Configuration and coordination of virtual production networks

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Abstract

Following the actual discussion concerning modern production concepts, the term "virtual production" or "virtual enterprise" plays an increasingly important role. The idea of virtual enterprises is to implement modern management trends like "concentration on core competencies", "distributed production" and "maximal customer orientation" by the application of advanced computer and telecommunication systems and services like "global networking" or "groupware systems". The objective is to establish a certain kind of a "Best of everything Organization" by a synergetic combination of core competencies of single partners (centers of competence) in order to perform a given business project to a maximum degree of customer satisfaction. Important features are a distinct form of network organization in combination with a high degree of organizational flexibility. Taking into account Williamson's theory of transactions costs, virtual enterprises can be interpreted as a certain kind of an intermediate organizational form between the institutional poles: market and hierarchical structured enterprises. According to this an evaluation will be given on the basis of transaction costs. In the following section structural and process-orientated questions of virtual production systems are formulated. From the viewpoint of production science, especially the allocation of sub-tasks to adequate project partners and the harmonization of distributed production processes in a network of independent companies seems to be very interesting. Principally, the decision support systems for such problems can be based on hierarchical or distributed control strategies. The characteristics of virtual production systems imply the application of decentralized approaches (e.g. multi-agent systems). A very interesting approach in this context is the application of distributed problem-solving strategies like contract networks.

Keywords: Virtual enterprise; Production network; Core competencies; Transaction costs; Multi-agent system

1. State of the art of "virtual enterprises"

The key idea of the concept of virtual enterprises is to implement future-orientated business strategies like "concentration on core competencies", "distributed production" and "maximal customer orientation" with the help of computer services like "global networking" or "groupware systems" [1]. The main objective is to form a certain kind of a "Best of everything Organization" by a synergetic combination of the core competencies of single, specialized partners (centers of competence) [2]. From this viewpoint similarities to the concept of strategic business units can be identified [3,4]. However, an important difference between these concepts is the temporary planning horizon of virtual enterprises.

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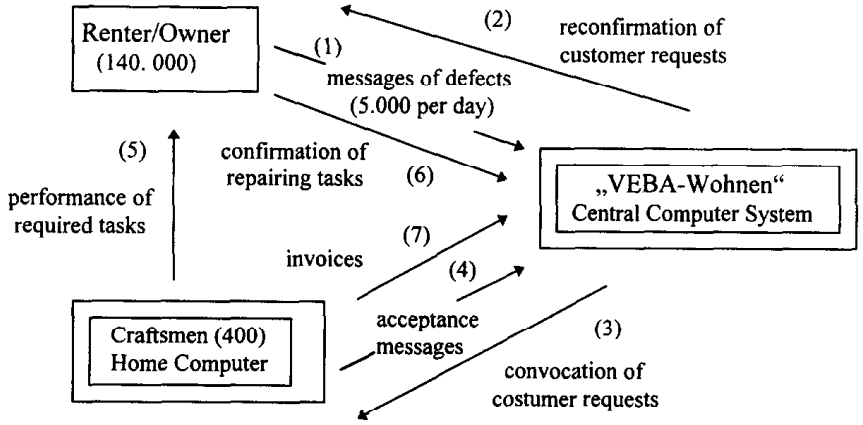

Fig. 1. Example of a virtual enterprise [3].

Depending on the purpose of the partnership and the type of transactions between potential partners, respectively, the opportunity costs of a substitution of single partners different forms of virtual enterprises can be identified. A well-known form is the temporary cooperation of dedicated enterprises in order to integrate their skills (e.g. emission of securities) in a certain project (e.g. introduction of a company to the stock market) and to reduce their individual risk (cooperating form). An example of this concept is a banking syndicate or a consortium of oil companies. A more advanced form is the establishment of a (new) cooperative enterprise as a network of mainly independent, principally substitutable companies (cooperative form). In this context virtual enterprises can be interpreted as a certain kind of a temporary, project-dependent portfolio of core competencies.

In general, the conception of virtual enterprises is characterized by a distinct form of network organization in combination with a high degree of organizational flexibility [1,2]. The term "virtual enterprise" itself is defined in a certain analogy to the term "virtual storage management", denoting the phenomenon that in case of a totally allocated random-access memory the base system can dynamically switch to another medium, the permanent storage medium. This allocation of external resources can be interpreted as a certain kind of outsourcing. It is a problem-specific extension of system resources and capabilities and is not transparent for a user who has the imagination of a larger (virtual) system capacity. The question whether this extension can be denoted as virtual or real, mainly depends on the definition of system borders and key competencies of the elements inside the system. This is especially interesting in the case of dynamically changing system borders. In this sense a virtual enterprise is a production system with mainly independent enterprises as single elements, which can be dynamically insourced or outsourced depending on the market demands.

Fig. 1 shows an example of a virtual service network initiated by a subsidiary of the VEBA AG, the so-called "VEBA-Wohnen" [5]. This company is involved in the construction and administration of houses and flats. The administration of about 140 000 units includes the treatment of about 5000 messages of different defects (including damages of water pipes) per day. In the case of a defect the renters or owners, respectively, send a message to the central computer of "VEBA-Wohnen". These messages are translated into job offers for processing units (craftsmen companies). The specified tasks (e.g. type of problem, location of customer, calculated costs) are sent via electronic mail to about 400 joined companies. Taking into account their production situation the mainly independent cooperation partners accept or reject a certain job offer. In the case of an accepted offer the global database will be updated. After finishing the job an invoice of tasks carried out is sent to the central database by the processing company. The computer system prompts the customer for a reconfirmation and initializes the payment.

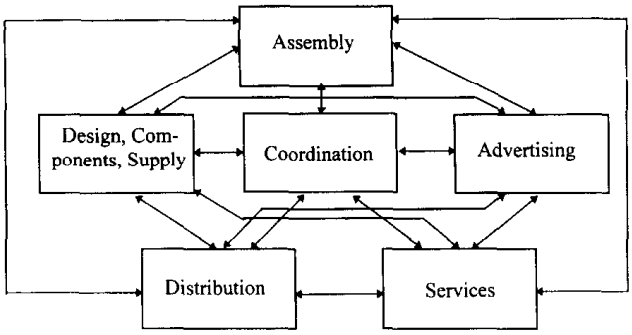

Fig. 2. Example of a virtual enterprise.

Another example of virtual production networks is a temporary cooperation of production and service companies in order to win a convocation or to perform a big business project like the construction of the SONY-Center in Berlin.

An example of a virtual production network often discussed is sketched out in Fig. 2. Besides some economic problems this is an interesting example to illustrate the concept of virtual production systems. The mentioned production system was initiated by one of its later elements called "AMBRA" [1,2]. AMBRA is a spin-off of IBM and employed in the beginning about 80 persons at Raleigh, North Carolina. The main task of this network element was the coordination of six independent enterprises, which produced complementary parts and services of a common product, a personal computer. At this point it must be mentioned that these companies were also involved in other projects with other companies at the same time. One of these companies was located in Singapore. It developed the product design, produced components and organized the common supply. A second company performed the assembly tasks. Other companies were involved in advertising, distribution of products and performing service tasks. Characteristic for this "virtual enterprise" is the marketing concept: to satisfy all requests for customization of hardware and software options at no extra cost, to produce individual products.

An analysis of these production networks shows some typical features of virtual enterprises:

Concentration on core competencies: The impetus of the production system sketched out in Fig. 2 was the synergetic combination of the core competencies of single partners (centers of competence). In this context two categories of competencies can be distinguished. The first category denotes technical respectively project specific competencies. The second category denotes meta competencies like "experience in distributed project management", "skills concerning the use of modern computer and telecommunication services" and a certain kind of "cultural flexibility". The second category denotes technical project-specific competencies.

Network orientation: Typically, virtual production systems form a network of independent companies, which in many cases represent a special type of a project team. The relations between the single elements depend on the type of transactions (chapter 2).

Organizational flexibility: Besides the network organization a maximum amount of organizational flexibility is typical for virtual enterprises. The goal is a cost "optimal" adaptation of skills and services according to the requirements of a dynamically changing market.

Technical infrastructure: The computer and telecommunication systems and services can be interpreted as the nerve system of a virtual enterprise. It is a preassumption to join a global partnership characterized by a maximum amount of flexibility and minimal production and transaction costs.

Hierarchy: One of the main interesting features of virtual enterprises is the required lack of hierarchies. This means in an ideal virtual enterprise, none of the system elements should dominate the other elements in order to maintain a maximum degree of flexibility.

Project Character: A further feature of virtual enterprises is the project character. Typical for virtual enterprises is the fact that with decreasing profits the network will often be resolved.

2. Evaluation of virtual enterprises on the basis of transaction costs

Analyzing the features described above the concept of virtual enterprises can be interpreted as an intermediate organizational form between two institutional poles: market and hierarchical structured enterprises. According to this an evaluation can be done on the basis of transaction costs

[6,7]. Transaction costs consist of costs for the acquisition of information, selection of potential partners, negotiation, agreement, settlement and controlling of distributed business processes [8]. They also include costs of a subsequent adjustment of processes in order to adapt to changing business conditions. These costs have to be analyzed both in markets as well as in hierarchical structured enterprises.

A framework for an evaluation is given by Williamson's theory of transaction costs. Following this approach, transaction costs depend on the specificity, uncertainty and frequency of transactions. With increasing specificity, uncertainty and frequency, the transactions should be organized indoors. In this case a self-production will be less expensive in comparison to an external supply. On the other hand, outdoor production should be preferred with decreasing specificity, uncertainty and frequency of transactions [8].

The key factor of those parameters mentioned above (specificity, uncertainty and frequency) according to Williamson is the specificity. This factor can be distinguished into four categories:

Specificity of capital in kind: By this machinery or production equipment is meant, which can only be used in a dedicated partnership and which is rather worthless, if the relations between the cooperation partners are resolved.

Conclusion for virtual enterprises: A typical criterion of modern production systems is the use of computer-based multi-purpose machines in contrast to product-specific production equipment. Generally, a computer-integrated production decreases the specificity of capital in kind.

Specificity of site: This means that two or more cooperation partners are forced, e.g. by technical reasons, to produce at the same production site. For instance this is typical for steel industry.

Conclusion for virtual enterprises: As an effect of global computer and telecommunication networks the determination of special production sites will be less important. Global production will be possible in many areas.

Specificity of human capital: This means all kinds of direct and indirect training costs, which are necessary to communicate and cooperate with specific knowledge and equipment of cooperation partners. Such specific expenditures are rather worthless, if the relations between the cooperation partners are resolved.

Conclusion for virtual enterprises: The specificity of human capital remains a critical point for virtual enterprises.

Common investments: This category denotes investments, which have to be shared by more than one partner.

Conclusion for virtual enterprises: A typical example for such investments in the field of virtual enterprises are investments in common computer or telecommunication systems. In this context the meaning of a sufficient global computer and telecommunication for virtual enterprises is obvious.

Evaluating the concept of virtual enterprises in addition to specificity, the categories uncertainty and frequency have to be considered:

Frequency of transactions: This denotes the number of transactions (between potential project partners) which are necessary to perform a special type of project.

Conclusion for virtual enterprises: The number of required transaction for a given business project mainly depends on the standardizations of communication protocols (e.g. drafts, recipe formulations, etc.), product elements and semi-finished products. In this context development of standards, application of methods like "group technology" and a modular design of product elements are important factors for successful establishment of virtual production networks.

Uncertainty of transactions: This addresses the possibility of opportunistic behavior between potential project partners as a function of unforeseen business events.

Conclusion for virtual enterprises: The danger of opportunistic behavior remains a critical point for virtual enterprises. It can only be reduced by the definition of common standards as a basis for the formulation and controlling of contracts between partners of a virtual production network.

This analysis shows that, in principle, with an application of advanced computer and telecommunication systems and services a tendency to business processes with reduced specificity can be identified. Concerning the frequency of transactions the efforts of standardizations of

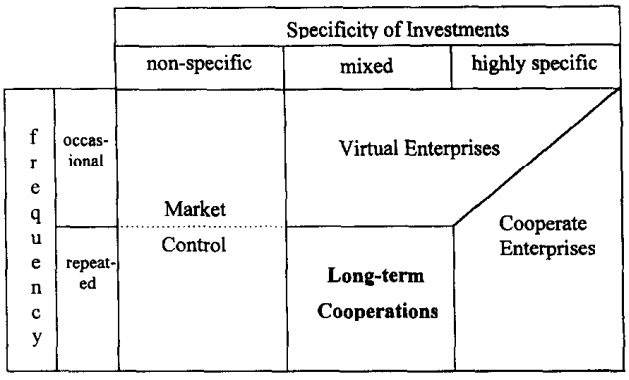

Fig. 3. Evaluation of the concept of virtual enterprises from the viewpoint of transaction costs [7].

communication protocols and product elements seem to be crucial. Taking into account Williamson's theory this implies a tendency to more market-orientated organization forms. To address the remaining specificity and specially the danger of opportunistic behavior intermediate organizational forms like virtual enterprises seem to be appropriate. They imply reduced transactions costs in future business processes (Fig. 3.).

3. Structural and process-orientated problems of virtual enterprises

Concerning the organization of a virtual enterprise structural and process-orientated problems have to be solved. Important structural problems are:

- Configuration and task profile of the coordination unit,
- Selection of an organizational form for the remaining network elements,

Important process-orientated problems are:

- Decomposition of the project in sub-tasks (convocation of sub-tasks),
- selection or allocation of the cooperation partners to sub-tasks and calculation of the project costs (configuration of the network, negotiation and agreement),
- harmonization of the production processes (production management),
- controlling of the project (settlement and controlling),
- redistribution of the project earnings.

According to the theory of Williamson the goal is to realize an organizational form which avoids any kind of additional transaction costs [7]. In achieving this goal the following procedure can be applied:

First the project must be decomposed in sub-tasks. The goal is to split the project in individual parts with a minimal amount of specific interactions. Connected sub-tasks (in the sense of the transaction theory) have to be combined for the convocation process. For combined sub-tasks only enterprises should be selected, which are able to perform all tasks indoor in order to save transaction costs. For all remaining sub-tasks individual companies should be selected. This structure guarantees a maximum amount of flexibility and minimal transaction costs.

A more sophisticated problem in this context is the type and configuration of the coordination unit. Main tasks of the coordination unit are the analysis and the decomposition of the project, negotiation with potential partners, the formulation of contracts (agreement), settlement and controlling of project and redistribution of the project earnings. Normally, these tasks imply a predominate role, which is in contrast to the non-hierarchical concept of virtual enterprises. Principally, the coordination unit can be a consulting agency or a computer-based system (e.g. multi-agent system).

From the viewpoint of production science one of the most interesting problems is the allocation of adequate project partners to sub-tasks and the harmonization of distributed production processes in a network of independent companies.

4. Decision support systems for virtual production systems

To address the process-orientated problems of virtual production networks the development of decision support systems seems to be crucial. These systems must be based on the characteristics described and the specific requirements of relevant

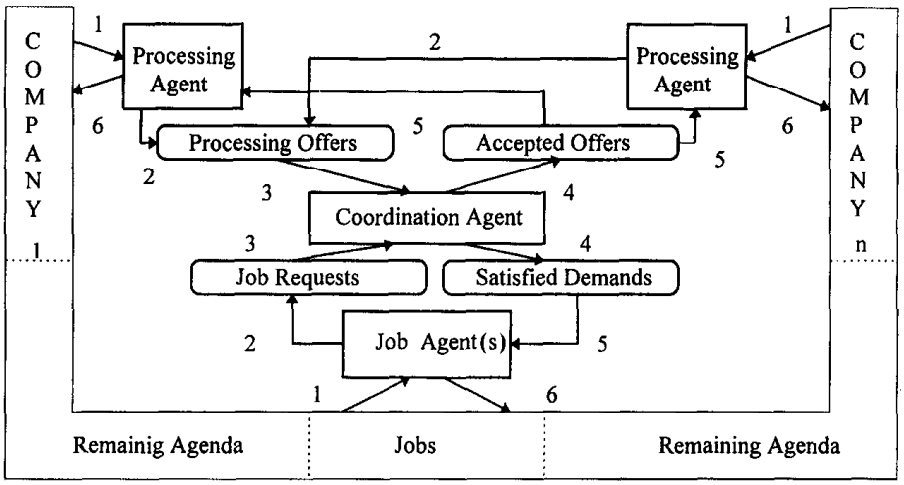

Fig. 4. Architecture of an exemplary contract network for virtual production networks [13].

decision problems. Main application fields are the selection of cooperation partners, the harmonization of distributed production processes and the redistribution of project earnings. In principle, decision support systems for such problems can be based on hierarchical (from the viewpoint of the coordination unit) or distributed control concepts. The characteristics of virtual production systems imply the application of decentralized approaches (e.g. multi-agent-systems). A very interesting method in this context is the concept of "distributed problem solving". Although this concept was developed as a special research field of artificial intelligence, applications concerning the coordination of business and production processes play an important role in this area. This is especially true for the development of future-orientated production planning and controlling systems. Due to their flexibility this approach seems to be very promising. In this context the term "distributed problem solving" means the cooperation of partly autonomous agents (information processing units) in order to perform a common task. In principle, the objectives of these agents are independent. Examples of this kind of multi-agent systems are future-orientated sensor systems, autonomous robot systems or networks of expert systems [9]. A very interesting variant of multi-agent systems in the field of management science are the so-called contract networks. The key feature of contract networks is the implementation of distributed-problem solving strategies on the basis of trading mechanisms [10,11]. The trading process can be implemented directly (without a coordination unit) or indirectly (with a coordination unit). In this context the coordinator plays the role of a broker.

To illustrate this approach an exemplary architecture of a contract network for the allocation of jobs (repairing tasks) to processing units (craftsmen) based on the example of "VEBA-Wohnen" will be given (Fig. 4). To demonstrate the modeling power of this approach the example described is enhanced by additional "ordering units" (administration companies), individual job offers (non-standard jobs) and the possibility to formulate own processing offers by the processing units (e.g. potential renovation or maintenance tasks).

In principle, the architecture of a contract-network depends on the structure of virtual production networks and the type of the considered decision problems. In this context important features are the number of ordering units (e.g. flat management companies) and the homogeneity of jobs (existence of individual jobs). In the case of multi-ordering units and individual jobs, an approach with advanced trading mechanisms (auction of individual offers) seems to be appropriate. This implies the application of contract networks with a coordination unit (broker).

Fig. 4 shows a conceptual design of such a network for the example of "VEBA-Wohnen". In a first step a so-called "processing agent" for each of the processing units (craftsmen) is introduced. The main task of this agent is the formulation of processing offers depending on the production situation and the preference structure (e.g. establishing of a constant high-level production rate, maximization of long-term profits). These offers will be sent to a so-called agenda of "processing offers" (2). The required information is drawn from a global database containing data of the general production situation and the queued jobs (1). In a second step for each of the potential employers (flat management companies) a so-called "job agent" is introduced. The task of this agent is to formulate job offers for all customer requests including all relevant parameters like the description of tasks, due dates, location of the customer and calculated costs. These requests are sent to the coordination unit via an agenda (3). In case of a successful allocation of a job the global database is updated (6). The main task of the coordination agent is the harmonization of processing requests and offers or the allocation of jobs to processing units. Accepted processing offers or satisfied requests are sent to the relevant agendas (4). In principle, the coordination process can be based on priority rules, pure trading mechanisms or mixed strategies.

Priority rules are especially interesting in the case of standard jobs and fixed rates. Priority numbers can be based on due dates or slack times. Considering non-standard jobs more complex coordination strategies using processing or opportunity costs (e.g. based on game theoretic approaches) or mixed strategies are recommendable [12,13]. Implementing mixed strategies in a first step, jobs can be queued according to priority numbers. In a second step the required processing units can be selected according to given processing costs (processing offers).

In the case of less complex structured problems (e.g. existence of a single job-giving unit) simplified approaches can be applied. Concerning a single job-giving unit (employer) the "job agents" and the "coordination agent" can be combined to a so-called "job manager" [10,13].

A very interesting feature of the concept of contract networks is the possibility to implement opportunistic behavior, which is also a key element in the framework of transaction costs. This can be done e.g. by the introduction of capacity-orientated prices or the implementation of auction mechanisms with different allocation and payment strategies (e.g. Vickrey auction) [14]. Implementing a Vickrey auction the processing unit with the lowest offer gets the job. But the payment is made according to the second lowest offer.

5. Summary

The idea of virtual enterprises is to implement modern management-trends like "concentration to key operations", "distributed production" and "maximal customer orientation" with the support of advanced computer and telecommunication systems. The objective is to establish a certain kind of a "Best of everything Organization" by a synergetic combination of core competencies of single partners (centers of competence). An important feature of this concept is a distinctive form of a network organization in combination with a high degree of organizational flexibility. The organizational concept of virtual enterprises can be interpreted as an intermediate form between the poles: market and hierarchical structured enterprises. In this context transaction costs are helpful criteria for the definition of the structure of virtual enterprises. Important structural and process-orientated problems concern the profile of the coordination unit, selection of cooperation partners, allocation of project tasks to processing units, harmonization of distributed production processes and redistribution of project earnings. Due to the characteristics of virtual enterprises, the implementation of multi-agent systems or contract networks seems to be a very successful approach to support process-orientated problems.

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