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Information infrastructure for electronic virtual organization management

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Abstract

In this paper we present a proposed information infrastructure framework for supporting management of electronic virtual organizations. We identify the life cycle phases (and their associated decision processes) of virtual organizations, describe the requirements for an information infrastructure to support the management of virtual organizations throughout their life cycle, and discuss how Inter/Intranet technologies provide the mechanisms required for virtual organization management. The importance of information infrastructure to virtual organization management is illustrated through a set of simulations that compare performance of traditional static (stable partnership) supply chains and dynamic (virtual) supply chains utilizing a dynamic material allocation (DMA) strategy to respond to environmental change. Our overall conclusion is that an information infrastructure, utilizing Internet and Intranet technology, can support the communication required for effective virtual organization management throughout its life cycle. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

The choice of how to organize your business has just gotten more complicated. It's no longer enough just to choose between functionally or divisionally organizing. The current technological environment enables businesses to virtually organize. As information technology (IT) has improved, coordination costs have declined [20], and firms are now able to form partnerships where separate firms specialize, and activities are coordinated through decentralized information systems. In this paper we address two major issues: (1) what type of information infrastructure is required to support the management of electronic virtual organizations?, and (2) what impact does this organizational structure, and its associated information infrastructure, have on organizational performance? There are two types of virtual organizations, non-electronic and electronic, differentiated by how they coordinate activities. Non-electronic virtual organizations use close geographic proximity for coordination. For example, ever since the collapse of the old Hollywood studio system, movies have been made by virtual corporations—assemblages of independent talents that come together for a

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specific project and then go their separate ways again [2]. The focus of our study is on electronic virtual organizations that use IT to support the communication necessary to coordinate activities across decentralized business units. In the following sections any reference we make to virtual organizations implies 'electronic' virtual organizations.

A limited amount of research has been completed related to virtual organization MIS issues. The vast majority of virtual organization literature, of which there is too much to list, is conceptual in nature and only describes how businesses are currently using variations of the structure. The conceptual link between IT, virtual organizations and supply chain networks has also been described [16]. We discuss how Inter/Intranet technologies can form a feasible information infrastructure for the support of virtual organization management, while also illustrating what performance gains can be expected. We present our findings in the following sections. In Section 2 we describe virtual organizations. We discuss the evolution of organizational structures, as well as discuss the features, advantages and disadvantages of electronic virtual organizations. We also discuss one example of how an organization has used this structure. In Section 3 we present a model of the life cycle of a virtual organization. The model describes the relationship between the virtual organization's major decision processes and its life cycle phases. In Section 4 we describe our proposed information infrastructure that supports the decision processes required for effective virtual organization management. We also discuss some current technologies that fit within our infrastructure. We discuss how both the Internet and Intranets are useful for supporting different phases in the management of virtual organizations. In Section 5 we illustrate the impact that our information infrastructure has on organizational operational performance. Because there are a limited number of firms currently operating as virtual organizations it would be difficult, if not impossible, to gather sufficient empirical evidence to study the impact of this new organizational structure, and its associated information infrastructure. For our study we simulate the operational performance of traditional supply chain networks (SCNs) and compare it with the performance of a more virtual SCN, supported by an improved information infrastructure, that is better able to dynamically adapt to its environment. A SCN is an instance of an operational phase virtual organization. We use cycle time and inventory costs as performance measures. Finally, in Section 6, we discuss the conclusions of our study.

2. Virtual (V-form) organizations

The late 1800s witnessed the emergence of the large, single-product, multifunctioned enterprise—in steel, meat packing, tobacco, oil, and so forth. These firms were organized along functional lines and are often referred to as unitary form (or U-form) organizations. The principal operating units in the U-form firm are the functional divisions—sales, finance, manufacturing, etc. [8]. Faced with the types of internal operating problems that emerge as the U-form enterprise increases in size and complexity, DuPont, under the leadership of Pierre S. DuPont, and General Motors, under Alfred P. Sloan, Jr., devised the multidivisional (M-form) structure in the early 1920s. This organizational innovation involved substituting quasi-autonomous operating divisions (organized mainly along product, brand, or geographic lines) for the functional divisions of the U-form structure as the principal basis for dividing up the task and assigning responsibility. Inasmuch as each of these operating divisions is subsequently divided along functional lines, one might characterize these operating divisions as scaled down, specialized U-form structures [36].

Today, a new organizational structure, the virtual (V-form) organizational structure, is emerging. In many cases it is replacing the M-form structure, just as the M-form structure replaced the U-form structure, because of the need for firms to remain competitive given environmental changes. Several factors are driving businesses toward the use of the virtual organizational structure. First, the pace of business is continually increasing with shorter product life cycles requiring quicker response to market opportunities. Second, the cost of market entry is often smaller than previously, especially in the information services and other technology-driven industries. Third, corporations are now driven more by customer demands than by internal needs. And finally, there is an increased need for globalization to remain competitive [4].

2.1. What is a virtual organization?

Because the virtual organization business model is still relatively new, it does not yet have one best definition. One definition of a virtual organization is that it is a temporary network of companies that comes together quickly to exploit fast-changing opportunities [6]. From this definition it is clear that there are some key attributes of the virtual organization that set it apart from the U-form and M-form organizational structures discussed previously. Virtual organizations involve an alliance of separate firms that can quickly bring together a set of core competencies to take advantage of a market opportunity. Core competencies are the two or three most tangible, value-added activities that distinguish one company from its competitors and provide access to a variety of markets and opportunities [5]. The alliance creates an organization where firm boundaries are blurred. The virtual organizational structure is enabled by an information infrastructure made up of continually improving information technology. Many different information technologies can be integrated to form an information infrastructure that can support the management of virtual organizations. This is one focus of this paper. IT has enabled a new set of organizational design variables beyond the conventional set. Examples of these new organizational design variables include virtual organizational subunits, technological leveling (IT can be substituted for layers of management and for a number of management tasks), production automation, electronic communications, and electronic customer/supplier relationships [19]. Virtual organizations take advantage of these IT enabled organizational design variables. Without the current capabilities of information technology the virtual organizational structure would be very difficult, if not impossible, to use. A virtual organization needs a great deal of integration and coordination between firms that often requires electronic storage and sharing of information. In the past, without these IT capabilities, firms were often forced to vertically integrate to attempt to minimize their information and external coordination costs. Now, given the current capabilities of IT, firms are more free to form interfirm partnerships.

2.2. What are the advantages of a virtual organization?

The virtual organizational structure has several advantages over the M-form structure.

Adaptability, flexibility, agility, and speed of a small company. Firms using this structure will, in general, be smaller than firms using an M-form structure. Because of this, there are less levels of bureaucracy which allows the interfirm alliance to react more quickly. Also, these firms will be more specialized to a particular task. For example, two smaller firms specializing in manufacturing and distribution will be better at these separate tasks than one large firm that attempts to do both. In the past, the costs of external coordination between the separate firms made their performance lower, but now, because of improvements in coordination technology, the separate, specialized, firms may actually perform better.

Resources (including money, technology, labor, managerial skills, etc.) of a large company. Firms using this structure are only limited by their ability to identify and evaluate a large number of potential partners. The resources available to a firm working in a virtual organization partnership, after it has been formed, is the sum of all of the resources of the partner firms.

Allows partner firms to concentrate on their ‘core competence’. In fact, these core competencies are the reason why firms would be chosen as partners. As the companies of the past learned the value of specialization of labor, virtual organization partnerships will be able to have improved efficiency and effectiveness through firm specialization. This specialization may result in a synergistic situation where the overall alliance has much better performance than the sum of the individual partner’s separate performances. Various combinations of firms may be uniquely suited to working together.

Ability to globalize. Firms that want to take advantage of a global market opportunity can ally themselves with a firm that has expertise or market share in a given region or country. An example could be a U.S. company that has a strong technological competence working with a firm that has a strong market presence (perhaps a brand name) in a foreign country. The U.S. company gains easier access to a market, while the foreign firm gains technological expertise. An example similar to this is discussed in Section 2.4.

Most of the advantages of virtual organizations come from their ability to modularize. A modular organization is one in which embedded coordination permits organizational processes to be carried out within a loosely-coupled organization structure in which each participating organizational unit can function autonomously and concurrently [27]. It has been suggested that a modular organization structure would have a superior ability to quickly link together the resources and capabilities of many organizations to form product development 'resource chains' that can respond flexibly—i.e. broadly, quickly, and at low cost—to new market and technology opportunities by offering new or modified products [26]. It is clear that virtual organizations attempt to incorporate many of the principles of modular organizations.

These four advantages make the virtual organizational structure a viable, and powerful, choice for many companies. This is especially true as information technology continues to improve which enables the information sharing and coordination necessary to operate within this structure. It would seem from these advantages that there are only advantages to using this business model, but there are also difficulties that arise from using this structure.

2.3. What are the disadvantages of a virtual organization?

Potential for loss of control of outsourced functions, proprietary information, and technology. The M-form structure, especially given a high level of vertical integration, allows for maintaining control over a broad range of activities, information and technology. Control over research and development, supply, manufacturing, distribution, and all supporting functions can be organized within a single firm. Problems of coordination and control can be handled through the existing hierarchy. The virtual organizational structure can be viewed as a much more loosely-coupled system that uses market mechanisms and contracts to coordinate and control operations. In a firm alliance, each firm has direct control over just a small part of the overall system. Also, proprietary information and technology must often be shared to coordinate the design, production and distribution of products. This leaves individual firms in a delicate situation. As discussed earlier, a high level of trust is involved in operating as a virtual organization. But, through credible commitments and credible threats, the incentives of the individual firms can be aligned to foster a trusting relationship. A partner that takes advantage of other partners in an alliance may never be chosen as a partner in future alliances. And a partner that performs well may have many more future alliance opportunities to choose from.

Requires managers to learn to trust outsiders and manage beyond their own walls. This is quite a change from managing within a large, M-form, vertically integrated firm. Instead of having direct control over most tasks, and the people doing these tasks, managers must now do much more interfirm negotiation and coordination. The changes required of managers may be the hardest part of the conversion to using a V-form structure. As is often the case, the changes required of the humans working in an organization are, in general, more difficult than any other part of the transition. Firms will have to adapt their performance evaluation and compensation systems to provide incentives to managers to work with other firms to improve the overall performance of the alliance.

Need for coordination of business processes, personnel, and information systems among the partner firms. Unlike a multidivisional company, a virtual organization requires the integration of processes and systems between separate firms. This often costs a great deal and can take a long time. A multidivisional already has a hierarchy in place to facilitate this coordination. IT plays a major role in minimizing the time and costs associated with overcoming this disadvantage.

2.4. Virtual organization example

The Rosenbluth Travel Agency provides an example of an electronic virtual organization [22]. Today one of the five largest travel agencies in the United States, Rosenbluth Travel, was in 1980 a regional agency with annual sales of US$40 million. Its growth to a national giant with sales over US$1.3 billion has been characterized by rapid and creative innovation driven by closeness to its market and a clear vision of its corporate customers' changing needs, and aggressive use of IT to build infrastructure for the delivery of services and to form a platform for continued innovation. Much of their success has come from their ability to globalize. Rosenbluth chose a unique structure for globalization, the Rosenbluth International Alliance (RIA). Rather than rely on expansion through development of its own offices abroad and attempt to develop the requisite local travel management expertise and capture the necessary shares of foreign markets, the company chose to work with the best foreign partners it could find.

Formed in 1988 as Rosenbluth Travel's primary mechanism for achieving a global presence, the RIA now includes 32 partners operating in more than 1200 offices in 37 countries. The RIA has a local presence in virtually every major travel market around the world and gross annual sales of more than US$6 billion. The alliance is an alliance of independent organizations bound by a common interest. Each member retains its own identity and autonomy, and all areas of cooperation are voluntary. To make this arrangement work, members had to be selected that 'fit' Rosenbluth's global vision, with a service orientation and culture compatible with those of the agency. The importance of member selection is reflected in the effort devoted to the process. Rosenbluth conducted careful competitive analyses of each local market, employing consultant and trade press reports and extensive discussions with clients and suppliers. To support cooperation, members do not compete in any markets. Decision making, as much as possible, is by consensus. To ensure that smaller members remain committed and that positions and decisions are global rather than regional or national, each member, regardless of size, is permitted one vote. There is little overhead or centralized bureaucracy in the alliance. RIA liaison offices are maintained in Philadelphia, London, and Singapore to provide same time-zone support and coordinate communications among alliance members and between the alliance and global clients. The resulting organizational structure is more of a dynamic network than a traditional, centrally directed hierarchy. Decision making is decentralized among autonomous units that coordinate as needed through direct, lateral communication. The nature of and mechanisms for coordination (e.g., committees and relationships) shift over time as environmental conditions change [22]. The RIA serves as a good example of the power of the virtual organizational structure. Through the use of this structure, Rosenbluth was able to capture the unique capabilities of its partners, at a much lower cost, to effectively globally expand. Traditional expansion strategies would most likely have been far less successful.

3. Virtual organization life cycle model

Virtual organizations go through four distinct phases during their life cycle. Our virtual organization life cycle model is shown in Fig. 1.

The organization's life cycle is made up of the identification, formation, operation and termination phases. Each of the phases is made up of two or more major decision processes. The identification phase involves opportunity identification, and opportunity evaluation and selection. These decision processes are sequentially related. The opportunities identified during the identification process serve as an input into the evaluation and selection process. The identification phase ends once the best available market opportunity has been selected to pursue. Information related to the selected opportunity is then input into the formation phase.

The major decision processes in the formation phase include partner identification, partner evaluation and selection, and partnership formation. As in the first phase in the organization's life cycle, the decision processes in the formation phase are sequentially related. The partner identification process uses the information from the identification phase as an input and outputs a set of potential partners. This information is then used as an input into the partner evaluation and selection process. The output of this process is a set of partners selected to work with in pursuit of the market opportunity. The partnership formation process involves the actual formation of these selected firms into the actual virtual organization. Once the organization has been formed, it can begin its operation phase.

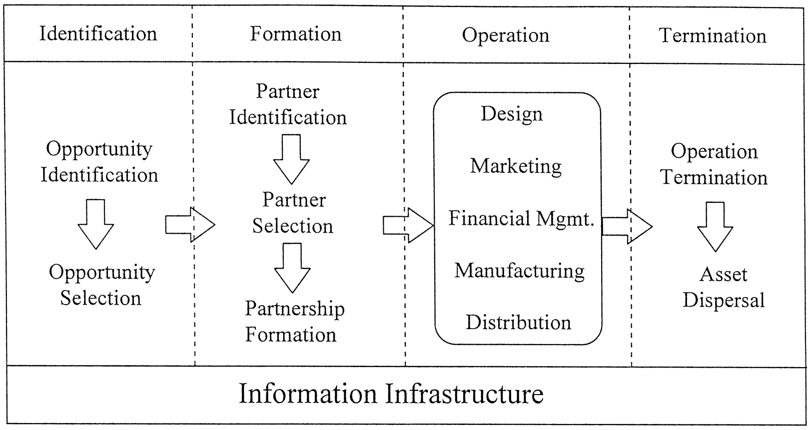

Fig. 1. Virtual organization life cycle model.

The operation phase generally involves five different major decision processes including design, marketing, financial management, manufacturing and distribution. In contrast to the relationship between the decision processes in the first two life cycle phases, the decision processes in the operation phase are not sequentially related. Each of the decision processes relies on input and output from the other decision processes on an ongoing basis. This tends to make this phase the most difficult to manage. The input into this set of processes is all of the information related to the market opportunity and the external alliance partners gathered during the first two phases. The information output from these processes is a summary of all of the activities and transactions that took place during the operation of the virtual organization. The operation phase ends once the market opportunity has passed. Once this has occurred the termination phase can begin.

The major decision processes in the termination phase include operation termination and asset dispersal. As in the first two phases, these decision processes are sequentially related. Current operational information such as inventory levels and orders that have not been completed are input into the operation termination process. Once all of the loose ends have been tied up the asset dispersal process can begin. The input into this process is all of the accounting and legal information required to terminate all contracts and disperse any partnership assets between the organization's firms. Once this has been completed the firms are free to pursue other opportunities and form other partnerships. This essentially means that this particular virtual organization is dead. Thus ends the organization's life cycle.

To further describe the life cycle of a virtual organization we present an example that describes how a virtual organization might be formed to distribute fashion skiwear. We use Aspen, Colorado-based Sport Obermeyer as an example of a fashion-ski-apparel supplier. In the fashion skiwear business, demand is heavily dependent on a variety of factors that are difficult to predict—weather, fashion trends, the economy—and the peak of the retail selling season is only two months long [11]. This is an industry where virtual organizations may be able to be used to quickly form distribution networks to respond to demand fluctuations for short life cycle products. In Fig. 2a we see the virtual organization in its identification phase when Sport Obermeyer is evaluating potential firms to integrate into their distribution network.

The next two figures describe a virtual organization after it has been formed and is operating. In one instance, Sport Obermeyer chooses Land's End as a mail order retail outlet. Land's End then chooses to use Federal Express and the United Parcel Service (UPS) to deliver its packages to the customers. This virtual organization is described in Fig. 2b. In another instance, Sport Obermeyer chooses J.C. Penney as a retail outlet for its skiwear. Skiwear is shipped to the various distribution centers, and they,

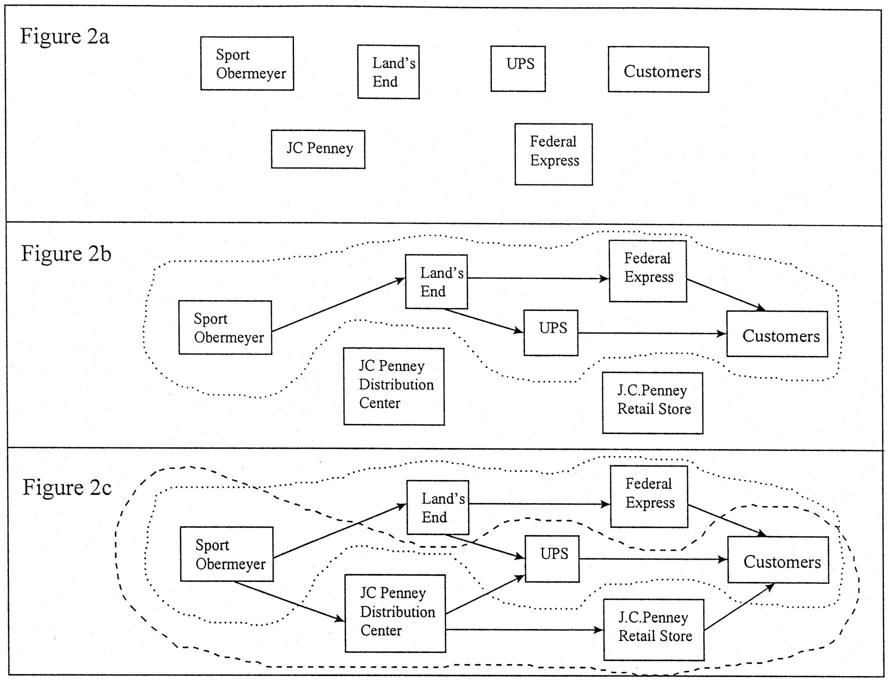

Fig. 2. Virtual organization identification, formation and termination example.

in turn, distribute the skiwear through UPS for catalog sales and also through their retail stores. This is described in Fig. 2c. Thus, Sport Obermeyer and UPS are actually part of two virtual organizations in this example. In reality, firms such as Federal Express are in many virtual partnerships. They are chosen because they are more competent at package distribution than are the clothing assemblers, retailers and so forth, and the IT exists to assist them in efficiently coordinating the shipment of orders. During the life cycle of the product, Sport Obermeyer can dynamically adjust its distribution network as needs change, or partners fail to perform up to expectations. Finally, after the retail selling season for fashion skiwear is over, the firms terminate their partnership and continue their ongoing search for new partners. This is shown in the original Fig. 2a.

A wide range of decision processes must be supported to enable effective virtual organization management throughout the organization's life cycle. Because of this, the decision processes must be supported by an information infrastructure that enables the required information to be available to management quickly and accurately. This information infrastructure is discussed in Section 4.

4. Information infrastructure framework for supporting virtual organization management

Effective virtual organization management requires a number of mechanisms. The mechanisms each fall within one of three categories: (A) pre-formation mechanisms, (B) external access mechanisms, and (C) interorganizational coordination mechanisms. The pre-formation mechanisms include: (1) identifying potential market opportunities in the identification phase, (2) advertising firm capabilities to potential partners, and (3) identifying potential virtual organization partners in the formation phase. The external access mechanisms include: (4) gathering information such as market research from the external environment in all phases, (5) advertising virtual organization products and services in the operation phase, and (6) supporting transactions between the virtual organization and its customers. And finally, the interorganizational coordination mechanisms include: (7) integrating processes between selected partners in the formation phase, (8) coordinating activities between partners in the operation phase, and (9) supporting intrafirm operational functions such as design, manufacturing, distribution, accounting, and so forth in the operation phase. These mechanisms are implemented through a set of component systems.

An information infrastructure for virtual organization management involves several components that must support each of each the mechanisms from above. These components include: (1) a global information network that supports electronic brokerage and contracting, electronic meeting and collaboration, product advertising, electronic payments and banking, business transaction processing, and on-line information services, (2) electronic access to external environment data such as market opportunity data, external firm data, customer data, market research data, global financial data, and economic data, (3) electronic connections between virtual organization partners to support business process and system integration, as well as process coordination, (4) electronic access to virtual organization operational data such as design data, marketing data, financial data, manufacturing data, distribution data, and legal data, (5) intraorganizational information system support for software development, process support, electronic data interchange (EDI), decision support, database support, telecommunications, local area networks (LANs), computer hardware, and a network interface, and (6) electronic connections to customers that support activities such as order fulfillment and customer service.

4.1. Information infrastructure framework

Each of the components specified in the previous section can be integrated to form a complete virtual organization management information infrastructure. Through Fig. 3 we can see the relationship between the specified components of this information infrastructure.

We feel that our infrastructure is complete because it addresses the changing managerial needs throughout the organization's life cycle. An information infrastructure that accounts for each of the spec-

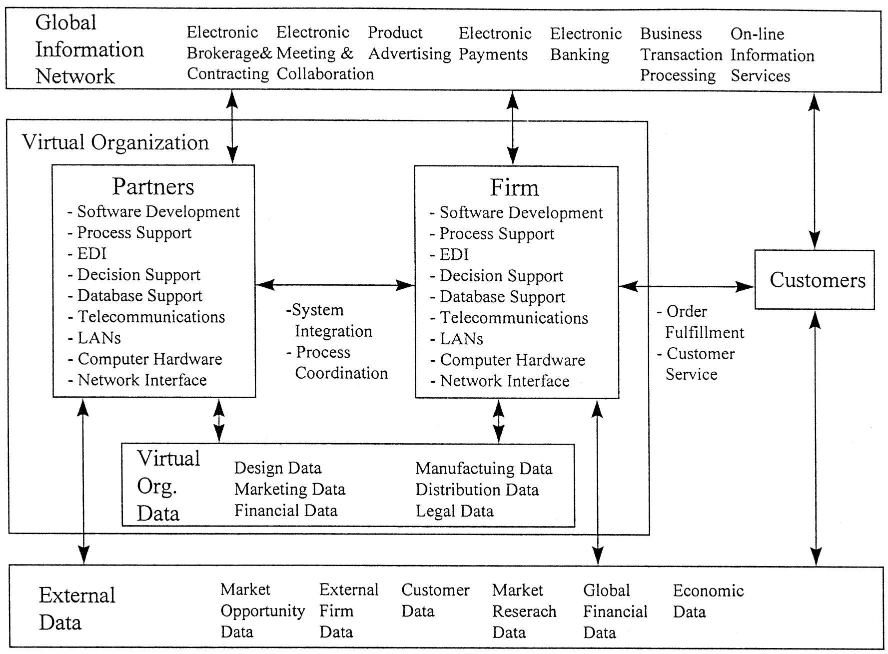

Fig. 3. Information infrastructure framework (firm perspective).

ifications, and the relationship between the specifications, that we have discussed, will enable effective virtual organization management. In Section 4.2 we discuss some current technologies that fit within our infrastructure. These technologies are what makes virtual organizations a feasible organizational structure option today.

4.2. Current technologies

In this section we discuss current technologies that may support the communication necessary to coordinate activities in virtual organizations. The technologies that we discuss include EDI, groupware, the Internet-based WWW, and Intranets.

EDI is a current technology used for computer-to-computer business-to-business transaction transfer. It involves the direct routing of information from one computer to another without interpretation or transcription by people, and to achieve this the information must be structured according to predefined formats and rules which a computer can use directly [13]. One example of where EDI has been shown to improve organizational performance is in inventory management, specifically a just-in-time (JIT) system. EDI technology was shown to facilitate accurate, frequent, and timely exchange of information to coordinate material movements between trading partners. Suppliers receiving JIT schedule information achieved better shipping performance. Similarly, suppliers with the ability to directly map incoming information to internal production control systems were found to enjoy even greater benefits. Moreover, as the supplier handles a higher fraction of customers electronically, it was found that shipment errors continued to diminish [30]. Each year the use of EDI increases as organizations look for methods to improve enterprise integration and interorganizational coordination. Numerous studies have been done on various aspects of EDI and they all draw the same conclusion. EDI increases the speed and the accuracy of processes compared with non-electronic transfer of information [29], and it is a potential source of competitive advantage [15]. When a supplier and a procurer use information technology to create joint, interpenetrating processes at the interface between value-adding stages, they are taking advantage of the electronic integration effect. This effect occurs when information technology is used not just to speed communication, but to change—and lead to tighter coupling of—the processes that create and use information. One simple benefit of this effect is the time saved and the errors avoided by the fact that data need only be entered once [20]. This is just one of several benefits derived from supply chain partners using more highly integrated information systems.

What is not so easy to see from this discussion is a practical problem that must be addressed when designing an EDI process. This problem is the lack of a globally recognized standard format for data storage and transfer [29]. Because of this lack of a standard, organizations must agree upon the translation software and data format on a project by project basis. Without an agreement upon a standard the EDI process will not work. This is one of the reasons why there will be a general movement away from these transaction specific connections to more flexible, standardized, methods of electronic information transfer. EDI is not a good choice for supporting communication in electronic virtual organizations because it lacks the flexibility required for quick response in the formation and operation phases of the life cycle. It also does not address any of the needs of the identification phase decision processes.

Another solution that has been considered is using groupware. The class of software known as groupware addresses some of EDI's drawbacks and has become popular for building collaborative environments. Groupware applications help coordinate work in three ways. They make available to project members a common body of information, they track work flows so that project members can—from a remote location—collaborate on the project, and they provide a platform for communication and interactive discussion. On the downside, groupware can be expensive and it cannot be used to gain access to remote computers that are not groupware servers [33]. Like EDI, groupware is not a good choice for supporting communication in electronic virtual organizations. It provides more flexibility than EDI, but is still not flexible enough to enable firms to quickly form a partnership to react to a market opportunity. Also, like EDI, it does not address any of the needs of the identification phase decision processes.

One solution to the inflexibility problems of EDI, and to a lesser extent groupware, that has been considered by a number of businesses is using the Internet-based WWW to support organizational communication. The Internet provides a current technology that supports several of the specifications of our infrastructure. It is an example of a global information network composed of an existing set of information technologies that provide a mechanism for electronic information sharing. Some of the information technologies (and their protocols) that are integrated into the Internet include: (1) the WWW (HTTP, Hypertext Transport Protocol), (2) Telnet (TELNET), (3) FTP (FTP, File Transfer Protocol), (4) Network News (NTTP, Network News Transfer Protocol), (5) Internet Relay Chat (IRC), and (6) Email (SMTP, Simple Mail Transport Protocol) [14]. Specifically the Internet provides a mechanism for electronic access to external environment data and electronic access to customers. One component of the Internet is the WWW. Although the WWW was not developed specifically for sharing of information among virtual organization partners, it provides a model for these types of systems. The Web was developed to be a pool of human knowledge, which would allow collaborators in remote sites to share their ideas and all aspects of a common project [3]. Because virtual organization management is similar to the projects the WWW was designed for (remote sites, shared knowledge, common project) it can serve as a method for sharing of information in a virtual organization. Netscape Navigator in an example of a Net browser, which is a type of global network interface, that provides seamless access to a wide range of data through the WWW. The major problem with using the Internet for virtual organization management is security. Experts say reports of Internet-related security breaches are rising. Nearly one in four respondents to an Information Week survey conducted in February 1996 say fear of Net break-ins is keeping them from using the Net [34]. The difficulty is to balance these security concerns with the Internet's open, flexible, architecture that is suitable for supporting virtual organization management. We feel that the Internet is the best solution for the communication needs of virtual organization management in the identification and formation phases of the life cycle. In these phases, access to information about market opportunities and potential partners is critical. The Internet provides access to a wide range of data from around the world. As the organization moves to the operations phase, security concerns become more critical. The focus of the organization moves from almost entirely external to a mix of external and internal information needs. The solution seems to be a more secure version of the Internet, an Intranet.

Intranets provide a current technology that supports the remaining specifications of our infrastructure. They merge the advantages of the Internet (global access) with those of local area networks (LANs) (security, easy management of resources and client/server functionality) [9]. It generally involves the same set of technologies as the Internet. It provides support for electronic connections between virtual organization partners and electronic access to virtual organization operational data. It also does not restrict firms from using their current intraorganizational information systems. An Intranet is essentially any site based on Internet technology but placed on private servers and designed not to allow outsiders in Ref. [23]. The outsiders in this case would be individuals and companies not directly involved in the management of the virtual organization. Intranets use Web-based and Internet technology to inexpensively and easily share [organizational] data across a private network [7]. We feel that the 'organization' can encompass several separate firms such as in a virtual organization. Intranet usage is predicted to overwhelm external Internet usage before the turn of the century. The key enablers of WWW growth are: (1) the proliferation of PCs, LANs, and modems, (2) open standards such as TCP/IP, HTTP, and HTML, (3) cross-platform support, (4) multimedia support and ease of use, and (5) support for secure transactions. [Organizational] Intranets can provide information in a way that is immediate, cost-effective, easy to use, rich in format, and versatile [25]. We feel that Intranets, utilizing the WWW and Netscape Navigator, provide an infrastructure that supports the communication required for effectively managing virtual organizations while providing a more secure environment than the Internet. Therefore, an Intranet, with its associated technology components, provides a set of existing technologies that fulfill the information infrastructure needs of the operational phase of the virtual organization. Firms can also easily disconnect from it in the termination phase once the partnership is over. Then they are free to seek new

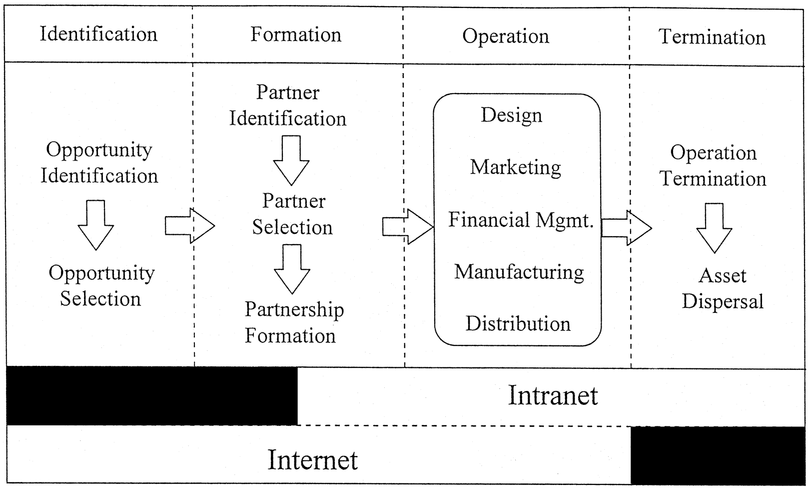

Fig. 4. Current IT to support the phases of virtual organization management.

partnership opportunities and cycle begins again. The match between virtual organization life cycle phases and what we feel is the best current technology is described in Fig. 4.

The Internet is necessary to support communications while identifying market opportunities, evaluating potential partners and forming the partnership, and, to a lesser extent, while operating the virtual organization. It provides a flexible system for firms to use to communicate with their external environment (e.g., potential customers, potential partner firms, information services and so forth). The virtual organization Intranet is formed at the time of partnership formation. It is then used to support most of the communication necessary for operating the partnership. It provides a system that is more flexible than EDI and groupware, is not geographically constrained like a LAN, and is also more secure than simply using the Internet. Thus, both the Internet and Intranets are useful for providing current technologies to support virtual organization management. Their usefulness evolves throughout the organization's life cycle.

4.3. Required mechanisms, Intranet technologies and real-world examples

In this section we expand on our previous discussion to match the mechanisms required for virtual organization management to specific Inter/Intranet technologies (and example applications) and discuss some real-world examples of how Intranets have been used to support these mechanisms.

To review, the categories of mechanisms required to manage virtual organizations include pre-formation mechanisms, external access mechanisms and interorganizational coordination mechanisms. Each category is composed of several specific required mechanisms. Major technologies integrated into Intranets include the WWW, Telnet, FTP, Network News, IRC and Email. These technologies provide a basis for developing functional applications. Pre-formation mechanisms can be supported by applications such as electronic markets and electronic advertising which integrate one or more Inter/Intranet technologies. These systems enable firms to access a wide range of global information to identify market opportunities and potential partners. It also enables firms to advertise their capabilities to potential partners. CommerceNet is an example of a system to support rapid partnership formation (including bidding and contracting, and so forth). It involves a consortium of about 50 northern California companies. CommerceNet hopes to make transactions work over the Internet so easily that a company in Palo Alto could put out a request for proposals in the morning, receive bids from all over the world by evening, and send out an electronic purchase order the next day [35].

External access mechanisms can be supported by technologies such as the WWW, Network News and Email. The Web and systems such as USENET are technologies that support pull-based advertising. Thousands of companies use this form of advertisement. Email may also be used for advertising, as support for push-based advertising, but it generally is considered to be a form of 'junk' mail that often results in a negative customer response. McDonnell Douglas uses Intranet technology for customer support. They provide their customers with proprietary technical bulletins via an extended Intranet solution. ''We have customers and suppliers all over the world. We wanted to eliminate processing paper. So we asked ourselves, what is the best platform for deploying information to our customers and suppliers worldwide? We didn't want to lock our customers into a proprietary system. We wanted to have something that took advantage of off-the-shelf software and industry standards'' [1]. Gateway 2000, a South Dakota based PC seller, integrates advertisement, product ordering and customer support into their WWW site to enhance their relations with their customers.

Finally, interorganizational coordination mechanisms can also be supported by the most common Inter/Intranet technologies. There are a number of examples of systems built on these technologies that enables firms, and partnerships, to better coordinate projects involving geographically distributed work units. Example functional applications include support for product development, sales and marketing, human resource management, and supplier communication. Technologies that support these functional applications include organization-wide database access, electronic software distribution, virtual laboratories, project-oriented communication, video conferencing, document management, and integrated software application access. John Deere uses Intranets for company-wide database access. They are in the process of implementing a parts database that employees can access via an Intranet. Electronic Arts uses Intranets for project-oriented communication. They are developing newsgroups so that teams can discuss projects and collaborate via the Web. As a result, Electronic Arts can quickly assembly virtual workgroups to tackle a project regardless of the location of employees. Cadence Design Systems (CDS) uses Intranets to support the entire sales cycle. In just three months, CDS built a dynamic sales and marketing Intranet. The system maps out each step of the sales cycle with links to sales support resources, uses Netscape forms to facilitate communication with headquarters, allows global account teams to share encrypted information, and provides a repository of sales tools and reference materials in a variety of document formats. Finally, Mobil uses Intranets for supplier communication. One of several applications Mobil has developed using Netscape software provides timely data, fed by Mobil's MVS applications, to its North American distributors for heavy product lubricants. It saves them money—no more reports or phone calls [1]. The conclusion is that Inter/Intranet technologies not only have the potential to provide support for virtual organization management, but in many ways are already being used for this purpose. One example of the impact that these technologies may have on virtual organization operational performance is discussed in Section 5.

5. Performance improvement enabled by the information infrastructure

Our infrastructure supports the decision processes required to manage virtual organizations in all phases of their life cycle. In this section we look specifically at the impact the infrastructure has on virtual organization management in the operations phase. We illustrate the usefulness of our information infrastructure by presenting and discussing results from simulations comparing the operational performance of a static supply chain with a more dynamic, virtual, supply chain. A supply chain is an instance of an operations phase virtual organization. In the past when business conditions were relatively stable and homogenous, communication was not overloaded or too complex, and efficiency was more important than innovation, decision making could generally be centralized. Today, conditions change rapidly during plan execution, conditions are different in different regions, communication hits bottlenecks and overloads, and innovation is more important than efficiency. This requires an adaptive innovation form of management [32]. We evaluate dynamic supply chain management as a form of adaptive innovation enabled by information infrastructures such as the Internet and Intranets. In this section we focus on one of the core business processes, the order fulfillment process (OFP), and use the Swarm simulation platform [28] to simulate the OFP in supply chain networks [17,18]. Swarm is a multi-agent simulation software platform developed for the study of complex adaptive systems. It was developed at the Santa Fe Institute and aims at providing a general purpose simulation tool for building simulation models. A detailed description of Swarm is outside the scope of this paper, but can be found in Ref. [18]. Our implementation of SCNs in Swarm is described in more detail in Section 5.3.

An order fulfillment process begins with receiving orders from customers and ends with having the finished goods delivered. It consists of several activities (sub-processes), such as order management, manufacturing, and distribution. The main objectives of the OFP can be generalized into two dimensions [10,12,17]:

1. delivering qualified products to fulfill customer orders at the right time and right place, and
2. achieving agility to handle uncertainties from internal and external environments.

The problem of supply chain management is summarized in Table 1 [31].

No one node of the supply chain network has the ability to manage the entire network by itself. The actors in a supply chain are the suppliers, manufacturers, distributors and customers. The activities within the supply chain network include material and information processing. The interdependencies include material orders and shipments, funds transfer and information sharing. The goals of supply chain management are to minimize capital asset and inventory costs, maximize customer service, minimize uncertainty, and minimize lead time. The overall supply chain objective is to balance each of these goals based on their importance to supply chain managers. In some situations costs may be the priority, while in other situations customer service may be the priority. We feel that, in virtual organizations, quick response is generally the priority. One measure of this is the order fulfillment cycle time.

5.1. Issues in managing SCNs for supporting the OFP

Because of the complexity of a SCN, it is a challenge to coordinate the actions of entities within the network to perform in a coherent manner. When orders come into an entity in a SCN, the lead time for delivering products (called the order fulfillment cycle time) is composed of (1) order processing times, including the order transfer time from customers to manufacturers or distributors, and the due date assignment process, (2) material lead times, including material planning and purchase lead time, supplier lead time, transport lead time, receipt and inspection lead time, assembly release time, and material order picking time, (3) assembly lead times, including waiting time, processing times, and trans-

Table 1
Supply chain management summary description

1. Actors	suppliers, manufacturers, assemblers, distributors and customers
2. Activities	material and information processing
3. Interdependencies	material shipments and orders, funds transfer, and information sharing
4. Goals	minimize order fulfillment cycle time, minimize inventory levels and costs, maximize capacity utilization, and minimize uncertainty
5. Overall objectives	balance individual goals based on priorities to produce the best ‘average’ performance, or the best ‘worst case’ performance over time

port time to the next stage, (4) distribution lead times, including dispatch preparation time (documents, packages), and transportation time to the customer, and (4) installation lead times. These components of the order fulfillment cycle time distribute across the network, and the variation of lead times at any stage will affect the execution of the other stages and result in uncertainties for the overall order cycle time. Take, for example, a product that is assembled by component parts from several different suppliers. The cycle time for assembling the product can be affected by the lead time of material supply from different suppliers. If parts from some of the suppliers come later than the other parts for assembly, the assembly will be delayed due to the unavailability of required parts. This also increases the inventory costs for those available parts. If the product is a component for the downstream manufacturing process, the delay for shipping this product will affect the consequent stages, and in turn, influence the whole network. Therefore, the first issue in managing a SCN is how to control the ripple effect of lead time so that the variability of a SCN can be mitigated. How to coordinate the policies of up and down stream entities in facilitating such variability reduction is the main concern. Demand forecasting is used to estimate demand for each stage, and the inventory between stages of the network is used for protecting against fluctuations in supply and demand across the network such as machine breakdown, extra large demand, etc. Due to the shortening of product life cycles, such protection seems unwise and actually reduces flexibility.

Because of the decentralized control properties of the SCN, control of the ripple effect requires coordination between entities in performing their tasks. The management of interdependencies is the key to smooth material flow within the SCN. The interdependencies between entities of the SCN can be described in the situations below.

(1) Producer/consumer dependence can be used to describe the supplier/manufacturer relationship in the SCN. This requires cooperation between suppliers and manufacturers in an efficient and effective way. Efficiency means to reduce material lead times, and effectiveness means to supply only the needed materials. This dependence also implies a constraint satisfaction problem, and through the network it is a constraint propagation issue too.

(2) Material flows within the SCN implies a synchronization problem, where related materials for a product are delivered to the manufacturer at a coherent speed which incurs minimal inventory and delay.

Inventory is an unwise approach to dealing with highly changing market demand and short life cycle products. This is especially true for many of the products associated with virtual organizations. The second main issue is how to manage the information flow within a SCN so that decisions made by business entities can take more global factors into consideration. In this way, we can increase SCN visibility.

These issues are brought up because of the essential concern: how to make the network respond effectively and efficiently to satisfy customer demand, which leads to the motivation of managing SCNs to support the OFP.

5.2. Strategies for changing the SCN structure

The SCN structure lays out a platform for the operations between entities in fulfilling orders. OFP improvement can be achieved by enhancing operations in the SCN structure, or by changing the SCN structure, and its associated processes. In this section we describe two strategies for structuring a SCN. These strategies include stable partnerships and dynamic partnerships utilizing dynamic bidding and contracting.

Stable partnerships. The maintenance of long-term stable partnerships between assemblers and suppliers have several advantages which may directly or indirectly benefit OFP performance [37]. These benefits include:

1. tighter integration of information systems between suppliers and assemblers to facilitate product design and manufacturing planning,
2. involvement of suppliers in product design to reduce the idea-to-product cycle,
3. incentives for suppliers to improve quality to maintain a long term relationship, and
4. encouragement for just-in-time (JIT) component delivery which is suitable for stable and repetitive order patterns.

However, single- or few-sourcing has its down side; for example, it leaves the assembler vulnerable to supply disruption. Moreover, facing constantly changing markets, meeting abruptly increasing demand under limited capacities with a few stable suppliers is a problem. One solution is to utilize a more dynamic, virtual, supply chain structure to better adapt to supply and demand uncertainty.

Dynamic bidding and contracting. Based on the stability and complexity dimensions of the organizational environment [24], there are four types of organizational structures found in specific environments. These organizational structures include: (1) decentralized bureaucratic, (2) decentralized organic, (3) centralized bureaucratic, and (4) centralized organic. Because of the dynamic OFP, and the complex SCN-based enterprise structure, we identify the organization for such an environment as an organic structure with decentralized control. The general coordination scheme for such organizations is mutual adjustment. The agents belonging to different organizations determine their action plans according to their local conditions, and aim to achieve the best collective performance.

One possible strategy for mutual adjustment is to use multi-agent planning through dynamic bidding and contracting. The capacity request is sent to the potential capacity providing agents, the task is assigned to the capacity providing agents based on the bids returned. Since the capacity providers and requestors belong to different organizations, the establishment of cooperation relies on mutually acceptable utility values. The decision of a capacity provider is based on the marginal costs for it to take the task, while at the same time there are other capacity requests from other external customers or from its own organization. The decision made by the capacity requestor to select the capacity from capacity providers is made by calculating which returned bid generates the best value in terms of reduction of cycle time and inventory. Such mutual adjustment requires further negotiation if the generated plan does not satisfy certain constraints, such as capacity limitations, delivery delay, or other cost constraints. The dynamic and volatile relationship between suppliers and assemblers described above is essentially a description of one form of electronic virtual organization.

5.3. The implementation of Swarm for simulation order fulfillment in SCNs

Fig. 5 describes the SCN implementation on the Swarm platform. The topmost swarm, the OFP Batch Swarm, is designed to control the whole simulation. It creates two swarms, the OFP Model Swarm and the Statistics Swarm, creates actions, and then activates the simulation process. The OFP Model Swarm is composed of an array of SCN Entities created while building objects. The SCN configuration with each entity's properties and product information are fed in during the entities creation. The OFP model actions are composed of each SCN entity's actions, and are activated when the OFP Model Swarm is activated. A SCN entity is composed of several agents, such as an order management agent, an inventory management agent, and a SCN management agent. An entity with manufacturing capability includes a production planning agent, a capacity planning agent, a materials planning agent, a shop floor control agent, and manufacturing systems agent. A SCN Entity Swarm holds entity level information such as suppliers, customers, order transfer delay time, and product delivery time, which are accessible by internal agents and other entities. The encapsulated agents perform certain functions in enabling the movement of information and material within the entity and between entities. The Statistics Swarm is used to compute the statistics data gathered through the simulation for analysis purposes.

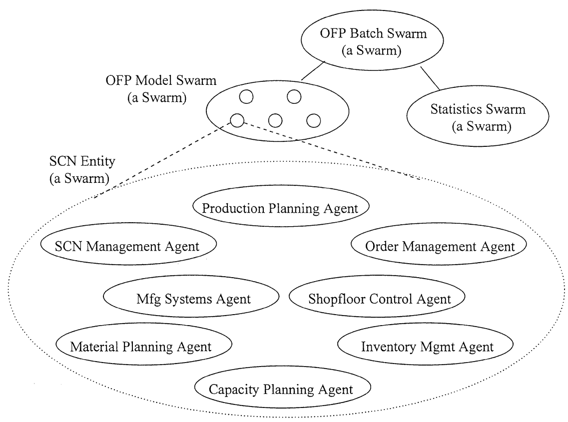

Fig. 5. The implementation of SCNs in Swarm.

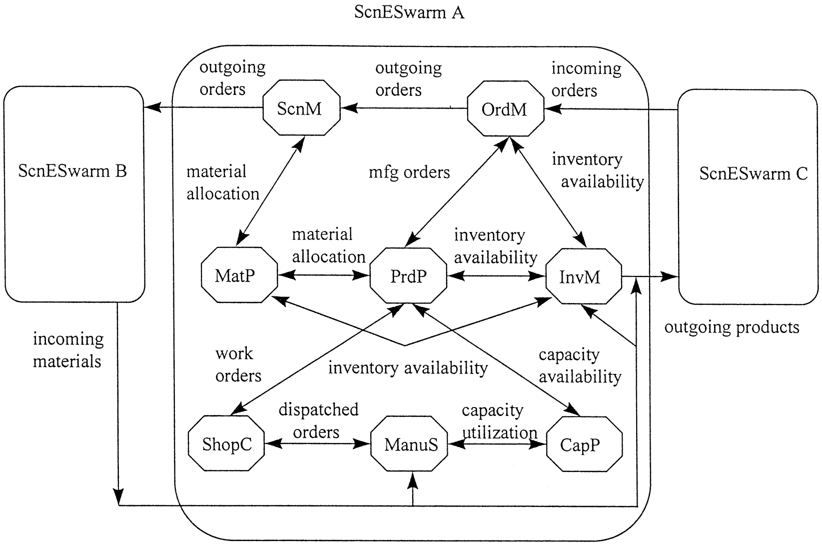

Fig. 6. SCN agent interactions in the Swarm implementation.

The following scenario describes the interactions among these agents, and Fig. 6 summarizes them. For example, an entity ScnESwarm A receives an order from its customer ScnESwarm C. The order flows to the order management agent (OrdM). According to the customer lead times, the inventory availability information (from InvM), the production plan (from PrdP), and the manufacturing capacity (CapP), the order management agent assigns a due date to the order. If the products are in stock, the order is filled by shipping the products from inventory. If the products are in receiving, the due date is set according to the delivery date of the products.

For an entity with manufacturing capability, the order is forwarded to the production planning agent (PrdP) where the schedule for making the products is planned. The capacity planning agent (CapP) and the material planning agent (MatP) are partner agents in generating achievable build plans. The material planning obtains build plans from the production planning agent to allocate materials for manufacturing. It also contributes information about material availability to production planning for scheduling. The capacity planning agent (CapP) plans capacity by taking the build plan from PrdP and sends capacity usage information to PrdP for scheduling the build plan. The SCN management agent (ScnM) takes the order information to choose suppliers in allocating material sources. The outgoing orders are transferred through its SCN Entity (ScnESwarm A) to be transferred to other entities (i.e. ScnESwarm B). This describes the information within an entity.

If the entity is a distribution center or a retailer without manufacturing capability, the ordered products are delivered from suppliers as end products to ship to its customers. For an entity with manufacturing capability, the ordered end products are supplied from the shop floor (ManuS) to its customers. The input materials are components for the end products. This represents the material flow with an entity. The

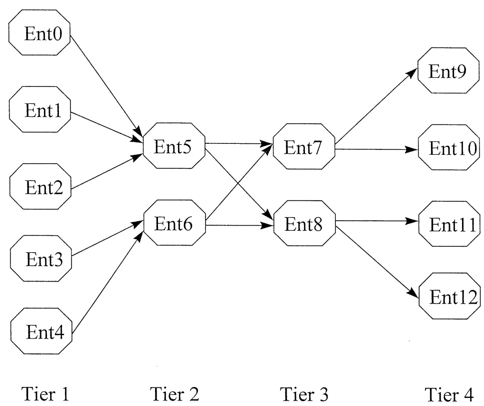

Fig. 7. Simulated SCN structure—‘Scn-G’.

Table 2
Product structure for Scn-G

Product names	Components	Assignment
pd5	pd0	Ent0
pd6	pd1	Ent1
pd7	pd2	Ent2
pd8	pd3	Ent3
pd9	pd4	Ent4
pd10	pd5, pd6, pd7	Ent5
pd11	pd8, pd9	Ent6

interaction of these agents enables the flow of materials and information within an entity, and, through the SCN Entity Swarm (ScnESwarm), the information and materials flow across the supply chain network.

In this section we described the components of our SCN simulation model. The specific business environments that we simulate are described in Section 5.4.

5.4. Impact of dynamic material allocation on supply chains

We implemented a generic SCN designed to execute the OFP under different business environments. 'Scn-G' in Fig. 7 describes this SCN. The SCN consists of 13 business entities aligned into four tiers. Entities of tiers 1 and 2 have manufacturing capability, while entities in tiers 3 and 4 do not.

The product group, its product structure, and product assignment are shown in Table 2.

In our experiments the dynamic bidding and contracting strategy described earlier is applied to demonstrate the dynamic material allocation (DMA) strategy. Supply uncertainty is simulated by using uneven delivery of materials at the initial tiers (material input to tier 1). Under this supply uncertainty, we compare OFP performance with and without the dynamic material allocation capability. Experiments are designed to compare OFP performance under demand uncertainties in terms of the fluctuation of order arrival and the variation of demand quantity.

The advantage of using a DMA strategy is to flexibly allocate materials or products needed for production or fulfilling orders. Such flexibility enables entities in a SCN to adjust under various uncertainties. We propose the hypotheses below.

(1) OFP performance is improved by using the DMA strategy under supply and demand uncertainties. The flexibility in allocating materials or products from suppliers using the DMA strategy smooths the material flow in a SCN even under great supply and demand uncertainties.

(2) The information infrastructure in a SCN significantly affects the use of the DMA strategy.

We conducted the experiments to evaluate OFP performance in static (stable partnership) SCNs and dynamic (dynamic bidding and contracting) SCNs. The performance measures we used included order fulfillment cycle time and inventory costs. We simulated a supply chain utilizing three different demand management strategies. Demand management policies, such as make-to-order (MTO), make-to-stock (MTS), and assembly-to-order (ATO) have their characteristics and application situations described in Table 3 [17,21].

If the amount of customization is low, the firm can usually employ a make-to-stock approach and then use inventories of finished goods to provide

Table 3
Demand management policies for the OFP

Analysis items	Characteristics	Application situations
Make-to-order	production is triggered by customer orders	high customization pressure but low responsiveness
Assembly-to-order	final assembly is order-driven, but the component parts are forecast-driven and built-to-stock	high customization pressure, high responsiveness, and products with late differentiation
Make-to-stock	production is triggered by inventory forecasts	low customization pressure

short lead times. For products with high customization, the make-to-stock strategy cannot efficiently and effectively match customer preferences. If customers are willing to wait for customized products after submitting orders, the make-to-order strategy can be applied to high-customization firms. When the product design allows the product differentiation stage to occur late enough in the production process, the firm can employ an assembly-to-order approach.

Figs. 8 and 9 show the order cycle times and the inventory costs respectively under the three demand management policies in static and dynamic SCNs. The order cycle time is the cycle time per order in the SCN. Inventory costs are the sum of the inventory costs across the SCN. From our results we can draw several conclusions. First, the DMA strategy enables cycle time to be reduced. From Fig. 8 we see a consistent result that cycle time is reduced for supply chains using MTO, ATO and MTS strategies. DMA enables the supply chain to shift materials to the entities that would otherwise have to wait to supply their component or product. Second, from Fig. 9 we see that inventory costs remain relatively stable for MTO and ATO strategies, but for MTS the inventory costs increase.

In all SCNs there is an inherent tradeoff between inventory costs and cycle time. In a virtual organization, where quick response to market opportunities is a priority, the DMA strategy generally enables the partnership to hold a similar level of inventory, but to reduce cycle time. Our third conclusion is that the best demand management strategy will vary based on the priority of minimizing cycle time or minimizing inventory costs. If minimizing inventory costs is the priority then the MTO strategy would be the best. This strategy results in little inventory, but slower relative cycle time. The MTO strategy benefits from DMA because inventory costs remain stable, but cycle time is reduced. If minimizing cycle time is the priority then the MTS strategy would be the best. This strategy results in quick response to orders, but much higher inventory costs. If balancing the minimization of cycle time and inventory costs is the priority then the ATO strategy would be the best. This strategy results in moderate inventory costs and cycle time.

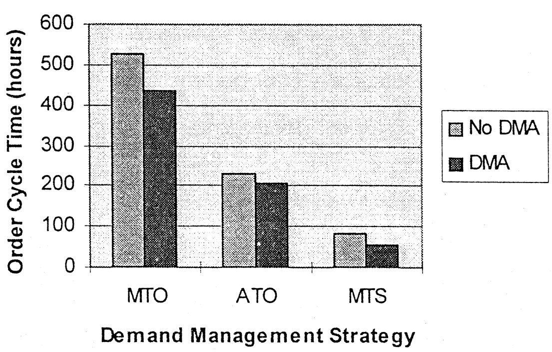

Fig. 8. Impact of the DMA strategy on SCN order fulfillment cycle time.

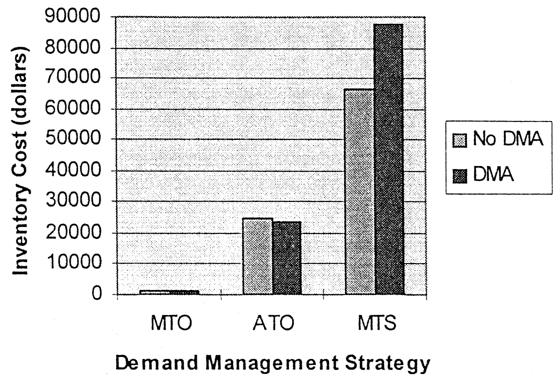

Fig. 9. Impact of the DMA strategy on SCN inventory costs.

6. Conclusions

Two sets of conclusions can be drawn from our study. The first set relates to findings specific to dynamic material allocation (adaptive innovation) in supply chains utilizing various demand management strategies, while the second set relates to overall findings concerning the relationship between information infrastructure and virtual organization management.

Overall we can conclude the following based on our DMA simulation results. First, the dynamic material allocation strategy is an effective approach to reduce OFP vulnerability under supply and demand uncertainties. This supports our first hypothesis. Second, the effectiveness of dynamic material allocation is highly influenced by the information transfer efficiency. With efficient information transfer the order cycle time is improved when compared with SCNs not using DMA. However, with inefficient information exchange, the OFP cycle time increases because of the time wasted waiting for information. This supports our second hypothesis, that information infrastructure is critical for supporting DMA in SCNs.

The findings from these experiments enhance the assertion that information technology is important for supporting the order fulfillment process in dynamic supply chain networks (virtual organizations). Overall, the dynamic material allocation strategy enabled by our information infrastructure results in improved market response, shown through reduced cycle times, while maintaining stable inventory costs. We can draw a common conclusion that information can substitute for cycle time.

We can also draw conclusions related to the more general issues related to information infrastructure and virtual organization management. The conclusion is that virtual organization management relies heavily on its information infrastructure. Our proposed information infrastructure supports not only operation requirements, but also the communications required in the identification and formation phases of the virtual organization's life cycle. It supports the pre-formation, external access and interorganizational coordination mechanisms. More specifically, our infrastructure supports not only first order coordination such as information sharing, but also second order coordination (adaptive innovation) where this shared information is utilized to decide how to reallocate resources across the organization. In the operations phase, virtual organization performance can be improved by dynamically adapting to its environment, using strategies such as dynamic material allocation, which is enabled by our infrastructure. Conclusions can also be made related to the match between current IT and virtual organization life cycle phase communication requirements. First, the Internet is a current technology that fits within our infrastructure to support opportunity identification, virtual organization formation, and, to a lesser extent, access to external data in the operations phase. It provides a global information network for electronic access to external environment data, and electronic connections to customers. And second, Intranets are a current technology that fit within our infrastructure to support virtual organization operations. They provide a system that supports electronic connections between virtual organization partners, and electronic access to virtual organization operational data. They also do not restrict firms from using their current intraorganizational information systems. An Intranet, with its associated components, provides a current technology that is more flexible than EDI and groupware, is not geographically constrained like a LAN, and provides increased data and message security relative to the Internet. Overall, we feel that an interorganizational information system designed based on our framework can support the processes and decision making required for effective virtual organization management.

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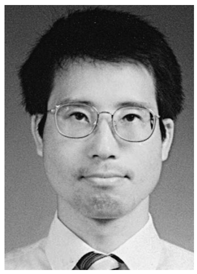

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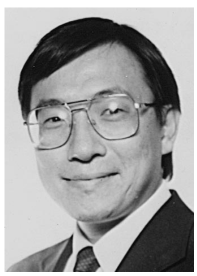

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