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ERP research, development and implementation in China: an overview

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An Enterprise Resource Planning (ERP) system is a highly integrated enterprise information system that manages all aspects of the business operations of an enterprise including production planning, purchasing, engineering design, manufacturing, marketing, distribution, accounting and customer service. In the last two decades, Manufacturing Resource Planning (MRP) and ERP have been successfully introduced into Chinese industry. Supported by sponsored research programmes, the research outcomes on ERP systems by Chinese academic researchers have been directly supporting the Chinese ERP software industry. An overview of ERP research and its development and implementation in China will be given here. The research trend of ERP systems will also be discussed.

Keywords: Manufacturing Resources Planning; Enterprise Resources Planning (ERP); ERP architecture; ERP development; ERP implementation

1. Introduction

Today, keen competition in the marketplace has challenged the survival of manufacturing companies throughout the world. Many Chinese manufacturing firms have recognized the importance of introducing advanced manufacturing and information technologies (Li and Li 2000). As a result, Chinese manufacturing firms have increasingly adopted information technology-based manufacturing software to maintain their competitiveness in the marketplace. Adopting Enterprise Resource Planning (ERP) systems is one of the major endeavours. ERP originates from the Manufacturing Resource Planning (MRP II), which in turn is an extension of the Material Requirement Planning (MRP) (Li and Li 2000, Xu 2000, Xu *et al.* 2003). Therefore, any comprehensive review of ERP should not exclude issues related to MRP II and MRP. APICS (the American Production and Inventory Control Society) defined MRP as a system that uses bills of materials, inventory and open order data, and master production schedule information to calculate requirements for materials (Regan *et al.* 1983). An MRP system generally consists of the following modules: master production scheduling, requirements planning,

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capacity planning, shop floor control and production accounting (Flapper *et al.* 1991). MRP systems presumably work in a stable environment where demand for end products is clearly known or at least predictable. In changing environments where orders are not certain, MRP systems must frequently reschedule production when order data are changed. Such frequent rescheduling may affect various aspects of manufacturing. To cope with the uncertainty of market order, feedback loops and other functional modules have been added that include purchasing, distribution and human resource management modules. The 'extended' MRP systems were named as MRP II, regarded as the second-generation MRP systems.

In 1981, the first MRP II system was implemented in China. It was introduced by a machine-tool company located in Shenyang. Since then MRP II/ERP systems have drawn growing attention from both academic and industrial circles. In the last two decades, ERP research and applications in China have made a long journey from initial pilot run to enterprise-wide full implementation, and from academic research initiatives to commercial development. To the authors' knowledge, over 100 research projects related to MRP II/ERP have been endorsed and conducted to gain insight from understanding of MRP II/ERP principles, to improve and develop the relevant algorithms, and to integrate MRP II/ERP systems with other applications such as PDM, MES, CRM and SCM systems. The research outcomes have stimulated industrial interest in using MRP II/ERP, which is considered an effective way to promote the competitive edge of China's manufacturing industry. For the time being, there is no exact number that can tell how many manufacturing firms have implemented MRP II/ERP systems. However, several surveys conducted by various associations and institutions estimate that nearly 1000 companies have implemented MRP II/ERP systems. According to a prevailing 'three-tier' opinion regarding the status of these ERP implementation, one-third of the implementations has been satisfactory, one-third has partially achieved the company goal, and the final one-third failed to achieve planned goals.

Despite its increasing acceptance, the high failure rate of MRP II/ERP implementation has drawn attention from researchers and practitioners. It is commonly accepted that an MRP II/ERP implementation may be very risky if it is undertaken without full preparation and/or a detailed feasibility study. Some practitioners even argue that MRP II/ERP systems are not suitable for Chinese manufacturing companies because of differences in economic systems, valuations, culture and business processes between industrialized nations and China. Sometimes, financial losses or stagnant development in companies was attributed to unsuccessful MRP II/ERP implementation. The diverse attitude toward MRP II/ERP systems has nonplussed some manufacturing firms, and they appear overly cautious about making decisions on adopting ERP systems. However, the advocates for MRP II/ERP systems apparently overwhelm those against, as it is difficult to find software substitutes to replace MRP II/ERP systems in manufacturing practice.

When MRP II/ERP systems were initially introduced into China, the commercial off-the-shelf products were provided by vendors including SAP, Oracle, Baan, PeopleSoft, and J. D. Edwards. Recognizing the enormous Chinese ERP market and economic benefits bought in by ERP systems, many Chinese universities and software companies started to develop their proprietary MRP II/ERP software packages, supported by the National High-Tech Research Programme of China and other public funding sources. These academic development efforts finally gave

rise to the emergence of an increasing number of IT companies with specific business interest in MRP II/ERP software packages.

Since the 1980s, the wave of information technology products focused upon traditional manufacturing firms has further fuelled the promotion of MRP II/ERP systems in China. The ERP market is booming in China, and the annual market is estimated in billions of US dollars. An increasing number of manufacturing companies are expected to implement ERP systems in the foreseeable future. Consequently, both the world's leading ERP vendors and domestic vendors are making tremendous efforts to compete for market share which directly leads to further academic interest for new algorithms related to ERP systems and better implementation approaches.

The goal of this paper is to provide an overview of the MRP II/ERP research, development and industrial implementation in China based on available data. The paper will also analyse and discuss the direction for ERP research and development, offering advice to researchers and practitioners. The paper is organized as follows. Section 2 gives an overview of the main research efforts on ERP systems including ERP architectures, specific approaches, and how ERP integrates with other applications. Section 3 introduces the major characteristics of ERP development in China in three successive stages. Then, a generic ERP system architecture is presented to demonstrate the ERP development trend toward J2EE platforms. Section 4 summarizes the industrial implementations of ERP systems in China. Section 5 discusses the future direction of ERP research and finally, section 6 provides a conclusion.

2. ERP research in China: an overview

Li *et al*. (2001) report a comprehensive study on MRPII implementation in Chinese. They analyse the benefits and weaknesses of MRPII implementation in China and summarize success factors that can be imitated by other companies that are interested in implementing MRP II/ERP systems.

Since its first appearance in China, MRP II/ERP systems have drawn attention from researchers of several disciplines such as operations and production management, manufacturing engineering, and information systems. The main focus of numerous research efforts has been to adapt the ERP system to China's industrial and business environment, to develop Chinese versions of ERP system architectures, to look for various optimization algorithms and to probe effective ways for integration with other applications (Li 1999, 2000a, b, Li and Li 2000, Feng *et al*. 2001, Li *et al*. 2001, Feng *et al*. 2003).

2.1 *Adaptation and localization*

One of the vital challenges to MRP II/ERP implementation is to adapt the system effectively to the unique Chinese industrial and business environment. Due to differences in management approach and systems, some Chinese companies run their business with processes that are unique to themselves. Business processes and operational decisions in such manufacturing companies are heavily based upon managerial experience and intuition. Management staffs communicate through hard copies of reports, which were passed from department to department.

In addition, there was also a lack of equivalent technical terms in manufacturing practice, which exactly match those used in MRP II/ERP systems. The essence of an ERP system is calculation of requirements for materials and resources to be consumed in manufacturing initially and concurrently; however, conventional managerial approaches used in some Chinese companies were to fulfil production plans presumably by determining the types and quantities of products to be produced in specific time horizons.

To fill the gap, such companies were asked to abandon their traditional planning systems and prepare production plans according to procedures or requirements embedded in ERP systems. Meanwhile, research was performed to identify specifically the pre- and post-conditions of ERP implementation. It was clarified that explicit business processes have to be specified before considering using ERP. Hence, numerous approaches were proposed to specify user requirements, and to design and represent business processes. It was further identified that elaborately prepared operation parameters are crucial to ERP performance, and some Chinese companies lacked accurate and standard operation parameters. To cope with this, several research projects were implemented to develop computer-aided methods for determining parameters related to lead-times and material. Some CAPP systems were developed to determine precisely manufacturing process parameters as the input to ERP systems.

When trying to adapt Chinese companies to ERP system environments, researchers also began to localize ERP systems. ERP modules were classified into three types: modules to be used as-is, modules to be used with modifications and modules to be discarded. For instance, modules such as material requirement planning, inventory control and customer order entry were basically adopted without major modifications, modules such as production planning and purchase control had to be modified to comply with the application scenarios, and modules such as finance control were partially discarded in early ERP implementations due to the considerable differences in the accounting and taxation systems. The ERP implementation experience in Taiwan Province also shows that the business models and business processes underlying most ERP software packages provided by major vendors mainly reflect North American or European industry practices. The business models or business processes in Taiwan Province are likely to be different from Western ones. Differences could arise from data format, business procedures, management styles, etc. (Sheu *et al.* 2004).

Numerous surveys have been administered to look into the cruxes that cause MRP II/ERP to fail to achieve their desired goals, and to summarize the best practices. Some publicly funded projects have conducted benchmarking analysis and developed a set of indicators for evaluating the performance of various ERP packages. Analytical methods were also developed to help companies make optimal decisions on ERP selections. For example, Wei and Wang from Tsinghua University at Xinzhu, Taiwan Province have proposed a comprehensive framework for selecting an ERP system specifically in the Chinese business environment (Wei and Wang 2004).

In addition to the issues mentioned above, studies were also conducted for specific optimization algorithms. In the context of material requirement planning, product structures represented as bills of materials (BOMs) are the basis of the calculations. Some approaches have been proposed to construct and decompose

various BOMs with advantages including high computation speed, low storage requirements, and easy access. Multiple production planning models were developed to help shop floor scheduling with considerations of earliness/tardiness penalties, emergent events, random and fuzzy parameters, and customer satisfaction levels. Some algorithms were worked out for capacity requirement planning with the purpose of increasing facility utilizations and/or minimizing maintenance costs. Some researchers made efforts to embed JIT into ERP, arguing that the hybrid approach would possess the merits of both 'push' and 'pull' methods.

For instance, Jiang *et al.* (2002) developed a production planning algorithm based on network graphs, which took time constraints and resource conflicts among process nodes into account simultaneously. The objective function was to minimize the total earliness and tardiness. The simulated annealing method was adopted to solve the problem, and the algorithm was later used in their ERP package. Hu *et al.* (2003) proposed a production-scheduling algorithm for cost optimization. The algorithm assumed that a production task consisted of a series of activities consuming a number of renewable and/or non-renewable resources. Each activity had different choices of resources, and the resources totally consumed by all activities constituted the overall cost of a production task. A heuristic algorithm based on the constraint propagation and decomposition technique was developed for problem solving. Xu and Tian (2002) analysed problems facing production planning in a petrochemical corporation with complex material, energy and information flows. A production-planning algorithm based on linear programming was developed to maximize the financial revenues in a certain planning horizon. The essence of the algorithm was to maintain the material balance among production units with the help of an input–output matrix. Liao *et al.* (2003) developed a multiple-objective optimization algorithm for production planning in a petroleum refinery, which aimed at maximizing a benefit function and minimizing a waste function in parallel. The model consisted of eight types of constraints such as material balance among the pipelined production units, unit processing capacities, stock levels, etc.

2.2 *Studies on ERP architectures*

With transitions from planning economy to market economy, Chinese companies began to place financial issues on high priority. Research efforts have been devoted to reduce and control manufacturing costs, as a result, various approaches for estimating costs and identifying cost factors were developed. Research shows that cost factors were not sufficiently addressed in commercial ERP systems, and so-called 'cost-control based ERP' was proposed. Researchers argued that all operation decisions in an innovative ERP package should be finalized based on cost justifications. Zhan and Xu (2002) argued that ERP has conventionally focused on time horizon based resource planning, while trivializing cost control in manufacturing. They proposed a conceptual ERP architecture to incorporate the two facets of time based planning and cost control. As shown in figure 1, the cost control activities are carried out in four different levels, namely the market level, supply chain level, company level and department level. It is believed that ERP systems characterized by cost control would ameliorate a company's in- and outbound capital flows, making best use of all resources.

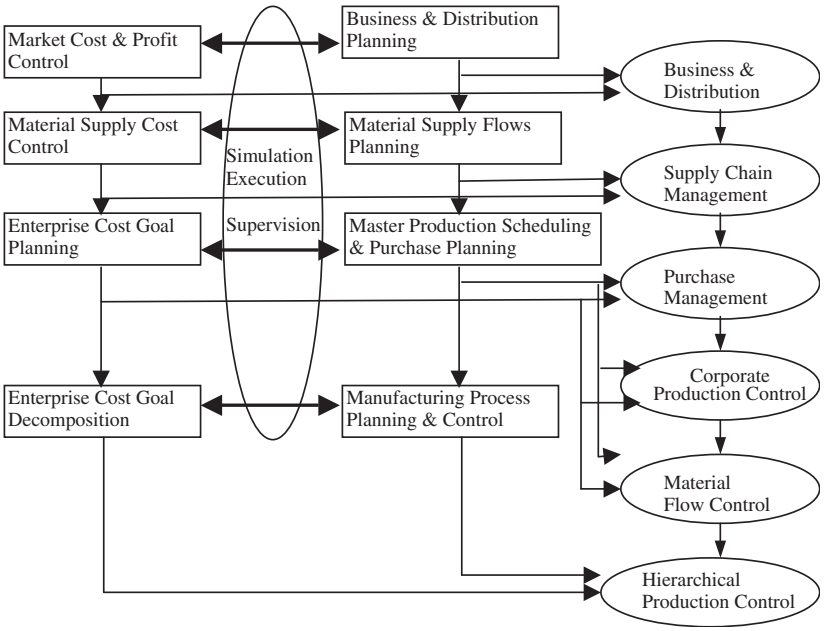

Figure 1. Time- and cost-based ERP architecture.

In the last decade, new manufacturing strategies or paradigms have continued to emerge such as agile manufacturing, virtual or extended enterprises, learning organizations, and intelligent manufacturing. All of these new manufacturing concepts have inevitably influenced the management philosophy and styles, which would eventually be realized by extending the existing ERP functions. In compliance with new manufacturing concepts, another noticeable trend has been to enhance software packages' modularity, autonomy, intelligence, and flexibility. To this end, new artificial intelligence (AI) achievements are intentionally introduced into ERP packages. Multi-agent systems become one of the major approaches to increase ERP's scalability, intelligence, and flexibility. It is suggested that agent-based ERP system can be flexibly reconfigured to adapt to external changes and support business process reengineering activities. Agent-based ERP systems have advantages of high adaptability, interoperability and the capability of synchronization. Figure 2 illustrates an agent-based ERP architecture of four transaction layers (Li and Sun 2002). The data layer is expected to manage all data related to enterprise models, products, customers, and so on. The tool layer is expected to provide tools to define, deploy, and manipulate data. The application layer forms the basic platform to carry out ERP functions, such as planning, execution, and control. The decision-making layer is presumably supposed to support management and make decisions on strategic issues.

2.3 *Integration with other applications*

It is widely recognized that information technology (IT) has given a significant impetus to the performance of manufacturing firms. As a result, IT applications have been installed on numerous heterogeneous platforms to facilitate data transactions

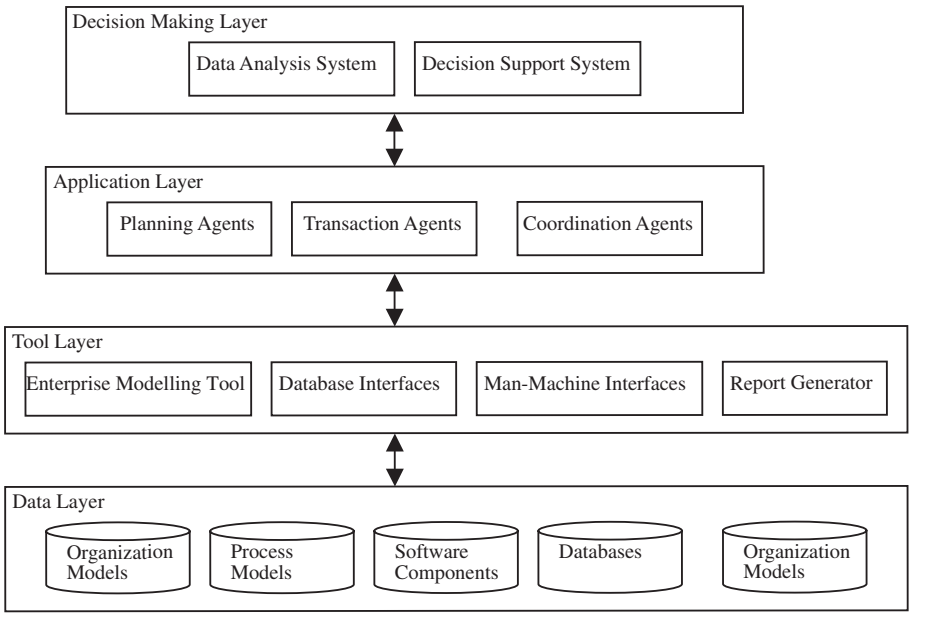

Figure 2. Agent-based ERP architecture.

within or across departmental boundaries. Nowadays, IT projects have to be carried out with communication requirements beyond company boundaries, as the concepts of virtual or extended enterprises are prevailing in industries.

It is rarely the case that an ERP was implemented in an environment with no existing information systems infrastructure. ERP systems frequently have to be implemented in environments with certain existing legacy applications or where other applications are being implemented in parallel. To bridge these so-called 'automation/information islands' seamlessly, manufacturing companies try to integrate ERPs with other application systems, among which the most notable off-the-shelf commercial software packages are PDM, CRM, and SCM systems. There are several reasons that make the integration requirements extremely challenging. First, all of those off-the-shelf software packages are independently developed. Though claiming to have adopted open system architectures, the software packages completely hide their data formats and processing transactions behind the interfaces. Second, these applications are distributed across a number of business departments and are deployed on heterogeneous platforms. To integrate these applications cost-effectively requires sophisticated knowledge and a solid understanding of the information infrastructures. Third, integration has to be planned prior to or at least in parallel with ERP implementation. Hence, integration considerations increase the complexity of ERP implementation, especially when one has no concrete knowledge of other applications. This gives rise to the need to develop approaches for integrating ERP with PDM, CRM, and SCM systems.

ERP's integration with product data management (PDM) is relatively straightforward since the two systems primarily interact upon information regarding product structure. In general, an ERP system has a function module responsible

for managing product BOMs while a PDM system declares its core competency by managing all product related data. The crux is to maintain the consistency between the product BOMs separately stored in ERP and PDM databases. Conceptually, the product BOMs in the PDM database are regarded as the master version, while those in the ERP database are considered as slave versions. ERP's product data have to be responsively updated when those in the PDM database change.

The integration between ERP, CRM, and SCM seems more complicated as the three systems are largely overlapping in their business functions. Originating from logistics management, SCM offers many business functions similar to those of ERP including aspects of purchasing, inventory, finance and distribution. Integrating ERP with SCM systems may involve making trade-off decisions on whether to disable the duplicated functions or not. The integration between ERP and CRM is conceptually conducted in a way so that a CRM system is considered the front-end of the ERP system. In the context of information, integration may be realized through transformation interfaces, API function evocations, and broker-based approaches.

The underlining essence of the broker-based approach is that all data transactions are conducted with help of the brokers. An integration architecture based on CORBA provides an ideal means to support distributed transactions involving multiple application objects and with multiple data sources spanning the Internet and company intranets (Wang *et al*. 2001). Within the integration framework, data sources are encapsulated into information objects, and are defined and registered by the brokers. The application systems are encapsulated as application objects, which are connected through adapters to a CORBA compliant object request broker (ORB) bus. Applications create connections with CORBA request/service brokers, which allow the applications to have access to data sources linking to the CORBA bus. Brokers maintain the information transparency in the environments, separating application objects from the details of data access. When an application object issues a request, the brokers will find the right target data object, invoke it, deliver a message to it, and return the response message to the application object. In this way, application systems gain access to and perform operations on remote data sources.

3. ERP development in China

3.1 *Milestones*

Evidences show that MRP-based systems will continue to dominate production planning and control in manufacturing industries (Kadipasaoglu and Sridharan 1997). Currently China's ERP market is booming, thanks to the promotion of IT-based manufacturing technologies. The enticing prospects of the Chinese ERP market have been continuously attracting many major ERP vendors. These ERP vendors include SAP, ORACLE, PeopleSoft and Baan. The companies are primarily making efforts to win orders from big corporations, taking advantage of their advanced software technologies. In view of the enormous business opportunities provided by the Chinese ERP market, Chinese institutions and software companies try to slice and obtain certain pieces of the 'ERP cake.' The development of domestic ERP systems can be classified into three stages.

The first stage can be traced back to 1980s that was characterized by the customization of ERP software. When major ERP vendors in the world first came to China, they began to create partnerships with Chinese universities and research institutes in order to facilitate ERP implementation in China. Research indicates that language, culture, government regulations, and management style can affect ERP implementation (Sheu *et al*. 2004). Those vendors understand that no universal ERP system could be implemented in different countries successfully without modification. The reason why the ERP vendors tried to seek help from academic institutions was that they had difficulty finding people with ERP background in industrial sectors. Due to the fact that technical problems were relatively easy to resolve, and communication barriers resulting from language differences were far more difficult to overcome, Chinese researchers were asked to translate documents such as installation manuals and user guides, and to literally change the software menu commands from English to Chinese. During this stage, the Chinese ERP glossary was gradually unified and consolidated. A variety of information dissemination events such as presentations, roundtable discussions, and/or press briefings were organized to build ERP awareness and promote the acceptance of MRP II/ERP in industries. These promotion activities slowly yet steadily took effect and a few manufacturing firms decided to adopt ERP. The pilot implementations in these companies quickly encountered difficulties brought forth by inconsistencies between ERP principles and the conventional business practices of the Chinese manufacturing companies. Consequently, academic researchers were asked to customize the ERP packages. Emphasis was placed on modifying inappropriate modules and adding complementary modules to adapt to specific characteristics of the manufacturing companies. At this stage, Chinese researchers were primarily offering a wide range of assistance and services to non-domestic ERP vendors including translation, promotion, and customization. The initial successful implementations led those vendors to develop Chinese versions of their products rather than simply providing the translated duplication versions only.

The second stage dates back to the first half of 1990s and was characterized by the development of an early version of Chinese ERP software. With increased knowledge and experience with ERP systems, Chinese researchers began to develop their own ERP systems. Its aim was to meet the unique requirements of Chinese manufacturing companies. At this stage, there was barely any commercial development, the research project teams at academic institutions were supported by public funding sources. The teams were devoted to developing a Chinese version of MRP II/ERP. These software packages incorporated the MRP II/ERP concepts and principles in the context of Chinese enterprise management (Gan and Zhang 1992). Shenyang Institute of Automation of Chinese Academy of Sciences was one of the first pioneers in developing MRP II/ERP systems, supported by the National High-Tech Research Program of China. In addition, Beijing Institute of Automation, Northeast University, Tsinghua University, and Shanghai Jiaotong University were also pioneer institutions for developing ERP systems. The outcomes of these research projects were only prototypes capable of performing limited functions. These early MRP II/ERP prototypes had quite a few technical problems to resolve that involved architecture, functionality, interfaces, and data transaction. These prototype ERP systems could only be used for demonstration purposes, and none of them could be directly implemented without substantial

re-development effort. However, their unbeatable low prices drew attention from companies such as SMEs that required uncomplicated functionalities in their business. Other advantages of the software was its ability to be fully customized, and that it could be used as a reference for further development efforts since it was a prototype rather than off-shelf products. The developers could continue modifying the system until customers felt satisfied. Factors such as low price, instant service and full customization granted growth opportunities for these ERP prototypes.

At the end of the 1990s, ERP development entered the third stage of commercial development. The third stage was driven by several factors. First, the ERP market became more competitive and customers demanded more prompt installation of matured products. Second, the researchers at the academic institutions were no longer supported by research funding to develop ERP products; instead, they were encouraged to conduct only scholastic research. In addition, academic institutions were not in the business of doing ERP sales promotion and product distribution. As a result, many researchers with ERP product development interests and experiences quit their jobs to run their own companies with their ERP prototypes. Nowadays, most of China's ERP companies are staffed with researchers with academic backgrounds.

In recent years the number of Chinese ERP companies has increased; most are small software companies with aspirations of netting a share of the Chinese ERP market. Such companies are providing ERP software suitable for use within the unique Chinese context since research findings confirm that the national differences affect ERP implementation in different countries. It is estimated that there are over 100 software companies specializing in ERP systems throughout China. However, only about a dozen of the ERP companies are known nationwide. Among them, the following four ERP vendors are worth mentioning.

Kingdee and UFSoft are two leading Chinese ERP vendors, and coincidentally both of them started their software business from developing and distributing financial information systems. They gradually added functions such as production planning, scheduling, inventory control, and purchasing, and finally come by their ERP systems. Kingdee has produced two ERP software packages, namely the Kingdee EAS and Kingdee K/3, which are expected to meet diversified requirements of business information management at large companies and SMEs. In addition to conventional ERP modules, the Kingdee software families also include modules dealing with supply management, customer relationship management and knowledge management. UFSoft promotes a complete ERP/SCM solution, called ERP-NC, claiming to support business excellence for enterprises based on management style called 'coordinated business and centralized management'.

The Golden Thinking Information Technology Corporation, unlike Kingdee and UFSoft, was transformed from a research institute in the Jiangsu Province. The development of its product JSERP has been supported by many public programmes, especially by the National High-Tech Research Program. JSERP adopts component technologies, and supports the concepts of dynamic enterprise modelling (DEM) and business processing reengineering (BPR). Hejia Software Technology Limited (HJSOFT) is a newly founded, yet fast-growing ERP vendor in China. It provides business software management services and products to business enterprises. Due to its effective promotion strategies, HJSOFT has been awarded many

public funds, and has successfully won contracts from many industries including machinery, metallurgy, pharmaceutical, food and chemical engineering.

3.2 *Generic ERP architecture on J2EE platform*

At present, the leading Chinese ERP packages have been elaborately designed based on rigorous requirement analysis and a thorough study of the leading ERP systems in the world. Researchers have made a wide range analysis of the featured business processes in the local Chinese manufacturing companies. Chinese ERP vendors make best use of this knowledge to align the ERP transaction processes and interfaces with those featured business processes to which Chinese business firms are used to.

Chinese ERP packages generally adopt client/server architectures which are found inflexible to handle data access and processing in changing business environments. Requirements to support web-based data access and analysis force vendors to transform their ERP systems to a J2EE platform. It is believed that the J2EE platform will give ERP systems high portability, scalability, and reconfigurability, allowing convenient ERP deployment on multiple operating systems and different database management systems. In this context, ERP vendors attempt to provide customized ERP systems by configuring pre-developed software components. The J2EE platform sheds light on the possibility that ERP systems can be easily configured to meet specific customer requirements and budget constraints. Therefore, ERP companies are seeking to develop reconfigurable ERP systems that allow users to customize their system configurations conveniently.

The concept of new generation ERP systems on the J2EE platform prevails now, and alternative designs of architecture have been proposed. Figure 3 shows

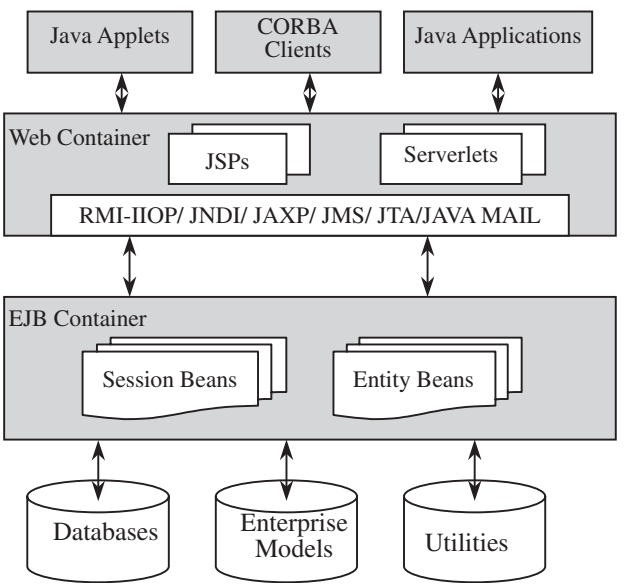

Figure 3. Generic ERP framework based on J2EE.

a conceptual ERP framework that represents the common features of the new generation ERP systems based on J2EE standards.

In the generic ERP framework, all business functions and data transactions are deployed through three layers. The front-end layer is responsible for interacting with external users through CORBA clients, JAVA applets and/or JAVA applications. CORBA clients and JAVA applications locate middleware brokers by naming services, and evoke the brokers with methods provided by CORBA/IIOP and RMI/IIOP respectively.

The middle layer is responsible for communicating with the front-end layer, executing ERP functions and processing related business data. As shown in figure 3, components in the middle layer constitute the main body of an ERP system. Serverlets and JSPs in web containers translate XML files into HTML files to be accessed by web browsers. The J2EE platform provides two types of enterprise java beans (EJBs) to encapsulate business components and data components. EJB containers provide EJBs with operation environments and services. Such ERP systems accommodate functions such as executive decision support, production planning, shop floor production order management, purchasing management, inventory management, financial control, and human resource management. These macro-functions are further decomposed into components of smaller granularities, which are coded as Session Beans. The data to be processed is represented as Entity Beans.

The back-end layer in the framework is responsible for connecting EJBs with the data physically stored in databases and files via JDBC methods. It provides mapping mechanisms between entity beans and physical data.

4. Industrial implementation of ERP systems in China

4.1 *Integral part of CIMS*

As mentioned above, a few companies introduced MRP II systems in the early 1980s in an attempt to reduce lead times and inventory levels, and to optimize machine utilizations. Thereafter, the introduction of MRP II was very sluggish until the beginning of the 1990s when China launched CIMS pilot projects. Computer-integrated manufacturing systems (CIMS), intended to link the isolated 'automation islands' up, were widely accepted as an effective way to enhance the competitiveness of Chinese manufacturing companies (Xue *et al.* 1994). In the 1990s, more than 200 manufacturing companies in China across many industrial sectors have implemented CIMS. MRP II systems had been considered an indispensable component of a CIM system, and CIMS initiatives became a major impetus to MRP II implementations. Figure 4 shows a widely accepted CIMS architecture that includes an MRP II/ERP system as the core component. For a long time, the IDEF methodologies were recommended as the standard modelling approach to describe system solutions in MRP II/ERP implementation. Some public funding sources have contributed to these industrial applications. Due to the rapid development in information technologies, the ERP installations have shifted from the workstation/UNIX platform to the PC/window platform, which considerably reduces the cost of hardware components.

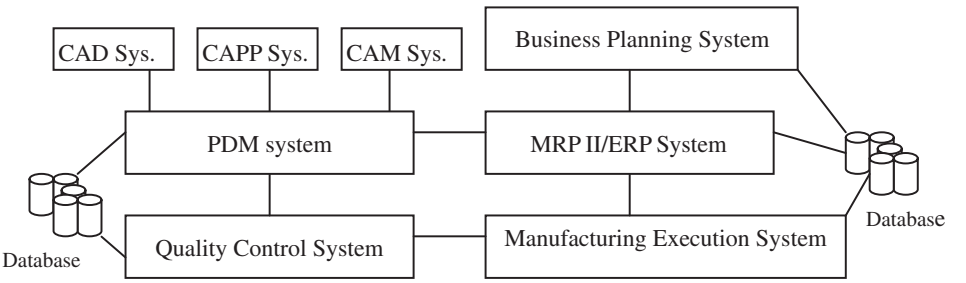

Figure 4. Functional CIMS architecture.

4.2 *ERP implementation experiences*

Today, reports on ERP implementations continue to appear in academic journals and mass-medias. Enterprises that implement ERP systems span a wide range of industrial sectors such as machinery, electronics, aerospace, ship-building, refinery, steel works and food processing. ERP vendors have not only found customers in manufacturing industries, but also in service industries such as port administration, news agency, hospital, and construction. Industrial practice has demonstrated the following factors are of pivotal importance to ERP implementation:

- Setting corporate strategic goals. The company should have clearly specified goals that are to be attained by ERP implementation. The goals should align with the strategic business vision of the company.
- High commitment. Commitment from all walks of employees, especially from upper management, plays a fundamental role in an ERP project. High commitment makes employees motivated and enthusiastic in preparing and adopting ERP applications. Commitment from top management drives users to learn new knowledge and to be positive to the possibility of change.
- Software selection. The market offers an increasing number of ERP products which makes it very difficult for a company to select an ERP package pertinent to their needs. An ERP acquisition must be based upon a detailed benchmarking study in terms of software architecture, functionality, cost, service, etc.
- Progressive implementation. An ERP project has to be gradually expanded from some pilot applications to company-wide applications. The progressive implementation has to be specified by a systematic ERP solution plan.
- Comprehensive training. Training programmes have to be developed for different classes of employees, to create an ambient atmosphere of working with an ERP system. Training will increase users' confidence and integrate human resources with ERP systems.
- Business process reengineering. The introduction of an ERP system brings forth foreseeable changes and impacts upon a business. A company has to adapt to the new requirements. To achieve the desired ERP performance, the company has to radically re-design and/or incrementally improve their business processes.

- Top management's project. Analysis of MRP II/ERP projects implemented in the 1990s indicates that ERP systems are not simply applications of information technologies. ERP implementation experiences in Taiwan Province show that the implementation is not only a technological exploration, but also an 'organizational revolution' (Wu *et al.* 2002). ERP implementations are closely related to management styles, organization structures, business processes, and enterprise cultures. ERP implementations demand people to change conventional business practices, learn new knowledge, and effectively cope with unexpected challenges. Once the basic modules have been implemented and the company wants to implement more advanced modules, coordination and cooperation between various departments are often required (Zhao *et al.* 2002). Hence, it is widely accepted that high commitment from management, especially top management, is a must to breakthrough resistance from employees and coordinate the implementation process. Hence, an ERP implementation is commonly referred to as a 'project for the top management', which means that an ERP implementation must be directed by an executive at the highest administrative level. As an ERP implementation involves many complicated transactions across different departments, the project should not be directed by a department head alone.

Because of the significant importance of managerial commitment, companies should obtain common consent from the top management before ERP implementation. It is imperative that a company's top management, namely a CEO, a general manager or a president, must consent to steer the project. Meanwhile, for a successful ERP implementation, ERP vendors need to seek support from the top management as well.

As shown in figure 5, ERP implementation requires a well-designed team structure that organizes and coordinates team members' work and synchronizes various interactive activities. The steering group, led by top management, consists of key staff members and is responsible for making corporate decisions on ERP. The steering group develops the strategic goals of ERP implementation in alignment with the company's business goals. It evaluates and ratifies the ERP requirements, application scopes, solutions, and estimated budgets. It makes trade-off

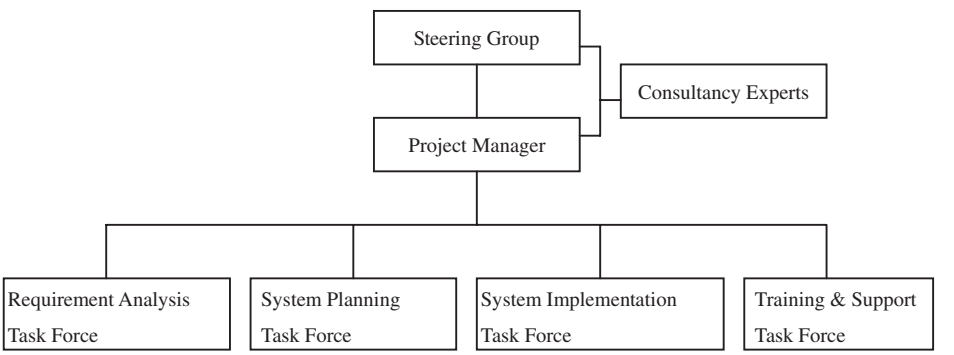

Figure 5. Typical ERP project team organization structure.

decisions on operation stability versus the improvement of business processes. Commitments from the steering group are crucial for motivating the project team and discouraging latent resistance from conservative parties. The steering group periodically holds sessions to review project progress, discuss emerging problems, and to decide further steps.

The project manager is delegated by the steering group to lead, organize and coordinate effectively the ERP implementation process. In addition to a thorough knowledge of the nature of the company's business, the project manager has to have solid knowledge of ERP and information technologies. To ensure smooth ERP implementation, the company normally seeks advice from external ERP experts. The ERP experts may be invited from academia or from companies that have previously implemented ERP systems. The ERP experts make presentations on the state of the art, best practices and lessons learned from previous experiences. They are often asked to help with evaluation and appraisal of phased and final project outcomes.

Subsequently, some task forces are established with members from both the company and the ERP vendors jointly to carry out implementation. The requirement analysis task force identifies and specifies user requirements through interviews or related documents. They analyse and refine requirements in the context of ERP functionalities and business scope, which will be the basis of system planning and implementation. The system planning task force is responsible for building the 'as-is' and 'to-be' models of the business processes using approaches such as IDEF and UML. The to-be models help to determine how business will be done and how information will be processed within the ERP system. System planning activities further specify what organization units and business processes will be affected by ERP implementation. The system implementation task force actually installs the software package and customizes interfaces and some modules. The training and support task force is responsible for training users at different levels and providing support services during system operation.

4.3 *BPR initiative*

One of the best-practice principles of ERP implementation is the accompaniment of business process reengineering (BPR). ERP implementation enables and requires companies to reengineer their business processes. The 'computerized' data transaction differs considerably from the paperwork-based data processing methods. Shifting from manual operations to computer-aided operations is by no means making electronic duplication of paperwork and the processes handling them. It is a must for companies to discard some traditional business processes that have became obsolete. Companies deciding to implement ERP must create and follow new business processes that accommodate general ERP requirements. In a certain sense, ERP implementation indeed provides an impetus to companies to update their business processes.

BPR generally starts with identifying and explicitly documenting the existing business processes. Then the existing redundant and inconsistent activities will be analysed against performance goals and ERP requirements. On the basis of this analysis, new business processes that appropriately align with ERP operations are developed. The business processes need to be hierarchically decomposed to differing

levels of detail. It is commonplace that enterprise organizational structures need to be changed to comply with the reengineered business processes.

Ng *et al.* (1999) proposed a model to design and implement an ERP system under the macroscopic context of business process re-engineering with a total quality approach. The proposed method can be summarized into two major phases. The first phase is to design a structural ERP model by using the IDEF design tool, together with the node index of the model. The second phase is to model and implement the design by OOM.

5. Future directions for ERP research and development

Originating from MRP and MRP II systems, ERP systems have evolved continuously to respond to emerging requirements and advances in technology. Within today's changing technological environment, attempts to predict technology development accurately may be unrealistic. However, experience and evidence allows us to make some comments upon the direction of ERP systems development in the future.

First, it is believed that an ERP system has to support emerging manufacturing strategies. An ERP system has to take many issues into consideration that include 'lean', 'agile', 'green' and 'intelligent'. It should extend production planning and control to collaborating enterprises through the use of Internet based technologies. An ERP system has to be process oriented, and workflow management techniques will be increasingly used to coordinate concurrent transactions.

Second, an ERP system has to offer flexible integration mechanisms to operate in conjunction with other applications. Meanwhile, ERP systems will continuously expand their business scope as ERP vendors try to provide total business solutions.

Third, an ERP system tends to include new module for capturing, managing and reusing enterprise knowledge. As the area of knowledge management grows and knowledge management becomes a buzzword, companies become aware of the values of managing their knowledge and know-how. To meet this requirement, an ERP system needs to be able to represent and reuse explicitly enterprise knowledge accumulated in all resource planning processes.

Fourth, an ERP system has to be reconfigurable to support customized implementation. By assimilating new developments in IT such as software components and middleware approaches, ERP functions will be encapsulated as software components, which offer multiple combination alternatives. With support of enterprise reference models, an ERP system could be dynamically reconfigured for any customization request.

Fifth, an ERP system has to offer rapid implementation to minimize disturbance to normal manufacturing operations. As demonstrated by previous ERP projects, implementation time horizons are a pivotal factor of user satisfaction. In addition to its core functional modules, an ERP system has to include a comprehensive suite of utilities to help quick deployment. An ERP system should provide utilities, such as requirement specification templates, modelling tools, reference models, a rapid system configurator, convenient report generator, and human–machine interfaces.

6. Conclusions

Over the past three decades, Chinese firms have learned the painful lesson that neglecting to implement advanced technology can affect the competitiveness of an industry. Chinese industry leaders have realized that a new industry turning point is around the corner; the task is to achieve competitive advantages through making integrated business decisions in a supply chain environment using ERP systems (Xu 2000, Xu *et al*. 2003). Whether Chinese firms can capture this turning point and take the lead in implementing ERP systems successfully in a supply chain environment will affect their position in the global competition for world markets. The advances in information technology and the shift of business strategies thus become two major thrusts to promote ERP development in China. Although at present the debate about the success of the ERP systems is by no means coming to an end, the Chinese ERP market continues to grow. ERP has become a major approach for many Chinese companies to reduce lead-times, costs and inventory levels, increasing throughputs, optimizing the use of resources and improving competitiveness. In many Chinese industry sectors, fully localized ERP systems provided by the world's leading vendors and the proprietary ERP systems developed by domestic vendors offer customers a wide range of selections. Academic research efforts have also been incessantly devoted to enhance ERP performance by continuously introducing new emerging technologies.

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