Virtual Enterprise Research
State of the Art and Ways Forward

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Abstract

The paper reviews research on virtual enterprises within the concurrent engineering domain and concludes that the initial focus on engineering methodologies and supporting IT infrastructure is giving way to a more encompassing view, especially including engineering management aspects such as knowledge management, organizational design and legal aspects. This shift of focus makes CE an interdisciplinary research domain, which amongst others implies that new research methods need be adopted. Action research could be a candidate method for future CE research in the way it combines design oriented engineering research and analytical management research.

Keywords

Virtual Enterprise Research, State of the Art, Reference Models

1 Introduction

The Concurrent Engineering - Network of Excellence (CE-Net) has grown over the years to a strong European or even global community of researchers and professionals creating knowledge in the relevant domains of concurrent engineering methods, virtual enterprises as the organizational context in which CE is undertaken, and knowledge management (Bullinger and Gudszend, 2002), because engineers of course are knowledge workers.

In this paper we review the research on Virtual Enterprises (VE) that has been undertaken in CE-NET community in the past decade. There is broad consensus that VE enable high flexibility or agility where partners bring their long-term developed core competences into a short-term cooperation to pursue a business opportunity. Concurrent engineering is the method engineers have developed for cooperation across traditional organisational and firm boundaries. It therefore comes as no surprise that the CE-NET community has adopted the concept of VE, even to the extent that they redefined 'CE' from 'concurrent engineering' to 'concurrent enterprising'.

Currently therefore CE incorporates insights from a number of academic disciplines to complement the traditional body of the methodological knowledge on concurrent engineering. CE is an information technology enabled way of working (Antoniac and Pulli, 2001, Benzekri et al., 2001) and it therefore is no surprise that the initial research focus was on computer sciences and information systems to understand its underlying information technology (Teich et al., 2002). From a strongly engineering based research domain, the focus of CE today has much shifted into the engineering management domain, including legal aspects of cooperation across firm boundaries (Hassan, 2001; Mazzeschi, 2001; Minbo et al., 2002), and organizational and project management (Laurikkala et al., 2001) for leading large virtual cooperative ventures, e.g. in aircraft, car, or telecom application design. In short, the variety of knowledge and involved disciplines has increased so much that there is a need to consolidate and structure the hitherto achieved results.

The objective of this paper is to provide compendium and overview on virtual enterprise research within the ICE conference and the CE NET community that sponsors it. We will do so by reporting the findings of a comparative study of about thirty virtual enterprise projects. This

research has been made possible with funding from three European projects VOSTER, VOmap and ThinkCreative that were assigned to research the state-of-the-art, future scenarios, and a research roadmap for virtual enterprise research respectively. We will complement this view with a review of the papers on virtual enterprise research that were published in the ICE conference series during the last two years.

The review results show an emerging consensus in several domains of virtual enterprise research: first, three distinct structural types of virtual enterprises are distinguished on the basis of their network topology. Professional networks tend to have multiple peer-to-peer relationships and distributed management roles, while lead-contractor networks, e.g. in the construction industry are led by a hub firm in a central role (Pawar and Harding, 2001, Minbo et al., 2002). The third configuration are linear chain networks, e.g. in supply chain configurations. Although authors acknowledge that the network topology has impact on VE institutions, processes, and the most appropriate architecture for supporting IT systems (Schultheiss et al., 2002), so far there is little research in the design consequences for organizations and IS systems. However, there is increasing awareness that the simple adoption of traditional engineering approaches, like enterprise modelling and engineering, faces limitations and that more specific approaches are needed to capture the specifics of networked environments.

Second, consensus is emerging that most successful agile VEs rely on underlying long-standing relationships, such as a regional clustering, mutual manufacturing relationships or private contacts of the involved actors. The importance of such stable networks leads us to a number of yet to address research questions such as: Are long-term relationships a precondition of VE or limit the adoption of the VE-paradigm? Can relationships be incubated to facilitate the adoption of the VE-paradigm? What approaches would be effective in seeding and developing active, successful and long-term networks?

Third, most projects define necessary management roles for the creation and administration of virtual enterprises, which entails detailing what is generally called the broker function. There is unanimity that more research is needed to understand the broker role and to provide methods, tools and organizational frameworks for professionals undertaking this function.

A fourth conclusion concerns the methodology for future research in CE. While the focus has shifted from engineering to management, most research is still undertaken with engineering methods, especially the systems engineering approach, which is not the appropriate method for many of the management-related research questions. From this study, we offer the recommendation to develop and introduce new, CE adapted research methods and shortly present action research as one candidate, because it combines design oriented engineering approaches with analytical research approaches from social and management sciences.

The paper is primarily intended to benefit the CE-NET research and professional community. In the last decade CE-NET has matured to a veritable research community and the ICE conference has enjoyed continuous growth. The paper consolidates and integrates that knowledge to allow for baseline on that future research can build. This facilitation mechanism allows for innovation without repetition and confusion. This contribution is timely, as the third day of the ICE 2003 conference will be dedicated to discussing roadmaps for future research in the VE domain and can build on the baseline provided by this review.

The reminder of the paper is structured as follows. We continue with the survey findings of thirty VE projects and blend this with the review of ICE publications. We will then turn to conclusions of the survey and dedicate one section of the paper to introduce and motivate action research as a CE-NET research method. The paper will be concluded with a summary and bibliography.

2 Research Method

The twenty-nine projects listed in Appendix 1 have been selected from a larger list of several hundred funded projects on the basis of published abstracts in a first round. In the second round, short-listed projects have been approached with a questionnaire from which the listed projects were finally identified as relevant. All projects were asked to provide reports, deliverables, and publications as well as a survey form on key VE results from which the here presented analysis was undertaken. The authors know all project coordinators allowing for occasional phone interviews where clarification was necessary. The research was undertaken between Mai and November 2002.

In addition, the authors have reviewed all 40 papers from the ICE conferences 2001 and 2002, which contributed to the understanding of virtual enterprises or present new methods or tools for set-up, operations or other support to them. These papers represent almost a fourth of all contributions in 2001 and even more than a third of all conference papers in 2003 demonstrating the importance of the topic for the CE-Net community. Many additional papers, which were set in a general environment of distributed working or made a very narrow contribution with little relevance to virtual enterprise understanding were omitted. We have used the same criteria to evaluate these papers as for the general project review.

3 State of the Art in Virtual Enterprise Research

The survey shows emerging consensus, but also open issues in several domains of virtual enterprise research, which we will discuss in the following sections:

3.1 Three Types of VE Topologies

All VE or network models assumed in the projects, but also in the papers could easily be categorized into one of three network types that are determined by their topology, which defines the structure of information and material flows (Rupp, 2002), but also of power and governance relationships (Figure 1). In a supply chain topology, the partners' interaction pattern mainly follows a chain, while in star topology all partners interact with one central hub or strategic centre. In the third topology, partners show high peer-to-peer interaction between all nodes.

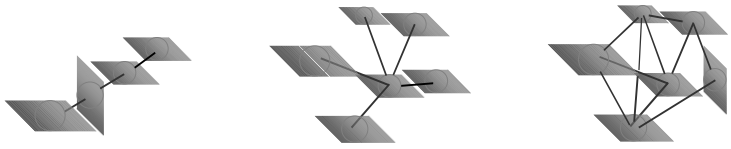

Figure 1: Topologies for virtual enterprises

Comparing projects revealed that supply chain topology projects assume the existence of very long-term partnership networks amongst the partner firms (Azarian et al., 2002, Fleisher, 2002), while projects that assume star topology networks allow for a more rapid reconfiguration of the partner network (Karcher et al., 2002). Again different were projects with peer-to-peer network topologies, which rely on personal networks and social relationships (Katzy and Ma, 2002) to a much higher degree than the other two network types, which primarily work on firm level.

However, about a fourth of the sample did not make an assumption of a VE model or at least did not show any awareness for the relevance of such model. And although the configuration has impact on institutions, processes, and the most appropriate architecture for supporting IT

systems, the majority of projects and papers using a reference model has not reflected much on the most appropriate design of the different elements.

Mechanisms of change that are necessary within any partner network to allow for rapid configuration are also not yet researched. This could be one reason for the low observed rate of operating virtual networks to which the research projects had access and the reported very low adoption of developed methods and tools. Only four projects provided answers about the size or growth of the underlying network, with one research project assuming that un-limited growth of the network is possible, while answers from the construction industry estimated feasible growth to be under 10% a year. More research is needed to clarify the impact of network structures on the (intended) agile behaviour of the VE.

3.2 Underlying Networks versus Operative VE Projects

Despite the fact that flexibility and short-term cooperation is the focus of all VE projects, 70% of the projects and papers make explicit or implicit reference to the existence of a more stable underlying network of companies or individuals for example to select project partners (Leppälä, 2001). We found this in stark contrast to the fact that only very few projects later include the network in their solution, or even model it (Sihn and Heeren, 2001). In all cases, a difference is made between the network and the operations or projects within (Wagner and Edelmann, 2002). Operative VE projects and networks are dealt with in a closely related manner in most projects assuming the star topology network (Yang et al., 2001). In supply chain networks the question of flexibility is already discussed in more detail, when very short-term in-/outsourcing decisions are distinguished from medium-term life cycle partnerships or long-term preferred supplier relationships (Stevens et al., 2002). Peer-to-peer network typologies often explicitly mention the role of long-term (personal) networks as an essential requirement for any short-term action.

Changes in the composition of operative projects in peer-to-peer and star topology networks were found to depend on several distinct factors. Projects, for example, distinguish VE approaches depending on the size of the project, the creative or determined nature of activities, and the complexity of the process and/or product. 40% of the surveyed projects state that changes during a project is minimal, with another 40% of the research projects that they did not cover this question and only the remaining 20% assumed constant change amongst partners. Rates of partner exchange from operative projects within VE were found to be dependent on the network topology. While peer-to-peer networks naturally assume the exchange of partners during operation, supply chain networks did not assume any partner change during single projects with star topology networks taking a middle position.

3.3 Management Roles

All projects and most papers implicitly assumed or explicitly modelled (Besembel et al., 2002) some management functions in the virtual enterprise, which were often referred to as ‘broker’ (van Leeuwen, 2002), ‘business architect’, ‘integrator’ (Santoro and Conte, 2001), ‘project manager’ (Laurikkala et al., 2002) or similar names (Gazzotti et al., 2001).

There is broad consensus from case studies on a number of management roles, such as project/operations management, marketing, building of virtual projects or financial audits and coaching of the network. Observation, however, shows that development of tool support and methods still has a focus on such functions that have already been researched in traditional hierarchies. Quality management (Fischer, 2002), operations- and planning and control (Takeno et al., 2001), for example is well researched, while there are much less solutions for innovation (Bullinger and Gudszend, 2001), the building or marketing of virtual enterprises.

Results from the projects further suggest that the critical innovation of virtual enterprises lies in the domain of the management functions with new methods of decentralized decision making,

distributed knowledge and intellectual property rights (Tononi and Amorosi, 2001) that lead to fundamentally new planning methods and even legal contracts.

3.4 Status of VE Engineering Methodology

One important survey item is the projects' models of their virtual enterprise. Interesting differences were found concerning the purpose for which the models are built. Some of these models are found to be explicit, e.g. when these are used for computer automation of operative or decision processes. Others are found to capture implicit assumptions e.g. as solution domain for the development of a specific tool, while a third category included frameworks for management understanding. In that regard, even models within the same modelling framework and language were found to be fundamentally different and not compatible and their results are not interoperable.

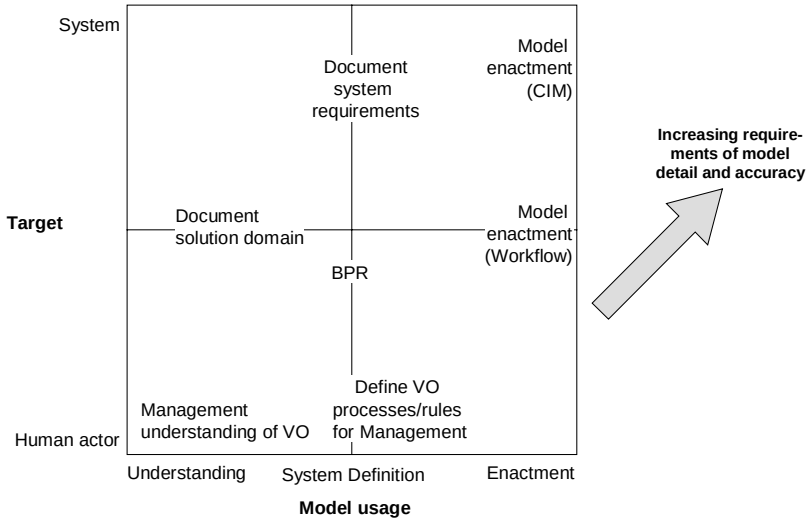

Figure 2: Positioning of Modelling Purposes

Figure 2 positions different purposes for modelling derived from literature findings in a matrix with one dimension being the target user (human actors use the model versus computer systems) and the other domain being the type of usage (understanding the enterprise versus enacting it). The lower and further left the objective for the modelling is positioned, the simpler and easier the models were found to be (Thoben et al., 2002). On the other hand, the further the objective is placed in the upper and right corner, the more detailed and accurate the models need to be. Management models for example typically are empty structures which need to be filled in by managers during their analysis (Van Schoubroeck et al., 2001, Weitzenboeck, 2001), while XML models of payment procedures are highly detailed and executable (Seilonen et al., 2001).

Enterprise engineering has developed approaches that combine these modelling extremes over the enterprise system life cycle (Jochem, 2002). The survey however, shows that the state of understanding and modelling virtual enterprises has not yet reached that integration (Schmidt and Rabe, 2001). Only a small percentage of projects went all the way from capturing the management level to detailed system design in their modelling effort (Delebarre et al., 2002, Katzy and Sung, 2001, Lillehagen et al., 2002). This however hampers a review and good understanding of the resulting systems and tools by the users. The status of virtual enterprise research can be characterized as having achieved workable solutions on the level of well-defined domains or modules, e.g. modules for workflow (Ferreira and Ferreira, 2001) planning (Filies et al., 2001) and control in the IT domain (Chung et al., 2002), or management models of broker functions. This research, however, does not yet provide consistent life cycle spanning support, which enterprise engineering has achieved for traditional hierarchies.

Additionally, research in virtual enterprise engineering seems to face a barrier in adopting proven modelling methods from traditional enterprise engineering. For process modelling in networks, for example, only 40% of the projects relied on formal methods like IDEF 0 and UML, while more than 60% were using Visio, PowerPoint and verbal descriptions in MS Word. Interesting enough is that a high number of projects that worked towards management models (see Figure 2-1) developed special modelling tools, e.g. VSD, Grade and Adonis. These kinds of tools allows presentation of process information in non-technical, easy-to-understand way. But as a summary, more research seems necessary on the specifics of enterprise engineering in VE (Yingjun et al., 2002).

4 Recommendations for a CE-NET Research Methodology

Despite the many pioneering results of the projects and papers in terms of methods, infrastructures and tools for virtual enterprises, the results overall still seem to be quite fragmented and often incomplete. One reason for this could be that many projects have targeted specific parts, functions and life-cycle phases of the virtual enterprise.

However, the research approach used for the broad majority of projects could be another reason for this situation. Almost all projects and 55% of the papers have adopted a system design approach. This approach consists of a requirement analysis, concept development, detailed system design and test cases for system validation. The system design approach is especially suited to develop concepts and tools in a domain, which is well understood. This is reflected in the many good results in classical areas, such as distributed planning or project management support, which have been extended to cross company borders into the VE domain.

These areas seem to have reached some saturation at least when limited to the specific functionality, while the understanding and support of fundamentally new elements of virtual enterprises, such as networked strategy development, or adaptive collaboration design, but also the network specific roles, is still in the early stages.

This survey of research projects reveals an inherent tension between engineering research and socio-economic research. While engineering aims at developing new tools (Tononi and Amorosi, 2002), management research aims at understanding the network relationships, processes, and roles of VEs. Multiple forces have pushed the concurrent engineering field to open up for insights from other disciplines, especially from the management and business field, but also from other social sciences. The earlier stated low adoption rate of developed IT solutions, for example, gave rise to the reproach that technical research projects operate too far from market needs. But our survey also showed that the limited understanding of the business domain hinders the development of more advanced and adopted architectures and tools, which in turn impedes business innovation. In short, virtual enterprise research operates at the cross road of concurrent innovation in the business field and the engineering field, which calls for appropriate, accepted methodologies. New activities in the projects such as extensive validation, best business practice documentation (Santoro and Conte, 2002), case studies (Petiot et al., 2001, Katzy and Horodiskiy, 2001), and business planning, have only partly overcome the problems, since they are often foreseen too late in the process and without much integration of the technical and business domains.

We suggest an adapted form of action research as a way forward in VE research. Action research has a long tradition (Lewin, 1943), especially in the socio-technical area. It is undertaken in iterative cycles of planning action, implementation, observation and capturing the knowledge (Susman and Evered 1978). For the CE-Net community is the concurrent planning and implementation of technology (e.g. early prototypes) and new business practices from the beginning and the researchers involvement in action of importance. The researcher learns from the experience in both domains, and can evolve technology and business practice in consecutive

cycles. Both academia and managerial practice share the intention of being involved in change, where the researcher develops versions of the conceptual framework to capture the relevant learning (Warmington 1980; Probst and Raub 1995). This jointly undertaken research process would avoid the separation of practical relevance and theoretical progress, if well designed.

To that end, action research needs to be designed as a concurrent research processes that integrates the system design approach from engineering in the phases of action planning and action intervention, with observation-base research from management and business research in the phases of reflection and capturing learning. Not different to other concurrent processes, an effective action research process strikes an appropriate balance between the need of each academic discipline and the need for integration into the overall research process, which no doubt requires experience and routine in undertaking such research. The CE-NET community has considerable knowledge about concurrent processes. Developing its distinct own research methodology would help overcoming challenges in many research projects and facilitate more cross learning between projects.

5 Summary

The objective of this paper is to contribute to the academic field of concurrent engineering, which has developed in size and content over the past decade. We review 29 ongoing or recent research projects and 40 papers in the field of virtual enterprise, which is one field of the main interests to many researchers in that community. From this review we draw conclusions in two directions.

First, progress in research on virtual enterprises has led to generally accepted concepts, e.g. the network typologies, which now opens a number of new research questions. Especially the impact of long-term networks on short-term cooperation or agility deserves more attention by the CE-NET community.

Second, with the opening up towards other academic disciplines than only engineering, projects within the CE-NET community face methodological challenges, for which action research could provide a solution. Adopting a generally accepted research methodology and its rigorous application would allow increasing research quality within CE-NET and give it a further distinct competence of undertaking a concurrent research process.

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7 Appendix: Reviewed European Funded Projects

1. **Supply-Chain Topology:** e-MMEDIATE (FhG-IAO), PRODCHAIN (FIR), PRODNET II (UvA)
2. **Star/Consortia Topology:** e-COGNOS (USAL), ELEGAL (Loughborough Univ.), GLOBMEN (VTT), ICCI (USAL), ICSS-BMBF (TU Dresden), ISTforCE (TU Dresden), OSMOS (USAL), ProDAEC (VTT)
3. **Peer-to-peer topology:** Business Architect (CeTIM), BIDSAVER (CEC), E-COLLEG (SUT), EXTERNAL (Computas), FETISH-ETF (Uninova), GENESIS (CeTIM), GNOSIS (VTT), MASSYVE (UvA), SYMPHONY (FhG-IAO), UEML (Computas), VDA (CeTIM), VL (UvA)
4. **Mixed/ undetermined Topology projects:** ALIVE (CEC), CE-NET II (CEC), KM Forum (FhG-IAO), NIMCube (FhG-IAO) NGMS (CAM-I), THINKCreative (Uninova)