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A Framework to Evaluate n-Tier Architecture ERP Systems

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Abstract

ERP systems are information systems that support the integration of value-added processes of enterprises. Based on the concept of modular structures, n-tier client/server architecture and centralized databases, numerous ERP systems have been developed in the market. The vast number of ERP products available has given users the chances to select suitable products for implementation. However, the lack of evaluation framework has made the selection process difficult. In this paper, a framework for analyzing and distinguishing ERP systems based on IT attributes is proposed. This design of the framework is based on client/server architecture, browser based computing, system integration standards and business enabling features. The framework includes 61 attributes and thus allows it to differentiate large number of software. Major ERP systems sold in the greater China area are evaluated with the framework to evaluate the discriminating capability of the framework. The result implies that the framework can reasonably discriminate major ERP systems.

Keywords: Enterprise Resource Planning (ERP), n-Tier Architecture, Software Classification, Cluster Analysis

1. Introduction

Information Technology has been viewed by enterprises worldwide as vital tools in improving efficiency and competitiveness. In the last decade, many companies turning to use information systems usually known as ERP systems to respond to competitive pressures and market opportunities (Bingi et al., 1999).

ERP systems are integrated information systems that support value-added processes of enterprises. Based on modular software structure and centralized database, information flows in manufacturing, finance, sales, distribution as well as human resources processes can be integrated in real time. The ERP systems have become one of the largest IT investments for many companies during the 1990s (Chung and Snyder, 1999). Davenport (1998) even described ERP systems as “the most important development in the corporate use of information technology in the 1990s”. Not only are enterprise systems used by large companies but also did it penetrate into small and medium companies (Holt, 1999).

It is expensive and time consuming for companies to implement ERP systems (Davenport, 1998). The companies can take many years to implement ERP systems, and cost $10 millions for a moderate size company and over $100 millions for a large international enterprise (Mabert et al., 2000).

Since ERP systems are critical to companies and expensive to acquire, many studies have been devoted to find the recipe for successful implementation. Among other important factors, product selection has been singled out by many research reports. For example, Jason and Subramanian points out that in order to implement and use ERP system successfully, company have to select right ERP packages to match its requirement (Janson and Subramanian, 1996). Esteves and Pastor also emphasize that the selection of ERP products and consultants is an important step in the proposed ERP Life-Cycle framework (Esteves and Pastor 1999). Al-Mashari et al. also list correct ERP package selection in the critical successful factors of ERP projects (Al-Mashari et al., 2003).

The trouble is that too many ERP systems are available in the market. In Taiwan along, there are 61 ERP vendors, and the CIBRES listed approximately 1500 different ERP solutions provided by a variety of vendors in 2000 (Anderegg, 2000). These products can differ from each other very much. The differences play an important role in software/vendor selection. The vast number of vendors and the difference of functionality and architecture have put much pressure on the system selection processes. Although software selection is important, to the best of our knowledge, no academic work has been devoted to provide formal framework to compare and contrast the characteristics of ERP systems. Such a framework should provide evaluation items comes with theoretic supports, be able to distinguish products with different attributes, and can be applied to distinguish a large

number of ERP systems.

In this paper, a software architecture evaluation framework for ERP systems based on client/server technology, browser based computing, system integration capability and support of globalization is proposed. To verify the quality of the framework, several ERP software that are widely used in greater China area are evaluated with the functional list designed with the framework. The results show that the framework can be applied to a wide range of software and can reasonably distinguish products designed with different complexities.

The rest of the paper is organized as following: Section 2 gives an overview of researches concerning taxonomies and classification of information systems. In Section 3 the research methodology is presented. The IT functional categories as well as their attributes are identified, and the classification framework based on n-tier architecture is provided in Section 4. In Section 5 a verification process is described. The verification is proceeded by sending surveys to software vendors and customers and cluster filled-out results to check if the clustering is reasonable. A reasonable cluster implies that the framework can reasonably distinguish enterprise software. Conclusions and future works are discussed in Section 6.

2. Literature review

Ein-dor and Segev (Ein-Dor and Segev, 1993) used attributes and functions to classify seventeen major types of information systems. Thirty-one attributes and twenty-seven functions were identified, Attributes were hardware and software components of information systems and functions described the functionality of each type of information systems. Combinations of attributes and functions were used to classify information systems in the research.

Raol et al. (Raol et al., 2002) used functions and features to identify and classify fifteen enterprise portal systems. The functions and features were grouped into ten main categories, which were customization and personalization, proactive/search, collaboration and community, secure/security, dynamic, extensibility/embedded applications, content management, scalability/network, administrative tools and ease of use.

Bafoutsou and Mentzas (Bafoutsou and Mentzas, 2002) used features related to collaboration services to classify forty-seven collaborative systems. There were 19 features included in the research. The features consisted of bulletin board, discussions, E-mail, E-mail notifications, online

paging/messaging, whiteboard, audio/video conferencing, task list, contact management, screen sharing, surveys/polling, meeting minutes/records, meeting scheduling tools, presentation capability, project management, file and document sharing, document management and synchronous work on files/documents.

None of these researches have considered the underline IT architecture required to support ERP systems operating in global environment. The aim of the research is to propose a framework to help enterprises analyze the IT architecture of ERP software, instead of performing a comprehensive classification of software products due to the sheer volume of ERP software available in the market.

3. Methodology

The research involves several major steps to establish and verify the framework. The steps are listed as following:

(1) With the secondary data review and expert interviews in related fields, we establish the major hierarchy of the framework which is organized as a concept tree. The bottom level of the concept tree consists of attributes of IT architectures of ERP systems. According to the concept tree, a questionnaire of the framework is generated.
(2) Major ERP vendors in the greater China area are identified from the data bank of Market Intelligence Center (MIC) of Information Industry Institute (III) in Taiwan.
(3) Questionnaires are sent to selected vendors to record the IT architecture of their products. The data submitted by vendors are verified with independent experts or users in customer sites. Only the reports that have consistent views from both parties are reserved for clustering analysis.
(4) The data collected in step 3 are clustered with binary squared Euclidean distance to verify the correctness of the framework. The result of the clustering does imply that the framework is able to correctly capture the major differences between ERP systems.

4. The main functions of ERP systems

Information systems are generally defined either in terms of their functions or attributes (Ein-Dor and Segev, 1993). The function definition focuses on what the system does; the attribute definition highlights the component employed by the system. Here, the functions are defined as activities which can be performed on an ERP systems and attributes as the characteristics of information technology employed by ERP systems.

A framework for analyzing ERP systems shows the IT infrastructure, major ERP modules, and their relationships with some external systems by interfaces as shown in Figure 1. The major modules of ERP systems may include finance, manufacturing, human resources, sales and marketing, and so on (Davenport, 1998; Dillon, 1999; Al-Mashari et al., 2003). After ERP systems implemented successfully, many companies are considering and implementing various extensions to the systems. The extendable external systems could include supplier chain management (SCM), customer relationship management (CRM), e-business or e-commerce solutions (B2B and B2C), data warehouse (DW), data mining (DM), business intelligence (BI), knowledge management (KM), and so on (Mabert et al., 2000; Tarn et al., 2002; Willis and Willis-Brown, 2002; Jacobs and Bendoly, 2003; Newell et al., 2003; Olhager and Selldin, 2003). By integrating ERP system with these external systems, company can improve the relationships with suppliers and customers and provide competitive advantage for the organization. According to Sprott (2000), ERP system can integrate with others applications by integration standards (such as XML, RosettaNet) and component interface protocols (such as CORBA, COM+ and EJB). For others systems to retrieve and store data in the ERP system, there are three most used methods from the experiences of professional consultants of ERP vendors and consulting companies. The three integration methods include predefined programs, temporary data files and read/write tables in database directly. In this paper, the focus will be on IT infrastructure that supported the ERP system operation.

4.1 N-tier architecture of ERP systems

In this paper, IT attributes of ERP systems are collected to define the framework. The ERP systems transform the value chain methodology into reality by applying software systems to links activities (functional areas) in a client/server architectural environment (Gupta, 2000; Rao, 2000; Akkermans et al., 2003; Sundarraj and Talluri, 2003). Many of the activities supported by ERP systems are performed across national borders and cross business units (Davenport 2000). Hence, the framework takes into consideration the attributes of client/server architecture, attributes supporting multilingual systems, and attributes supporting multiple business unit management.

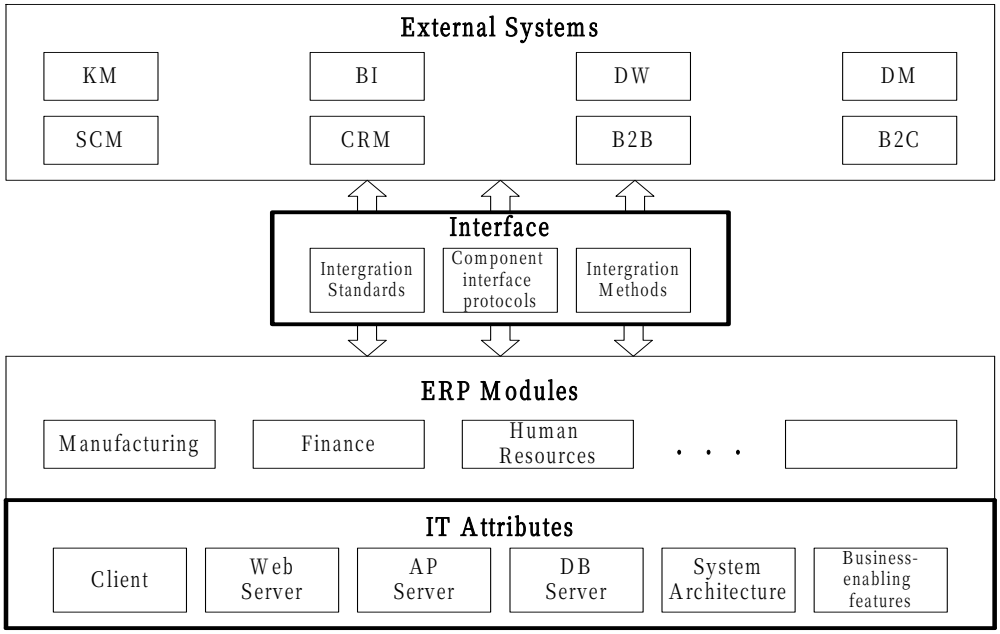

Figure 1 The framework for analyzing ERP systems

In client/server architecture, Sinha (1992) pointed out that following issues had to be addressed:

- Client: (1) workstation operating system, (2) hardware constrains, (3) connectivity constraints, (4) object-oriented design, (5) GUI, (6) division of responsibility.
- Server: (1) scalability, (2) server interface, (3) gateway to mainframe, (4) disk space, (5) security and access control, (6) backup, recovery and logging, (7) fault tolerance and uninterrupted power supply, (8)performance and system management, (9)internetworking.

Many of these issues are factored into the design of the framework. The issues excluded are hardware constraints, disk space, internetworking, OO design, fault tolerance and uninterrupted power supply. The issues of hardware constraints, disk space and internetworking are excluded since resources problems that plague the systems in 1992 are no longer scarce. OO design is excluded since it is a software development methodology but not a system attribute. Fault tolerance and uninterrupted power supply is excluded since the issue of software fault tolerance is subsumed by the issues in n-tier architecture and database server which will be explained later. The issue of uninterrupted power supply is a hardware issue that is not characterized as an attribute of enterprise systems. The issue of the gateway to mainframe is

extended to the gateway to external systems since many major systems in enterprises have been migrated to other client/server systems or even PCs.

Information technologies have evolved from client/server computing to the Internet computing. The evolution also changed client/server architecture from traditional two tier architecture to n-tier web-based architecture (Dreyfus, 1998). The web-based architecture typically consists of four layers of servers: client (browser), web server, application server and database server. With the development of mobile technology, mobile devices can also access information systems through web servers (Kalakota and Robinson, 2001). Hence, the architecture adapted by the framework is n-tier client/server architecture as shown in Figure 2. The original definition of server in (Sinha 1992) is extended to web servers, application servers and database servers. Since the software resides in the application servers are the main products of enterprise system vendors, attributes of application servers are the focus of the research. Therefore, server issues discussed in (Sinha 1992) are evaluated against application servers in the framework and client issues are evaluated against the client software of ERP systems. From the view of application servers, web servers are parts of clients. Thus, only connectivity and scalability between application servers and web servers are examined. From the viewpoint of application servers, database servers are devices for data storage. Hence, the issues examined are data integration and scalability. Data integration examines if data are logically integrated. Only systems with such attributes can integrate data in real time. Scalability checks the connectivity between application servers and the physical database severs.

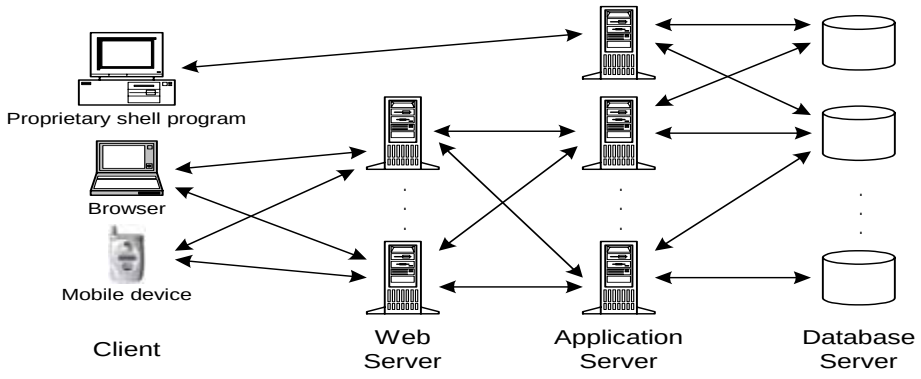

Figure 2 N-tier architecture of ERP system

As Davenport (2000) pointed out that ERP systems should include

business enabling features to support business process crossing national borders and business units.

In summary, the issues examined in the framework are listed in Figure 3. The first level in the framework consists of major components in web-based client/server architecture and business enabling features. The second level list the issues that are examined in the framework and the third level contains the technical options of each issues examined. Options in the third level are represented with Dichotomous questions. Following paragraphs will explain the third level options listed under each second level concept.

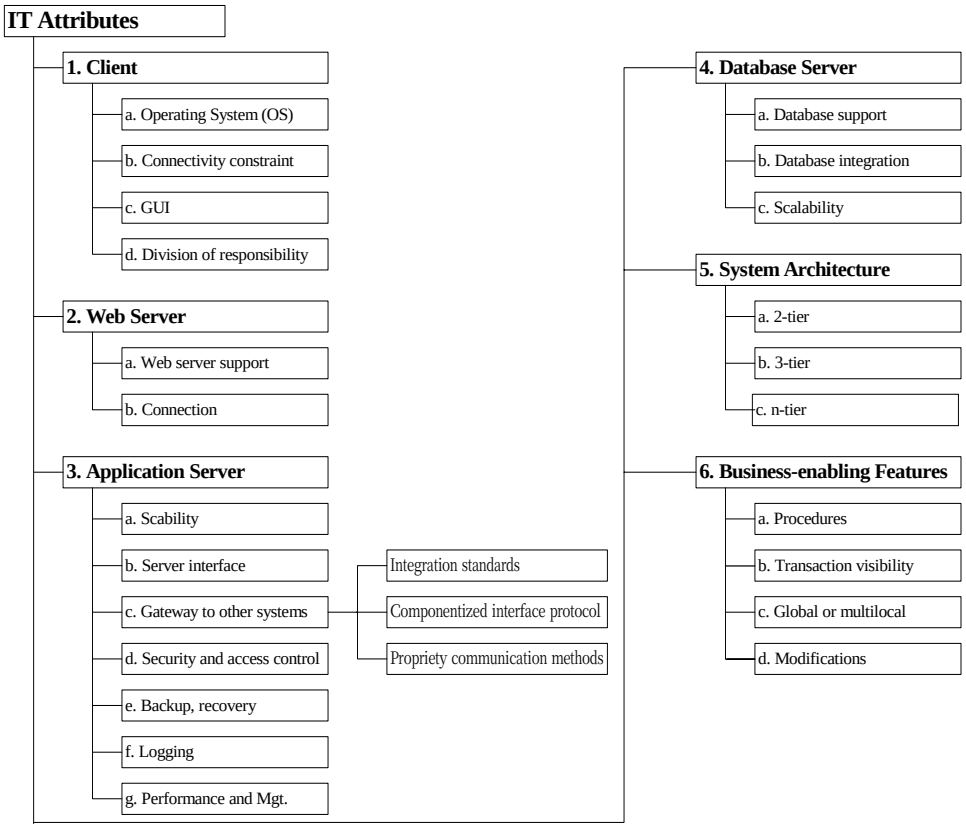

Figure 3 The framework of IT attributes

4.2 The third level options

Client The client attribute includes four second level nodes: operating system (OS), connectivity constraint, GUI and division of responsibility. The issues in operating system include the type of OS supported by client software and if clients installed on different OS can connect to the same server. The connectivity constraints check the types of networks that can connect clients to application servers and if the same client software can connect to multiple application servers which are installed on different OSs. The types of user interfaces include proprietary shell programs provided by ERP vendors, browser interface and mobile device such as personal digital assistant (PDA) or cellular phone. The responsibilities of clients check if clients are thin or fat clients, namely, if clients only display data or have to perform computation according to business rules.

Web server The web server issues include server supports and connectivity. The options listed in the first issues are type of major web servers supported by the application servers and the options listed under the second issues are as following:

- A web server connects to different AP servers in the same ERP system.
- An AP server connects to different web servers in the same ERP system.
- An AP server connects to heterogeneous servers in the same system.

Application server The issues under application servers are scalability, server interfaces, gateway to other systems, security and access control, backup and recovery, logging, and performance and system management. The scalability issue checks if the system supports multiple AP servers and if every AP server can connect to every client in the same system. The server interface checks if clients can connect to AP servers without knowing the OS types of AP servers, that is, clients can connect to AP servers transparently.

The gateway to other systems examines the tools provided by the system to communicate with other systems. The gateway tools are classified into three tiers. The systems in the bottom tier provide propriety programs, temporary data files, or direct read/write to database tables. The systems in middle tier encapsulate gateway programs into standard protocol, such as CORBA, COM+/DCOM and EJB. The systems in the topic tier provide documents in standard format, such as XML, ebXML, or RosettaNet for information exchange.

The security and access control check password encryption during transmission, and access controls to programs and data. The backup and

recovery issues examine if a system provides tools or interfaces to perform database backup and recovery. The logging issue checks if user activities can be logged in a system. The system performance and management issue checks if a system supports load-balances in application servers and if a system administrator can manage system resources, such as memory allocations, from one of the application servers.

Database server The issues under database servers include supported databases, database integration and scalability. The supported database checks the brand of databases that are supported by an ERP system. The database integration checks whether an ERP system integrates all data into one logical database and use a single user to access all data. The integration capability is especially important to ERP systems since data in ERP systems have to be integrated in real time (Adnoun-Helm et al., 2003). The database scalability checks if an ERP system support distributed database servers and if these multiple DB severs can connect to a single AP server.

System architecture

The system architecture issue checks if the supported architectures are 2-tier (client/server), 3-tier (client, application server, database server) or n-tier (client, web server, application server, database server) architecture.

Business-enabling features The issues under the category are procedures flexibility, transaction visibility, multilingual structure and package modifications. Procedure flexibility has the options of autonomous procedures and directive procedures where systems with autonomous procedures allow local business units to tune business processes whereas systems with directive procedures enforce the same business processes over entire enterprises. The transaction visibility feature checks if systems provide multi-dimensional cubes to help users navigate through data. Multilingual structure examines the system’s support of multiple languages. The options examines are data of different language stored in a single Unicode field , data of different languages stored in different fields, and data of different languages stored in different fields with the field names marked in corresponding languages to help programmer understand the meaning of the fields. The package modifications feature examines if the system can be tuned by parameter settings. The complete tree-structure of the framework is shown in Table 1.

Table 1 The complete tree-structure of framework

- ■Client
  - ■Supported Operating system(OS)
    - ▪Windows
    - ▪UNIX
    - ▪Linux
    - ▪Mac
    - ▪Heterogeneous OS
  - ■Connectivity constraint
    - ▪LAN
    - ▪WAN
    - ▪Clients connect to AP servers that installed on different OSs
  - ■GUI
    - ▪Proprietary shell program
    - ▪Browser
    - ▪Mobile device
  - ■ Division of responsibility
    - ▪Display data(thin client)
    - ▪Compute data(fat client)
- ■Web server
  - ■Web server support
    - ▪Microsoft IIS
    - ▪Apache
    - ▪Support more than one brand of Web servers in the same system.
  - ■Connection
    - ▪A web server connects to different AP servers
    - ▪An AP server connects to different web servers
    - ▪An AP server connects to web servers installed on different OS platforms
- ■Application server
  - ■Scalability
    - ▪ERP systems can have multiple AP servers
    - ▪Every AP server can connect to every client
  - ■Server interface
    - ▪Clients connect to AP servers transparently
  - ■Gateway to other systems via
    - ▪Integration standards
      - ·XML
      - ·ebXML
      - ·RosettaNet
    - ▪Componentized interface protocol
      - ·CORBA
      - ·COM+, DCOM
      - ·EJB

- ▪Propriety communication methods
  - ·Predefined programs
  - ·Temporary data files
  - ·Directly read/write tables in database
- ■Security and access control
  - ▪ Password encryption during transmission
  - ▪ Authorization in program level
  - ▪ Authorization in both program and data level
- ■Backup and recovery
  - ▪Tools or interfaces to perform database backup and recovery
- ■Logging
  - ▪Logging user activities
- ■Performance and system management
  - ▪Load-balanced support
  - ▪An application server manages its own resources
  - ▪A central application server manages resources in all application servers
  - ▪Each application server can manage resources in every application server

■Database server

- ■Database support
  - ▪DB2
  - ▪Informix
  - ▪MS SQL
  - ▪Oracle
  - ▪Sybase
  - ▪Support multiple brands of database in the same system?
- ■Database integration
  - ▪Integrate all data into one logical database
  - ▪Use a single user to access data
- ■Scalability
  - ▪Support multiple DB servers in the same ERP system
  - ▪Multiple DB severs connect to an AP server

■System architecture

- ■2-tiers(client/server)
- ■3-tiers(client, AP server, DB server)
- ■4-tiers(client, Web server, AP server, DB server)

■Business-enabling features

- ■Procedures
  - ▪Autonomous
  - ▪Directives
- ■Transaction visibility
  - ▪Allow users to drill-down aggregated data
- ■Global or multilocal

- ▪Description field implemented with Unicode
- ▪A description is stored in multiple fields where every major language has a corresponding field
- ▪ A description is stored in multiple fields where every major language has a corresponding field and the field name itself is kept in corresponding languages.

■Modifications

- ▪By setting parameters
- ▪By modifying the program code

5. Data collection of verification phase

A total of 61 ERP software vendors were identified from the Market Intelligence Center (MIC) of Institute of Information Industry (III) in Taiwan. This vendor list consists of major ERP vendors in Taiwan and well-known international ERP vendors which have branch offices or agents in Taiwan. Among the 61 companies, 32 are taken away from the list since they do not have branches operate in Mainland China or Hong Kong. Phone calls are made to the remaining 29 companies to invite them to join the research. 25 out of the 29 companies agree to review the forms derived from the framework.

After reviewing the framework, 16 companies do not express their interest to attend the research. After one month of intensive communication, 9 out of the 25 companies return their forms. To verify the data, the same form is also used to interview experienced users or experts not employed by vendors. Three out of the nine returned questionnaires are screened by such a verification procedure either due to customers do not use the latest versions or the experts are out of the country when the survey is performed. Hence, the framework verification phase successfully obtains the analysis reports of six products from six companies. Their characteristics are listed in Table 2.

Table 2 Characteristics of the ERP products under analysis

Symbol	Founded year	Major market area	Company profile
A	1982	Taiwan and China	The leading ERP vendor in Taiwan and Number Five in China
B	1994	Taiwan and China	Aggressively expending ERP vendor
C	1977	Worldwide	The second largest ERP vendor based in U.S.
D	1987	Taiwan and China	The second ERP vendor in Taiwan and aggressively expanding in China
E	1972	Worldwide	The leading ERP vendor in worldwide market
F	1994	Taiwan and China	Aggressively expending ERP vendors

5.1 Cluster analysis

The result of the survey is clustered with complete link cluster with binary squared Euclidean distance methodology to exam if products under survey can be grouped to show that the framework can reasonably distinguish products. Clustering technology groups objects into sets with the distances among objects in the same set should be relatively small whereas the distances among objects in different sets should be relatively large (Johnson and Wichern, 1998). The binary clustering technology takes into consideration that data represented by binary numbers are in fact categorical data. That is a '1' in a particular field of the survey means the system has such an attribute and a '0' means otherwise. In complete linkage clustering algorithm, the distances between clusters are determined by the distance between the most distant pair of points within the two clusters. This algorithm tends to find relatively compact, hyperspherical clusters composed of highly similar objectives (Aldenderfer and Blashfield, 1984). Figure 4 shows the result of analyzing the surveys with SPSS10.0.

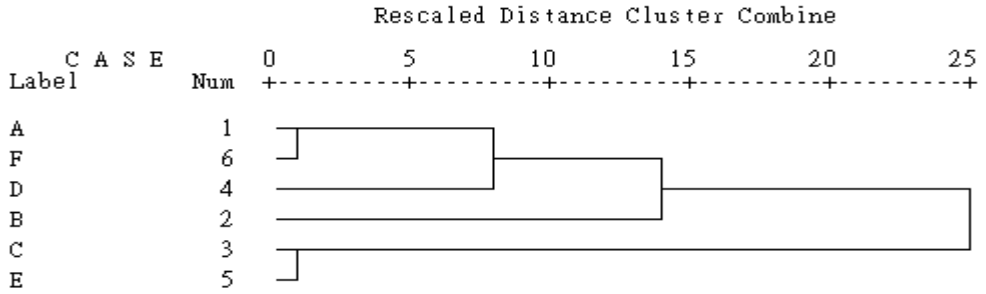

Figure 4 The cluster analysis of ERP systems based on IT attributes

Figure 4 shows that two closely related clusters can be formed, namely, product C and E in one group, and product A and F in one group. Product D can also be included to the second cluster with the distance of 10 and with distance 15; product B can also be included into the second cluster. The first group includes two products marketing worldwide. The second group includes two to four products only marketing and selling mainly in greater China area.

The result coincides with the general conception that the leading global products have comprehensive attributes whereas the products developed in greater China area are primarily Microsoft centric and lack attributes supporting multi-platforms and heterogeneous environments. Products such

as product B developed in the area and support also web architecture thus marked a considerable difference with other products. Hence, Figure 4 implies that the framework can reasonably distinguish products.

Theoretically, this framework can distinguish 2 ^ 61 products since it has 61 Dichotomous options and each can be marked as selected or not. In practice, among all the nine surveys collected so far, no two are identical.

6. Conclusions and future works

Correct product selection has been singled out by many researches as critical ERP success factors (Al-Mashari et al., 2003; Esteves and Pastor 1999; Janson and Subramanian, 1996). The framework developed in this paper can help companies to analyze the IT attributes of enterprise systems. The analysis can then be used as part of criteria to select the software.

The framework consists of six major IT attribute categories, namely, client, web server, application server, database server, system architecture and business-enabling features. The framework incorporates client/server technology (Sinha, 1992), browser based computing (Dreyfus, 1998), system integration standards, and supports of business enabling feature (Davenport, 2000). Since there are more than 1500 ERP products in year 2000 along (Anderegg, 2000), the framework is developed based on academic theories instead of on product surveyed.

We also have strong confidence that the framework can reasonably distinguish large number of mature enterprise systems. The clustering analysis in the verification phase implies that the framework can reasonably distinguish products. During the process of data collection, we have not found any company complains that the framework is not suitable to evaluate their products. From the friendly response, we have strong confidence that the framework can be applied to mature enterprise systems. Since there are 61 questions in this framework, the framework can potentially distinguish 2^61 ERP systems.

The study strives to establish IT attributes analysis framework of ERP systems. However, a complete ERP system also includes application functionality besides IT attributes. In future work, we suggest to include manufacturing and financial analysis to the framework since financial modules have the highest installed priority (Mabert et al., 2000) and ERP systems have the highest penetration rate in manufacturing industries(Van Everdingen et al., 2000).

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