positive arguments in favor of the use of MAS in VE, there are also some obstacles. MAS technology is still lacking some important characteristics that represent inhibiting factors for its application in real world VEs:

– Robustness of development environments.

- Easy interface with legacy systems.
- Security mechanisms and virus protection.
- Standards and common ontologies to support interoperability. FIPA, the de facto standardization organization in MAS, has not addressed yet the needs of VE/VO.
- Culture interchange between AI and BP communities.
- Realistic demo cases that help to establish best practices and facilitate acceptability of the technology.

Furthermore the technology still lacks other robustness facets, like proper support for persistence and easiness of universal agent identification. Restoring the situation when one node goes down, not only in terms of state, but also in terms of environment awareness and global agents identification is still a difficulty with most agent development platforms.

3.3 Specialized collaboration frameworks

Collaborative engineering. Once a VE infrastructure is available, more integrated cooperation forms (level 4 integration) can be supported. That is the case, for instance, of *concurrent* or *collaborative engineering* where teams of engineers, possibly located in different enterprises, cooperate in a joint project such as the co-design of a new product. A large number of computer supported cooperative tools are becoming widely available for synchronous cooperation. Some examples are teleconference, and chat tools combined with application sharing mechanisms. Considering the geographical distribution, the autonomy of the VE members, the local corporate cultures, and also the individual working preferences of the team members, it is likely that most of the activities will be carried out in an asynchronous way. In order to assure the proper progress in this loosely coupled environment it is necessary to implement flexible coordination of activities for these collaborative processes (level 4 of integration). It is very important to support:

(i) Sharing of information models, ontologies, and process models, describing the product model and its manufacturing process and the design/planning process itself. The requirement is not only for a bi-lateral exchange of information, but also for the establishment of shared spaces among the team members.
(ii) Provision of adequate visibility and access rights definition and management.
(iii) Coordination of (asynchronous) activities performed in different places by different actors.
(iv) Provision of notification mechanisms regarding major events in the design / planning process (e.g. conclusion of a step by one actor).

A number of recent projects in the European IST program are addressing some of these needs e.g. GLOBEMEN, E-COLLEG. The federated database paradigm represents a suitable approach to develop shared spaces with the appropriate mechanisms to specify and ensure the visibility levels and access rights as represented in the CIMIS.net project (Afsarmanesh et al., 1994). A flexible notification mechanism can also be implemented by combining the federated information management with a workflow-based coordination system (Camarinha-Matos et al., 1998).

In terms of coordination, several approaches to develop *flexible workflow* systems have been proposed (Heinl et al., 1999). In the case of processes mainly executed by humans, rigid forms of procedural control are not adequate. People like to keep their freedom regarding the way they work. Product design, like any other creative process evolves according to a kind of “anarchic” flow of activities. It is therefore necessary to support *loosely constrained* sets of *business processes*. Another aspect is the representation of *temporal interdependencies* among activities. For instance, in the case of the processes *Product Design* and *Process Planning*, although they can proceed with some degree of concurrency (i.e. process planning can start once a first draft of the product is made), *Process Planning* cannot finish before *Product Design* finishes. At least some details of the process plan definitely depend on the final commitments on the product model. One solution for achieving coordination flexibility was first introduced in the CIM-FACE system (Osorio and Camarinha-Matos, 1995) and later discussed for the context of virtual enterprises (Osorio et al., 1998). In this system, instead of rigid precedence rules, other types of relationships, inspired in the Allen’s temporal primitives, are possible: *start_before, finish_during, start_after, finish_after, do_during*, etc. Other constraints such as pre- and post-conditions can be specified. But additional coordination mechanisms can be supported by the use of a multi-agent approach.

Other related ideas aiming effective support to communities of people that collaborate in the framework of virtual organizations (**virtual communities**) are emerging in various sectors e.g. non-governmental care organizations (IST LENSIS project), small services (IST VOSS project), or elderly care (IST TeleCARE project) (Camarinha-Matos and Afsarmanesh, 2002).

Remote supervision. Advanced forms of cooperation mostly in the area of design and manufacturing require mechanisms to support a controlled “intrusion” of a company, for instance the VE coordinator, into the “territory” of its partners. An initial example of this “intrusion”, which is properly supported by the federated database paradigm, is the access to selected (authorized by the cooperation agreements) subsets of the information (for instance, the orders’ status, stock levels, etc.) (Klen et al., 1999). But this process may assume more extensive forms. Consider the case that a company wishes to “open a window” over the shop-floor of its partner to monitor the manufacturing process of the ordered parts and even have an interference on the shop-floor processes, i.e. supervise them from distance and in cooperation with the local people. Mobile computing also suggests new forms of tele-operation and tele-supervision of processes (Fig. 6).

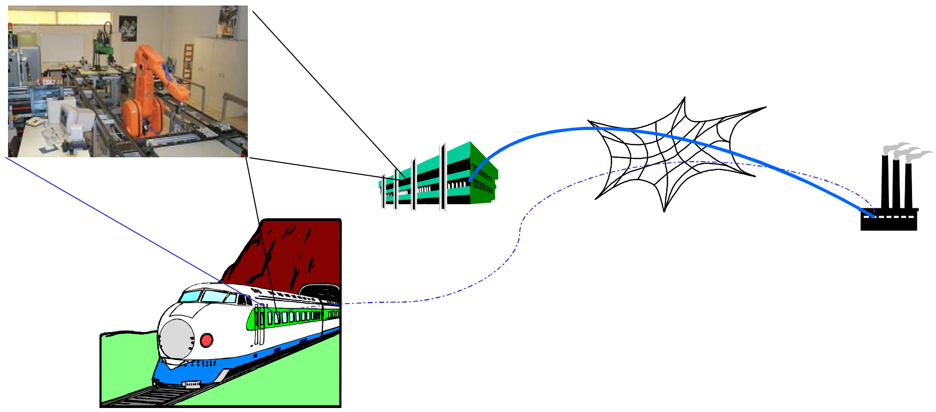

Figure 6 – Example of remote supervision

The design of a proper support system for collaborative remote supervision (CRS) – when the supervision process involves the collaboration of various actors, located at different remote places - can benefit from the contributions coming from a number of areas that, although conceptually close, are usually addressed by different communities of researchers with little interaction among them. The two main contributing areas to remote supervision are the Telerobotics and Virtual Laboratories. Furthermore, other areas of research and development contributing to CRS include the Virtual Reality, Virtual Organizations, and Computer Supported Cooperative Work.

The remote operation of machinery has been addressed for many years, mainly for security related applications. However, the Internet has been opening new opportunities for remote operation due to low costs and widespread availability, what makes it very appealing as a basis for remote operation. In fact several examples of connection of robots, cameras, and other devices to the WEB were implemented during the last years. Remote operation in manufacturing via Internet suffers however, from several problems: i) Internet is still characterized by long and irregular time-delays and very often, suffers from low levels of availability, raising new challenges in what concerns the reliability of the implemented system and its dependence on the characteristics of the network; ii) when complex application domains are considered, high levels of heterogeneity are expected in the availability of sensors and equipment at the remote places, which can degrade the flexibility and scalability of the system; and iii) the composition of the execution environments are potentially unstructured and unknown, which means that it is not adequate to resort to deterministically programmed systems. Complementarily, the increased use of wireless networking (mobile / ubiquitous computing) requires short connection periods.

In order to cope with the mentioned difficulties, an approach based on adaptive mobile agents was developed in the framework of the TeleCARE project (Camarinha-Matos and Vieira, 1999; Vieira and Camarinha-Matos, 2000). The mobile agents paradigm shows important advantages when remote manipulation and remote supervision are considered, since: i) moving the code to the places where the machines and sensors are located, contributes to enable close to real-time response, and so, the availability, delays and reliability of the network become less of a problem; ii) new mobile agents can be built and sent for remote execution whenever needed, thus greater flexibility and scalability is achieved. However, in order for the same mobile agent to be executed at several places, it must carry only a general action plan, which must be refined/adapted when the agent reaches every target place. Therefore, agents must be equipped with decision-making and plan refining capabilities, which allow them to, based on the abstract plans they carry, build specific plans suitable for execution in the particular environment of each site they reach.

In addition to the mentioned generic advantages of the mobile agents approach (Camarinha-Matos and Vieira, 1999), the remote supervision application can also benefit from the autonomy of the agents in order to not require a synchronous availability of the participants in different nodes as these participants can delegate to their agent representatives the actual realization of some task, which will be done when the necessary conditions are satisfied.

Virtual Laboratories and application of GRID infrastructure. Recent advances in networking, high performance computing and resource management have introduced new possibilities for secure communication and computation intensive resources management. The GRID (Foster and Kesselman, 1998) is a world-wide effort in this area, that takes advantage of the improvements in the overall network bandwidth, and adds a new dimension to the distributed computing. Through the GRID environment, a large number of workstations and supercomputers can be connected in an efficient way, offering users a vast amount of computational power.

The GRID infrastructure is promising for the Virtual Laboratory (VL) environments (DOE, 2000) supporting scientists and engineers with their complex collaborative experimentation. In particular for scientific purposes, where the research and academic institutes "*freely"* share all their resources, the GRID architecture and environment prove to be priceless. So far mostly addressing the scientific community, VL nodes in a network *register* themselves and become GRID nodes. The GRID-based nodes will then share their full computational and storage capacity, properly managed by the GRID resource management facility. As such, collaborating scientific nodes are supported by a close-to-standard communication infrastructure, empowering them with high-performance and/or high-throughput computing machinery, which is extendable with more resources, as other nodes join the GRID. Another advantage of using GRID for the scientific community is the possibility to share the free *published data* among the nodes.

There is already a huge amount of scientific data generated from experiments conducted world-wide in many areas, e.g. biology, physics, medicine, astronomy, etc. Through the GRID-based virtual laboratory, scientists will be able to access an environment in which data producing equipment are connected to the computation, storage, and visualization centers, which are usually not located on the same site. Furthermore, connectivity from huge science laboratories such as CERN, or huge databanks such as public GENBANK, to other research and academic institutes becomes feasible.

However, the development of communication infrastructures such as the GRID architecture and the supporting GRID middle-ware (e.g. the GLOBUS toolkit), are on going world-wide efforts which will not be completed any time soon. Therefore, although GRID is promising as a *foundation for networked organizations*, still many of its facilities are under the development, and in specific at its current state, GRID falls short of supporting the necessary base for collaboration among autonomous business-oriented organizations. Unlike the pure scientific research, many organizations are keen about their *autonomy* and their rights to both their proprietary data and local resources, as it is also required in most applications within the VE/VO paradigm. Therefore, GRID is so far mostly being used as a *partial infrastructure,* on top of which, depending on the application, other functionality is developed.

The ICES/KIS-II project VL-E (Virtual Laboratory for e-science) (Afsarmanesh et al., 2001; Kaletas et al., 2001) is one effort in this direction. The VL-E aims at the design and development of an open, flexible, scalable, and configurable framework providing necessary GRID-based hardware and software, enabling scientists and engineers in different areas of research to work on their problems via experimentation (a virtual scientific community), while making optimum use of the Information Technology. The VL-E provides a distributed high performance computing and communication Virtual Laboratory infrastructure with advanced information management functionalities, addressing in specific the experimentation requirements in the scientific domains of biology, physics, and systems engineering. As such, access to physically distributed data and processes among many sites in the virtual laboratory, that is necessary for the realization of complex experimentations, will be totally transparent to the scientists, giving them the image of working in a single physical laboratory (a special type of virtual organization). An architectural overview of the GRID-based VL-E is given in Figure 7. The Web-based portal and workbench interface together with the modular design of the VL-E architecture provides a uniform environment for all experiments.

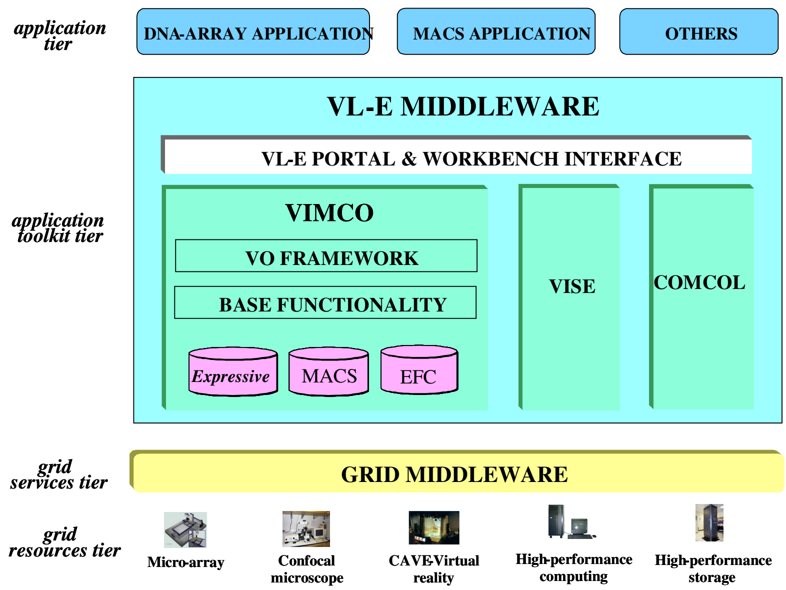

Figure 7 – VL-E architectural overview

The VL-E makes it possible to attach a wide range of software tools to the laboratory; from basic tools such as simulation, visualization, data storage / manipulation, to advanced facilities. The main functionalities of the VL-E middleware include: remote controlling of devices (COMCOL), visualization in a virtual reality environment (VISE), and federated advanced information management (VIMCO). The VL-E solves many technical problems that scientists face, hence enabling them to focus better on their experiments, while using the GRID infrastructure, simultaneously reducing the costs of experimentation by sharing the expensive resources among them.

Although VL-E is aimed at helping scientists during their experimentation, further extensions are required to properly support the interoperation and collaboration among diverse heterogeneous and autonomous organizations. Rules of cooperation must be defined and mechanisms to preserve the autonomy of the independent companies must be provided. Clearly, being involved in a "joint development" means having some rights (e.g. sharing information) as well as some responsibilities and liabilities (e.g. reporting of progress and/or problems) towards other organizations, in order to achieve the common goals. For instance, access rights to the local data of other organizations and the code of conduct (organizations' behavior) should follow the specific rules specified in a "contract". Reaching a common goal by the member organizations can only be achieved through the distribution of the "common tasks" into subtasks, in order to be executed by different organizations (a kind of distributed business process). Furthermore, the monitoring and coordination of activities are required to help the smooth process of activities and to identify possible obstacles and trying to resolve them.

The Virtual Organizations concept properly addresses these issues. Extending the VL-E environment by applying the VE/VO concept and infrastructures provides a strong infrastructure to support the requirements of scientists in the biosciences domain. Having the necessary infrastructure, the cooperating institutes and companies in our example can establish a Virtual Organization as represented in Figure 8.

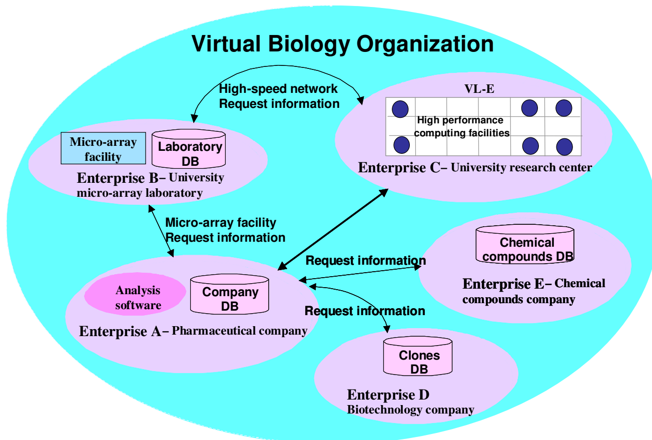

Figure 8 –Virtual Biology Organization

The VO support infrastructure contains a catalogue and a federated framework. The catalogue stores information related to enterprises and the VOs. The federated framework will provide the mechanisms to define access rights on the available resources (data/information, hardware/software resources, etc.) as defined within the VO contract and the enforcement of the contractual terms for task execution and monitoring during the VO life cycle.

3.4 Infrastructures summary

Fig. 9 summarizes the various levels of required infrastructures to support not only inter-enterprise collaborative networks but also more human-oriented networks, i.e. virtual communities of practice and virtual research communities that can emerge in the context of a VE/VO.

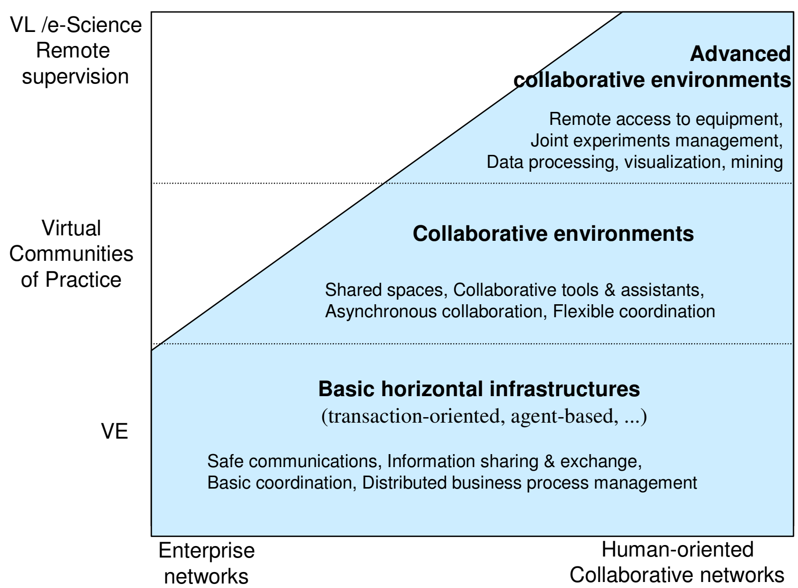

Figure 9 – Classes of infrastructures

Table 1 summarizes the key facets that can be found in both the two VE/VO horizontal infrastructures and the two specialized collaborative frameworks described in this paper. Some of the main limitations of current approaches are also indicated.

Table 1 – VE/VO infrastructures and collaborative frameworks – facets and limitations

Key facets	**Current limitations**
Transaction-oriented layer-based horizontal infrastructure	
❑ Safe communications - Cryptography, symmetric & asymmetric keys, digital	❑ No common reference model ❑ Need to integrate different technologies

signature, certificates - VPN ❑ Information sharing and exchange - Distributed/federated information management - Specification of access rights / visibility ❑ Workflow-based coordination ❑ Standards for exchange of some classes of information - EDIFACT, STEP - More recently XML based structures ❑ Various approaches for remote objects & services access - RPC, CORBA, RMI, EJB, Jini	(from different vendors) o Technical complexity o Unclear responsibilities ❑ Infrastructure is still complex, difficult to configure and poor interoperability ❑ Limited support for distributed business process management ❑ Lack of support for VE dissolution ❑ Limited mechanisms for tracking and auditing ❑ Poor support for breeding environments management

Agent-based horizontal infrastructure	
❑ Support for VE creation - Partner search and selection based on negotiation - Virtual market places and brokers - Preliminary steps towards e-contracting ❑ Some support for VE operation - Dynamic scheduling functions - Combination of inter-agent communication and federated information management - First steps in contract management	❑ There are many development platforms for MAS, namely some FIPA compliant (e.g. JADE, FIPA OS) but they are not robust enough when operating over Internet ❑ Security and persistence mechanisms are not yet well integrated with MAS ❑ Lack of integration between AI and BP communities (e.g. there is a need to integrate ACL with BP languages) ❑ Developments mostly at prototype level; real demonstration cases missing

VCP-support infrastructure	
❑ First steps towards “shared working spaces” ❑ Large number of “small” tools (e.g. chat, instant messaging, teleconference, CSCW) ❑ Some application sharing mechanisms ❑ First steps towards flexible workflow and asynchronous coordination of activities, notification mechanisms ❑ Basic VCP management	❑ Very limited integration of tools and mechanisms ❑ Limited coordination facilities ❑ No adequate VCP management for professional communities (Virtual Communities of Practice - VCP) able to capture multi-level relationships ❑ No integration of IPR issues in the VCP management services ❑ Limited support for mobile contexts

Remote operation / e-science support infrastructure	
❑ Various mechanisms to connect equipments to the web ❑ Application of mobile agents to increase autonomy and independence of network characteristics ❑ First attempt to use GRID as a general infrastructure for resources management ❑ Preliminary mechanisms for collaborative experiments management ❑ Specialized tools for data visualization and data mining ❑ First attempt for heterogeneous data integration for multi-disciplinary research	❑ No integration of access rights / visibility mechanisms ❑ The “business perspective” including intellectual property rights is not addressed yet in this context ❑ Lack of extensive and robust demonstration cases ❑ Poor understanding of cooperation processes ❑ Poor error recovery mechanisms

4. NEW EMERGING REQUIREMENTS AND SOLUTION APROACHES

4.1 Agility, trust building, and breeding environments

The agility and dynamism required for networked organizations is limited by the process of trust building. Even if flexible support infrastructures become widely available, the aspects of trust building and the required reorganization at the enterprise level are hard to cope with in cooperative business processes. “Trusting your partner” is a gradual and long process. The definition of “business rules”, contracts for VE/VO or even common ontologies also take time, especially when different business cultures are involved. In this sense, very dynamic organizations formed by enterprises without previous experience of collaborating together might be limited to scenarios of simple commerce transactions (e.g. buy-sell). Even in application domains such as tourism, for which the result of a collaboration process is the materialization of a value added service composed of the aggregation of simpler services, the open market model is not adequate, as the involved organizations need to first trust their partners due to the liabilities involved.

The creation of long term *clusters* of industry or service enterprises represent an approach to overcome these obstacles and can support the rapid formation of VE / VO according to the business opportunities (Camarinha-Matos and Afsarmanesh, 2001). The concept of cluster of enterprises, which should not be confused with a VE, represents an association or pool of enterprises and related supporting institutions that have both the potential and the will to cooperate with each other through the establishment of a long-term cooperation agreement. Buyer-supplier relationships, common technologies, common markets or distribution channels, common resources, or even common labor pools are elements that typically bind the cluster together. This is not a new concept as a large number of related initiatives have emerged during the last decades, namely in Europe and USA (Bergman and Feser, 2000). But the advances in information and communication technologies now bring new opportunities to leverage the potential of this concept, namely by providing the adequate environment for the rapid formation of agile virtual enterprises.

The more frequent situation is the case in which the cluster is formed by organizations located in a common region, although geography is not a major facet when cooperation is supported by computer networks. Nevertheless, the geographical closeness has some advantages for cooperation as it may facilitate better adaptation to the local (culture) needs and an easier creation of a "sense of community". But with the development of more effective communication infrastructures such long-term associations are not necessarily motivated by geographical closeness. Cultural ties, even particular human relationships are also motivating factors to form such associations which represent in fact the VE **Breeding Environments** (VBE) for the dynamic formation of VE/VOs. For each business opportunity found by one of the BE members, acting as a **broker**, a subset of the VBE enterprises may be chosen to form a VE for that specific business opportunity.

The enterprises involved in a given breeding environment are normally "registered" in a directory (part of a portal), where their core competencies are "declared". Based on this information, the VE initiator / creator can select partners when a new business opportunity is detected. Clearly, several VEs can co-exist at the same time within a VBE, even with some members in common. A VBE, being a long-term organization, presents an adequate environment for the establishment of cooperation agreements, common infrastructures, common ontologies, and mutual trust, which are the facilitating elements when building a new VE. The concept of breeding environment is evolving in parallel with the emergence of other forms of relationships, such as "virtual communities of practice" or "virtual research communities", representing a general trend to the emergence of a kind of "society of relationships".

A VBE does not need to be a closed organization; new members can adhere to the association but they have to comply with the general operating principles of the association. Similarly, for the formation of a VE, preference will be given to VBE members but it might be necessary to find an external partner in case some skills or capacities are not available internally. The external partner will naturally have to adhere to the common infrastructure and cooperation principles. In addition to enterprises, a VBE might include other organizations (such as research organizations, sector associations, etc.) and even free-lancer workers. The establishment and management of VBEs through adequate infrastructures represent therefore an important support for the creation of agile virtual enterprises (Fig. 10).

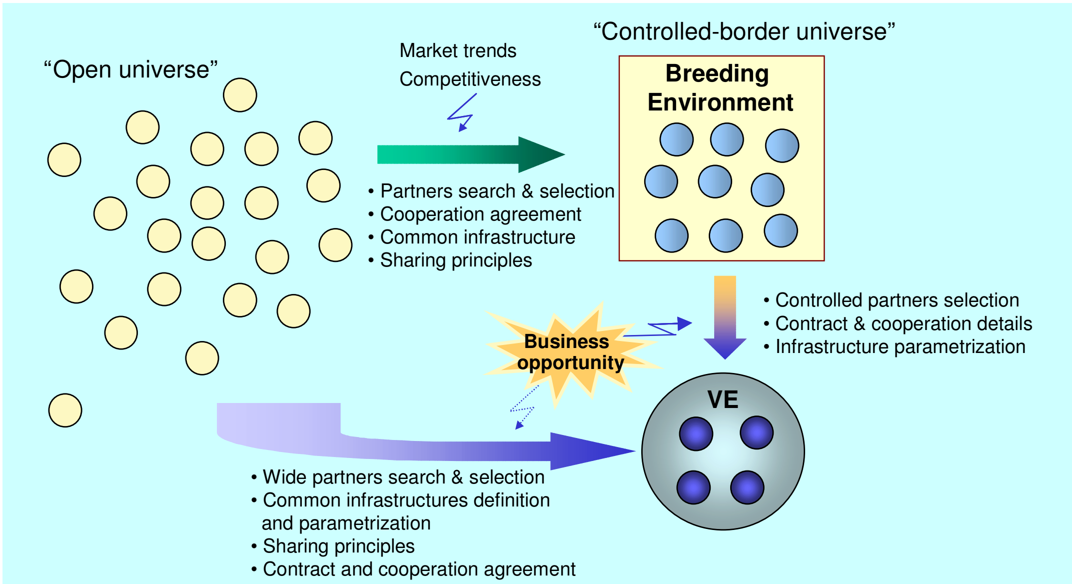

Figure 10 - Two approaches for VE formation

The idea of using a cluster as the basis for the formation of virtual enterprises has been identified in other research works such as the COSME/VIRPLAS (Molina et al., 1998) or VIRTEC (Bremer et al., 1999) projects. These projects have identified some of the major characteristics and needs of cluster management, but did not introduce the necessary IT infrastructure and support tools.

From a regional perspective, a well-managed VBE may offer the opportunity to combine the necessities of both "old" and "new" economies, and form a sustainable environment (local business ecosystem) leveraging and preserving the regional assets and culture. The VE breeding environment concept can support the exploitation of local competencies and resources by an agile and fast configuration of the most adequate set of partners for each business opportunity, and therefore extending the scope of intervention of manufacturing companies into the services area. Furthermore, the local VBEs can gather and empower a unique set of competencies tailored to regional culture and local customers' preferences, allowing a concerted offer of cooperation to global companies. In this way, members of the local industry cluster can play an important role in the customization and final assembly of products to local markets even though the basic components may be produced elsewhere. Therefore, in times of tough competition and market turbulence, the organization and effective management of the local industry or service enterprises, VBEs focused on the characteristics of SMEs, provide a promising approach for regional sustainability. In addition to the mentioned benefits of cooperation on dynamic VE/VO, there is also the opportunity to share experiences and costs in the learning process of introducing new IT within an industry cluster, and to reduce the risk of failure.

4.2 Breeding environment management functionality

Various projects have been contributing to the identification and definition of management functionality for breeding environments (Mejia et al., 2002; Harbilas et al., 2002; Camarinha-Matos and Afsarmanesh, 2001).

One of the obvious components of a management system is a directory where the VBE members are registered and their competencies / skills and capacities are declared. This directory, located in a specific node – the service promote node - is therefore a set of member profile records. Considering that competencies of VBE members are represented (to some extent) by services (service functions), this directory shall include a catalog of services (Fig. 11).

Due to the members autonomy (and legacy) there might be a large heterogeneity / diversity in the way services are implemented. However, in order to facilitate service selection ("shopping") and utilization, a common service interface needs to be agreed among the VBE members and, in case of legacy implementations service adapters have to be developed. Emerging standards such as UDDI and WSDL might contribute to the implementation of this concept. A service interface can be decomposed in two parts: service specification descriptor and service invocation wrapper (or proxy), i.e. a representative of the functionality of the service.

The service specification describes the characteristics of the service such as service name and identifier, service provider, version, functionality, I/O specifications, applicability conditions, access rights, etc. When a client is looking for a specific service in the catalog, the search criteria are expressed against the properties (attributes) of the service specification component. The service proxy, on the other hand, describes the programming interface of the service, that is, for instance the methods available, their parameters and return values, etc. It acts as a representative of the actual service, providing transparent access to the service by hiding the implementation details, such as remote invocation, security and communication mechanisms. A client (application) will get a copy of this proxy from the catalog, and through that will be linked to the application memory space to be used for the remote (transparent) invocation of the service.

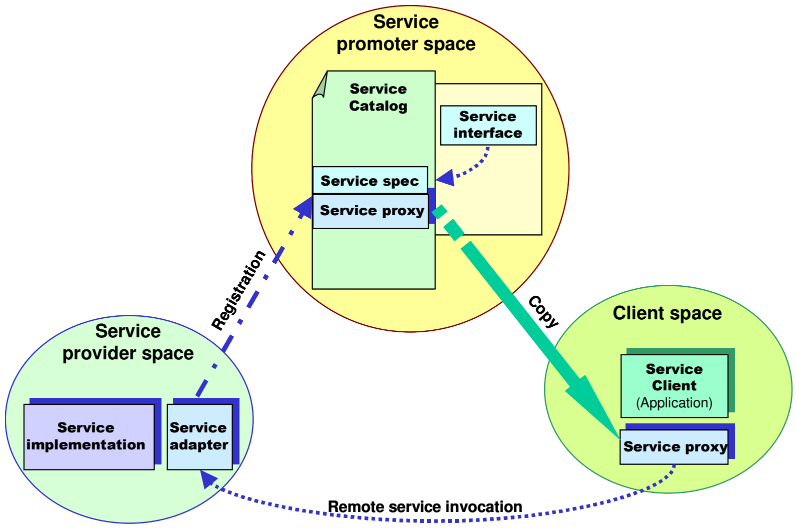

Figure 11 - Services registration and invocation

VBE members advertise their services by registering them in the cluster service catalog. Implementations based on multi-agent systems and service federation systems are being pursued in different projects.

It is important to notice that the same service type can have a number of different implementations, provided by different members of the VBE. However the common interface has to be guaranteed (by the service providers) in order to facilitate the identification and use of these independently developed services. For this purpose a common ontology and common functional interface rules have to be agreed among the VBE members.

It shall be mentioned that several VE projects have tried to adopt / combine different standards such as EDIFACT, STEP or UDDI in order to eliminate the ontological mismatch among members of a VE. However, in spite of these efforts it is difficult to have general-purpose solutions due to the fact that:

- for different classes of information handled in a cooperation process there are no common standards, considering the wide variety of information and the specificity of every new product and service developed in a VE; and e.g. quality-related information
- for the specific applications that EDIFACT or STEP can be applied, these standards cover a lot of detailed information, (wide application areas) and therefore for any practical application subsets have to be selected and agreed among partners.

Although difficult to be solved in general terms, the problem is more tractable in a smaller (closed) universe as the one represented by a VBE. Common rules and principles can be agreed by the initial members of the VBE and be included in the contract. Future members, in order to join the association, are required to accept those principles, as a part of their adhesion contract. As the VBE envisions a long-term relationship, in opposition to a single short-term cooperation opportunity, the required investment / adaptation may be affordable and give the VBE true agility whenever opportunities for cooperation arise.

The implementation of a harmonized representation of services in the service catalog does not necessarily mean that all members have access to all services all the time. Service providers shall keep their autonomy and the right to specify who and under which conditions, has access rights to their registered services. Therefore there is a need for an <u>access rights manager</u> component (Fig. 12) allowing the definition and validation of access rights. For example, a service provider can specify that a given service description is available for lookup only to a specific set of service requesters.

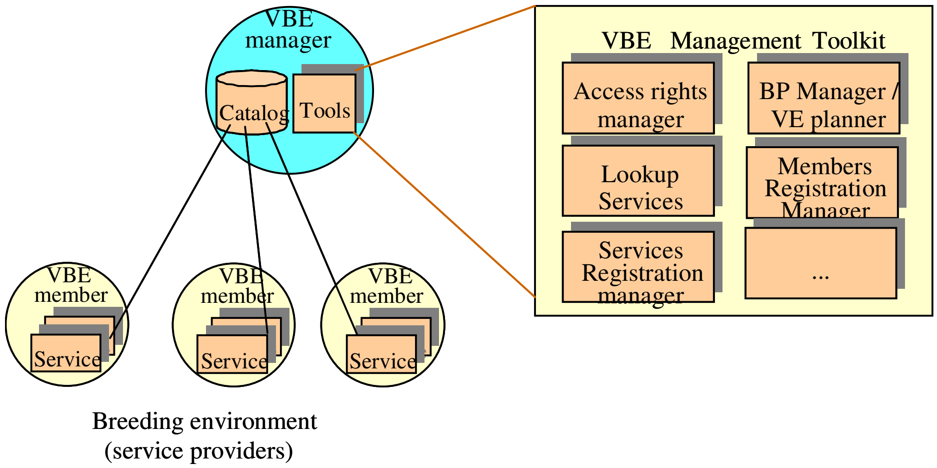

Figure 12 – VE breeding environment management functionalities

When a business opportunity is found by a member of the BVE, this member assumes the role of broker, or VE initiator. This broker will typically elaborate a plan of activities (as a business process – BP) that are required to satisfy the business goal. In order to perform these activities, the broker, using a BP manager component, may search and select a number of service methods from the catalog. When service methods are assigned to the various steps of the BP, this BP may in fact become a distributed BP, as different parts of the process are performed by different service providers. One example prototype following this approach is the PROMAN system (Camarinha-Matos and Afsarmanesh, 2001). The selection of a suitable set of service methods for a particular BP, in other words the creation of the VE, is a very important functionality that, in addition to the type of services required, has to take into account a number of other factors such as: performance history of the service provider (e.g. how reliable it is), compatibility (joint performance) between different service providers, visibility rules / access rights, and other specific requirements.

Therefore, the service catalog component shall offer intelligent **search** / **selection** / **filtering lookup** functionalities, based on the service attributes, to assist the activity of the broker.

Higher level services, or value added services (VAS), might be created by a composition of different low-level services available in the catalog. Therefore, a service provider might be as well a service client as well, since he can also look for and select services from the catalog to compose his VAS. A new VAS can be registered in the catalog in the same way as a basic service.

In addition to the basic elements described, there is a need for additional functionalities such as: a members certification function - to perform an assessment of partners and how they performed in the past cooperation relationships; and service assessment / certification function - handling issues such as reliability of the service, compliance with the common interface specifications, performance, addressing Quality of Service functionality; etc.

5. CONCLUSIONS - NEEDS FOR ADVANCED INFRASTRUCTURES

Considerable progress has been made in terms of design and development of infrastructures and support services for VE/VO, namely in the framework of many international research projects. Taking into account the current state of the art and trends in terms of new organizational forms / new ways of doing business, there is still a large number of challenging issues requiring further research as identified by the THINKcreative project, such as:

- Horizontal infrastructures. There is a prominent need to do further research towards the establishment of generic, interoperable, pervasive, free (low-cost) and invisible (user-friendly) infrastructures. Here, the key issues include: identification, design, and development of required base reference architectures and innovative approaches to advanced federated / distributed information management, interoperability mechanisms and tools, distributed activity coordination and languages, and integration of legacy systems, inter-domain transactions, recovery mechanisms, tracking and auditing services, among others.
- Breeding environment management and VO creation. Important challenges include: Management of VO breeding environments (e.g. regional clusters), VO creation frameworks, trust and regulation of electronic support institutions (e.g. e-notary and certification services),

modeling and management of contracts and cooperation agreements, negotiation, methodologies for transforming existing organizations into VO-ready organizations, etc.

- Collaborative networks operation support. Key areas requiring urgent attention include: Coordination, administration and management of highly distributed activities, risk management and assessment tools, development of value added-services, dynamic evaluation of revenues, rights and liabilities, in combination with the understanding of new value systems, soft-modeling and reasoning, e-contract management, advanced simulation tools for collaborative networks, and new user interfaces seeking an entertainment facet as a way to overcome cultural barriers.
- Support VO evolution and dissolution. Examples of key research challenges include: Definition of legal and organizational frameworks for terminating cooperation processes, mechanisms for handling post-cooperation IPRs and liabilities, and traceability mechanisms.
- Virtual Laboratories (VL) and remote supervision. In addition to the generic infrastructure needs, further issues include: Coordinated and dynamic resource sharing for collaborative problem solving, high-performance data integration, tele-supervision and tele-operation assisted by intelligent mobile agents, facilities for definition of information and services access rights and visibility levels, representation languages for cooperation formalization, social aspects of remote collaboration, support for asynchronous cooperation and delegation, extended error recovery, training methodologies based on VL for manufacturing professionals, new integrated and comprehensive methodologies for shop-floor reengineering, combination of re-engineering and remote supervision approaches.
- Virtual Communities (VC) and Virtual Communities of Practice (VCP). Require additional aspects such as: Development and management of shared, smart spaces for geographically distributed teams, understanding and modeling multi-level relationships in contract-bound communities, coordination and notification mechanisms, frameworks for collaboration in mobile contexts, and mechanisms to handle Intellectual Property under social contracts.

The development of such functionalities cannot be separated from the socio-economic, organizational, and business models issues. Therefore, a stronger emphasis on multidisciplinary research is necessary in this field. Of particular importance is the recognition of the role that can be played by VE breeding environments in the formation of truly agile virtual enterprises.

One of the main weaknesses in the VE/VO area, which prevents a proper understanding and also its recognition as a scientific discipline, is the lack of appropriate theoretic definitions, consistent specification paradigms and formal modeling tools, in order to concisely describe its static and dynamic facets. It is therefore urgent to launch fundamental research on theoretical foundations and identification of suitable formal modeling approaches that better facilitate the definition / characterization of collaborative organizations. Examples of topics of interest here include: formal theories, graph theory, normative models, visual modeling, theories of complexity, algebraic reference models, ontologies, multi-agent systems, game theory, emerging behavior in complex collaborative networks, modeling social aspects of collaborative networks: Social actors networks, soft modeling, simulation and experimental modeling, and models integration / models interoperability.

As a VE may involve members from different geographical regions, even in different continents, there are obvious advantages in aiming a wider standardization of the basic levels of the infrastructure. To achieve this goal, there is a need to identify the basic level of functionalities that are needed to become common practice, defining a reference model, which also motivates a more global international cooperation. At present, solutions developed for one particular region, are not necessarily easily adaptable to other regions due to the many technological, legal, cultural, and business practice differences.

In order to contribute to the harmonization effort among multiple VE-related activities, several initiatives such as: the IFIP TC5 project COVE (Co-Operation infrastructure for Virtual Enterprises and electronic business) whose objective is the creation and operation of a cluster / forum of participants and projects active in the field, or the European THINKcreative and VOSTER networks of experts might play an important role.

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6. REFERENCES

1. Afsarmanesh, H., E. C. Kaletas, A. Benabdelkader, C. Garita, and Hertzberger, L. O., 2001, A reference architecture for scientific virtual laboratories, Future Generation Computer Systems, 17.
2. Afsarmanesh, H., W. Wiedijk, A.C. Ferreira and N.P. Moreira, 1994, Distributed Database Support for a Concurrent Engineering Environment, Journal of Studies in Informatics and Control, 3(2-3), 135-143, IC Publications, Romania.
3. Alzaga, A. and J. Martin, 1999, A design process model to support concurrent project development in networks of SMEs, in: L.M. Camarinha-Matos, H. Afsarmanesh, eds., Infrastructures for Virtual Enterprises - Networking Industrial Enterprises (Kluwer Academic Publishers, Boston).
4. Angelov, S. and P. Grefen, 2002, Support for B2B e-contracting – the process perspective, in: V. Marik, L. M. Camarinha-Matos, H. Afsarmanesh, ed.s, Knowledge and Technology Integration in Production and Services (Kluwer Academic Publishers, Boston).
5. Beaune, P., F. Biennier and E. Marcon, 2002, A guideline to organize communication infrastructure for alliances of SME, in: L.M. Camarinha-Matos, ed., Collaborative Business Ecosystems and Virtual Enterprises, (Kluwer Academic Publishers, Boston).
6. Bergman, E. M. and E. J. Feser, 2000, Industrial and regional clusters: Concepts and comparative applications, www.rri.wvu.edu/WebBook/Bergman-Feser.
7. Bernus, P., R. Baltrusch, J. Vesterager, M. Tolle, 2002, Fast tracking ICT infrastructure equirements and design, based on enterprise reference architecture and matching reference models, in: L.M. Camarinha-Matos, ed., Collaborative Business Ecosystems and Virtual Enterprises, (Kluwer Academic Publishers, Boston).
8. Bremer, C. F., A. Mundim, F. Michilini, J. Siqueira, L. Ortega, 1999, A Brazilian case of VE coordination, in: L.M. Camarinha-Matos, H. Afsarmanesh, eds., Infrastructures for Virtual Enterprises - Networking Industrial Enterprises (Kluwer Academic Publishers, Boston).
9. Burgwinkel, D., 2002, Managing contractual relationships in virtual organizations with electronic contracting, in: L.M. Camarinha-Matos, ed., Collaborative Business Ecosystems and Virtual Enterprises, (Kluwer Academic Publishers, Boston).
10. Busschbach, E., B. Pieterse, A. Zwegers, 2002, Support of virtual enterprises by an integration infrastructure, in: L.M. Camarinha-Matos, ed., Collaborative Business Ecosystems and Virtual Enterprises, (Kluwer Academic Publishers, Boston).
11. Camarinha-Matos, L. M. and H. Afsarmanesh, 1999, Infrastructures for Virtual Enterprises - Networking Industrial Enterprises (Kluwer Academic Publishers, Boston).
12. Camarinha-Matos, L. M. and H. Afsarmanesh, 2001, Virtual Enterprise Modeling and Support Infrastructures: Applying Multi-Agent Systems Approaches, in: M. Luck, V. Marik, O. Stpankova, R. Trappl, eds., Multi-Agent Systems and Applications, Lecture Notes in Artificial Intelligence LNAI 2086, 335-364.
13. Camarinha-Matos, L. M. and H. Afsarmanesh, 2001, Service Federation in Virtual Organizations, in: Proceedings of PROLAMAT'01 (Kluwer Academic Publishers, Boston), 7-10 Nov 2001, Budapest, Hungary.
14. Camarinha-Matos, L. M. and H. Afsarmanesh, 2002, Design of a virtual community infrastructure for elderly care, in: L.M. Camarinha-Matos, ed., Collaborative Business Ecosystems and Virtual Enterprises, (Kluwer Academic Publishers, Boston).
15. Camarinha-Matos, L.M., H. Afsarmanesh, C. Garita and C. Lima, 1998, Towards an architecture for virtual enterprises, Journal of Intelligent Manufacturing, 9(2).
16. Camarinha-Matos, L. M., H. Afsarmanesh, A. L. Osorio, 2001, Flexibility and safety in a web-base infrastructure for virtual enterprises, International Journal of Computer Integrated Manufacturing (Taylor & Francis, UK), 14(1).
17. Camarinha-Matos, L. M. and C. Lima, 2001, Cooperation coordination in virtual enterprises, Journal of Intelligent Manufacturing (Kluwer Academic Publishers, Boston), 12(2), 133-150.
18. Camarinha-Matos, L.M. and W. Vieira, 1999, Intelligent mobile agents in elderly care, Journal of Robotics and Autonomous Systems (Elsevier), 27(1-2).
19. Davis, R. and R. Smith, 1983, Negotiation as a Metaphor for Distributed Problem Solving, Artificial Intelligence, 20, 63-109.
20. Davidrajuh, R., Z. Q. Deng, 2000, Identifying potential supplier for formation of virtual manufacturing systems, in: Proceedings of 16th IFIP World Computer Congress 2000, Vol. ITBM, Beijing, China.
21. Dignum, V. and F. Dignum, 2002, Towards an agent-based infrastructure to support virtual organisations, in: L.M. Camarinha-Matos, ed., Collaborative Business Ecosystems and Virtual Enterprises, (Kluwer Academic Publishers, Boston).

22. DOE, 2000, Collaboratories, "http://www-unix.mcs.anl.gov/DOE2000/collabs.html".
23. Foster, I. and C. Kesselman, 1998, The Globus Project: A Status Report., in: Proceedings of IPPS/SPDP '98 Heterogeneous Computing Workshop.
24. Goranson, H.T., 1999, The Agile Virtual Enterprise – Cases, metrics, tools (Quorum Books).
25. Harbilas, C., N. Dragios, G. Karetsos, 2002, A framework for broker assisted virtual enterprises, in: L.M. Camarinha-Matos, ed., Collaborative Business Ecosystems and Virtual Enterprises, (Kluwer Academic Publishers, Boston).
26. Heinl, P., S. Horn, A. Jablonski, J. Neeb, K. Stein, M. Teschke, 1999, A comprehensive approach to flexibility in workflow management systems, in: Proceedings of Joint Conference on Work Activities Coordination and Collaboration, San Francisco, USA.
27. Kaletas, E. C., H. Afsarmanesh and L. O. Hertzberger, 2001, Virtual Laboratory Experimentation Environment Data Model, University of Amsterdam, Informatics Institute, Amsterdam, Technical report CS-2001-01.
28. Klen, A., R. Rabelo, M. Spinosa, A. Ferreira, 1999, Distributed business process management, in: L.M. Camarinha-Matos, H. Afsarmanesh, eds., Infrastructures for Virtual Enterprises - Networking Industrial Enterprises (Kluwer Academic Publishers, Boston).
29. Li, Y.; B. Q. Huang, W. H. Liu, C. Wu and H. M. Gou, 2000, Multi-agent system for partner selection of virtual enterprises, in: Proceedings of 16th IFIP World Computer Congress 2000, Vol. ITBM, Beijing, China, 21-25 Aug 2000.
30. Mejía, R. and A. Molina, 2002, Virtual enterprise broker: Processes, methods and tools, in: L.M. Camarinha-Matos, ed., Collaborative Business Ecosystems and Virtual Enterprises, (Kluwer Academic Publishers, Boston).
31. Molina, A., M. Flores, D. Caballero, 1998, Virtual enterprises: A Mexican case study, in: L. M. Camarinha-Matos, ed., Intelligent Systems for Manufacturing, (Kluwer Academic Publishers, Boston).
32. NIIIP. www.niiip.org.
33. Osorio, A.L. and L. M. Camarinha-Matos, 1995, Support for Concurrent Engineering in CIM-FACE, in: Balanced Automation Systems (Chapman and Hall, Boston).
34. Osorio, A.L., N. Oliveira, L. M. Camarinha-Matos, 1998, Concurrent Engineering in Virtual Enterprises: The extended CIM-FACE architecture, in: Proceedings of BASYS'98 – 3rd IEEE/IFIP Int. Conf. On Balanced Automation Systems, Intelligent Systems for Manufacturing (Kluwer Academic Publishers, Boston), Prague, Czech Republic.
35. Rabelo, R., H. Afsarmanesh and L. M. Camarinha-Matos, 2000, Federated multi-agent scheduling in virtual enterprises, in: E-business and Virtual Enterprises (Kluwer Academic Publishers, Boston).
36. Rabelo, R. and L. M. Camarinha-Matos, 1994, Negotiation in Multi-Agent based dynamic scheduling, International Journal on Robotics and CIM, 11(4).
37. Rabelo, R., L. M. Camarinha-Matos, H. Afsarmanesh, 1999, Multi-agent-based agile scheduling, Journal of Robotics and Autonomous Systems (Elsevier), 27(1-2).
38. Rabelo, R., L. M. Camarinha-Matos and R. Vallejos, 2000, Agent-based brokerage for virtual enterprise creation in the moulds industry, in: E-business and Virtual Enterprises (Kluwer Academic Publishers, Boston), 281-290.
39. Rabelo, R., A. Klen and E. Klen, 2002, A multi-agent system for smart coordination of dynamic supply chains, in: L.M. Camarinha-Matos, ed., Collaborative Business Ecosystems and Virtual Enterprises, (Kluwer Academic Publishers, Boston).
40. Rocha, A. and E. Oliveira, 1999, An electronic market architecture for the formation of virtual enterprises, in: L.M. Camarinha-Matos, H. Afsarmanesh, eds., Infrastructures for Virtual Enterprises - Networking Industrial Enterprises (Kluwer Academic Publishers, Boston).
41. Schlenoff, C., M. Gruninger, F. Tissot, J. Valois, J. Lubell and J. Lee, 2000, The Process Specification Language (PSL): Overview and Version 1.0 Specification, NISTIR 6459, National Institute of Standards and Technology, Gaithersburg, MD.
42. Shen W. and D. H. Norrie, 1998, An agent-based approach for distributed manufacturing and supply chain management, in: G. Jacucci, ed. Globalization of Manufacturing in the Digital Communications Era of the 21st Century: Innovation, Agility, and the Virtual Enterprise, (Kluwer Academic Publishers, Boston).
43. Smith, R., 1980, The Contract Net Protocol: High-Level Communication and Control in a Distributed Problem Solver, IEEE Transactions on Systems, Man, and Cybernetics, 29, 1104-1113.
44. Vieira, W. and L. M. Camarinha-Matos, 2000, Adaptive mobile agents: Enhanced flexibility in Internet-based remote operation, in: Advances in Networked Enterprises (Kluwer Academic Publishers, Boston).

45. WfMC, 1994, The Workflow Reference Model, Document Nr. TC00 - 1003, Issue 1.1, Brussels.
46. Zarli, A. and P. Poyet, 1999, A framework for distributed information management in the virtual enterprise: The VEGA project, in: L.M. Camarinha-Matos, H. Afsarmanesh, eds., Infrastructures for Virtual Enterprises - Networking Industrial Enterprises (Kluwer Academic Publishers, Boston).