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Perspectives on Internet-based Frameworks/Infrastructures for Virtual Manufacturing Enterprises: A Literature Review

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Abstract: Virtual manufacturing enterprises (VMEs) are a current, viable, and strategic form of organization for business and other organizations. The perspectives described in this literature review are based upon a basic cluster analysis that identified and classified papers into homogenous subgroups with meaningful themes, or categories. These general themes are related to strategies for business organization and advanced information technologies, virtual industrial/manufacturing organizations/enterprises, frameworks supporting virtual manufacturing enterprises (VMEs), and information technology infrastructures for VMEs.

Key-Words: - virtual enterprises, information based manufacturing, distributed manufacturing

1 Introduction

Manufacturing organizations worldwide are interested in exploring and adopting the concept of a 'Virtual Manufacturing Enterprise' to meet changing customer demands using Information Technology (IT) while ensuring higher product quality and lower product development costs. The phenomenal advances in IT are catalyzing the evolution of a new breed of manufacturing organizations, which are adopting innovative methods and IT to accomplish diverse manufacturing activities using geographically distributed resources. Investigations of computer architectures and IT based methods to support the seamless information exchange across heterogeneous computing platforms which are geographically distributed continues to be needed for those organizations that plan to develop and implement a VME (Cecil, 2004). This literature review explores strategies for business organization and advanced information technologies, virtual industrial/manufacturing organizations/enterprises, frameworks supporting virtual manufacturing enterprises (VMEs), and information technology infrastructures for VMEs.

This literature review is based upon a cluster analysis, which identified and classified papers into homogenous subgroups with meaningful themes, or categories. The Internet, the library resources at New Mexico State University and Sandia National Laboratories, and associated electronic journal databases were searched to find relevant papers. The categories of papers that were reviewed include strategy, advanced information technology (IT), virtual manufacturing enterprises, IT frameworks, and IT infrastructures.

The organization of the paper is as follows. Part 1 presents definitions, concepts, and scope of Virtual Organizations/Enterprises and Virtual Manufacturing Enterprises (VMEs). Part 2 deals with strategy, advanced information technology (IT), frameworks, and infrastructures that are related to VMEs.

2 Definitions

Virtual Organizations/Enterprises:
Advances and maturity in the global information infrastructure (e.g., the Internet) and business practices have enabled businesses and organizations to consider a new organizational paradigm – virtual organizations (or enterprises) (Goranson, 2002). The virtual organization (or enterprise) model has proven to be a method of economic growth, which is

based upon collaboration (Adams, Wallace, & Sengupta, 2001).

A virtual organization is an organizational model that is an opportunistic (or temporary) network of core competencies throughout several independent, geographically dispersed organizations, which include suppliers and customers that perform as a single enterprise. It dynamically links people and their skills, assets and costs, and ideas with the use of technology and modern telecommunications (Byrne, Brandt, & Port, 1993; Goldman, Nagel, & Preiss, 1995; Fitzpatrick and Burke, 2000). The resources of the individual partners are available to virtually the other partners (Chang, Wysk, & Wang, 1998).

Key characteristics of a virtual organization include partnering, collaboration, and cooperation; agility and adaptability; world-class capabilities and technologies; geographically distributed; borderless operations; trusting and trustworthy behavior; and integrated business development, project management, systems engineering, and information technology capabilities (Byrne, Brandt, & Port, 1993; Goldman, Nagel, & Preiss, 1995; Adams, Wallace, & Sengupta, 2001; Allen, 2002; Cecil and Gobinath, 2004). Core capabilities are maintained within each partner, and other activities (e.g., inventory, warehousing, staffing, etc.) are externalized (Werther, 199O).

Goldman, Nagel, and Preiss (1995), state that the strategic reasons to consider a virtual organization include, but are not limited to, the sharing of infrastructure, R&D, risk, and costs; linking complementary core competencies; reducing the product realization process cycle-time through sharing; increasing facilities and apparent size; gaining access to markets and sharing market or customer loyalty; and migrating from providing products to providing solutions.

A virtual organization is a web (or network of organizations) that is an "open-ended collection of pre-qualified partners that agree to form a pool of potential members" (Goldman, Nagel, & Preiss, 1995). Although Virtual Enterprises are partially defined by the use of heterogeneous computer systems (Cecil and Gobinath, 2004), technology is important to develop and sustain this web (Byrne, Brandt, & Port, 1993), and computer networks will allow teams from different organizations to work concurrently in real time (Goldman, Nagel, & Preiss, 1995). A common infrastructure of networks and standards is necessary for a virtual organization so that the organizations and information systems can communicate with current and potential partners in the web of organizations (Byrne, Brandt, & Port, 1993). The strategic effectiveness of a virtual organization presumes that easy, fast, and efficient and high-performance electronic communication and information exchange) tools are available (Werther, 1990; Hardwick and Bolton, 1997; Allen, 2002). Currently, the technology for meaningful integration between the partners exists, including collaborative computing (Binstock, 2000). The World-Wide Web (WWW) and artificial intelligence (AI) are examples of the technologies that can be exploited for the implementation of virtual organizations (O'Leary, Kuokka, & Plant, 1997).

In Cecil and Gobinath (2004), several distinct phases have been identified to enable the successful creation and implementation of Virtual Enterprises. These phases include (a) the development of an understanding of a given VE's product(s) and customers, (b) identification of the potential VE partners and formation of the product development team, (c) development of an Information Oriented Enterprise Model (IOEM) of the VE's collaborative activities and tasks, (d) design and implementation of an Internet-based distributed software system, (e) identification of metrics to evaluate functioning of the VE, (f) initiation of a pilot initiative, and (g) identification and adoption of necessary changes.

Virtual Manufacturing Enterprises (VMEs)

Virtual Manufacturing Enterprises (VMEs) are a type, or subset, of Virtual Organizations / Enterprises. Cecil (2004, November) describes VMEs as a "consortium of manufacturing companies with diverse resourses and expertise forming a temporary partnership in order to respind quickly to changing global market opportunites." Cecil (2004) states that the characteristics of a VME are as follow:

1. Partners in a VME should belong to different organizations with different areas of expertise.
2. Partners should be geographically distributed.
3. The computer-based systems used must be heterogeneous.
4. The software applications used must be implemented in a variety of software languages (e.g., Java, C, C++, etc.).
5. Information Technology (IT) used must support seamless information exchange.

According to Tu (1997) and Gunasekaran and Yusuf (2002), the manufacturing industry, strives to be lean, agile, and global. This tendency leads to the concept of a VME with several sub-production units that are strategically and geographically dispersed in the world as branches, joint ventures, subcontractors, and alliances. In order to effectively meet today's challenges, a VME must be formed based upon core-complementary competencies, organized to manage change and uncertainty, and able to leverage people and information (Gunasekaran and Yusuf (2002).

3 Strategies for business organization and advanced information technologies*:*

According to Treacy and Wiersema (1995), 21st century organizations need to consider four strategic premises that include lower costs, higher performance, higher levels of customer service, and higher product quality and capabilities. Organizations cannot increase prices to offset higher costs. They must attempt to lower costs to match their customers' expectation for lower purchase costs. Organizations must provide performance that is effortless, flawless, and instantaneous from the customers' perspective. Customers demand high levels of service. Organizations must produce products that have high levels of quality and innovation. Treacy and Wiersema (1995) encourage organizations to consider one of three value disciplines: product leadership ("best product"), operational excellence ("best total cost"), or customer intimacy ("best total solution"). Each of these disciplines requires a different business model, which inherently impacts business processes, structures, and management systems. Porter (1980) concludes that it is important for organizations to pursue only one of the generic strategies of cost leadership, differentiation, or focus at once, and that the pursuit of more than one strategy is rarely possible.

However, the availability and use of flexible manufacturing and advanced manufacturing innovations allow manufacturing organizations/enterprises to simultaneously pursue multiple strategies (Schwenk, 1995; Morgan, 2003). Tools that are needed for the implementation of multiple strategies are provided by information technology, and the growth and convergence of communications, computing, and knowledge technologies enable organizations to pursue these strategies (Ferguson, 1996). The extent and comprehensiveness of today's technological change require a fundamental review of business strategy (Feeny,
2001).

Frameworks supporting Virtual Manufacturing Enterprises (VMEs):

VMEs rely on electronic business (e-business) applications, which are conducted using electronic media via Internet technologies. E-business projects need to be modeled and analyzed, and an integrated framework for the development of e-business projects has been developed, which includes the following elements (Hegde and Radovilsky, 2003):

1. A strategic model describes the three economic levers creating value in e-business projects.
2. A business model that is based on e-business products and processes related to strategic value creation.
3. An application model, which describes the classification of e-business applications.
4. A technical architecture, which is, associated with the e-business systems architecture, IT implementation, and support.

The design and implementation of an Internet based system to support virtual manufacturing activities is one of the distinct phases that has been identified to enable the successful creation and implementation of VMEs (Cecil and Gobinath, 2004). Mobile agent, Semantic Web, agent based evaluation, e-business integrated, and distributed information based frameworks have been considered as candidate models which can considered to support the realization of VMEs.

Mobile agents in VMEs provide a framework to link the manufacturing resources (i.e., software applications), which are dispersed among the distributed partner companies and organizations (Cecil and Gobinath, 2004). Green, et. al. (1997) define mobile agent as "a software entity, which exists in a software environment. It inherits some of the characteristics of an agent. A mobile agent must contain all of the following models: an agent model, a life-cycle model, a computational model, a security model, a communication model, and a navigational model." Shoham (1999) and Cecil and Gobinath (2004) describe mobile agents as "software agents that migrate from one system to

another in a network to accomplish the predefined functionalities."

In a distributed manufacturing context (e.g., VMEs), the creation of a Semantic Web based framework has significantly more potential than a model agent based framework, because software modules and applications in a VME would be capable of understanding the needs of the customers and then collaboratively respond more efficiently and quicker in developing a plan of response, which subsequently can be implemented. The use of such a Semantic Web based framework provides a new dimensionality of "meaning", thereby enabling better cooperation between machines and humans (Cecil and Gobinath, 2004). According to McIlraith, Son, and Zeng (2001), Hender (2001), and McIlraith and Martin (2003), the development of new Internet mark-up and ontology languages associated with Artificial Intelligence (AI), encoding, and describing Web content (e.g., OIL, DAML+OIL, DAML-L, OWL) is necessary for the realization of the Semantic Web. Additionally, Euzenat (2002) has proposed the following questions that need to be answered before the annotation (i.e., the formal representation of content) of electronic documents, Web pages, etc. is begun, which is necessary for the successful retrieval of information in the Semantic Web:

1. What aspect of the content must be represented?
2. What are the subject and form of the knowledge to represent?
3. Are annotations only descriptions?
4. Must we reify some classes in descriptions?
5. Is some background knowledge necessary?
6. Is the background knowledge part of the ontology?
7. Can the background knowledge and ontology evolve?
8. Is the Semantic Web common knowledge or distributed knowledge?

VMEs can take many forms and are complex, and require a variety of infrastructure services. A one-size-fits-all solution is not currently available. Additionally, the cost of developing a technical solution and infrastructure for each individual VME situation is high. Additionally, a wide range of technologies and architectures has emerged to support VME activities, and need to be analyzed. Therefore, it is prudent to clearly understand the applicability of a technology, which will support a VME. An agent based evaluation framework and other models can be used to determine if an approach to a specific VME situation is applicable (Umar and Missier, 1999; Petersen, 2003).

Huber (1990) contends that advanced information systems (i.e., devices (a) that transmit, manipulate, analyze, or exploit information; (b) in which a digital computer processes information integral to the user's communication or decision task; and (c) that have either made their appearance since 1970 or exist in a form that aids in communication or decision tasks to a significantly greater degree that did pre-1971 forms) affect organizational design and intelligence, and that they should reduce centralization in centralized organizations but increase centralization in decentralized organizations.

The Internet has also affected new strategy opportunities for organizations. Processes can be reengineered, online services can be introduced, new business segments can be approached, and strategic business models can be recreated (Feeny, 2001; Ross and Beath, 2002). Extensive use of the Internet as a core organizational strategy also supports a product innovation strategy and the networked organizational model (Kraemer and Dedrick, 2002). Organizations can become involved with the development of Information Technology (IT) systems to support various business practices and strategies. Applications (e.g., standard Enterprise Resource Planning (ERP) suites), a vigorous IT infrastructure, and architectural standards are included in these types of IT systems. A network-based system supports the applications that are used for the essential business systems, and include intranet, extranet, and Internet programs and their associated interfaces. This combination of networks, applications, and systems can be used as a strategy for scientific and industrial leadership, and for the support of an organizational framework and infrastructure, which is developed to implement the strategy (Kraemer and Dedrick, 2002).

As an organization successfully develops and implements a new IT strategy and the associated infrastructure, the support for innovation, experimentation, and flexibility must be balanced with the support for efficiency and standardization with a flexible infrastructure as one of the goals (Prahalad and Krishnan, 2002).

4 Information Technology Infrastructures for VMEs

Developing and implementing a strategic and flexible information technology (IT) infrastructure for sustained competitive advantage is a goal of businesses and organizations, especially VMEs. IT investments can enable or impede the initiatives that are necessary to achieve this goal (Mata, Fuerst, and Barney, 1995; Weill, Subramani, and Broadbent, 2002). The IT infrastructure for organizations that include a number of units (e.g., VMEs) includes infrastructure investments at the public, enterprise wide, and business-unit levels. The public infrastructure includes electronic exchanges, telecommunications service providers, and industry networks. The enterprise wide infrastructure includes PC/LAN service, electronic mail, large-scale processing, and an organizational database. The local IT requirements in a corporate or business-unit infrastructure include order processing, knowledge management, and financial management (Weill, Subramani, and Broadbent, 2002). IT infrastructure services can be divided into ten clusters, which include channel-management services, security and risk-management services, communication services, data-management services, application-infrastructure services, IT facilities and management services, IT management services, IT architecture and standards services, IT education services, and IT R&D services (Weill, Subramani, and Broadbent, 2002). Mata, Fuerst, and Barney (1995) conclude that of the five attributes of IT studied, only IT management skills are a likely source of completive advantage when a resource-based logic is applied.

To be successful, a VME needs an agile manufacturing information system, because the interactions between and among the partners are frequent and dynamic (Song and Nagi, 1997). However, heterogeneity, autonomy, and the geographical distribution of VME partners add complexity and challenges to the development and implementation of an integrated IT system for a VME (Song and Nagi, 1997).

The virtual agile manufacturing information system framework developed by Song and Nagi (1997) has addressed the requirements and functionality described above. Additionally, Offodile and Abdel-Malek (2002) have demonstrated that a framework for the integration of IT and manufacturing strategies and activities using telemanufacturing is possible.

5 Conclusions, Limitations and Suggestions for Future Research

Virtual manufacturing enterprises (VMEs) are a current, viable, and strategic form of organization for business and other organizations. The perspectives in this literature review are broad, and encompass the general themes related to strategies for business organization and advanced information technologies, virtual industrial/manufacturing organizations/enterprises, frameworks supporting virtual manufacturing enterprises (VMEs), and information technology infrastructures for VMEs. Additional literature research is needed to uncover the details associated with these broad themes. For example, the details of agent-based and multi-agent modeling approaches supporting infrastructure interdependency/disruption, supply chain management, manufacturing execution systems, manufacturing control, and production planning and control need to be explored. Additionally, concurrent design and manufacturing activities (e.g., design for manufacturability, product design and modeling, CAD/CAM, rapid prototyping, cost estimating, process planning and control, computer-controlled manufacturing systems, automated robotic assembly and machining, and automated contracting) and their relationship to, and use for, VMEs needs to be explored in more detail.

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