CHAPTER 10

e-Supply chain management

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Abstract

E-Supply chain management in a manufacturing context, is a series of Internet-enabled value-adding activities to guarantee products created by a manufacturing process can eventually meet customer requirements and realize returns on investment. Supply chains have advanced in the last two decades with improved efficiency, agility and accuracy. The recent advancement of Internet technology has brought more powerful support to improving supply chain performance. In this context, e-supply chain management becomes a new term that distinguishes itself by net-centric and real-time features from traditional supply chain management. In this chapter, principles and methodologies of e-supply chain management are discussed. It focuses on a fundamental challenge for supply chain management: how to efficiently integrate and optimize supply chain operations with widespread marketplaces and characteristic demands using the latest advances in information and communication technologies. A case of e-supply chain management application is also described in this chapter. As Internet and related technologies have been discussed in detail in other chapters of this book, this chapter will focus on e-supply chain management principles, approaches and methodology.

1 Introduction

Supply chain is a series of business processes in which products or services are produced and delivered to customers through value adding activities implemented by involved parties. In a manufacturing supply chain, the value

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adding activities mainly include product development, product design, raw materials supply, manufacturing the product, product packaging, delivery to customers, and post sale services. Supply chain management for a manufacturing company refers to incorporating its manufacturing process to all value-adding activities implemented by parties who add values to its final products. The term, supply chain, is a simplified description for vertically related business processes. Nowadays, it is more frequently referred as supply networks or supply chain networks because a company is likely to be involved in more than one supply chain and the related companies form business networks.

Since information technology became an enabler of improving business processes, supply chain management has gained tremendous benefits from applying ICT to various aspects of its tasks. IT application moves from data management to control automation, and then moves to enterprise integration. Supply chains have advanced the last two decades with improved efficiency, agility and accuracy. However, it was only at the time when the Internet technology became a practical means of information exchange in industries, that supply chain management started changing its way of allocating and controlling resources across organization boundaries. When business activities of a company are electronically incorporated in value-adding processes throughout the supply chain, e-supply chain management becomes a new term that distinguishes itself by Internet-supported, net-centric and real-time features from traditional supply chain management. In this chapter, principles, methodologies and examples of e-supply chain management will be discussed in the following sections.

2 Principles of e-supply chain management

The fundamental challenge for supply chain management is how to efficiently integrate and optimize supply chain operations with dispersed marketplaces and characteristic demands using the latest advances in information technology. *e-Business* using Internet technology to facilitate information exchange and communication in business networks has emerged as an innovative approach further exploring value-adding opportunities in supply chains. The e-business approach plans and executes front-end and back-end operations in a supply chain using Web-based applications [1]. Incorporating e-business approach in supply chain management has been proved as a competitive method for increasing values to be added and improving process visibility, agility, speed, efficiency, and customer satisfaction.

e-Supply chain refers to the business activities that incorporate e-business approaches into supply chain processes. *e-Supply chain management* involves applying e-business technologies to assist and optimize value-adding activities in supply chains. A more detailed definition of e-supply chain management can be found in the description of Norris *et al.* [2]:

"Electronic supply chain management (e-SCM) is the collaborative use of technology to enhance business-to-business processes and improve speed,

agility, real-time control, and customer satisfaction. Not about technology change alone, e-SCM is about culture change and changes in management policy, performance metrics, business processes, and organizational structures across the supply chain."

A key feature of e-business equipped supply chain management is network-centric. This focuses on connectivity, co-operation, co-ordination and information transparency. Networked supply chain partners share information, knowledge and other resources in real time. The networked relationships change the traditional supply chain information flows from linear transmission to end-to-end connections, i.e. information can be transferred directly from any partner of the supply chain to another partner without distortion and delay. Figure 1 shows a simplified traditional supply chain structure and a networked supply chain structure.

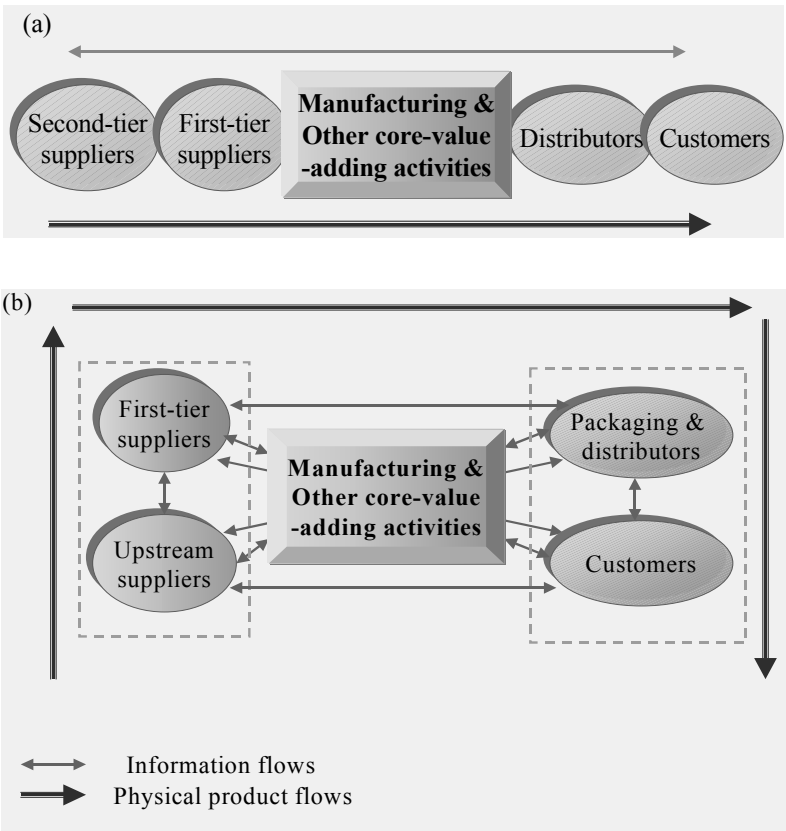

Figure 1: (a) Traditional supply chain structure.
(b) Networked supply chain structure.

This networked information transfer provides transparent customer demand information to any part of the supply chains. Impacts of information transparency on supply chain operations are not only in shorter leadtime and leaner production, but more importantly, changes in the way that supply chain partners collaborate. Partnerships are built on enhanced mutual trust and interdependency [3]. Based on the principle of network-oriented organizations [4], supply chains in an Internet-enabled environment should be managed by concentrating on their core business competence and contact with other partners for the other functions; sharing common goals of the supply chain and operating as an integrated system; co-operating with each other based on co-operative norms and solving conflicts; and recognizing and relying on interdependence of resources. In this section, the main principles of e-supply chain management will be described.

2.1 Adding values to e-supply chains

Manufacturing supply chain management should focus on maximizing values added to products to be delivered to customers. The value-adding activities form a value chain which connects a company's supply side with its demand side to transform concepts and materials to final products.

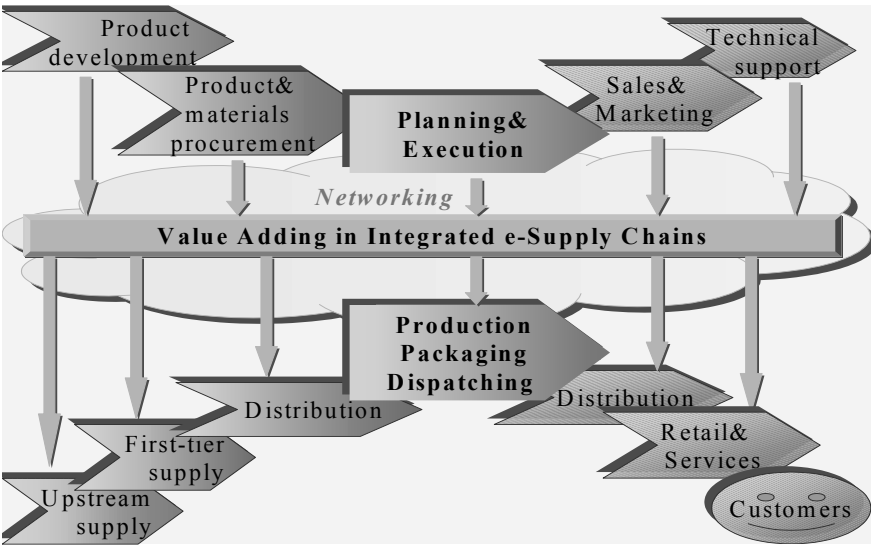

Figure 2: Value-adding activities of an e-supply chain.

Traditionally, values are mainly added by primary supply chain functions, such as inbound logistics, production, outbound logistics, sales and post sale services. Information systems, finance and human resource management are

supporting activities which are input and infrastructure of the primary activities [5]. Incorporated with the e-business approach, supply chains have now been enhanced with more efficient value-adding capabilities and new business models, e.g. more agile manufacturing processes due to visible real-time demands of end customers and virtual integration of manufacturing with retail store controls, etc. The information systems are therefore key activities for adding value to e-supply chains. Figure 2 describes the value-adding activities of an e-supply chain. In networked e-supply chains, information flows are integrated by ICT, particularly the Internet technology. Supply chain members are directly connected with customer demands and real-time operational information of all supply chain stages. This leads to synchronized supply chain planning and co-ordination, with more efficient physical product flows.

2.2 e-Supply chain management focused on core competence

An enterprise should concentrate on the core competence of its business in e-supply chains. Focusing on core competence will maximize value creation for both the enterprise itself and the whole supply chain while maintaining flexibility in uncertain markets.

Internet technology is able to facilitate implementation of this strategy as information exchanges and business interactions can be more easily realized between partners. This strategy can either be applied to the virtual enterprise strategy discussed in the next section, or to long-term relative stable supply chain partnerships. Outsourcing non-core value-adding activities takes advantage of flexible and agile enterprise structures or dynamic enterprise formation. With the assistance of Internet technology, it becomes possible to dynamically organize a virtual enterprise based on either short-term or long-term partners. According to traditional transaction cost theory, decisions on organizational structure and make-or-buy should be made by balancing costs of managing inter-organizational relationships and costs of maintaining internal operations. In today's competitive marketplace, agility is a key competency of manufacturing companies for satisfying varying customer requirements. With the advancement of Internet technology, costs of managing inter-organizational relationships have decreased. The strategy of focusing on core competence is therefore the logical option for forming an agile organizational structure and implementing mass customization strategies.

2.3 e-Supply chain integration

Supply chain integration ensures a supply chain operating seamlessly as an extended enterprise. The integrated supply chain will facilitate agility, shorten leadtime, and reduce operation costs. The integration implies that supply chain operations (e.g. product development, materials supply, product manufacturing, assembly, packaging, delivery, stock control, and customer support, etc.) are synchronized with virtual enterprise planning which aims at integration and co-

ordination of the supply chain operations. It is obvious that supply chain integration focuses on information system integration instead of organizational integration. It is Internet-enabled technologies that makes supply chain integration practically feasible and efficient. An e-supply chain is actually an integrated virtual enterprise. e-Supply chain integration ensures that supply chain legacy systems and operational systems are seamlessly incorporated into a networked business environment connected through the Internet and other information and communication facilities. e-Supply chain integration is at different levels with different focuses.

2.3.1 Synchronization-oriented integration

With synchronization-oriented integration, supply chain partners are fully connected in a business network. Transaction information such as retailer's sales, stock level at stores and depots, manufacturer's finished products in stock, work in progress, etc., is visible to or directly assessed by other partners. The real-time transparent operational information is then used in each partner's synchronized operational planning to avoid demand distortion, reduce leadtime, and increase responsiveness. The integration focuses on efficiency and agility by improved connectivity and transparency.

2.3.2 Co-operation-oriented integration

With co-operation-oriented integration, the transparent information is used not only for reducing costs and increasing agility, but also for improving co-ordination and joint decision support in a supply chain. Partners share the real-time information and convert it into knowledge for joint decision making, e.g. joint demand forecasting, product pricing, promotion planning, and new product development, etc. The integration focuses on co-operation and decision-making. An example of supply chain integration is collaboratively using retail sales information by Safeway UK (a retail company) and its suppliers in a retail supply chain [6]. Safeway developed a supplier information system with IBM to provide real-time information of sales and stocks to its suppliers. The system was built as an extranet which aims at fast availability of data to the retailer and its suppliers to ensure visibility of demand changes and quick reactions. Benefits of the extranet have mainly come from cutting out the wastage and storage costs that follow on from over-ordering. In the first year of trial, Safeway saved in the region of £700,000. The suppliers have been involved in the co-operative supply chain management project by proactively integrating their information systems with Safeway's supplier information system. It has been reported that proactive use of the transparent information from Safeway has led to even higher profits by co-operative forecasting and planning.

2.3.3 Innovation-oriented integration

The Internet equipped supply chains do not only obtain benefits from the visibility of supply chain operations, but also create new business models. For

instance, ordering digital products can be automatically processed on-line and delivered to customers through the Internet without any intermediary services. The seller-side e-marketplace provides customers with 7 days a week and 24 hours a day services. The Web enabled direct access to product catalogues and interactive interfaces allowing customers to configure their preferred products on-line. The e-business approach facilitates the mass customization strategy by dynamically planning production based on real-time and large-quantity customized orders.

2.4 e-Supply chain co-operation

Co-operation is a strategic term in supply chain management. It is an important factor for supply chain success. Research from various perspectives has been conducted to explore the impacts of co-operation and opportunism on supply chain partnership success [3]. Key factors which positively affect partnership outcomes have been found, such as interdependent organizational structure, co-operative attitude, normative contracting format and behavior transparency, etc.

2.4.1 Partnership and co-operation

In traditional supply chain management, a long-term relationship has been strongly encouraged to take advantage of mutual trust, resources and knowledge sharing within this stable relationship. The attitude of the partners is crucial. For instance, when a refrigerator manufacturer enters a new market, local retail partners are crucial to its success. The interdependence between them is not symmetric. It will be beneficial for the retailers to exchange consumer feedback with the manufacturer, be actively involved in the product design process, and share sales information with the manufacturer for supply planning and inventory control. However, to take advantage of its dominant role in the chain, it is also possible that the retailer opportunistically tries to lower the refrigerator purchasing price from the manufacturer, and disguise real sales information for bargains. This harms the manufacturer's business and reduces profit for the retailer as well in long run. If the refrigerator brand becomes popular one day, the manufacturer may in turn become the opportunist. Even in a symmetric interdependence situation, without any intention of co-operation, opportunism can also happen. Therefore, building partnerships based on mutual understanding and trust is a key step for working co-operatively in supply chains.

2.4.2 Information exchange and co-operation

To encourage co-operation, besides interdependency, information exchange and perception of partners' co-operative behavior are also key enabling factors [7]. Frequent exchange of operational information facilitates perception of partners' attitude and behavior. It increases trust. Disclosing operational information to partners has been named as a co-operative strategy - information transparency. The benefits of information transparency have been broadly recognized, such as reduced information distortion, earlier problem detection, quick response to

changes, increased mutual understanding and trust [1]. With the advancement of Internet technology, information exchange can be easily implemented through Internet-based applications. This has significantly enhanced information transparency in supply chains.

2.4.3 Virtual organization and co-operation

As the result of Internet-based technologies, organizations can be dynamically connected as virtual enterprises. Based on shared resources, remote process control, and real-time demand information as a result of an e-business approach, supply chain partners may be dynamically organized in a virtual enterprise (details are discussed in the next section) against active customer requirements. Partnerships may not be as stable as those with traditional supply chain management technologies. This can have a negative effect on trust and co-operation. However, the transparent information can, to some extent, offset this drawback. In dynamically formatted e-supply chains, participants position themselves by incorporating their core competences into the business network. Real-time operational information can be easily accessed through extranets. This allows participants to easily perceive mutual benefits and collaborative activities. It therefore facilitates co-operation in e-supply chains.

2.5 Managing e-supply chains as virtual enterprises

By applying an e-business approach, at least part of supply chain operations can be implemented through Web-based information systems. This implies that the supply chains are at least partly virtual, i.e. not physically, or by common consent, existing. They may operate as a virtual enterprise (VE) with Internet technologies which govern and co-ordinate networked supply chain transactions efficiently with lower costs. The characteristic "virtual" creates opportunities to improve flexibility, agility and efficiency for e-supply chains. A virtual enterprise can be defined as *"a temporary alliance of enterprises that come together to share skills or core competencies and resources in order to better respond to business opportunities, and whose Co-operation is supported by computer networks*" [8].

2.5.1 Properties of e-supply chain virtuality

The most relevant properties of virtuality to supply chains are virtual environment, virtual aggregation, and virtual organization [9].

2.5.1.1 Virtual environment Internet has been applied to developing various applications to support e-supply chain management. The applications provide a virtual environment for partners and customers to exchange information and complete transactions. The virtual environment can be created at any supply chain stage.

For instance, a retailer's e-marketplace provides a virtual environment for consumers to access to product catalogues, ordering preferred products and completing transactions. Tesco Supermarket on-line is a Web portal through

which customers can order commodities in a catalogue and complete transactions on-line. The portal also provides financial services for customers and allows customers to customize the Website according to their preference. Such a Web portal is a seller-side e-marketplace which is a virtual environment for downstream supply chains to directly connect retailers with end customers.

Web-based applications can be developed as a virtual environment for manufacturing control. It can be used to monitor and control a manufacturing process and provide product design services, etc. Wiptrac.com is a Web based manufacturing control system. It monitors shop floor manufacturing processes and control product qualities. Engineers can review process and quality control charts in real time. According to the on-line information, manufacturing process can be remotely monitored. Alarms demonstrated by the system can be responded to in real-time. Processes can be shut down when they are out of control. For an enterprise with distributed manufacturing sites, a virtual environment of manufacturing control works as a virtual control centre to synchronize the distributed manufacturing processes.

OneSpace Collaboration is anther example of virtual environment that allows engineers to work interactively in a team. It supports collaboratively loading, viewing, inspecting and modifying product design models and drawings. The system virtually integrates distributed design teams to view and share documents and drawings, mark up data, capture issues and ideas by marking up models and documents, make and document decisions, schedule meetings and automatically generate email invitations to participants. The application works as a virtual department of product design connecting supply chain partners to sharing knowledge.

2.5.1.2 Virtual aggregation and integration When all of the supply chain functions are integrated by various e-business applications, the whole supply chain virtually operates as a vertically integrated enterprise. The distributed operational processes in different companies can be aggregated and synchronized based on end customer requirements. Workflows or business processes (BP) are controlled by Web-based systems which make the whole process visible to all involved partners. The workflow can be automated to some extent through multiple agent systems without or with limited human interactions.

2.5.1.3 Virtual organization Virtuality in the virtual enterprise context emphasizes virtual organizational structures. A supply chain can be formed based on particular customer requirements and may be reconstructed later according to different requirements. The advantages of dynamic structures of virtual enterprises are the best combination of core competence of participants, flexible value-adding capabilities, and agile processes to serve demand changes. Internet technology makes it possible that e-supply chains can be formed dynamically, for instance, a brand product manufacturer outsourcing components in manufacturing, assembly, packaging and delivery services. It remotely controls and integrates the distributed processes as a virtual enterprise. With varied customer requirements, the virtual enterprise can be dynamically

configured through combining core competence from different partners. Figure 3 illustrates a VE creation case [10] for implementing four business processes (*BP1, BP2, BP3* and *BP4*) with eleven potential VE members (*E1* to *E11*) and three potential VEs (*VE1, VE2* and *VE3*). *VE1* is the selected team for given business objectives.

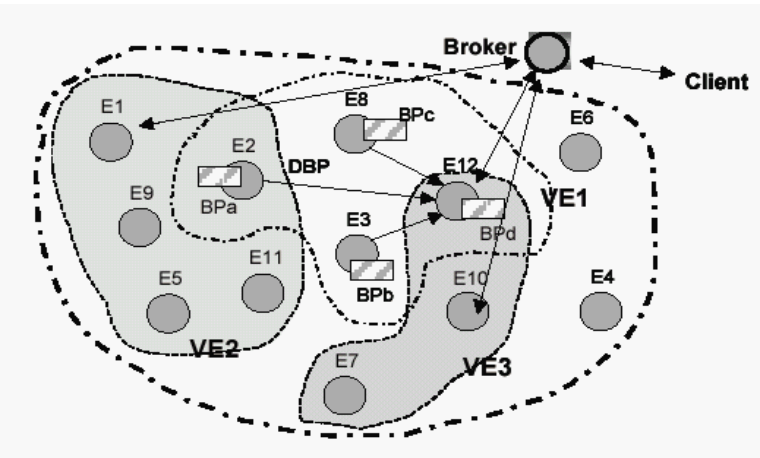

Figure 3: Virtual enterprise formation (Source: [10]).

2.5.2 Functions of virtual enterprise

Functions of a virtual enterprise can be summarized as customer interaction, asset configuration, knowledge leverage [9] and virtual process co-ordination.

2.5.2.1 Virtual customer interaction This function concerns customer service activities including information publishing, virtual marketing (on-line advertising, on-line-retail, on-line distribution, on-line payment), customer relationship management (service customization, interactive communication), community marketing (forms a many-to-many communication environment as a virtual community). Implementation of virtual customer interaction is the most common business-to-customer e-business application. Examples of such applications can be found at Amazon.com, Dell.com, Safeway.com, etc.

2.5.2.2 Virtual asset configuration This function concerns virtual enterprise formation based on a business opportunity. Through Internet-based applications, potential partners can be found, consulted, negotiated, and contracted. The enterprise asset should be dynamically configured based on customer requirements. Asset configuration is also referred to virtual sourcing.

2.5.2.3 Virtual knowledge management With e-business applications, knowledge can be more easily shared through intranet, extranet and other

information systems. Experts or knowledge of specified domains can be accessed through the Internet when it is necessary. This is very important to supply chain co-operation as the barriers in distance and time prevent partners' collaboration in complex engineering and operational issues. Transferring knowledge on-line makes it possible for partners to solve problems and conflicts responsively.

As a virtual enterprise approach for cutting stock applications proposed by Gary [11], complex models and tools for optimizing the material's size, product designs and then cutting plans are developed into a Web-based system which is assessable on the extranet by partners. Suppliers, manufacturers and customers can be linked by the system which functions as a broker. The system is particularly valuable for SMEs which do not have the capability to develop or purchase such complex tools. The manufacturers who need to optimally cut the materials for product processing can consult the system interactively for cutting plans based on given materials. In this process, suppliers and customers are also likely to be involved by co-operating in the optimal overall solution for the material's size, product specifications and cutting plans. The partners work together to share the knowledge of operations optimization.

2.5.2.4 Virtual process co-ordination The dynamically organized workflows should be planned, executed, controlled and monitored co-ordinately. A dominant enterprise may play the role of a co-ordinator in a VE operation. The co-ordination is more centralized in such a situation, e.g. the automobile manufacturing companies and their suppliers. In a VE with members of equal power, rules of co-ordination need to be negotiated and agreed in a more democratic manner, e.g. networks consisting of small retailing companies, packaging companies and commodity manufacturers.

3 Methodology and tools for e-supply chain management

The Internet technology has fundamentally changed the way in which supply chain partners communicate and co-ordinate with each other. Internet technology, to some extent, virtually removes the geographical distance and time lags of transactional processes between distributed supply chain partners. Telecommunication networks, electronic data interchange (EDI), particularly the recently dominant Internet technology, enables supply chain partners to exchange data in real time across organizational boundaries. The World Wide Web (WWW) built on Internet provides standard interface between users and the computer networks, and facilitates information transfer by standard mark-up language (HTML, XML) and graphical user interfaces (GUI). The advance of ICT has not only contributed to improving supply chain performance, but also created new business models and technologies of supply chain management. In this section, the basic information technologies and approaches to applying the technologies to support e-supply chain management will be described.

3.1 Application scenarios of the Internet technology to supply chain management

With applications of the Internet technology, e-business and virtual enterprises have emerged as innovative collaborative business strategies from which supply chain management has gained significant benefits from increased communication capability, agility, dynamic and real-time information exchange. Internet-based tools have already been intensively explored for information management, supply chain management and virtual enterprise modeling [9][12]. To enable e-business implementation for supply chain management, companies with a network of suppliers, vendors, and distributors need a fast, efficient way to disseminate information, provide interactive communications, and dynamically invoke co-operative business processes through Web-based applications. The major components required for such applications are customized extranet, Web servers and relevant middleware, database systems and groupware as integrated collaborative systems. A key objective is to provide clarity to supply chain partners by the Web-enabled legacy systems and to integrate a company's business processes with supply chain processes.

Internet technology applications for supply chain management can be summarized in four categories [13]. The different scenarios of the Internet applications have different focal points on e-supply chain management.

3.1.1 Information publishing

Information publishing is one of the basic functions of e-business applications. Internet is applied to supply chain management for providing one-direction information without receiving feedbacks and interactions. This application category is usually aimed at reaching partners to make operational processes transparent and marketing the organization to attract customers. Information can be accessed by customers and supply chain partners in real time without time delay. CircuitWorld Online Services is an on-line electronic manufacturing guide. Electronic manufacturers register and publish their products with this service. Customers of electronic circuit products can use the Web-based service to search for preferred products, manufacturers and distributors. Such an application assists manufacturers directly reaching customers for their marketing purposes.

3.1.2 Interaction support

Most of the present Web-based applications provide more than just mere information publishing. They normally support interactive activities for knowledge and information exchanges. In this scenario, Web-based applications support interaction among supply chain partners and focus on providing Web services to users according to user requests. Information delivered to users through the Internet is therefore dynamic, specific and interactive. This type of two-way communication system was developed for information and knowledge exchanges, negotiation of business proposals, joint decision making, monitor and control business processes, etc. Examples of tools for such purposes are email,

groupware, video conferencing, on-line industrial communities, forums for information exchange, remote processes control and monitor systems, etc. Through such applications, customers can pursue on-line services from manufacturers. Supply chain partners can share information and knowledge, and obtain particular services from registered communities.

3.1.3 On-line transaction

In this scenario, Internet technology is used for interactive implementation of transactions. The applications not only perform information exchanges, but also combine information flows with cash flows and instructions to physical supply chains. Interactive on-line processes will lead to actual transaction implementation within a supply chain. An example of this type of application is Dell Computer Corporation's e-commerce implementation. On-line services are provided by Dell for receiving customized orders and scheduling manufacturing to order. Customers can specify their requirements and complete transactions on-line. The system distributes the orders to relevant regional manufacturing sites for production and delivers final products to customers. The Website interface of the system is illustrated in Figure 4.

3.2 Information systems for e-supply chain management

A *supply chain system* is a work system implementing business transactions, product transformation, process co-ordination, and movement of goods through raw materials suppliers to final product consumers. The information flows are managed by information systems relating to the supply chain functions. In an e-supply chain, information systems supporting supply chain operations are likely to be incorporated with advanced ICT and Internet technologies such as intranet, extranet, Web services, Web portals, agent-based business automation technologies, wireless networks, etc.

3.2.1 Development history of supply chain information systems

At the early stage (1960s to 1970s), supply chain information systems focused on materials supply control, inventory management and production scheduling. It internally integrates system output (customer orders and finished products), transformation process (scheduled production) and system input (materials and purchasing orders) as a synchronized supply chain process within a company. The system was named materials requirement planning (MRP). MRP schedules production according to received orders over a period of time. Based on bill of materials (structure of products describing relationships among products, components and materials), each manufacturing job can be determined in quantity and time. Then inventory levels and dates of purchasing raw materials can be derived. In the 1980s, MRP evolved to a manufacturing resource planning system by including production planning, inventory control and logistics (distribution) planning functions. It integrates almost all primary value-adding activities in a company.

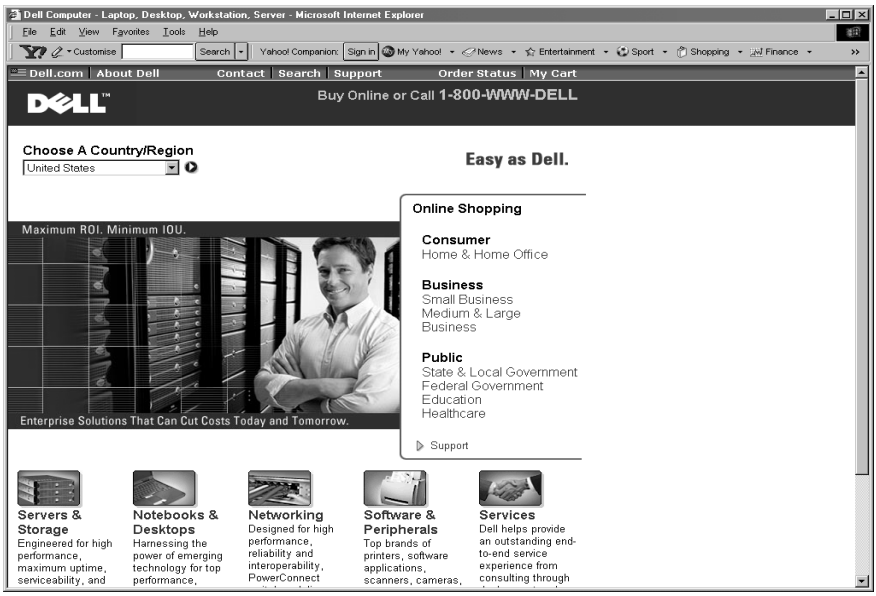

Figure 4: Dell Computer on-line ordering Website (Source: Dell.Com).

In the 1990s, MRP II was further evolved to enterprise resource planning (ERP) systems. ERP is a more standard enterprise system and controls all enterprise resources. It is a standard, fully computerized enterprise-wide information system with best practice model and modularized structure. ERP integrates enterprise resources by building a coherent information repository and centrally manipulating operational data in all business aspects. The business processes controlled by ERP are integrated within and across business functional areas so that the enterprise operations can be automated to some extent.

As principles and methodologies of supply chain management advanced from traditional internal orientation to partnership development in the 1990s, more opportunities for reducing costs, improving product quality and agility have been expected from integrating internal business processes with external processes. As the result of this change, ERP systems have been further developed to embrace supplier relationship management (SRM) and customer relationship management (CRM) functions. This extension broke through organizational boundaries and provided an enterprise with integrated workflow information over a supply chain.

In the past decade, the Internet has been a promoter of the ICT evolution. Supply chain management technologies have been significantly affected by such an evolution. Information systems supporting supply chain management are moving from enterprise oriented systems to open systems for all participants without location, distance and time limits. Web-based supply chain information systems integrate enterprise systems of supply chain partners into a synchronized workflow which is planned according to end customer demands.

The Web-based integration is characterized by "dynamic" and "real-time". The connected supply chain members may change from time to time. All supply chain activities exposed to the Internet will be transparent to partners with real-time status. Although a supply chain can be dominated by a product/service brand owner, the e-supply chain system is frequently a network of enterprise systems instead of a system hosted by a single enterprise, i.e. the planning process is implemented co-operatively by supply chain partners. Figure 5 shows the development history of supply chain systems.

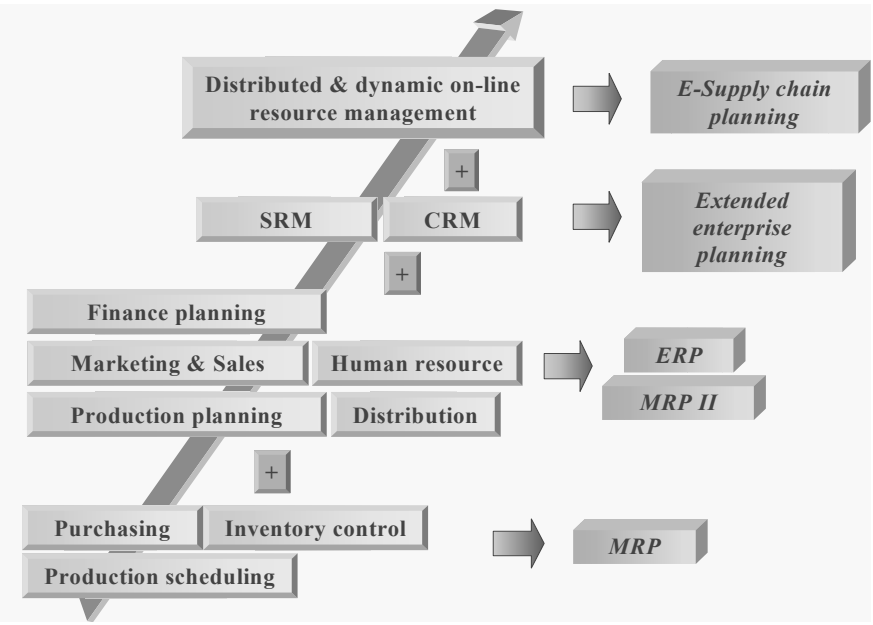

Figure 5: Development history of supply chain planning information systems.

3.2.2 Infrastructure of information systems for e-supply chain management

An e-supply chain system is networked information systems which serve different value-adding activities for different supply chain partners. Typical information systems in e-supply chains include:

- Communication systems (CS)
- Transaction processing systems (TPS)
- Management information systems (MIS)
- Executive information systems (EIS)
- Decision support systems (DSS)
- Enterprise systems (EPS)

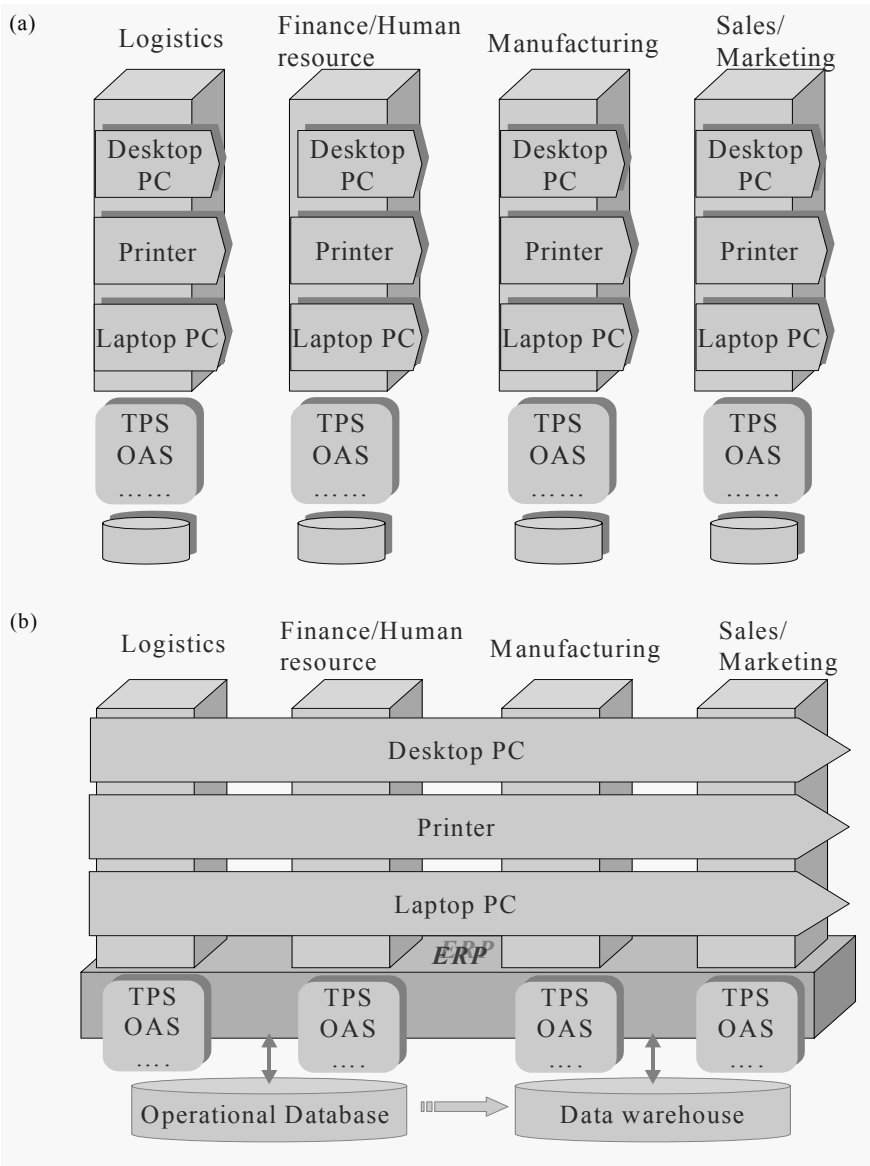

Figure 6: (a) Function focused enterprise information system infrastructure.
(b) Process driven, customer focused enterprise information system infrastructure.

Theses information systems support different business functions within or between organizations. The systems can be a stand alone, client-server based,

Web-based or part of wireless networks. Computerized information systems were firstly applied to accounting and finance management, and office automation functions. Computers were later used in other business functions, such as computer aided product design (CAD), numerical control and computer aided manufacturing (NC, CAM), etc. However, the computerized systems from early times are generally isolated, working for different business functions. For instance, transaction processing systems may be used in a company in different departments. The operations department uses a TPS for processing product requirements, monitoring productions, recording job start and finish dates, etc. At the purchasing department, a TPS is used for issuing purchasing orders, control materials stocks, processing materials requisitions, etc. Product data is stored and processed at both of the departments for different purposes. Such an infrastructure of information systems does not only waste system resources due to data redundancy, but also leads to possible inconsistency of the same data in different departments due to human errors. More importantly, this disconnection reduces operational efficiency in an enterprise due to information transfer and interpretation between the systems. This disconnected infrastructure is function focused. The infrastructure later changed to process driven, customer focused for integration of internal business functions. Such an infrastructure improves process efficiency by reducing information transformation costs and time. The information systems share integrated company-wide data sources and process transactions by automatically updating all related changes in all functional departments. The process driven infrastructure aims at responsive customer service and efficient co-ordination. This integrated network of information systems with company-wide database systems forms the integrated enterprise system. Figure 6 describes the infrastructures of information systems in an electronics manufacturer.

An early successful integration example of information systems was the point of sales system (POS) which emerged in the 1980s. A POS manages sales transactions at checkout counters with barcode and scanners. The system links to sales and marketing systems for sales and customer management. Today, information from POS has become a crucial information resource which is used to connect retailer stores, depots, manufacturing plans and other upstream suppliers with end customer demands. The information systems have therefore been moved from functional focused to enterprise process driven, customer focused, and then moving to supply chain process driven, end customer focused infrastructure. e-Procurement and e-marketing systems for information exchange and transaction implementation between buyers and sellers have been important e-business approaches. They create new procurement and marketing channels to automate e-supply chain operations. Figure 7 describes an e-supply chain system infrastructure based on these technologies. e-Marketplace and Web portals are strategic approaches and technologies to integrate business functions and collect information for e-supply chain management. These approaches will be discussed in detail in the following sections. As seen in Figure 7, the integration of an enterprise system with customers and suppliers has alternative options, i.e. through system integration or e-marketplace. For supply chain partners with

relatively stable relationships, the enterprise system may be integrated with a partner's enterprise system by sharing operational information and co-ordinated planning and implementing supply chain transactions. For spot trading transactions, an e-marketplace may be used to purchase or sell products.

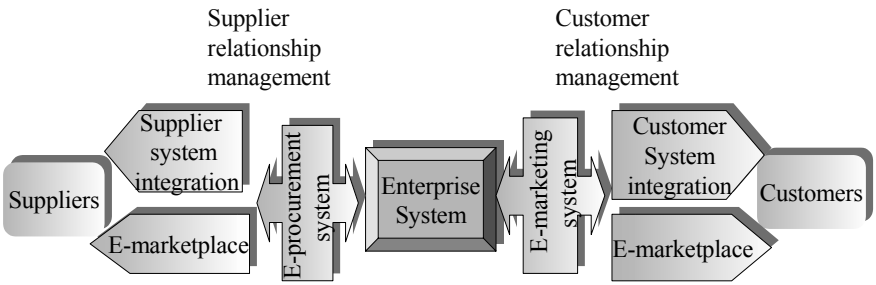

Figure 7: e-Supply chain information system infrastructure.

3.2.3 Communication systems

Communication systems facilitate people exchanging information and in collaboration for affiliated tasks. The Internet is the latest development in communication technology. The World Wide Web creates an open communication system to the public through standard protocol and format for information exchange. Technologies used in electronic communication systems are email, voice mail, fax, teleconferencing, workflow systems, electronic data exchange (EDI), Web-based systems such as instant messaging, chat rooms, groupware, intranet, extranet, etc. [14].

3.2.3.1 Functions of communication systems Primary functions of communication systems include:

(1) Obtain and exchange information between individuals or groups. These are basic functions for all communication technologies. Some tools are for one-way communication by sending messages or multimedia data to business partners, such as fax, email, voice mail. The others are two-way communication tools, such as teleconferencing, on-line chat room, groupware, intranet, extranet. Web-based communication systems are a key technology in e-supply chains for customers and supply chain partners sharing information through which e-business strategies, new marketing and procurement channels can be created.

(2) Share knowledge between users. With communication systems, particularly intranet and extranet, supply chain partners share knowledge of customer requirements, product development, manufacturing technologies to solve problems and how to improve their product quality.

(3) Facilitate decision-making. Efficient communication systems such as teleconferencing, or knowledge management systems facilitate decision making using enriched information from customer, manufacturing processes, etc. Grid computing as a new Internet technology facilitates application outsourcing, e.g. remotely run optimization applications at a service provider or at a partner's application server with spare time and capacity. Such a virtual application integration provides great computing and decision making capability which is not available to every company.
(4) Facilitate co-ordination between users. Internet technology has provided low cost, flexible and convenient communication tools for obtaining and exchanging real-time, dynamic information. As a result of this, information transparency as a new supply chain management philosophy has greatly improved supply chain co-ordination. The transparent information can make both operational and decision making processes visible to supply chain partners to some extent. It helps planning synchronization and joint decision making.

3.2.3.2 Types of communication systems These include:

(1) Teleconferencing. It includes audio teleconferencing and video teleconferencing. It electronically transmits voice and/or images at a same-time, different-place meeting for remotely exchanging real-time information. It supports more than two groups of people communicating.
(2) Email, voice mail, and Fax. They are electronic transmission of messages.
(3) Instant messaging, chat room and news groups. They are Web-based information exchange tools for flexible individual interactions. This facilitates on-line discussion and sharing knowledge.
(4) Groupware. It is the software for sharing information within a work group on the Internet. Lotus Notes is a prominent product in this category for sharing text and images by team members [14]. TeamNow.com provides a tool supporting storage, update and sharing of documents via the Internet. Some groupware has been developed into more complex tools than merely exchanging information. These are used for workflow control which monitors and co-ordinates multi-step tasks (sequence control) by team members in disparate places. This category of tools may also be considered for transaction processing systems.
(5) Intranet and Extranet. They are communication systems built on the Internet and are a specialized control for private use. Intranet is part of Internet, built on a local area network (LAN) and behind a firewall. It can only be accessed by the LAN users. Extranet is an extended intranet, with data encryption and other security control technologies,

built on a wide area network (WAN). It can only be accessed by authorized users on the Internet. Unlike specialized groupware, intranet and extranet provide a flexible communications environment for a large group of users for exchanging information as well as running various e-business applications.

(6) Knowledge management system – communication systems for sharing and finding knowledge among employees or/and partners. Knowledge is the understanding of a specialized field through study, or experience through accumulated information, e.g. a computer system trouble-shooting advisor shares his experience with the developer and customers to solve problems in software.

3.2.4 Transaction processing systems (TPS)

TPS is an information system to monitor and control transactions. A transaction is a complete unit of a business process which processes all required changes caused by an event. For instance, a transaction for delivering a customer order will probably include a series of tasks – schedule the delivery and notify the customer, record the order as delivered in the customer order lists, remove the delivered products from stock. These tasks will be implemented as an "atom" in a workflow by a transaction system with an integrated enterprise database.

TPS collects and stores data of transactions, and manages concurrency and recovery with technologies such as serialized schedule, locking, transaction logs, two-phase commit, etc. Transactions may be completed by transaction systems interactively with people. Some transactions may be automatically implemented without human intervention. Transaction systems are therefore built with workflows, business rules, autonomous software agents and appropriate interfaces for monitoring and execution. POS is a typical TPS. It receives product sales data from scanned barcodes. The product codes are used to retrieve product details automatically from the enterprise database. Then, total costs will be calculated. A receipt will be produced. Payment will be recorded into the accounting system through the integrated database. The checkout data will also trigger a series of updates for stock level changes, sales data changes, etc. As seen in this example, database systems are the back-end of transaction processing systems for implementing tasks. Tools for transaction processing are primarily evolved from database management systems, e.g. Oracle, Sybase, DB2, and many other database products. Today, many of these database-oriented tools have already been developed to include integrated company-wide transaction processing functions and appropriate user interactions which make them actually enterprise systems. A dominant tool, e.g. Oracle 11i, is actually an integrated enterprise system with Web-enabled functionalities supporting e-supply chain management.

To adopt e-business strategy, many TPS have been developed in three-tiered architecture:

(1) Database systems as the back-end for implement transactions;

(2) Intermediary layer for processing business rules, transmitting data in a platform-independent format such as XML and connecting Web with databases by middleware using server-side scripting languages, such as .NET, ASP, JSP, Coldfusion, PHP, etc.;
(3) Presentation layer as the front end for interacting with users on the Internet in standard HTML format and processing data by client-side scripting languages such as JavaScript, VBScript.

With three-tiered architecture, transaction systems can be deployed over distributed geographical locations and business objects (e.g. data sources, transaction interfaces with different workflows) which can be virtually integrated. e-Supply chain approaches such as e-procurement, e-marketing and other Web-based transaction processing functions can be implemented on Extranet and Internet as seen in the Dell.Com example in Figure 4.

Workflow management systems are more advanced transaction processing systems. They do not only implement transactions, but also manage business processes. They can be used to control distributed applications such as co-ordinated supply chain planning and distributed manufacturing control, etc. Workflow systems as business process management tools will be discussed in Section 3.4.

3.2.5 Management information systems (MIS) and executive information systems (EIS)

MIS is designed for monitoring and analyzing operational data based on performance indicators to provide performance information for organization management. MIS works with TPS to extract and aggregate transaction data for performance reports. A frequently produced outcome of MIS is the sales report of an enterprise. The report demonstrates sales results by company, store, region, time period, product category and so on, so that business performance can be monitored and problems can be found and dealt with. EIS is a type of information system with similar functions. However, it provides flexible and interactive access to performance information for executives of an enterprise. It provides interactive system interfaces to users to produce reports based on users' requirements. For e-supply chain management, such information needs to be presented on Web interfaces so that e-business partners and distributed enterprise sites can monitor real-time supply chain performance. For instance, Compuware OptimalView as an e-business portal enables plug-in of dynamical MIS output in MS Excel format on the Web browser.

3.2.6 Decision support system (DSS)

DSS are interactive information systems that provide information, models, data manipulation tools for decision making with semi-structure or unstructured information. Decision support technologies include simulation, optimization, multi-dimensional data analysis (e.g. on-line analytical processing, OLAP), data

mining, expert systems, neural networks, intelligent agents, etc. Although all conventional decision support technologies can be used for e-supply chain management, with Web-based applications, decision support systems are particularly required to equip on-line, responsive decision-making with real-time information. To achieve such an objective, decision-making models can either be embedded into Web-based applications, or be virtually integrated into a supply chain system by application integration technology or outsourcing. For instance, data mining tools can be imbedded into enterprise portals, which is an integrated Web site to interact with suppliers or/and customers, to recognize customer behavior patterns and find business opportunities by automatically collecting and analysing received data from portal users. Another example is outsourcing on-line decision-making services [15]. Small manufacturing companies lack computation facilities for optimizing their operations. One of the issues is optimising materials by cutting operations to reduce costs at the pre-manufacturing stage. By outsourcing on-line optimization services, manufacturers can obtain responsive service from application service providers (ASP).

Technologies of the conventional decision support system can be classified as model intensive approaches, data intensive approaches and knowledge intensive approaches.

Model intensive DSS can be found in the category of simulation tools and optimization tools. Data intensive DSS includes data warehouse, OLAP and data mining. Knowledge intensive DSS is based on artificial intelligence technologies which include expert systems and case-based reasoning, neural networks, fuzzy logic, and intelligent agents.

It has been expected that the next generation of e-business will focus on optimization and automated negotiation [16, 17]. Decision support systems are crucial to optimize e-supply chain operations and to automate co-ordination activities. Current e-business approaches applied to e-supply chain management are still transaction oriented. They focus on improving supply chain visibilities and implementing on-line operations instead of support decisions. More and more decision support functionalities are expected to be integrated with current e-business technologies in the near future to facilitate e-supply chain automation and optimization.

3.2.7 Enterprise systems (EPS) in e-supply chains

EPS is an integrated information system that deals with entire enterprise transaction processes and an integrated database. It transforms data in company-wide business processes into an integrated consistent information resource. As indicated in Section 3.2.2, enterprise information systems were not integrated at the early stages. It was only in the 1990s that enterprise systems become company-wide "operational information organizers". As enterprise systems evolved from the manufacturing resource planning (MRP II) systems, they were named as enterprise resource planning (ERP) systems. However, functions of

today's ERP systems are far beyond resource planning capabilities. Current ERP system vendors are integrating planning, transaction management, business performance monitoring, and supply chain integration into their packages as well as the Internet connectivity. As EPS is a major component of e-supply chains, it is discussed in detail in the next section.

3.3 Enterprise resource planning system (ERP)

An ERP system is the hub of an enterprise [2]. It is an integrated multi-module application software package. An ERP serves and supports multiple business functions based on an integrated database system. It is a major component of e-supply chains as it organizes value-adding activities in each enterprise and builds connections of the enterprises with e-supply chain partners. Primary ERP tools on the market are currently mainly by SAP, Oracle, Baan and PeopleSoft as listed in Table 1.

Table 1: Major ERP commercial tools.

Who Does What ERP vendors and the industries they serve	Aerospace/ Defense	Automotive	Consumer Packaged Goods	Electronics	Industrial/ Manufacturing	Oil/Gas	Pharmaceuticals
Baan Baan Series	✓	✓		✓	✓		
J.D. Edwards & Co. One World, One World Software		✓	✓	✓	✓	✓	✓
Oracle Corp. Applications	✓	✓	✓	✓	✓	✓	✓
PeopleSoft Inc. PeopleSoft 7.5		✓	✓	✓			
SAP R/3	✓	✓	✓	✓	✓	✓	✓
% Planned Penetration	10-15	5-10	35+	40+	35	30	20

Source: Benchmarking Partners Inc.

3.3.1 Functions of ERP systems

Basic functions of an ERP system include execution, control, monitoring, and analysis of business transactions. Initially, ERP systems are enterprise focused,

i.e. they are internally oriented. The functions of an ERP system include the following aspects as described below [18].

3.3.1.1 Operations management An ERP system enables companies to execute, control, monitor and analyze business transactions across all relevant enterprise functional areas. Operations management of an ERP system covers an enterprise's major value-adding activities, i.e. procurement management, inventory management, manufacturing management, maintenance and quality management, delivery management, and sales management. Figure 8 illustrates an interface of EPR sales order management.

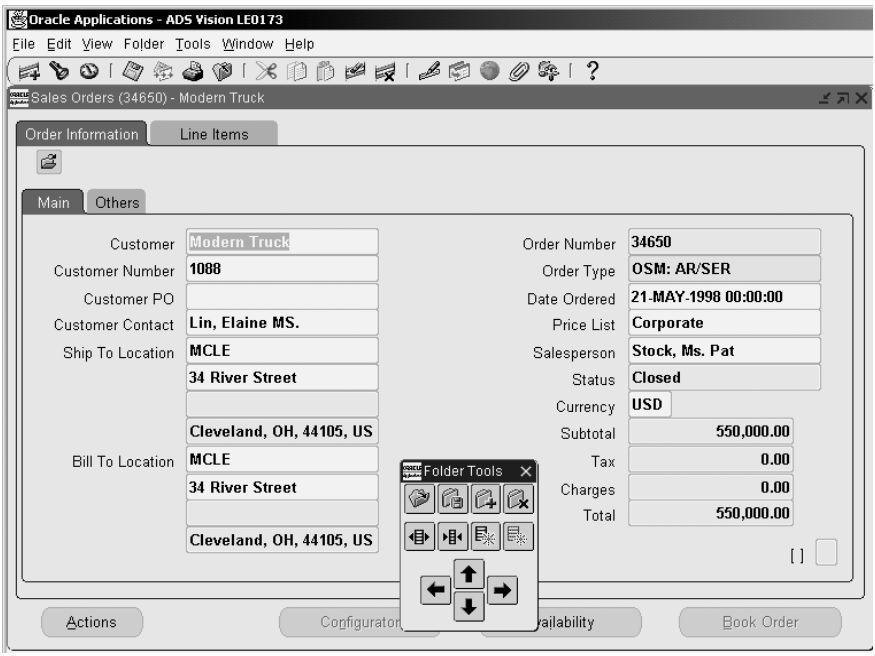

Figure 8: An example of ERP sales order management interface (Source: [19]).

3.3.1.2 Financial management An ERP system helps a company to monitor and control value creation from internal transactions and co-operative operations in supply chains. It does not only maintain recorded sets of business transactions in a financial format, but also reports on financial performance for analytical applications. Financial management functions cover managerial accounting, and manager self-services for manager access to all relevant business information.

3.3.1.3 Human resource management ERP systems support employee development management, recruiting management, employee relationship management, etc.

3.3.1.4 Performance analysis An ERP system supports strategic enterprise management and operational performance analysis. Based on integrated database systems, an ERP system enables companies to monitor and analyse business performance in all business areas in the enterprise. The analytic function helps executives and managers to identify problems and opportunities within and beyond the enterprise. The analysis function focuses on making aggregated key information, analysing profit and loss, market shares, forecast accuracy, delivery reliabilities, fill rate to customer orders, etc. It can be seen that ERP systems embrace functions of MIS and EIS.

3.3.2 Extensions of ERP systems

Currently, ERP systems have been extended to integrate external business relationships and e-business technologies with internal business processes so that business information and processes can be open to business partners, and efficiency and agility of customer service can be achieved. In the collaborative areas such as supply chain management, CRM, SRM, and product life cycle management, ERP systems link enterprise business processes (workflows) with supply chain partners by enabling global visibility of business information. As a result, planning of supply chain partners can be synchronized through Web-based communication and information exchange. Figure 7 has illustrated such extensions. An example of the extension is integrating information in POS, CRM with ERP systems. The primary data flows in the integration include:

(1) Products selected from supplier inventory directly into the different departments of a retailer.
(2) Automatic polling of sales orders from the Web to supplier fulfilment.
(3) Transparent POS data and inventory data (shelf, store, depot) to suppliers.
(4) Centralized data entry, for both inventory management and the e-business catalogue.
(5) Consolidated customer history, tracking, and call centre services integrated with personalized on-line services and knowledge management tools leading to direct marketing.
(6) Synchronized customer order notification and stock availability notification to customers and operations planning of an ERP system.

e-Business portal has been an important approach to providing an integration interface for inter-organizational transactions processing and application integration. A portal comprises enriched enterprise information and user interaction interfaces connecting distributed e-supply chain operational

processes. The Web portals have been included in most of the commercialised ERP tools.

3.3.2.1 Integration of ERP systems A main issue of ERP system implementation is the complexity of supply chain networks, software and hardware platforms, and various business applications. To allow various technologies to communicate and co-ordinate efficiently, they need to be integrated by standard protocols. Figure 9 describes today's enterprise system architecture.

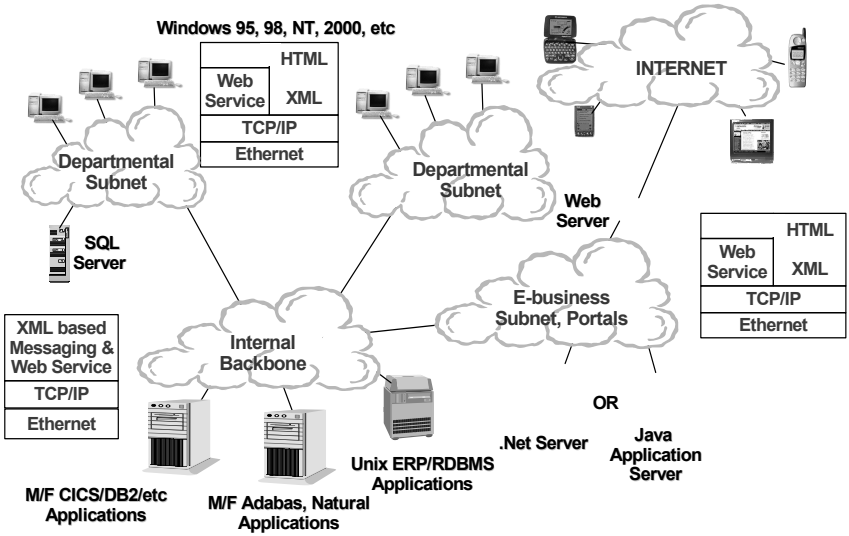

Figure 9: Enterprise system architecture today (Source: [20]).

3.3.2.2 Enterprise application integration (EAI) To enable different application packages to communicate, applications within or in different companies need to be integrated by standard, mutually understandable intermediary software. There are three main streams of EAI standards, Common object request broker architecture (CORBA), Distributed component object model (DCOM), and Java 2 enterprise edition (J2EE). These standards enable applications to communicate with one another and independently from software, hardware platforms and locations (DCOM is for Microsoft Windows only). Latest development of protocols on the Internet has been Web services with the protocol named as simple object access protocol (SOAP) based on the extendable markup language (XML). Web service standard has simplified communication through the Internet and facilitated integration of enterprise applications.

3.3.2.3 Integration with business process management The dynamics of an e-business environment requires enterprise systems to manage business processes. The enterprise business processes in a virtually integrated e-supply chain are required to link e-supply chain partners, respond quickly to market variations, support customized business logics, synchronize and automate transaction flows**.** Business rules and processes designed into enterprise systems should be easy to adapt to the changes of markets and enterprise systems.

Nowadays, business processes or workflow execution and control engines have been integrated with some ERP system packages (e.g. Oracle, SAP, etc.) so that business processes can be flexibly configured based on changes of internal and external workflows of an enterprise. There are also specialized workflow management tools, e.g. OptimalFlow from Compuware. The business process management approach will be discussed in a separate section below.

3.4 Business process management in e-supply chains

Business process management (BPM) is a business-driven technology. BPM provides the capability to present real-time status of business processes, and updates the underlying processes to a dynamic e-supply chain environment.

3.4.1 Functions of BPM systems

Business process management systems handle business events and execute business processes for automation, integration, and collaboration. A BPM system enables modeling and continuous improvement of business processes, routing information according to user-defined business rules [21].

3.4.1.1 Business process definition Through a BPM system, workflows in an e-supply chain can be designed according to enterprise organizational structures, roles of employees, routes of transactions, priorities of tasks, and rules of implementing each transaction. Definition of workflows is the first step in implementing a BPM system. To deal with changes, alternative transaction processing paths or new procedures can be added into the system, and existing workflows can be modified without changing any codes in database systems and components of the BPM, unless new components need to be inserted. Some BPM systems, e.g. Oracle Workflow, even allow modifications of the system without interrupting active processes while the system engine is running.

3.4.1.2 Business process automation A BPM can automate execution of distributed business tasks within and across an enterprise to some extent based on the definition of the workflows. For interactive tasks which require human interactions, the BPM system will load relevant interfaces and pass it on to employees for processing, e.g. a received customer order for approval by a sales manager. For automatic tasks, the BPM will process them based on business rules, e.g. a received job order for automatic assignment to an assembly line.

3.4.1.3 Business process integration A BPM system links enterprise legacy systems to the relevant business tasks in a workflow, and manages data sharing between different applications and business tasks. Distributed tasks can be remotely executed based on given locations and IDs of the tasks in the system directory. Messaging services of a BPM system are based on open server systems which support execution of processes with heterogeneous technologies in different enterprises. The open server systems are normally Java implementations or Web services for communications in the XML format. Therefore, through the workflow engine and communication mechanism, workflows and applications can be easily integrated across e-supply chains. Figure 10 shows an example of a Web-based user interface based on a BPM component for implementing an interactive procurement task. The interface is derived from the BPM tool, OptimalFlow of Compuware Corp.

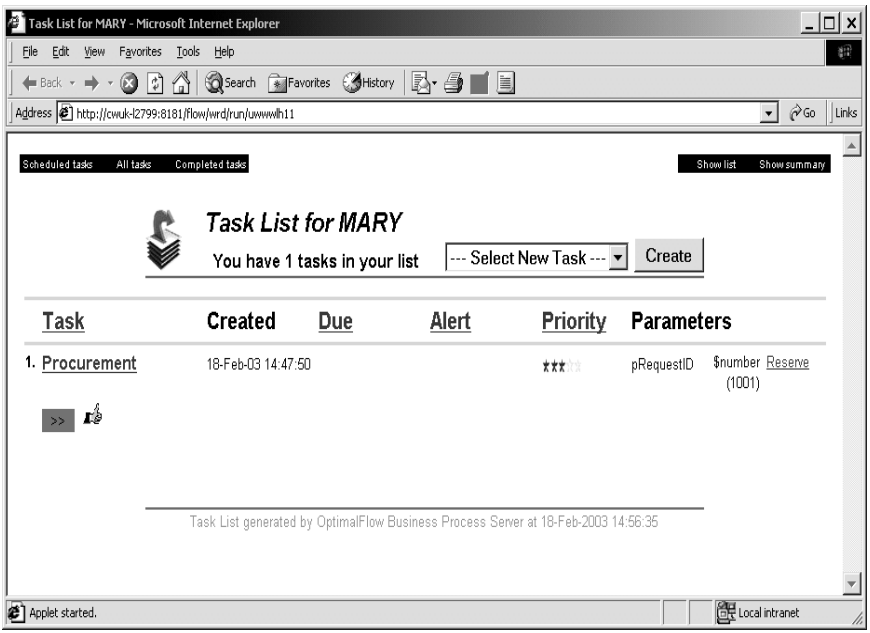

Figure 10: A user interface for a task from a BPM tool, OptimalFlow.

3.4.2 Business process modeling and business process management

The BPM approach has been evolved from the business process modeling approach. A business process modeling approach firstly employs standard modeling language, e.g. uniform modeling language (UML), to describe the business process. Then, a data model is designed according to the business model. Data flows and applications within and across the application communicate with each other through messaging services. With the business

modeling approach, business process integration is implemented by data integration plus open connectivity. This approach is an IT initiative task and requires system modeling knowledge. The integrated system lacks flexibility to changes in business processes. Systems development is facing the challenge of increasingly complex software engineering tasks responding to environment changes.

A BPM system firstly builds a business process (workflow) orchestration model and then integrates data sources and business process components with the orchestration model. The workflow engine data flows and applications communicate with each other. With this approach, business process integration is implemented by the orchestration of applications and data sources into a flexible process which can be easily updated and extended. This approach improves the e-supply chain's agility and productivity, and reduces complexity of system maintenance. The graphical user interface of BPM systems facilitates monitoring process performance.

3.4.3 e-Supply chain portals for BPM

Some BPM tools developed Web-enabled work portals for workflow management. Such tools provide a single access point to business process applications and enterprise information. Figure 11 describes the portal-driven BPM system architecture. With the Web portal, enterprises can more easily extend and integrate applications and data sources. The portal improves transparency of supply chain wide business processes and facilitates monitoring enterprise and supply chain performance.

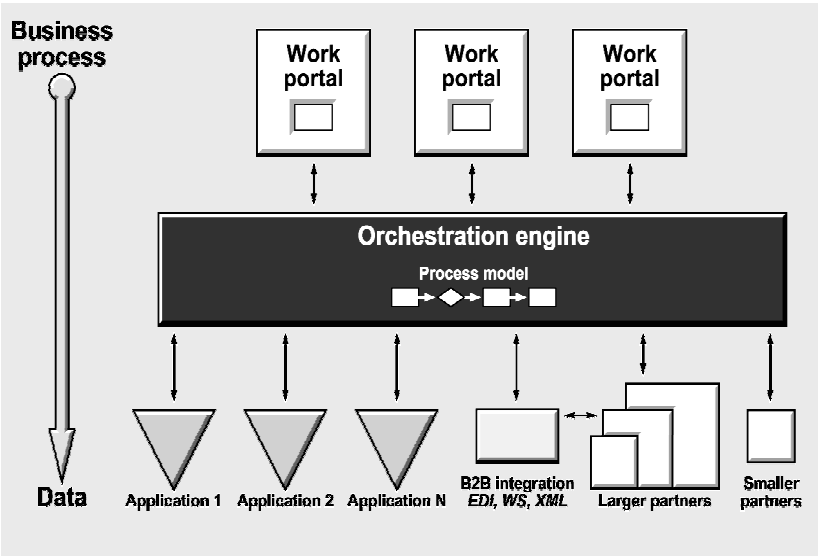

Figure 11: Portal-driven BPM system architecture (Source: [22]).

3.5 Approaches for e-supply chain management

The e-supply chain management technologies discussed above have provided great opportunities to enhance supply chain management and develop new business models for e-supply chain management. The IT-enabled approaches and Web-based technologies have brought e-supply chain management with benefits mainly in the areas of visibility or transparency, connectivity or integration, and automation. Such benefits are consequently leading to potential improvement in agility, flexibility, co-ordination, and optimization. The following approaches facilitated by e-business technologies are beneficial to enterprises [2].

3.5.1 e-Procurement

Procurement is the activities to obtain items from suppliers including purchasing and inbound logistics. e-Procurement is an Internet-based purchasing system that offers electronic purchase order processing and enhanced administrative functions to buyers (sometimes to suppliers as well, if the system is public marketplace), resulting in operational efficiencies and transaction cost savings. e-Procurement implements the procurement activities supported by ERP systems and Internet technologies. e-Procurement can use either vendors' Web-based systems or the public marketplace to complete the transactions.

With a vendor's e-marketing system, the enterprise can log-in to suppliers' marketing Websites and search required products on e-catalogues. The approach reduces time and costs for purchasing transactions. There is also an opportunity to build co-ordinated supply chain planning between vendors and buyers. Manufacturing and logistics can be synchronized with the procurement activities when the vendor's system provides transparent information about enterprise manufacturing planning and stock levels of ordered items. The information helps buyers planning their production and controlling stocks.

With a public e-procurement marketplace, e-procurement can be implemented through the marketplace service. Buyers need to locate a vendor at first, and then requisite quotes and raise orders on-line. This approach provides an opportunity to further reduce purchasing costs and improve product quality by expanded supplier selection base. However, closed co-ordination is more difficult to build up due to the spot trading relationships between buyers and vendors.

In a case of e-procurement with NC@YourService in US, a public Website, NC E-Procurement@YourService, has been created as a state-wide marketplace for suppliers and buyers. The Website is used to search for vendors registered with the service. This service provides a way to search for vendors by vendor name, vendor tax ID, vendor location, commodity code and construction code. Search results provide detailed information about the vendor including whether the vendor participates in the e-quote process. The e-procurement service performs all procurement activities electronically, including requisitioning, purchase order transmission, notification of electronic quotation requests and

electronic quote response for informal bidding, and receipt of goods. The automated transaction processing reduces order cycle time and transaction costs. Another example is a Web portal, industry2industry (www.ind2ind.com), developed as an e-marketplace of e-business (B2B) on-line trading for chemicals, plastics and energy. The Website is for both buyers and sellers to trade their products. The difference from an e-procurement Website is the product category for trade. At an e-procurement site, product category is narrowed for only one group of customers.

3.5.2 e-Supply chain portal

As described in Section 3.4.3, a Web portal of an enterprise can provide a single access interface for BPM. A Web portal can support collaboration by providing knowledge to collaborators, and transaction information to customers and suppliers. The e-procurement approach can actually be implemented through Web portals. In a case of e-supply chain portal application to US Defense department, the use of portals as integrated e-supply chain architectures has integrated diverse sectors and organizations [23]. The portal allows more effective management of the supply chain by providing the necessary tools to everyone involved and allows the links of the supply chain to work together to produce the best possible outcomes with the least manual work. Table 2 highlights the diffusion of supply chain portals. Benefits of the e-supply chain portal application were also reported in this case as accessibility to enterprise information, reduced time for transactions, etc.

Table 2: Diffusion of supply chain portals [23].

Organization	Portal description
Sealy Corporation (bedding manufacturer)	Launched supplier portals to handle procurements for its 20 major US plants from its top 20 suppliers accounting for 96% annual purchase (*Computer World, June 11, 2001*)
Delphi Systems Corporation (automotive parts company)	Provided portals to 5,000 suppliers to reduce delivery delays
Celestica Corporation (high tech equipment manufacturing)	Deployed supplier portals to link services to 36 global manufacturing plants (*Computer World, Dec. 17, 2001*)
Sun Microsystems (server manufacturing)	Uses portals to link supply chain community of 30,000 key suppliers and distributors in real time (*interviews*)

3.5.3 Co-ordinated e-supply chain planning and decision-making

The transparent operational information supported by Internet and enterprise systems underlie various co-ordination opportunities in e-supply chains.

3.5.3.1 Co-ordinated supply Suppliers can plan their production co-operatively with customers' operational situations, e.g. WIP, sales, product in stock, etc. An effective approach of co-ordinated supply is vendor managed inventory (VMI). VMI is not new in supply chain management technologies. However, with Web-based technology, this approach can now be implemented much easier as real time demand and production information of customers can be viewed by suppliers. The information can also be integrated with a supplier's enterprise system or BPM system. This can be achieved by using the stock level or other appropriate information of the customer to trigger supplier's production based on pre-defined rules. The VMI approach builds a mutually agreed replenishment model for the supplier. Stocks of the customer are replenished automatically by the supplier when an alert message is received. While suppliers keep alert on a customer's operations, the customer can also examine the supplier's situation. If a risk of a supply delay can be perceived, the customer can take action to pursue alternative resources when necessary. In a case of the VMI approach application a clothing company, Fruit of the Loom, producing underwear, casual wear, etc., set up a VMI system for its customers [24]. The VMI system has helped the company with improved utilization of its own inventory by synchronizing its production with the customers' POS information.

3.5.3.2 Co-ordinated product development Product development is crucial to reduce time-to-market, improve product quality and reduce costs. To find out a suitable technology for a given design, Web-based search can be used for the best solution. This can be implemented by searching an Intranet with a community for knowledge sharing, or searching openly on the Web. During product design, design information can be shared among e-supply chain partners. Web-enabled CAD and concurrent engineering tools facilitate synchronized design planning and sharing product design drawings, specification data, design changes, etc., with the design team members. A Web-based knowledge sharing tool for engineering design and manufacturing operations was developed by Toussaint and Cheng [25]. The Web-based engineering approach enables engineers to implement tolerancing design for manufacturing co-operatively by sharing on-line design data through a graphical interface. Benefits are reduced design time, consistent product data, knowledge sharing among supply chain members for implementing a concurrent engineering process for better product quality and lower lifecycle costs.

3.6 e-Supply chain automation and optimization with agent-based technology

e-Supply chain operations are frequently implemented in a dynamic virtual integrated environment due to incorporating e-business approaches as discussed in Section 2. To deal with the dynamics, virtuality and complexity of e-supply chain networks, automated transaction processing is in demand for e-supply chain management. At present, e-supply chain management technologies can only automate some simple transaction tasks without human intervention. This is due to the complexity of e-supply chain operations, which require human decisions on conflict operational tasks, selection of critical resources, making agreement on negotiations, optimizing operations, etc. In the networked, dynamic e-business environment, transaction complexity, demanding promptness, dynamic partnering and a heterogeneous technical platform make co-ordination and negotiation tasks with on-line partners a great challenge to e-supply chain managers. It is obvious that e-supply chain management tools need more intelligence to assist people perform the management tasks. One of the promising technologies for this purpose is the intelligent agent-based system. An intelligent agent is an active object (software unit) which possesses certain abilities to perform tasks and communicate with other agents for system goals [26]. Agent-based systems have been extensively studied in academic research for automating business operations. Application cases in supply chain management and e-business can also be found. In this section, applications of the agent-based technology to e-supply chain management will be introduced.

3.6.1 Functions of agent-based systems

Functions of intelligent agents can be classified into internal functions and external functions [27]. They are summarized as follows:

Internally oriented functions:

(1) Autonomy. Agents perform autonomously based on pre-defined protocols and system goals. They cannot be directly invoked. The function enables agents to complete tasks independently (to some extent).
(2) Self-learning. Agents can learn from the environment in which they are working. This function enables agents to adapt themselves to environment changes.
(3) Proactivity and reactivity. Agents respond to environment events reactively in a timely fashion. This function enables agents to recognize environment changes. Agents can also proactively complete tasks based on systems goals. The function enables agents to pursue predefined objectives.

Externally oriented functions:

(4) Co-ordination and Co-operation. Agents perform tasks co-operatively with other agents so that common goals can be realized. The agents can also co-

ordinate with other software agents or human agents to solve conflicts in tasks.

(5) Communication. Agents are able to receive and send messages so that they can interact with the environment.

3.6.2 Applications of intelligent agent systems to e-supply chain management

Intelligent agent technology has been applied to many aspects of supply chain management and e-business. The technology can primarily assist e-supply chain management in three areas: automation, co-ordination, and optimization. Agents are designed for implementing a small range of tasks, e.g. communication agents, negotiation agents, optimization agents, etc. The narrowed functional design enables the agents to autonomously complete assigned tasks. However, a real transaction requires a series of tasks and needs more than one agent to complete the transaction. Therefore, multi-agent systems should be developed for e-supply chain tasks.

3.6.2.1 Automation of e-supply chains Automation means that systems can automatically and flexibly interact with each other. Due to the complexity of e-supply chain operations, tasks for conflict-solving, negotiation, and making decisions are difficult to be automated without human intervention. Static and structured processes can be, and have already been automated, e.g. on-line order processing, on-line payment, issuing invoices, etc. However, to automate dynamic and unstructured/semi-structured processes, information systems for e-supply chain management must be able to autonomously and intelligently perform the tasks so that the human workload can be taken over to some extent. Intelligent multi-agent systems have been developed for this purpose in some cases.

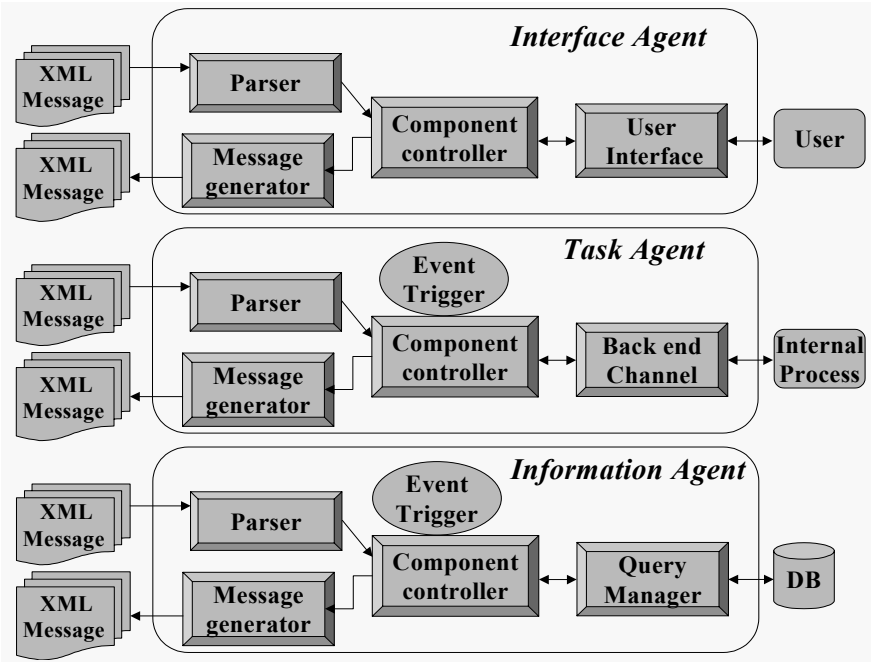

Figure 12: Internal structure of three types of agents (Source: adapted from [28]).

An example of agent-based supply chain systems is a system for managing a logistics process of product maintenance service [28]. This case aims at improving the capability of the timely provision of critical maintenance services and service parts. For this purpose, a product-support logistics chain with supply chain partners (equipment manufacturers, parts distributors, customers) has to collaborate for the efficient exchange of relevant information. The system focuses on facilitating timely sharing and exchanging of information through agent communication for business process automation.

In the case, a multi-agent system was developed for various tasks at the manufacturers, distributors and customers in the chain. Three types of agents were developed: interface agents, information agents, and task agents. Interface agents are designed to interact with users. Information agents are responsible for communicating with other agents. Task agents are assigned to workflow tasks. A protocol was designed to guide interactive behavior of the agents. An XML format is used for transferring messages between agents. To automate the Web-based service supply chain system, the three types of agents work together controlled by an interaction protocol, and communicate in a standard language. Figure 12 illustrates three types of agents to autonomously execute tasks in this case. Through automated and timely agent interaction, the system improved

communication speed, data correctness, and responsiveness to customer demands in the supply chain.

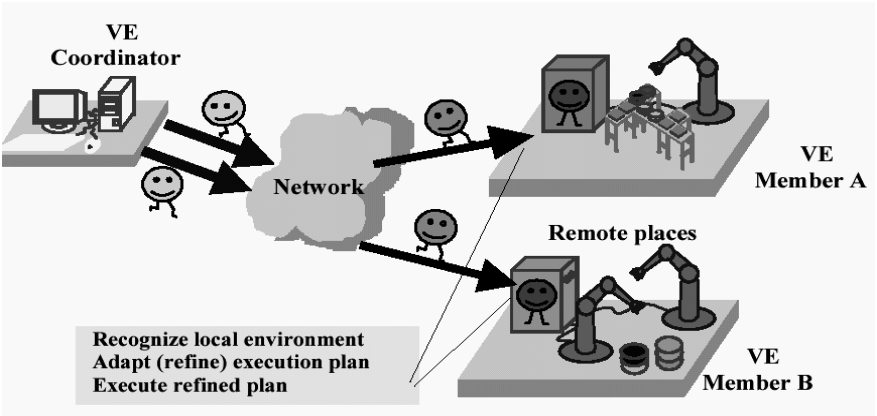

Figure 13: Mobile agents applied to a VE remote supervision environment (Source: [9]).

Another example is a remote control system for manufacturing process automation. In a virtual e-supply chain environment, some tasks need to be executed remotely in a timely manner, particularly for tasks of distributed manufacturing control, and railway transportation control, etc. Agent technology has been employed to monitor and control remotely distributed tasks. The agents can move from one Internet site to another site to assist human agents controlling tasks at multiple sites at the same time. This type of agents is called mobile agents. Mobile agent is a software application that moves on its own to different sites, and then is activated to execute tasks [29]. Figure 13 illustrates an example of mobile agents for control of distributed manufacturing processes. Through the agent-based remote control, the distributed manufacturing processes can be efficiently monitored and synchronized in the virtual enterprise (VE).

3.6.2.2 e-Supply chain co-ordination and optimization In essence, e-supply chain automation cannot be realized without successful co-ordination between supply chain partners. Co-ordination, particularly negotiations for an agreement to execute business processes, is critical to automation and optimization of e-supply chain operations. The dynamic and unstructured interaction contents and format make the co-ordination an important issue in e-supply chain management. For co-ordination, the most complex and unstructured activity is negotiation. To automate a negotiation process requires modeling human behavior, defining negotiation languages, and developing protocols. The protocol will tell agents how to interact with other agents and when to call human agents for making a decision.

Research on negotiation protocols, ontologies, and languages have been reported in the literature over the past three decades. However, only in the 1990s did the automated negotiation technology become a practical issue due to the emerging new business opportunity, e-business. In recent negotiation research, there are mainly three themes: game theory-based approach, heuristic-based approach, and argumentation-based approach. These approaches are modeled by different theories. When e-supply chain partners use different negotiation approaches, automation of the negotiation process becomes a very difficult task. Therefore, approaches to connect different negotiation systems are required.

In the case of supply chain co-ordination and optimization [30], the agent-based technology and a co-ordination model are used to automate and optimize the e-supply chain co-ordination process. In this case, a co-ordination system was built in a retail supply chain context. The agent-based system has been developed with three layers, i.e. decision layer, co-ordination layer and optimization layer. There are four major components in the system – a business abstraction model, a decision agent, a co-ordination agent and an optimization agent.

Planning		Source			Conversion			Delivery	
		Supplier leadtime	On-time supply	…	Work cost	WIP	…	Product stocks	Shipping leadtime
Reliability	On time delivery	Relationship matrix (parameters to indicate importance of each decision factor to objectives)							
	Order fill rate								
	……								
Cost	Product price								
	……								
Flexibility	Upside flexibility								
	Response time to change								
	……								
Speed	Order fulfil leadtime								
	……								

Figure 14: The matrix for abstracted decision processes (Source: [30]).

The system structure and the three components are described below:

(1) Business abstraction model. The model was developed based on an extended quality function deployment (EQFD) tool (as seen in Figure 14). The model is integrated into the co-ordination system for two purposes. Firstly, it is used to provide transparent decision-making information for enhancing mutual understanding between e-supply chain partners, so that negotiations can be more efficiently completed with an agreement. Secondly, the extended EQFD model provides a tool to co-ordinate business processes among supply chain partners by evaluating impacts of each local (company level) decision on partners and the whole supply chain. The evaluation results are displayed by performance indexes and used in co-ordinated planning processes. As seen in Figure 14, the model contains key decision factors, objectives and their relationships. This information is programmed into the system, and displayed on user interfaces, so that decision processes can be abstracted into a visible graphic format to support decision-making.

(2) Decision agent. The decision agent at the decision layer includes communication control, planning module and data service module. They are responsible for local (company level) decision-making. The decision-making approach and negotiation strategies are domain and organization specific. Therefore, they cannot be standardized. The decision processes are completed locally, based on internal and external constraints and instructions given by the co-ordination layer and optimization layer.

(3) Co-ordination agent. A coordinator agent at the co-ordination layer includes communication control, argumentation module and co-ordination module. The argumentation module will be developed as the core component in co-ordination agents based on the decision-making transparency principle and the business abstraction model. The co-ordination module is an analyzer that collects information from the argumentation module and requests argumentation messages from related partners. The information is analyzed to present key constraints and key enablers to improve performance of the company and whole network. The agents will also instruct a negotiation process to start, continue and terminate.

(4) Optimization agent. The agent at the optimization layer aims at directing local decisions towards global optimization which maximize joint gains for supply chain partners. The agents include communication control and optimization module. The optimization module will be designed to request performance, priorities of objectives and other decisional parameters from related partners. The module provides recommended solutions on decision factors to pursue maximum joint benefits. The agent calculates direct and indirect impact of local decisions and provides guidance for local decision-making. Figures 15, 16 and 17 illustrate the architectures of the agents.

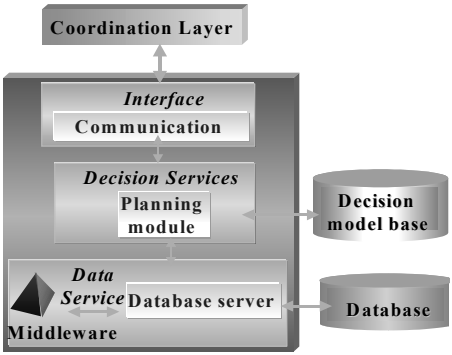

Figure 15: The architecture of a decision agent (Source: [30]).

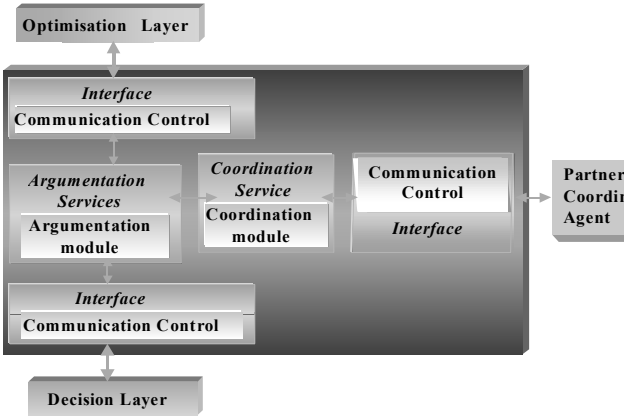

Figure 16: The architecture of a co-ordination agent (Source: [30]).

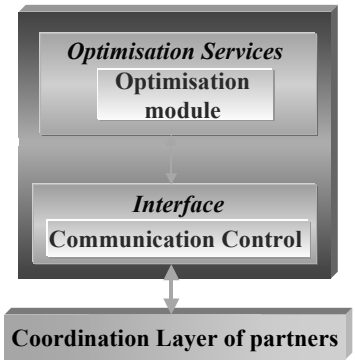

Figure 17: The architecture of an optimization agent (Source: [30]).

The co-ordination system with three-layered architecture separates individual negotiation and decision-making platforms from the global co-ordination approach, so that a standard and flexible co-ordination protocol can be implemented. The system reduces co-ordination time and man-made errors; increases customer numbers which can be dealt with at the same time for negotiations in e-supply chain operations, improves negotiation interface with transparent decision information; improves trust and mutual understanding, and maximizes joint gains from negotiation results for e-supply chain partners.

3.7 Next generation technologies and e-supply chain management

It has been broadly recognized that the grid computing technology will significantly affect the next generation of Internet technology and the e-business roadmap. Grid computing technology includes data grids which enables seamless access to distributed data in files and databases, computational grids which leverage spare computing power to solve complex problems, and service grids which create an infrastructure for sharing Web services [31]. These technologies will greatly improve integration capability of Web-based systems. As a result, application of grid computing technologies will further facilitate e-supply chain integration and improve the efficiency. Currently many business functions have been automated with online systems. The grid technology with current available standards (TCP/IP, SMTP, FTP, HTTP, HTML, XML, Web services, etc.) and more advanced hardware (faster chips and network wide band) will seamlessly connect all supply chain elements, and automate and optimize more supply chain operations. Currently, technologies in enterprise networks and supply chains have not been fully integrated, as shown in Figure 18.

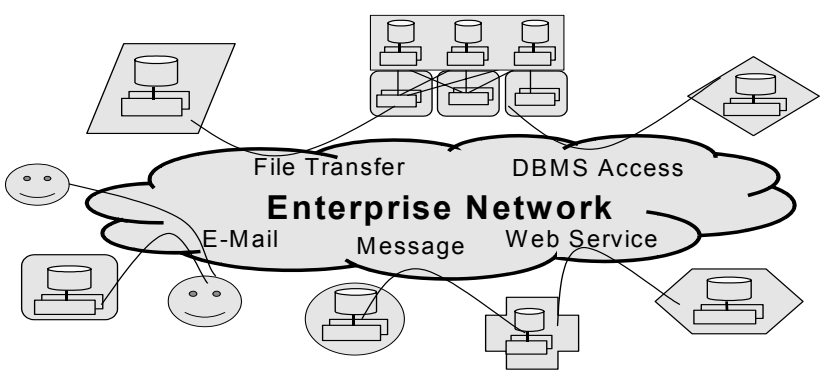

Figure 18: Conventional enterprise system architecture (Source: [32]).

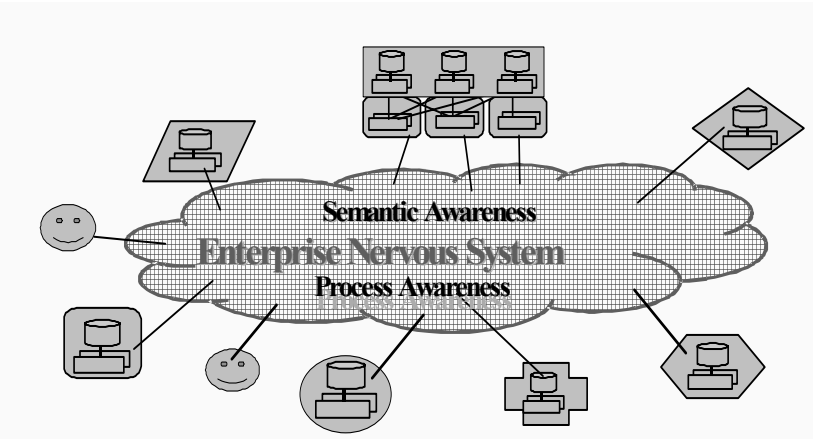

Figure 19: Enterprise nervous system (ENS) architecture (Source: [32]).

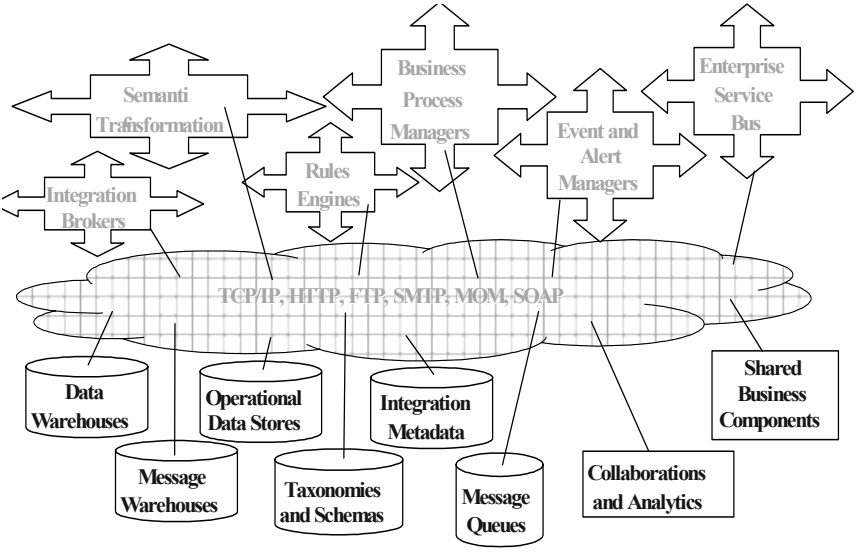

Figure 20: Technology for the Grid and ENS (Source: [32]).

The worldwide grid and enterprise nervous systems (ENS) will facilitate the world-wide integration of business processes, as illustrated in Figures 19 and 20. More and more supply chain operations will be able to be dynamically optimized through the computational technology. Spare computing capacities will be efficiently utilized for analyzing and optimizing business processes for supply chain members. Currently, this is virtually out of reach for the majority of small and middle sized companies. Such technological advancement aims to e-supply

chain management with simplified network access, seamless connectivity, increased efficiency, improved agility, and lower costs.

The other trend of technology development is Web-based intelligence. The next generation e-supply chain management is expected to be more intelligent, i.e. provide more decision support functionality to business. Today, more and more decision support technologies include data warehouse, data mining, on-line analytical processing, and knowledge-based systems. Neural networks computing and agent-based systems have been applied to Web-enabled business process management. This development will add more capabilities to current on-line services, most of which focus on merely transaction processing. The Internet-enabled intelligence will then allow e-supply chains to operate more efficiently.

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