ABSTRACT

Title of Document: **Risk Management for Enterprise Resource Planning System Implementations in Project-Based Firms**

Yajun Zeng, Doctor of Philosophy, 2010

Directed By: Professor Miroslaw J. Skibniewski, Project Management Program, Department of Civil & Environmental Engineering

Enterprise Resource Planning (ERP) systems have been regarded as one of the most important information technology developments in the past decades. While ERP systems provide the potential to bring substantial benefits, their implementations are characterized with large capital outlay, long duration, and high risks of failure including implementation process failure and system usage failure. As a result, the adoption of ERP systems in project-based firms has been lagged behind lots of companies in many other industries. In order to ensure the success of ERP system implementations in project-based firms, sound risk management is the key.

The overall objective of this research is to identify the risks in ERP system implementations within project-based firms and develop a new approach to analyze

these risks and quantitatively assess their impacts on ERP system implementation failure. At first, the research describes ERP systems in conjunction with the nature and working practices of project-based firms and current status and issues related to ERP adoption in such firms, and thus analyzes the causes for their relatively low ERP adoption and states the research problems and objectives. Accordingly, a conceptual research framework is presented, and the procedures and research methods are outlined. Secondly, based on the risk factors regarding generic ERP projects in extant literature, the research comprehensively identifies the risk factors of ERP system implementation within project-based firms. These risk factors are classified into different categories, qualitatively described and analyzed, and used to establish a risk taxonomy. Thirdly, an approach is developed based on fault tree analysis to decompose ERP systems failure and assess the relationships between ERP component failures and system usage failure, both qualitatively and quantitatively. The principles and processes of this approach and related fault tree analysis methods and techniques are presented in the context of ERP projects. Fourthly, certain practical strategies are proposed to manage the risks of ERP system implementations.

The proposed risk assessment approach and management strategies together with the comprehensive list of identified risk factors not only contribute to the body of knowledge of information system risk management, but also can be used as an effective tool by practitioners to actively analyze, assess, and manage the risks of ERP system implementations within project-based firms.

RISK MANAGEMENT FOR ENTERPRISE RESOURCE PLANNING SYSTEM IMPLEMENTATIONS IN PROJECT-BASED FIRMS

By

YAJUN ZENG

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2010

Advisory Committee:
Professor Miroslaw J. Skibniewski, Chair
Professor Gregory B. Baecher
Professor Henry C. Lucas, Jr.
Associate Professor Guangming Zhang
Professor John H. Cable
Assistant Professor Qingbin Cui

Dedication

To the memory of my mother

To Liping, my wife

And to Tianyi, my daughter and first child

Acknowledgements

I am extremely grateful to my advisor, Prof. Miroslaw J. Skibniewski, for his mentoring, steadfast encouragement, and constant support over the years. It has been an intellectually stimulating and rewarding – and personally enjoyable – experience pursuing my Ph.D. under his supervision. My deepest gratitude also goes to Prof. Hank Lucas and Prof. Gregory Baecher. Without their insightful guidance and inspirational advice, this dissertation may never come into reality.

I would like to express my appreciation to Prof. Guangming Zhang, Prof. John Cable, and Prof. Qingbin Cui, for their valuable reviews, comments, and questions throughout this research. I thank all the organizations and individuals that help me complete the empirical part of the research. I also wish to thank my fellow members of the e-Construction research group in the Center for Excellence in Project Management for their help and sincere friendship.

Finally, the love and unflinching support from my family, especially my lovely wife Liping, is the driving force that makes it possible for me to tackle the challenges in the past years, and those ahead.

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1 Introduction

1.1 Background

Widely regarded as one of the most important and innovative technological applications emerging in the past decades, Enterprise Resource Planning (ERP) systems have had an enormous impact on businesses and organizations around the world (Davenport, 1998; Howcroft & Truex, 2001). ERP represents an ideology of planning and managing the resources of an entire organization in an efficient, productive, and profitable manner, and is manifested in the form of configurable information system packages (Laukkanen, Sarpola, & Hallikainen, 2005). ERP systems are multifunctional in scope, integrated in nature, and modular in structure (Mabert, Soni, & Venkataramanan, 2001). They promise seamless integration of all the information flowing through an organization; and they fulfill this promise by integrating information and information-based processes within and across the functional areas in an organization, and further, by enabling the integration of information and processes beyond the organizational boundaries.

As the interest of many organizations in moving from functional to process-based IT infrastructure continues to grow, ERP system has become one of today's the most widespread IT solutions. In a survey of the IT managers responsible for managing ERP projects, two thirds of the respondents view their ERP systems as the most strategic computing platform in their organizations (Sweat, 1998). According to an AMR research, the total application revenue in the global ERP market was $28.8

billion in 2006; it was projected to increase to $47.7 billion in 2011 (Jacobson, Shepherd, D'Aquila, & Carter, 2007). The ERP market is the largest segment of the applications budget (34%) in business organizations, with ERP penetration at 67% among large companies (Sirkisoon & Shepherd, 2002). ERP is also increasingly deployed in small- and medium-sized companies, as ERP vendors turn their sights to smaller enterprises for new business growth with tailored products. In recent years, a range of technologies has emerged, such as e-commerce, software as a service (SaaS), customer relation management (CRM), supply chain management (SCM) and so on, which can enhance the capability of ERP systems. Indeed, ERP has been recognized as the most imperative information technology infrastructure of modern companies (Shah, Goldstein, & Ward, 2002).

1.2 Problem Statement

The adoption and implementation of ERP systems in business organizations could turn out to be a blessing and a curse. If successfully deployed, ERP systems can provide the potential to significantly save cost and cycle time, and increase productivity and effectiveness. By providing real-time, organization-wide information access, ERP system can also enable management to make informed decisions, support organizational change and business growth, and create or enhance competitiveness in the marketplace (Shang & Seddon, 2000).

On the other hand, the stake is very high. The acquisition and implementation of ERP systems typically requires substantial investment of money, resources and effort, and may take a long time to be completed. According to a recent survey on nearly 1,600 organizations around the world that have implemented ERP systems within the last 4 years, the average implementation duration was 18.4 months, and the average total cost of ownership of enterprise software solutions (the expenses of hardware, training and others were excluded) was $6.2 million, representing 6.9% of the annual revenue in these organizations after different company sizes are normalized (Panorama, 2010). Nevertheless, about 57% of the ERP implementations took longer than expected, some of them were behind the schedule significantly; and 54% of ERP implementations went over budget (Panorama, 2010). Since ERP systems aim to run virtually every aspect of any business, their generality often misfit the specific conditions of the organization. Moreover, the implementation of ERP systems is more complex than most, if not all, of other IT projects because it requires business process reengineering and organization-wide change. An organization implementing an ERP system usually has to be prepared to see the organization reengineered, its staff disrupted, and its productivity drop before the payoff is realized. The technological challenges of ERP project are often accompanied or even overshadowed by critical dimensions related to the management of the transformational effects brought about by the implementation. An earlier study conducted by the Standish Group in 1994 reported that three quarters of ERP systems installations were judged unsuccessful by the companies paying the bills (Griffith, Zammuto, & Aiman-Smith, 1999); another study by the Gartner Group in 1998 reported that 70% of ERP projects failed to be fully implemented, even after three years (Gillooly, 1998). Although ERP success rate and customer (executive and employees) satisfaction has been improved considerably in recent years, there are still a majority of companies, to some extent, reporting failure to realize the measurable business benefits of ERP systems (Panorama, 2010). Many companies have seen no alternative but to terminate their ERP projects during the implementation phase once their resources have become depleted. The failure of ERP system implementation could bring about severe negative impact on a company, even leading to bankruptcy (Scott, 1999).

One reason for any software project failure is that managers do not properly evaluate and manage the risks involved in their projects (Keil, Cule, Lyytinen, & Schmidt, 1998). Risk management processes are often perceived as extra work and expense, and thus expunged if a project schedule slips (Kwak & Stoddard, 2004). Indeed, inadequate risk management during the ERP adoption and implementation process, characterized by the lack of formal risk management planning and communication, the inability to forecast and assess risky issues, and/or the failure to respond to risks in a timely and proper manner, is one of the prior causes for ERP project failure. In order to avoid the disastrous consequences of implementation failure and reap the benefits of ERP systems successfully, actively managing the risks inherent in ERP adoption and implementation is of critical significance for organizations that seek to create business value and competitive edge.

1.3 Research Objectives

The objective of this research is to develop an innovative approach to analyze, assess, and manage the risk in ERP projects. The approach can be utilized before ERP adoption to assess the risks of ERP projects and help the decision making of ERP adoption and selection, or during the ERP implementation process to manage and control risks and ensure successful project delivery. The settings of the research are project-based industries, particularly the Engineering and Construction (E&C) industry, whose fragmented and project-centric nature, combined with the lack of appropriate customized ERP systems suitable for the particularities of the industry, further complicate the evaluation and implementation process of an ERP system (Vlachopoulou & Manthou, 2006).

The overall objective of developing a new risk assessment, minimization and management approach includes the following sub-objectives:

(1) To systematically identify and enumerate the risk factors in the process of ERP selection and implementation in project-based firms and analyze their characteristics;

(2) To analyze and understand the interdependencies and interrelationships among different components of ERP system, and various risk factors;

(3) To examine the likelihood of occurrence of risk factors and ERP system component failure, and assess their potential impact on the ERP project using fault tree analysis;

(4) To propose practical strategies for managing and minimizing risks in ERP system implementation projects incorporating the relevant risk factors;

(5) To calibrate the developed approach through its use in practical settings.

1.4 Significance of the Research

Inquiring the veracity of recent developments in the area of information system implementation with a focus on the project-based industry, the aforementioned research objectives are of both theoretical and practical significance. The discrepancy between the desired and actual outcomes of ERP system implementations highlights a possible gap between what is offered in theory by researchers and what is used by practitioners. There have already been a considerable number of existing studies addressing the risk management issues of ERP systems. However, according to a recent literature survey (Aloini, Dulmin, & Mininno, 2007), many of those extant studies aim to discover and analyze the critical success factors (CSFs) rather than the risk factors that lead to ERP implementation failure. Also, most of the studies investigating ERP risks simply list the risk factors and suffer from a lack of systematic efforts in critically evaluating factors. Furthermore, in spite of the attempts to identify various risk factors, quantitative analysis of ERP implementation risks is quite rare, making it difficult to undertake thorough risk management in practice. In addition, few, if any, research deals with ERP risk management in project-based industries considering their fragmented nature. This research intends to fill the gap in literature and become an addition to the body of knowledge in ERP system implementation and risk management.

This research will also provide a useful methodological framework for the management of project-based firms to improve the decision making process on ERP system adoption and implementation. As ERP projects are more expensive, time-consuming, complex and failure-prone than most other IT applications, sound risk management is the key to the success of ERP implementations. Equipped with the approach developed in this research, practitioners will be enabled to effectively analyze, assess, mitigate, and minimize the risks of ERP implementation. Also, by taking risk management into account, firms of project-based nature would be more prepared for ERP system implementation, thus increasing the acceptance of ERP systems in the industry.

1.5 Outline of the Research

This research comprises 8 chapters. Chapter 1 introduces background information and the motivation to conduct the proposed study, identifies research problems and establishes the overall research objectives. Chapter 2 provides an overview of ERP systems, their adoption and implementation in project-based organizations and related research issues. Chapter 3 introduces the conceptual framework, designs the research process, and describes the research methodology to be followed. Chapter 4 reviews various risk factors that may occur in ERP project implementation, classifies them into different categories, and qualitatively analyze these risk factors. Chapter 5 develops an approach to model the failure of ERP systems and their components with fault tree analysis; it also discusses the theoretical foundation, processes, and methods to evaluate the fault trees both qualitatively and quantitatively. Chapter 6 summarizes the findings of three case studies that tests and verifies the applicability of the proposed approach. Based on the results of prior chapters, risk response and treatment strategies for ERP system implementations in project-based firms are discussed in Chapter 7. In the end, chapter 8 reiterates the key points of the proposed ERP risk management approach and summarizes the research findings. In addition, the contributions of this research to the body of knowledge and the limitations of the proposed approach are discussed, and the direction of further study is also outlined.

2 ERP Systems for Project-Based Firms

2.1 Overview of ERP Systems

2.1.1 Emergence and Evolution of ERP Systems

The evolution of ERP systems closely followed the unprecedented development and growth of Information and Communication Technologies (ICT) driven by the advances of microelectronics, computer hardware, and software systems over the past decades. The historical origin of ERP dates back to inventory management and control software packages that dictated system design during the 1960s (Kalakota & Robinson, 2001; Rashid, Hossain, & Patrick, 2002). In the 1970s, Material Requirements Planning (MRP) systems were developed to automate all aspects of production master scheduling. Following this route new software systems misnamed as Manufacturing Resources Planning (MRP II) were introduced in the 1980s with an emphasis on optimizing manufacturing processes by synchronizing the materials with production requirements. MRP II not only extended MRP’s traditional focus on production processes into other business functions such as order processing, manufacturing, and distribution, but also provided automated solutions to a wider range of business processes covering engineering, finance, human resources, project management, etc. (Kalakota & Robinson, 2001; Rashid et al., 2002; Sammon & Adam, 2004)

Based on the technological foundations of MRP and MRP II, ERP systems first appeared in the late 1980s and the beginning of the 1990s with the power of enterprise-wide inter-functional coordination and integration. ERP system differs from the MRP II system, not only in system requirements, but also in technical requirements, as it addresses technology aspects, such as graphical user interface, relational database, use of fourth-generation language, and computer-aided software engineering tools in development, client/server architecture, and open-systems portability (Russell & Taylor, 1995; Sammon & Adam, 2004; E. Watson & Schneider, 1999). Besides, while MRP II has traditionally focused on the planning and scheduling of internal resources, ERP strives to plan and schedule supplier resources as well, based on the dynamic customer demands and schedules (I. J. Chen, 2001).

Kalakota and Robinson (2001) position ERP as the second phase (Wave 2) in the "technology" and "enterprises internal and external constituencies" integration process, while Wave 1 of the evolution of ERP addresses the emergence of Manufacturing Integration (MRP), as illustrated in Figure 2.1. During recent years, ERP vendors added more modules and functions as "add-ons" to the core modules giving birth to the "extended ERPs." Due to the proliferation of the Internet which has shown tremendous impact on every aspect of the IT sector, ERP systems are becoming more and more "Internet-enabled" (Lawton, 2000). This environment of accessing systems resources from anywhere anytime has helped ERP vendors extend their legacy ERP systems to integrate with newer external business modules such as Supply Chain Management (SCM), Customer Relationship Management (CRM), Sales Force Automation (SFA), Advanced Planning and Scheduling (APS), Business

Intelligence (BI), and e-business capabilities (Rashid, et al., 2002). Figure 2.2 illustrates the interrelationship of ERP with other value chain elements, in which ERP systems and their implementations represent essential enables of improvement, development, and growth with and ultimately among firms (Bendoly & Jacobs, 2005). The developments of innovative add-on modules and extensions driven by the advances of new technology and evolving business demands will lead to the next wave of ERP systems.

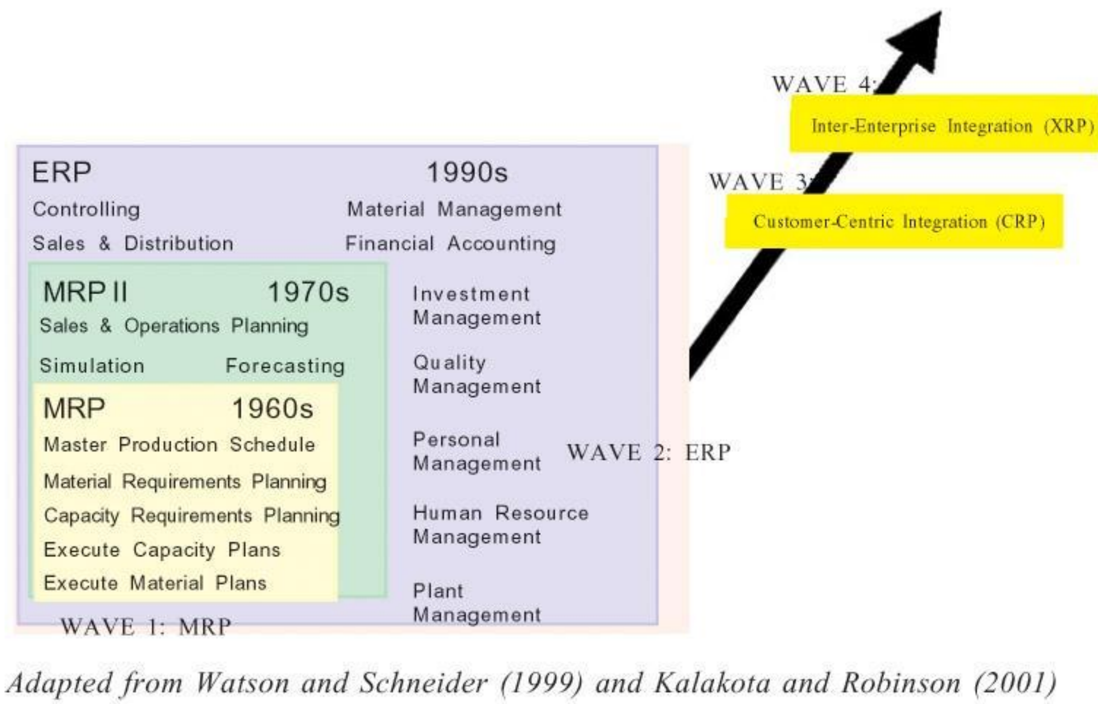


Figure 2.1 Evolution of ERP Systems

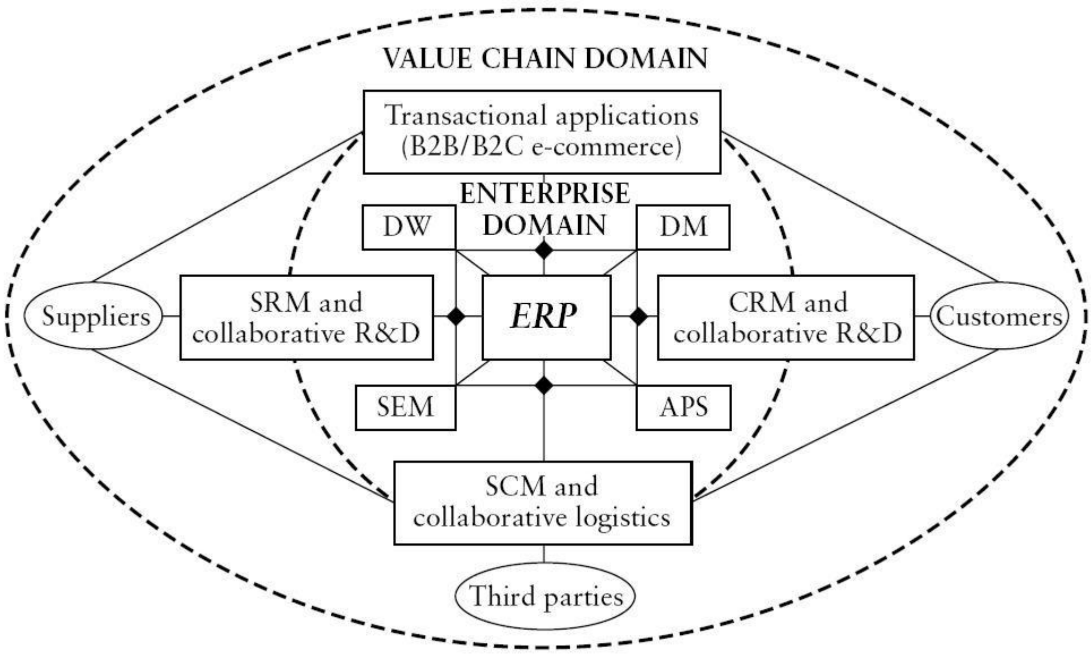


Figure 2.2 The Interrelationship of ERP with Other Value Chain Elements

Adapted from (Bendoly & Kaefer, 2004)

2.1.2 Definition and Characteristics

The role of Enterprise Resource Planning (ERP) does not match its name: it is about neither planning nor resources, but is rather related to the enterprise. ERP systems are often being referred to as "Enterprise Systems" (I. J. Chen, 2001; Davenport, 1998) and "Enterprise-wide Information Systems" (Milford & Stewart, 2000). There is no universally agreed upon definition for ERP systems so far. According to Davenport (1998), "ERP comprises of a commercial software package that promises the seamless integration of all the information flowing through the company– financial, accounting, human resources, supply chain and customer information." ERP systems can be defined as "configurable information systems packages that integrate information and information-based processes within and across functional areas in an organization" (K. Kumar & Van Hillsgersberg, 2000). ERP systems are also defined as "computer-based systems designed to process an organization's transactions and facilitate integrated and real-time planning, production, and customer response" (O'Leary, 2000).

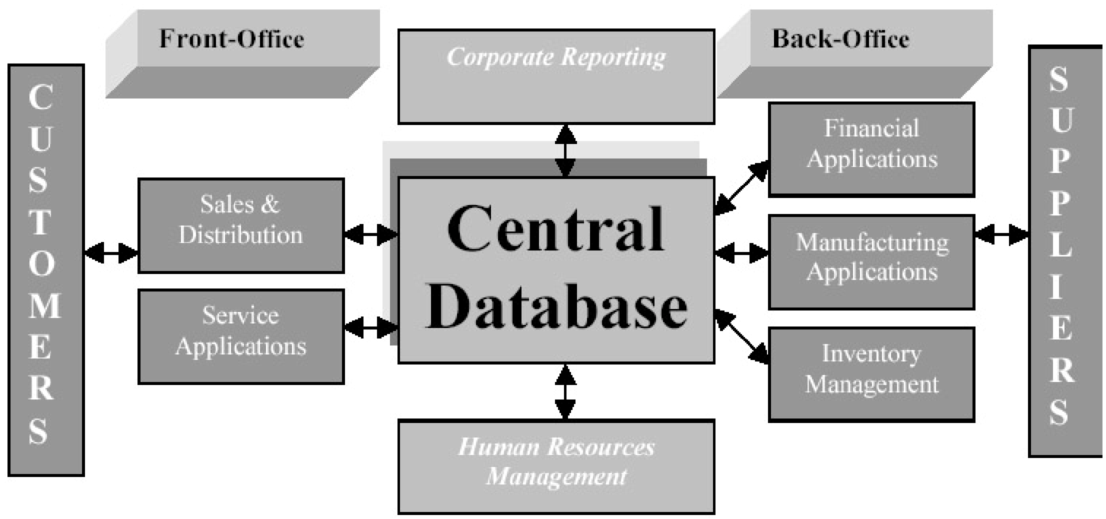


Figure 2.3 ERP System Concepts

The concept of ERP systems is illustrated in Figure 2.3. ERP system attempts to integrate all departments and functions across an organization into a single, integrated computer system based on a centralized common database that can serve all those different departments' particular needs. A common database management system (DBMS) allows every department of a company to store, update and retrieve information in a real-time basis, and enables information to be more reliable, accessible, and easily shared. Thus one of the key properties of ERP systems is that they are integrated in nature. They are also multi-functional or all-encompassing in scope, aiming to tackle a full range of business processes and activities throughout an organization including finance, accounting, sales, manufacturing, human resources, procurement, project management, and so forth. Thirdly, they are modular in structure and usable in any combination of modules (Mabert, et al., 2001). An organization can implement all the modules or a subset of them, as well as connect to other support systems such as "add-ons". Besides, ERP systems are customizable mega-packages of high complexity that require careful consideration before selection, implementation, and use (Sammon & Adam, 2004).

2.1.3 Advantages and Disadvantages

It is evident in literature that ERP systems, if properly implemented, can achieve substantial benefits for business computing (Watson & Schneider, 1999). Among those reaping the benefits are Fujitsu, General Motors, Boeing, IBM, Oracle, Coca Cola, and so on. Numerous cases of ERP projects in a variety of industry sectors have proven that successfully implemented ERP systems do offer many advantages unparalleled by the co-existence of various stand-alone, custom-built software applications which neither collaborate with each other nor effectively interface. Table 2.1 lists a number of major advantages provided by ERP systems. Shang and Seddon present a comprehensive framework of business benefits that organizations might be able to achieve from their use of ERP systems (Shang & Seddon, 2000).

Table 2.1 Advantages of ERP Systems

Adapted from Koch (2002) and Rashid, *et al*. (2002)

What	How
Seamless integration and reliable information access	Common DBMS, consistent and accurate data, improved reports.
Standardization of business processes	Business process reengineering with the customization of ERP systems to fit organization and achieve best practices.
Business processes automation	Real-time information sharing and transmission through the value chain.
Improved managerial decision making	Timely and accurate information dissemination.
Elimination of data and operations redundancy	Modules access same data from the central database, avoids multiple data input and update operations.
Delivery and cycle time reduction	Minimizes retrieving and reporting delays.
Cost reduction	Time savings, improved control by enterprise wide analysis of organizational decisions.
Easy adaptability	Changes in business processes easy to adapt and restructure
Improved scalability	Structured and modular software design.
Improved maintenance	Vendor-supported long-term contract as part of the system procurement.
Global outreach	Extended modules such as CRM and SCM.
E-Commerce / E-Business	Internet commerce, collaborative culture.

In spite of the many advantages as described above, ERP systems have some disadvantages. Some of ERP systems' notorious disadvantages are listed below.

- Substantial investment. Implementation of ERP systems requires a substantial investment of money and internal resources and is fraught with technical and business risk (Hitt, Wu, & Zhou, 2002). A typical ERP installation has a total cost of about $15 million and costs can be as high as two to three percent of revenues (O'Leary, 2000).
- Long implementation periods. ERP implementation takes a long time compared with the installation of other software applications, ranging from several months to many years. A three to five year implementation period of ERP systems is fairly common in a large company (Chung, 2007). During this period, the benefit of ERP systems may not be able to be fully delivered.
- Implementation difficulty and complexity. ERP implementations are also known to be unusually difficult, even when compared to other large-scale systems development projects. Part of this difficulty is due to the pervasiveness of the changes associated with ERP, the need for simultaneous process redesign of multiple functional areas within the firm, and the need to adapt processes to the capabilities of the software (Hitt, et al., 2002). There is also a high degree of managerial complexity.
- Inflexibility and vendor dependence. Once an ERP system is established in a company, it is too difficult to change how the company works and is organized or to switch to another vendor.

- Overly hierarchical organizations (Davenport, 2000). ERP systems presume that information will be centrally monitored and that organizations have a well-defined hierarchical structure. Therefore, these systems will not match with organizations of empowerment or with employees as free agents.

Additionally, re-engineering of business processes to fit the "industry standard" prescribed by the ERP system may lead to a loss of competitive advantage; and resistance in sharing sensitive internal information between departments can reduce the effectiveness of the system. Overall, the adoption and implementation of ERP system involve high complexity and risks, which lead to a high failure rate of ERP projects. Therefore, it is generally a misleading perception that implementing an ERP system will improve organizations' functionalities overnight. The high expectation of ERP is very much dependent on how good the chosen ERP system fits to the organizational functionalities and how well the tailoring and configuration process of the system matched with the business culture, strategy and structure of the organization (Rashid, et al., 2002).

2.1.4 The ERP Market and Major Vendors

The ERP software market is one of the largest and fastest-growing markets in the software industry. Over the 1990s, organizations worldwide spent around $300 billion on ERP implementation (James & Wolf, 2000). According to AMR Research Inc., fueled by globalization, midmarket growth and other factors, the market for ERP software was $28.8 billion in 2006, and will reach $47.7 billion by 2011, with an estimated compound annual growth rate of almost 11% (Franke, 2007). Today, ERP systems are almost ubiquitous in large organizations, with an estimate that over 70% of Fortune 1000 companies have installed ERP systems (Bingi, Sharma, & Godla, 1999). ERP vendors are targeting the untapped Small to Medium Enterprise (SME) market with supposedly scaled-back systems suitable for smaller firms by offering simple, cheaper, and pre-configured easy-to-install solutions within budget and time constraints. For example, SAP, one of the leading ERP vendors, recently started selling its products to customers in the $150 million to $400 million revenue range. In the rapidly changing ERP environment, penetrating SME market as well as vertical market such as engineering and construction seems to be of a very high strategic move (Skibniewski, 2005).

Table 2.2 lists major ERP vendors in the world and their market share.

Table 2.2 Market Share of Major ERP Vendor, 2005-2006

2006 Revenue Rank	Company	Revenue, 2005 ($M)	Revenue, 2006 ($M)	Revenue Share, 2005	Revenue Share, 2006	Growth Rate, 2005-2006
1	SAP	10542	11753	42%	41%	11%
2	Oracle	5166	6044	20%	21%	17%
3	Infor	480	2114	2%	7%	340%
4	Sage Group	1438	1830	6%	6%	27%
5	Microsoft	844	996	3%	3%	18%
6	Lawson	346	560	1%	2%	62%
7	Epicor	291	384	1%	1%	32%
8	IFS	279	309	1%	1%	11%
9	Exact Software	281	303	1%	1%	8%
10	Activant	260	289	1%	1%	11%
11	CDC Software	202	240	1%	1%	19%
12	QAD	222	236	1%	1%	6%
13	Deltek Systems	151	230	1%	1%	52%
14	Glovia	212	212	1%	1%	0%
15	SSA Global*	733	0	3%	0%	-100%
16	Geac*	445	0	2%	0%	-100%
17	MAPICS*	178	0	1%	0%	-100%
Subtotal		**22069**	**25499**	**87%**	**88%**	**16%**
Other ERP Vendors		**3289**	**3321**	**13%**	**12%**	**1%**
Total		**25358**	**28820**	**100%**	**100%**	**14%**

*Acquired by Infor in 2006.

Source: AMR Research, 2007

Among these ERP vendors, SAP AG and Oracle Corporation are the market leaders. Headquartered in Walldorf, Germany, SAP was founded by five former IBM software engineers in 1972 for producing integrated business application software for the manufacturing enterprise. Its first ERP product, R/2, was launched in 1979, using a mainframe-based centralized database that was then redesigned as client/server software R/3 in 1992. R/3 was a breakthrough and by 1999 SAP AG became the third largest independent software supplier in the world and the largest in the ERP sector. MySAP ERP, the successor to SAP R/3, is the first service-oriented business application on the market based on SAP NetWeaver, an open integration platform that allows new applications to be developed. As of 2008, SAP employs about 46,100 people in more than 50 countries, and has more than 43,400 customers worldwide (SAP, 2008).

Oracle, founded in 1977 in the USA by Larry Ellison, is best-known for its database software and related applications and is the second largest software company in the world after Microsoft. Oracle's enterprise software applications started to work with its database in 1987. In 2005, Oracle closed the gap with SAP in the ERP market by buying PeopleSoft Inc. for $10.3 billion. Previously, PeopleSoft merged with JD Edwards, so Oracle now has three different product lines in enterprise solutions: Oracle's "E-Business Suite," PeopleSoft's "Enterprise," and JD Edwards's "EnterpriseOne" and "World." The new combined company plan is to incorporate the best features and usability characteristics from Oracle, PeopleSoft, and JD Edwards products in the new standards-based product set. The successor product, named Oracle Fusion, is expected to evolve over time and incorporate a modern architecture, including the use of web services in a service-oriented architectures (Oracle, 2008). The current Oracle ERP package, named Oracle E-Business Suite, has almost 50 different modules in seven categories: Finance, Human Resources, Projects, Corporate Performance, Customer Relationship, Supply Chain, and Procurement. It also offers industry-specific solutions, most of which were acquired from companies that had developed them to a certain degree.

2.2 Adoption of ERP Systems in Project-Based Firms

2.2.1 Overview of Project-Based Firms

Project-based firms, or project-based organizations, refer to a variety of organizational forms that involve the creation of temporary systems for the performance of project tasks (DeFillippi, 2002; Lundin & Söderholm, 1995). In such kind of organizations, the project, which is defined as "a temporary endeavor undertaken to create a unique product, service, or result" (PMI, 2008), is the primary unit for production organization, innovation, and competition. As such, project-based firms have certain characteristics that distinguish them from those companies which are organized in different departments with continual business operations. At first, since the organizing unit of project-based firms are essentially mission-oriented and resource-limited, the organizational hierarchies are normally flattened and the firm's internal boundaries weakened, which could facilitate the networks of collaboration and the restructuring of competition between firms (Whitley, 2006; Zeng, Skibniewski, & Tadeusiewicz, 2008). Second, the decentralized nature and time-constrained ways of working, combined with loose coupling between projects, usually create highly distributed working practices in project-based firms (Bresnen, Goussevskaia, & Swan, 2004; Lindkvist, 2004). Project work is generally carried out by teams composed of people from a wide variety of knowledge disciplines and dispersedly located in different physical locations; virtual teams are widely adopted and remote communication is prevalent. External stakeholders with different expectations might also be closely involved in the project life cycle. Third, the uniqueness and temporary nature of projects makes it hard to fully standardize the working process, as project-based organizations are employed to meet the highly differentiated and customized nature of demand. While project-based firms in their many varieties are put forward as a form ideally suited for managing increasing product complexity, fast changing markets, cross-functional expertise, customer-focused innovation, and technological uncertainty (Hobday, 2000), these characteristics pose a challenge for centralized information integration and for the implementation of ERP systems.

Project-based organizations are found in a wide range of industries. These include consulting and professional services (e.g. accounting, advertising, architectural design, law, management consulting, public relations), cultural industries (e.g. fashion, film-making, video games, publishing), high technology (e.g. software, computer hardware, multimedia), and complex products and systems (e.g. construction, transportation, telecommunications, infrastructure). Since the Engineering & Construction (E&C) industry is the one where project-based organization is originated and ubiquitously used, the empirical part of this research will be mainly placed within its context.

2.2.2 Engineering & Construction Industry

Producing all types of buildings and infrastructure – homes, workplaces, shopping centers, hospitals, airports, roads, bridges, and so on, the Engineering & Construction

(E&C) industry is one of the largest industry sectors in the national economy. The term Engineering & Construction (E&C) industry is often used interchangeably with Construction industry, although the former appears wider in scope and more inclusive. The construction industry conservatively accounted for $611 billion, or 4.4% of the gross domestic product (GDP) in the United States in 2007, more than the amount contributed by many other industry sectors such as agriculture, mining, information, and food services (Bureau of Economic Analysis, 2009). If the value of installed equipment, furnishings, and other elements necessary to complete a building were included, construction would account for 10% of the GDP (National Science and Technology Council, 1995). It is also a major generator of jobs, directly employing almost 11 million people, about 8% of the U.S. workforce in 2007 (Bureau of Labor Statistics, 2008).

Despite its size and importance in the economy, the productivity of the construction industry has been lagged behind other non-farm industries (Teicholz, 2004). Its low productivity increase is often attributed to relatively low investment in research & development and passiveness in adopting advanced technologies including information technology. As concerned in this research, ERP systems, although having been widely used by many manufacturing and financial service firms, still have relatively low penetration in the E&C industry. In spite of the fact that there has been a wide adoption of information technology by the E&C industry over the past decades, these applications tend to run in a stand-alone mode focusing solely on a specific operation or process, which neither provide information integration nor permit improved collaboration by the project teams. Much information can now be generated, stored and processed by computers; and some business processes can be automated. However, more than often paper outputs are ultimately produced and manually reviewed, so that relevant data can be entered into another program for the next stage of work or for other stakeholders in the project. This lack of integration, also the so-called ”islands of automation” (Hannus, 1998), leads to increased effort and cycle time and has greatly reduced the ability of the project team to respond quickly and effectively to constantly evolving circumstances - changes in work scope or site conditions, material shortage, quality problems, and so on. As a result, despite the widespread use of IT, the overall productivity of E&C industry has considerable potential to be improved. Implementing organization-wide information systems becomes a natural solution to overcome the fragmentation caused by stand-alone applications and improve the performance and productivity of project-based firms in the E&C industry.

2.2.3 General Concepts of ERP System in Firms within the E&C Industry

The E&C industry is fragmented, complex and competitive, consisting of a vast diversity of players from owners/developers, architects, engineers, general contractors, to specialized trade contractors, subcontractors, and material and equipment suppliers. .Figure 2.4 shows the typical business activities in engineering and construction (Skibniewski, 2005). Due to segmented phases and various participants, management of engineering and construction is inclined to be problematic.

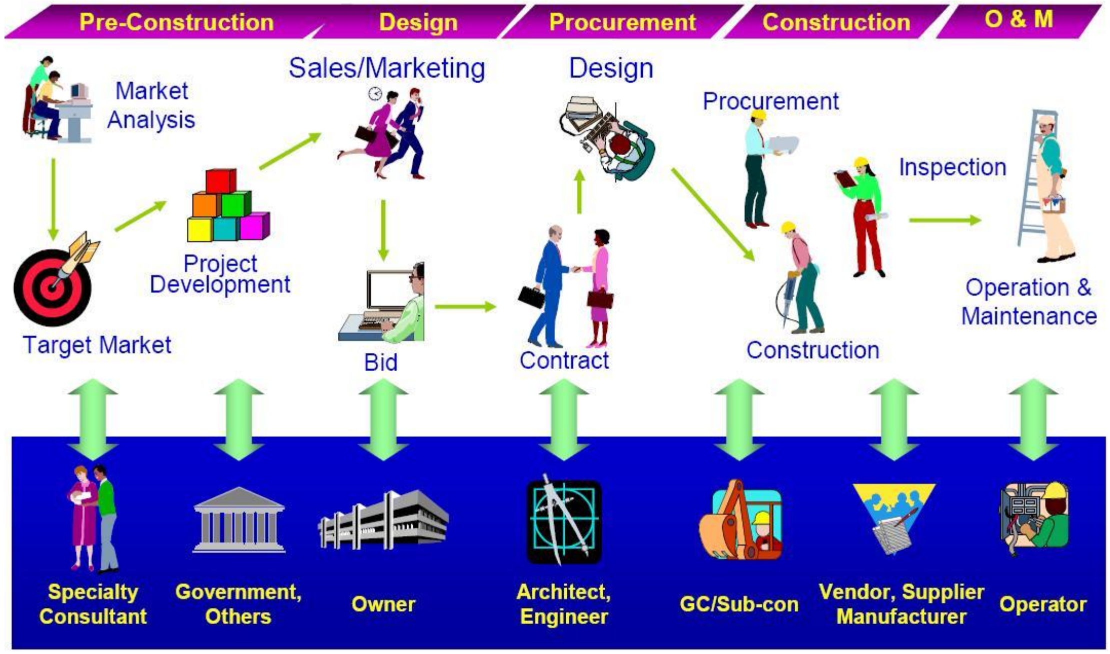


Figure 2.4 Typical Business Processes in Engineering and Construction

The general concept of ERP system structure and major functions for engineering and construction firms is illustrated in Figure 2.5 (Chung, 2007). Although the business processes of E&C companies differs due to a variety of factors such as organizational structure, sub-market orientation, business culture and so on, there are many similarities in the business functions because of the project-centric production in engineering design and construction. The major application areas of ERP systems for engineering and construction are Financial Accounting and Project Management. These two core functions are tightly connected with each other, and all the other functions support them to streamline the whole business processes (Chung, 2007). Other functional modules which are not shown in the figure can also be included in a company's ERP system depending on its specific needs.

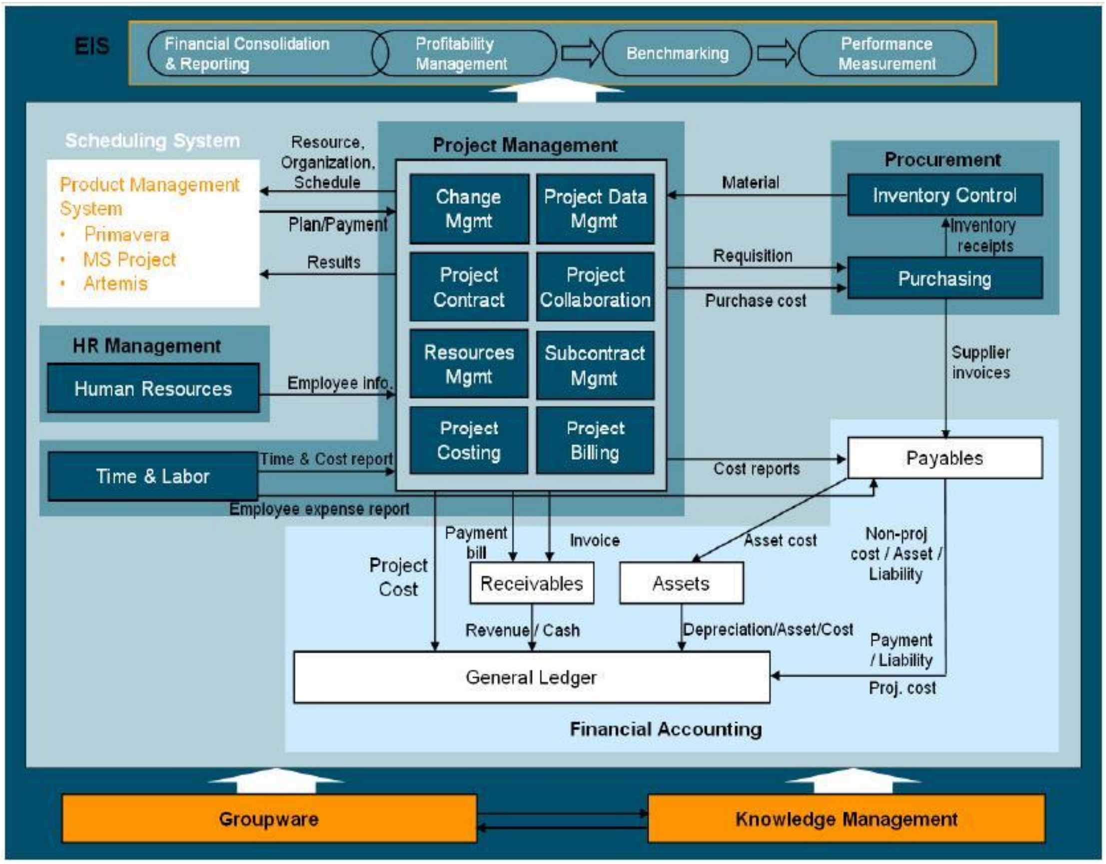


Figure 2.5 General Concepts of ERP Systems in Engineering & Construction

Due to the unique nature of the E&C industry, some research has been conducted to identify the essential components of an ERP system for use in this industry in order to achieve successful implementation. Shi and Halpin (2003) suggested several features for a successful ERP system for use in construction industry, including project-oriented, integrated, parallel and distributed, open and expandable, scalable, remotely accessible, transparent, and reliable and robust (Shi & Halpin, 2003).

2.2.4 ERP Adoption in Project-Based Firms: The Case in the E&C Industry

The E&C industry has remained one of the few unexplored major industry sectors for ERP systems. According to a survey conducted in 1998, project industry, which included the E&C industry and other project-based industries, has the lowest ERP penetration rate among the six major industries under study (van Everdingen, van Hillegersberg, & Waarts, 2000). In 2003, another national construction technology survey indicated that construction firms had been accelerating the adoption of information technology; however, the high priority is given to traditional IT applications such as project management software, estimating/bidding software, and so forth (Augenbroe, 2006). Thus the E&C industry has still been lagged behind other major industry sectors in the national economy in adopting ERP systems and reaping their benefits. Moreover, it is well documented that those having adopted ERP systems in the E&C industry are mostly large organizations that have the financial and technological capabilities to implement ERP systems (Ahmed, Ahmad, Azhar, & Mallikarjuna, 2003; Chung, 2007; Costantino & Pietroforte, 2006). Besides, regarding the regional difference in ERP adoption, more European companies have adopted ERP solutions than American companies (Costantino & Pietroforte, 2006; Skibniewski, 2005).

As discussed above, the high risk of implementing ERP systems due to substantial investment, long implementation periods, and considerable difficulty and complexity prevents E&C firms from adopting ERP systems. This is one of the most recognized causes of the low ERP adoption rate in the E&C industry. Particularly, the high failure rate of ERP implementations have been widely cited in literature (Chung, 2007; Davenport, 1998). Large IT projects such as ERP implementations have more exposure to failing in delivering benefits/value as proposed or expected within the time and budget limit and meeting the specifications. In the last decades, many studies have identified that the success rate is approximately 25%, the failure rate is also about 25%, and partial successes and failures exist around 50% (Kozak-Holland, 2007). Failures with the implementation of ERP occur for a variety of reasons, such as the need for business process change, lack of top management support, education and training, and lack of data accuracy and integration (Benson & Rowe, 2001; Verville & Halingten, 2003). Many failure cases about ERP implementation projects have been reported. In 1996, FoxMeyer Drug, a $5 billion drug distributor, declared bankruptcy after failing to implement an ERP system over a three-year period, and sued its ERP vendor – SAP AG, stating that its system was a “significant factor” that brought about the company’s financial ruin (Davenport, 1998). In 1997, Dell Computers, after months of delay and cost overruns (about $115 million spent out of original budgeted $150 million), abandoned their ERP project, because they found that the new system was not appropriate for its decentralized management model (Stefanou, 2000). A latest failure case is that trash-disposal giant Waste Management cancelled its ERP implementation project after spending three years and about $100 million (Kanaracus, 2008). These ERP project failure cases, especially the damaging consequences of ERP implementation failure to the companies which paid the bills, make many project-based firms more conservative and reluctant as regard to adopt ERP systems.

The low adoption of ERP systems in the E&C industry could also be ascribed to the nature and characteristics of this industry as mentioned above, which are quite different from other industries focusing on continual business operations. Some researchers argue that the failures of ERP implementation in construction industry are due to the unique nature of the industry (Shi & Halpin, 2003). Each construction project is characterized by a unique set of site conditions, a unique working team, and the temporary nature of the relationships between project participants. Thus, even although most ERP benefits are obtained by standardizing business processes, E&C business organizations typically need extensive customization of pre-integrated business applications from ERP vendors. Unfortunately, such an extensive customization may lead to ERP implementation failure. A case study by Chung (2007) presented an abandoned ERP project by one of the biggest U.S. homebuilders because the company needed mass customization as its buyers usually want to change an average of 30–40 options in home design. Furthermore, E&C projects are complex dynamic systems that are subject to a multitude of random external processes. In some sense, activities in the E&C industry are still short of a common language. Companies in this industry still lack the ability to properly plan, estimate and execute projects in a consistent, efficient and reliable manner (AbouRizk & Mohamed, 2002). Thus implementing integrated systems in engineering and construction presents unique challenges, different from those in the manufacturing or other service sector industries. Besides, the E&C industry is predominately composed of a large number of small clients, vendors, designers, general contractors and sub-contractors who are often not in a position to provide leadership for the adoption of new technology and practice including ERP systems; they lack either the willingness to take the risk or the financial capability of adopting ERP systems. Last but not least, the educational level of users in the E&C industry is relatively low, but ERP is a mature technology which may not be easy to use for those users without adequate literacy or technological exposure, and an arduous training process would be indispensable for the adoption of ERP systems.

From the perspective of ERP vendors, the unique nature of the E&C industry and its requirements for specific data fields, customizability, flexibility and scalability should be taken into consideration. ERP systems must consolidate project data and finances, and also provide construction-specific data fields, common database, and a holistic view of the enterprise and internet capabilities. ERP systems should also have an easy-to-use interface for those users with low educational level.

The ERP market has survived the Internet bubble and continued to grow rapidly exploring the industry sectors with low ERP penetration. To date, ERP systems have matured to the core of successful information management and the information technology backbone of corporate infrastructure. As major ERP vendors such as SAP, Oracle and Microsoft have successfully developed ERP solutions specifically targeting the E&C and other project-based industries and are actively marketing their solutions to companies across the industry, more and more E&C firms are embarking to adopt or consider adopting ERP systems to better integrate their various business processes and functions. Considering that the stake of implementing ERP systems is still very high and there is a lack of widely accepted methods to ensure its success, it is increasingly important to develop a risk management scheme in support of ERP implementation for project-based firms including those in the E&C industry, which is the purpose of this research.

2.3 Chapter Summary

This chapter provides an overview of ERP systems and their adoption in the project-based firms, mainly in the E&C industry. At first, ERP system is introduced in a detailed way, including its definition, origin and evolution, characteristics, system architecture, advantages and disadvantages, the ERP market and its major players. Based on a review of the characteristics and practices of the E&C industry, this chapter also described the general concepts of ERP systems for E&C firms and core application modules. Furthermore, the chapter introduces the current status and typical problematic issues of ERP system adoption in project-based organizations as exemplified by those in the E&C industry, and analyzes underlying causes for the low ERP adoption. It is anticipated that ERP systems will continue to penetrate in the project-based industries including the E&C industry from large companies to midsize or even small size companies, due to the fact that ERP vendors are improving and customizing their solutions with an industry-centric focus to target unexplored markets and many project-based firms are continuously seeking to make better use of information technology so as to improve performance and productivity. This trend makes it increasingly important to develop a sound risk management approach to help project-based firms to achieve success in ERP systems implementation.

3 Research Design and Methods

3.1 Introduction

In Chapter 2 the literature relevant to ERP systems and their adoption in the project-based firms exemplified by E&C firms is reviewed. Understanding ERP system implementation and the nature and characteristics of project-based firms provide grounds for developing the conceptual research framework and research methodology in this study. The purpose of this chapter is to present a conceptual research framework that links the research problems and objectives identified in Chapter 1 and the process of developing for the proposed risk management approach. This chapter is divided into four parts. At first certain assumptions of this research and the proposed risk management approach are introduced. Secondly, the logic processes and procedures to conduct this research are designed. Thirdly, research methodologies to be used for each part of the research are described. Finally, concluding remarks are presented in the chapter summary.

3.2 Assumptions

3.2.1 Existence of Legacy Systems

As information technology has penetrated all industry sectors, almost all project-based companies today have somehow been using computers and some kinds of software applications for communication and automation of work. For those firms that want to implement ERP systems, the typical case is that a variety of stand-alone applications are in use, which have various interface design, use different databases and data standards, and provide little, if any, interoperability and integration. Thus for the purpose of investigating ERP implementation risks, it is assumed that there exists a legacy system in the firm, typically a combination of stand-alone applications which do not integrate with each other and do not interface effectively. In addition to outdated information technology, legacy system also encapsulates the existing business processes, organizational structure, and culture (Bennett, 1995).

According to capital budgeting theory, adopting ERP systems is a capital project since the cash flows to the firm will be received over a period longer than a year. Capital budgeting projects can be divided into several categories: (1) Replacement projects to maintain the business; (2) Replacement projects for cost reduction; (3) Expansion projects; (4) New product or market development; (5) Mandatory projects; and (6) other projects, such as pet projects of senior management or research & development projects (Clayman, Fridson, & Troughton, 2008). In this sense, investment in ERP systems can be treated as a replacement project for business continuance or cost reduction or an expansion project that is taken to grow the business.

3.2.2 Consideration of ERP System Life Cycle

The ERP life cycle consists of several stages that an ERP system goes through during its whole life within the hosting organization: (1) adoption decision phase; (2) acquisition phase; (3) implementation phase; (4) use and maintenance phase; (5) evolution phase; and (6) retirement phase (Esteves & Pastor, 1999). This research will only take into account the activities and risk factors within the adoption decision (or selection), acquisition, and implementation phases, which have an impact on the outcomes of ERP implementation. It appears that the activities before the initialization of ERP implementation, in other words, in the adoption decision and acquisition phases, are out of scope based on the title of the study. However, these activities and related risk factors have direct impact on project delivery, thus they are integral parts of the ERP project and must be considered in conjunction with the implementation process for the purpose of managing the risks. Although post-implementation review that officially concludes whether the implementation is successful or not takes place after the system becomes stably in use, post-implementation activities including regular maintenance, upgrading, new-lease management, evolution maintenance and so on do not influence the original implementation project. In the evolution phase, additional capabilities provided by extensions, such as Business Intelligence (BI), Customer Relationship Management (CRM) and Supply Chain Management (SCM) etc. are integrated into the ERP system to obtain additional benefits. These extensions should be evaluated and managed independently as new projects when such needs emerge, and thus be excluded from the scope of this study.

Additional assumptions regarding the proposed approach are stated in Chapter 5.

3.3 Conceptual Framework and Procedures of the Research

3.3.1 Conceptual Research Framework

In order to illustrate the contents of the proposed risk management approach and the process towards its establishment, a conceptual research framework is developed as shown in Figure 3.1. This conceptual research framework provides direct connections between different components (or phases) of the proposed risk management approach and the research objectives (1) to (4) as defined in Chapter 1; it also links the literature review in Chapter 2 and the risk identification and quantitative risk modeling in the following chapters. While the development of the proposed risk management approach is primarily based on general theory and practice in project risk management and a better understanding of ERP system implementation processes, this approach will be tested, calibrated, and validated by case studies in a few project-based firms, most of which are in the E&C industry.

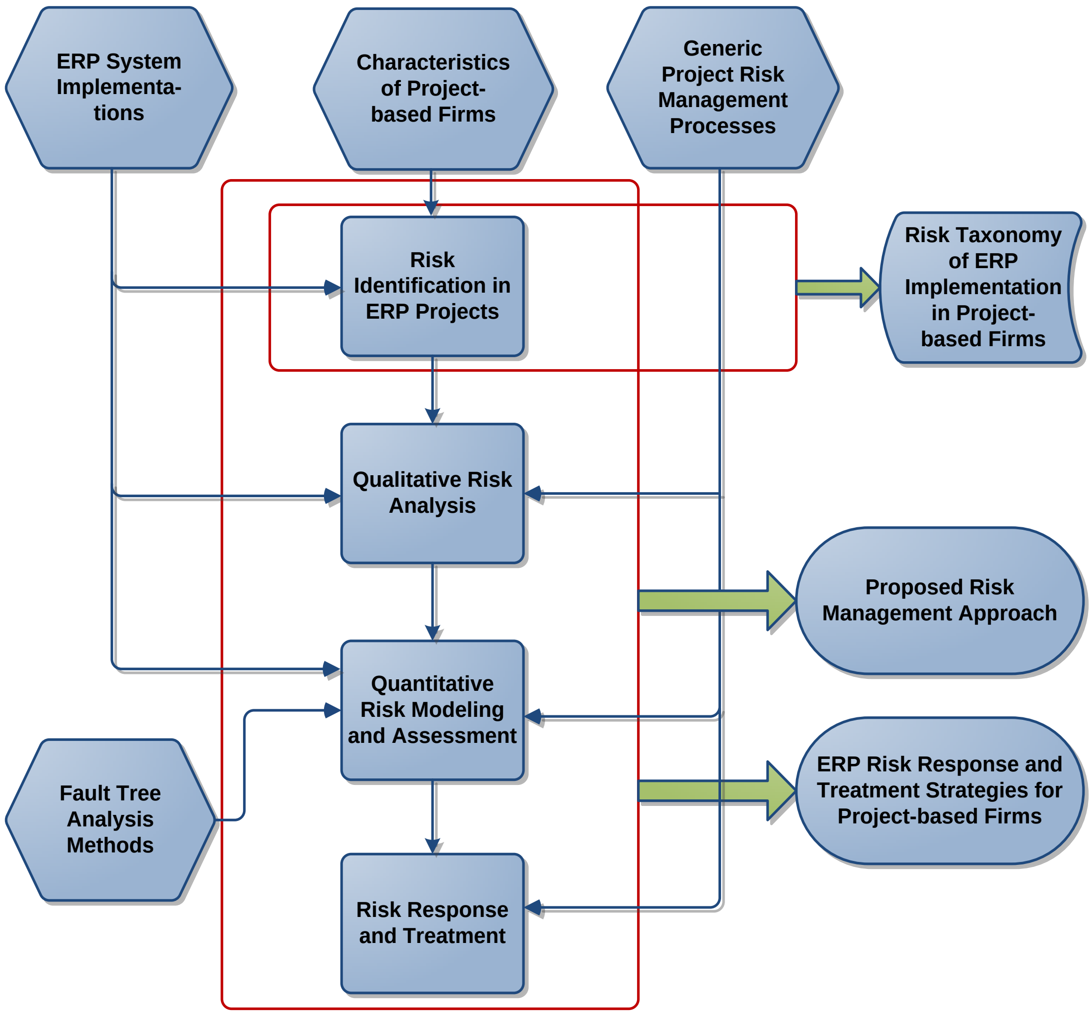


Figure 3.1 Conceptual Research Framework

3.3.2 Research Procedures

According to the way this research is organized (Chapter 1) and the conceptual research framework as presented in the previous section, and in continuation with the literature review completed in Chapter 2, a series of procedures are presented below to carry out this research towards the achievement of its main objectives.

(1) ERP risk identification:

- Identify and understand the risk factors in the processes of adoption decision, acquisition and implementation of generic ERP systems;
- Identify the risk factors in ERP projects that are specifically or more probably associated with project-based organizations;
- Classify the risk factors into different categories based on their common features and the way to be analyzed and treated;
- Establish a risk taxonomy for ERP projects in project-based firms;

(2) Qualitative risk analysis:

- Examine and describe the characteristics of the identified risks factors in the context of project-based firms;
- Evaluate the potential impact of risk factors on ERP project outcomes;

(3) Quantitative risk modeling and assessment with fault tree analysis:

- Explore the methods and criteria to conduct ERP system decomposition;
- Describe the processes and techniques to develop fault tree models for ERP system usage failure; discuss the methods for failure mode definition and basic event probability estimation;
- Examine the principles and methods to conduct probabilistic assessment on fault trees;
- Assess and interpret the impact of events/component failures on the entire ERP system usage failure.

(4) Development of risk response and treatment strategies for ERP projects in project-based firms based on the above steps.

(5) Calibration and validation of the proposed risk management approach.

Overall, the above research procedures represent a logic sequence to develop the proposed risk management approach and use it for practical purposes in the project-based firms.

3.4 Research Methods for Developing the Risk Management Approach

3.4.1 Literature Survey

Different research methods will be used to achieve the different parts of the main research objective. For sub-objectives (1) – (2), extant literature are investigated to extract the risk factors, hierarchies and effects of ERP implementation and examine their effects on ERP component/event failure and the total project failure, while ERP project failure needs a clear definition as well. Recent studies have attempted to list the risk factors and establish a risk framework in ERP projects (Aloini, et al., 2007; Huang, Chang, Li, & Lin, 2004; Sumner, 2000a), which could provide very useful references for this research. However, few of these studies assume a sector-specific perspective; neither do they delve to the interactions among various risk factors. These issues are important for the risk analysis, and thus need to be addressed in this research.

The literature survey is primarily based upon secondary sources, mostly peer-reviewed articles published in either research journals or conference proceedings. These articles are found in the databases provided by Science Direct (Elsevier), Springer, Emerald, and IEEE-Xplore etc. A few publications by ERP vendors, consulting companies, and industry associations are also considered, including those in the form of case studies. Due to the rapid pace of change in the ERP market and the evolving perception on ERP implementation, less literature prior to the late 1990s are reviewed and cited. Also, there is much less studies specifically addressing ERP system implementation and risk management in project-based industries.

3.4.2 ERP System Failure Modeling with Fault Trees

This research attempts to model the risk relationship of ERP system components during the implementation process using fault tree analysis (FTA). Originally developed in 1962 at Bell Laboratories and introduced in military and aerospace, over the decades it has been expanded to most engineering domains ranging from nuclear, electronics and electric power to chemical, mechanical and civil engineering (Ericson, 1999). Fault tree analysis has been widely used as a powerful and efficient tool for reliability analysis and safety prediction. It is a detailed deductive analysis that requires considerable system information and can also be a valuable design or diagnostic tool.

In order to accomplish sub-objective (3), both static and dynamic gates can be used to capture the relationships and interdependencies of ERP failure events and their impact on project failure. Based on the analysis of component failures, fault tree models can be constructed and depicted in the form of diagrams. They are then evaluated using certain techniques and methods, both qualitatively and quantitatively, in order to find the minimal sets, calculate the probability of top event, and understand the failure patterns of the system. As a result, failure-prone ERP components and the risk events to component failures will be identified in the process of ERP implementation, and corresponding preventive or corrective actions can be taken to increase the chance of successful ERP project delivery.

3.5 Research Method for Calibration of the Proposed Approach

This research uses case study to calibrate the proposed risk management approach. Case study is now accepted as a valid research strategy within many disciplines including the IS research community (Klein & Myers, 1999). Case research moves away from rigor towards practicality, which may suggest more relevance for practitioners. The natural setting gives case researchers the opportunity to conduct situational and in-depth studies of complex phenomena that is not always possible because of the restrictions on studies conducted under laboratory conditions. In natural settings, researchers are able to explain more clearly the causal links through real-life interventions, describe the real-life context in which an intervention occurred and explore those situations in which the intervention being evaluated has no clear, single set of outcomes (Yin, 2002).

In this research, three case studies on ERP system implementations in different project-based firms are conducted to calibrate the developed risk management approach based on fault tree analysis. Two of the companies have completed the implementation of ERP systems, which are currently in use; the other one had considered ERP adoption and evaluated ERP system implementation options but eventually did not commit to the project. The case study consists of solicitation of ERP implementation project records and documentations, semi-structured interviews with leading professionals in the projects, and estimation of the risks through a questionnaire.

4 Risk Identification and Qualitative Analysis of ERP Projects

4.1 Risk Management Processes

Companies must take risks to pursue profits in the marketplace that is full of uncertainty. According to ISO 31000, risks, as the effect of uncertainty on objectives, can be both positive and negative (ISO, 2009). In fact, however, the negative side is often emphasized, and risk thus refers to an unwanted future event or issue among a set of uncertain outcomes. It is proportional to both the results that can be caused by a hazardous event and the likelihood of occurrence of such event. While the existence of risks in the course of human endeavors is hardly avoidable, risks can be managed through early diagnosis and mitigated by taking preventive or corrective actions. Risk management plays a very important role in enabling organizations to perform their work towards the realization of desired objectives. Many models have been developed in recent years to address the need of a more effective risk management, most of them typically used an iterative approach to risk management problems (Aloini, et al., 2007; Keizer, Halman, & Song, 2002; PMI, 2008).

The major phases in the risk management processes are:

- Context analysis, which involves understanding the domain of interest and the environments, identifying various stakeholders, establishing the basis upon which risks will be analyzed, and planning the remainder of risk management processes;

- Risk identification: identifying and listing the threats, hazards, problems, and other negative issues that may affect the system;
- Qualitative risk analysis: documenting the characteristics of the risks, analyzing their effects on the system, and understanding their relationships;
- Quantitative risk assessment: estimating the probability of occurrence of the risks, and numerically assessing their impact on the system;
- Risk response: planning and developing options and actions to prevent or reduce the negative impact of risks on the system, and enhance their positive impacts.

This chapter aims to identify, organize and describe the risk factors inherent in ERP system implementation projects. These factors are analyzed in a qualitative manner and put together to comprise a risk taxonomy.

4.2 Definition and Classification of ERP System Implementation Failure

Success is relatively rare in ERP projects. The reported high rate of failure in ERP implementations appears implausible with the increasing popularity of ERP systems in organizations. One possible reason may be the difference in the perceived meaning of failure – or success – in the minds of people who appraise the performance of ERP projects. The definition of general IS/IT project success has been examined in a number of researches. Cost, time, and quality are widely mentioned as the conventional success criteria in the literature on project management (PMI, 2008;

Turner, 1993). Additional criteria such as profitability, meeting expectations, happiness of users, stakeholders' views, and even social dimensions are suggested as well (Agarwal & Rathod, 2006; Kendra & Taplin, 2004; Wateridge, 1998). Lyytinen and Hirschheim (1988) categorized IT project success by assessing the resulting system against the planned objectives, user expectations, project budget and time goals by obtaining consensus on the differences. In ERP projects, user satisfaction is often cited to be one of the important success measures (Chung, Skibniewski, & Kwak, 2009; DeLone & McLean, 1992; Wu & Wang, 2006). While the definition of success of ERP projects is somehow elusive, defining ERP project failure is supposed to be more straightforward, although there have been few such attempts. Failure may not simply be the opposite of success, as there is usually a transition in between, in other words, partial success. Thus, failure by its name implies that the project performance is lowered to a certain level that is no longer acceptable to both the organization that sponsors the project and the stakeholders that utilize the system. In this study, ERP project failure is defined as the failure to meet planned objectives in terms of cost, time, and the stated requirements or expectations of the users on the usefulness and ease of use of the ERP systems.

Agarwal and Rathod (2006) propose that software project success can be viewed through two perspectives: internal perspective linked to time, cost and scope (functionality and scope combined) that underline the value of project monitoring and controlling processes, and external perspective focused on customer satisfaction and project priorities. Wateridge (1998) suggests that IS/IT projects can be measured for success by two groups of people: project managers and users, each with different priorities and expectations. Adapted from these classification schemes, the failure of ERP projects can be classified into two different types: implementation process failure and system usage failure. Process failure mainly concerns the ERP project sponsor and manager(s), and means that the project is not completed within the required cost and time limits. System usage failure is defined from the perspective of senior management, users and other key stakeholders. It indicates that the usefulness and ease of use of the system, which are the foundation of technology adoption as stated in the Technology Acceptance Model (Davis, 1989), do not meet the explicit or implicit requirements or expectations; nor does the system deliver promised or expected benefits. It is a matter of functionality, system and information quality, and user friendliness. Ultimately, system usage failure hinders the organization from reaping the benefits of the ERP system.

Lyytinen & Hirschheim (1988) classify information system project failure into four types, one of which is process failure as described above. The other three are elaborated as follows:

- Correspondence failure, when the system design objectives are not met. It is generally believed that design objectives and requirements can be specified clearly in advance, and their achievements can be accurately measured (Lyytinen & Hirschheim, 1988; Yeo, 2002). Correspondence failure is viewed to be primarily technical in this research.

- Interaction failure, which refers to low satisfaction, negative attitudes, and/or less than normal extent or frequency of system use from the users. The level of end-user usage of the information system is suggested as a surrogate in information system performance measurement (DeLone & McLean, 1992; Yeo, 2002). In this study, interaction failure mainly concerns the ease of use of ERP system, and the effectiveness of end-user training in order to make full use of the new system.
- Expectation failure, when the information system does not meet stakeholders' – particularly project sponsors' or users' – expectations or requirements (Lyytinen & Hirschheim, 1988). Because information system failure is largely stakeholder-dependent (Lyytinen, 1988), stakeholders other than project sponsors and users, such as external consultants or non-user in the firm, are excluded as regard to expectation failure in the study; besides, users may include both internal users and customers/clients that are recipient of the output of the ERP system. Expectation failure is perceived as the difference between the actual and desired state of the system and its use, and thus represents the failure of the implemented system to deliver expected business benefits or values. Broadly speaking, expectation failure may involve the system's inability to meet design (technical) specifications (Yeo, 2002) and insufficient system use by users to realize the benefits. But as the latter two are covered by correspondence failure and interaction failure, respectively, expectation failure therefore are mainly associated with the elicitation, analysis, and specifications of the requirements or expectations of the hosting

organization, and the translation from these requirements or expectations to detailed business process redesign and technical specifications.

These three kinds of failures as a whole constitute the system usage failure addressed in the study. System usage is mostly overlapped with project quality from a standpoint of project management, but the former is a broader concept because it involves lots of pre-implementation and post-implementation activities. While the identified risk factors and their qualitative analysis findings can be used to deal with potential ERP implementation process failure, the proposed risk management approach using fault tree analysis is developed to analyze and manage the risk related to ERP system usage failure, which is one of the main focuses of the study.

4.3 Identification and Enumeration of Risk Factors

4.3.1 Risk Factors in General ERP Projects

Risk factors are often used interchangeably with critical success factors or, less frequently, uncertainty factors. Literally, a risk factor could be derived from the opposite of a corresponding critical success factor. These factors are mostly discussed in the context of generic ERP implementation projects or other software projects, and thus deemed applicable in ERP projects within project-based organizations.

A number of researches have attempted to systematically understand the risks of ERP projects (Aloini, et al., 2007; Camara, Kermad, & El Mhamedi, 2006; Huang, et al., 2004; O'Leary, 2000; Sumner, 2000a). An earlier study by Sumner (2000) examines risk factors in enterprise-wide/ERP projects through case studies with organizations implementing ERP systems. Aloini et al. (2007) presents a comprehensive review of the literature in risk management in ERP project introduction, in which 19 risk factors are listed based on the frequencies of their appearance in literature (shown in Table 4.1). Since the review is one of the latest and deemed comprehensive, it could be a reference point for the ERP risk enumeration in project-based firms. These risk factors are basically generic and high-level, each of them a summarization of a series of lower level risk elements that share certain common characteristics.

Table 4.1 Frequency of Risk Factors in Literature
(Aloini, et al., 2007)

Risk Factor	Frequency	Rate of Frequency in literature
Inadequate ERP selection	36	High
Poor project team skills	23	Medium
Low top management involvement	20	Medium
Ineffective communication system	18	Medium
Low key user involvement	19	Medium
Inadequate training and instruction	24	Medium
Complex architecture and high number of implementation modules	6	Low
Inadequate business process reengineering	22	Medium
Bad managerial conduction	24	Medium
Ineffective project management techniques	27	Medium
Inadequate change management	24	Medium

Inadequate legacy system management	11	Low
Ineffective consulting services experiences	10	Low
Poor leadership	10	Low
Inadequate IT system issues	18	Medium
Inadequate IT system maintainability	14	Low
Inadequate IT supplier stability and performances	8	Low
Ineffective strategic thinking and strategic planning	31	High
Inadequate financial management	1	Low

4.3.2 Risk Factors in ERP Implementation associated with Project Firms

There has been much less, if any, literature addressing ERP implementations risks specifically in project-based firms. The fact that almost every ERP implementation is organized as a project or a series of projects indicates that the risk factors identified in a different organizational environment, i.e. functional or matrix organizations which are more focused on repetitive business operations, are probable to occur in project-based firms. It also indicates that risky issues occurring in other types of projects or similar information technology projects in other contexts may also inflict ERP implementation, thus some other risk factors which are less frequently or seldom discussed in extant ERP literature may need to be taken into account as well.

The misfit between ERP system and organizations has been frequently cited as a cause to ERP failure (Hong & Kim, 2002; Morton & Hu, 2008; Sumner, 2000a), although it might also be a result of unsuccessful ERP implementation, as treated in the review by Aloini et al. (2007). Project-based firms tend to be more distributed in terms of physical dispersion and working practices, which pose extra challenge to standardize the business processes and integrate all the information across different functional departments and locations. Thus, organizational structure, IT infrastructure, readiness for new technology, sufficiency of resources and other organizational factors must be evaluated before and during ERP decision making, selection, and acquisition.

Successful fulfillment of project deliverables is critically dependent on the involvement and support of project stakeholders. Different stakeholders, external or internal, often have different or sometimes conflicting requirements and expectations. Ignoring their influence is likely to be detrimental to project success. The need to achieve project objectives that fully address stakeholder expectations throughout the project lifecycle has been stressed in previous studies (Bourne & Walker, 2005; Cleland & Ireland, 2006). As regard to ERP projects, stakeholders not only include those participants in the implementation processes, but also include the stakeholders in the projects carried out by the organization during and after the implementation. It is these projects that bring profits to the firm and make the ERP adoption worthwhile. Examples of such key stakeholders include major clients of the company, as well as suppliers, regulators, and collaborating partners. According to a study by Hartman & Ashrafi (2002), one of the major reasons for project failures in the IT industry is the lack of a clear definition or a common view of what success constitutes among key stakeholders, or in the presence of a clear vision, it is neither effectively communicated nor well understood. This leads to conflicts between departments, scope creep, inappropriate measurement, churn in developments, specification changes, delays, and other issues (Hartman & Ashrafi, 2002). Therefore, maintaining the relationships with stakeholders and involving key stakeholders including, but not limited to, in-house users into the implementation process should be considered as a success factor of ERP projects; in other words, inadequate stakeholder involvement and relationship management would be a critical risk factor.

An ERP system is designed with the aim to integrate all information in an organization across different functional departments, thus they can replace a vast variety of stand-alone applications such as accounting, sales, or materials planning applications. However, none of currently available ERP systems has the technological capability to meet all the information needs of project-based firms (or other types of firms), especially those relying on specialized technologies or software applications for their core business. For example, the functionalities of aircraft design and simulation applications for an aerospace & defense company, or Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) software for a project-centric mechanical contractor, or a Building Information Modeling (BIM) tool for an architectural design firm can hardly become available in ERP systems, even in the foreseeable future. Although ERP systems do not have to – and may not be able to - provide such kind of highly specialized capabilities, sharing information between ERP system and non-ERP system is often a must. Consider a simple case in a construction firm: after the engineering design of a skyscraper is completed using a

BIM application, materials information may need to be transferred to the material management module of ERP system in the firm for the purpose of budgeting and procurement, information about project activities may need to be shared with the ERP project management module for the purpose of project planning and controlling. There have been efforts by a few specialized software vendors to integrate their products with mainstream ERP systems. There also been some preliminary studies on the integration between ERP systems and third-party non-ERP systems, such as ERP and CAD/CAM (Soliman, Clegg, & Tantoush, 2001), ERP and BIM (Ghosh, Negahban, Tatari, & Skibniewski, 2010), etc. But in general, as reflected in the health care industry (Grimson, Grimson, & Hasselbring, 2000), the integration of information between ERP systems and non-ERP systems is very limited thus far, not to mention the information sharing with external organizations. This leads to repetitive data entry, loss of valuable information, and/or frequent occurrence of error. As such, the lack of information sharing and integration between ERP system and non-ERP system, although it should not be taken to evaluate the performance of the implemented ERP system itself, may have a negative impact on the business performance of the organization. Therefore, it is treated as a risk factor in this study, particularly with the wide reliance on non-ERP specialized software in project-based firms is considered.

Legal and regulatory risks are also an important factor in ERP projects (Grossman & Walsh, 2004; Saharia, Koch, & Tucker, 2008). On one hand, companies of all kinds, especially public-traded companies, are subject to laws and governmental regulations on taxation, internal control, financial reporting and disclosure, etc. An example is Sarbanes-Oxley (SOX) compliance for public companies (Emerson, Karim, & Rutledge, 2009). On the other hand, contracts between a company and its ERP vendors and consultants have direct influence on the outcome of ERP implementation. As project-based firms are more inclined to enter binding legal agreements when executing their projects, meeting the obligations to their clients, suppliers, and other partners is very important and should be vigilantly dealt with during ERP implementation; legal and regulatory considerations should also be reflected in ERP system customization and configuration.

Cultural and environmental issues are another concern of ERP implementation (Avison & Malaurent, 2007; Boersma & Kingma, 2005; Krumbholz, Galliers, Coulianos, & Maiden, 2000; Plant & Willcocks, 2007; Waarts & Van Everdingen, 2005). Because project-based firms typically operate as a collection of many project teams scattering in different geographic locations or even across different countries, they are notoriously known for their vast diversity in project teams' composition, culture, customs, and other contextual factors. Also, the off-the-shelf ERP packages in the home country of the vendor may not suit the culture and customs in another nation.

As a result of the physical dispersion of project teams, ERP systems in project-based firms have to be implemented in a multi-site manner, which presents special concerns (Umble, Haft, & Umble, 2003). The conflicts between centralized control and individual site autonomy and between corporate standardization and localized optimization increase the complexity of ERP implementation and entail difficult trade-offs. The selection of cutover strategy is also a hard decision to make. The organization may choose an approach where the implementation takes place simultaneously in all facilities, or a phased approach by module, by product line, or by project site with a pilot implementation at one facility (Umble, et al., 2003). Further, since project-based firms are characterized with high mobility, moving from one site to another with reshuffled staff in the team as a project is completed, the temporariness of project team composition and site location makes it very difficult to carry out ERP implementation and manage the IT asset.

4.3.3 ERP Risk Taxonomy in Project-based Organizations

The risks of ERP implementation could be loosely categorized into six dimensions: organizational, managerial, operational, technological, human-related, and miscellaneous risks. The organizational dimension refers to the factors in the organizational environment that may impact the success of ERP implementation. The management and leadership dimension mainly focuses on the management of project teams and system implementation activities. The operational dimension includes those risk factors related to either ERP implementation processes or post-implementation operational performances. The technological dimension, by its name, covers risky issues in various technical aspects of ERP system. The human dimension refers to the user involvement, project team skills, and relationships amongst project team members, different functional departments, or between the project team and external stakeholders.

Based on the above analysis and also adopted from previous studies and reviews of literature (Aloini, et al., 2007; Huang, et al., 2004; Keil, et al., 1998; Sumner, 2000a), a risk taxonomy for ERP implementation in project-based firms is developed as shown in Table 4.2. It is noteworthy that some risk factors can be classified into different dimensions. For example, low top management support and involvement, and insufficient training and instruction are human-related risk factors as well. While legacy system management is both an organizational and a technological factor, it only falls into the technological dimension here because the nontechnical aspect of the legacy system can be addressed by reengineering business processes.

The occurrence of those risk factors during ERP implementation generates negative impacts on the outcome of the project or the post-implementation performances of the organization, which may lead to or become a part of ERP project failure (see Table 4.2). Figure 4.1 illustrated the effects of various risk factors on ERP system implementation, which is adapted from Aloini, *et al.* (2007).

Table 4.2 List of ERP Risk

Dimension of Risks	Risk ID	Risk Factor
Organizational	R1	Ineffective strategic thinking and strategic planning
	R2	Organizational misfit
	R3	Inadequate ERP selection
	R4*	Low top management support & involvement and lack of a project champion
	R5	Cultural and environmental issues
Managerial	R6	Ineffective project management techniques and practices
	R7	Bad managerial conduct
	R8	Inadequate change management
	R9	Poor leadership
	R10	Inadequate financial management
Operational	R11	Inadequate business process reengineering
	R12*	Inadequate training and instruction
	R13	Ineffective communication system
	R14	Ineffective consulting services
	R15	Inadequate IT supplier stability and performance
Technological	R16	Technical complexity
	R17	Inadequate IT system capabilities
	R18	Inadequate IT system maintainability and upgradability
	R19	Inadequate legacy system management
	R20	Lack of information sharing or integration with non-ERP systems
Human	R21	Low key user involvement
	R22	Poor project team composition and skill mix
	R23	Inadequate stakeholder relationship management
Miscellaneous	R24	Legal and regulatory risks
	R25	Multi-site issues

(* the risk factor may be categorized into the human risk dimension as well.)

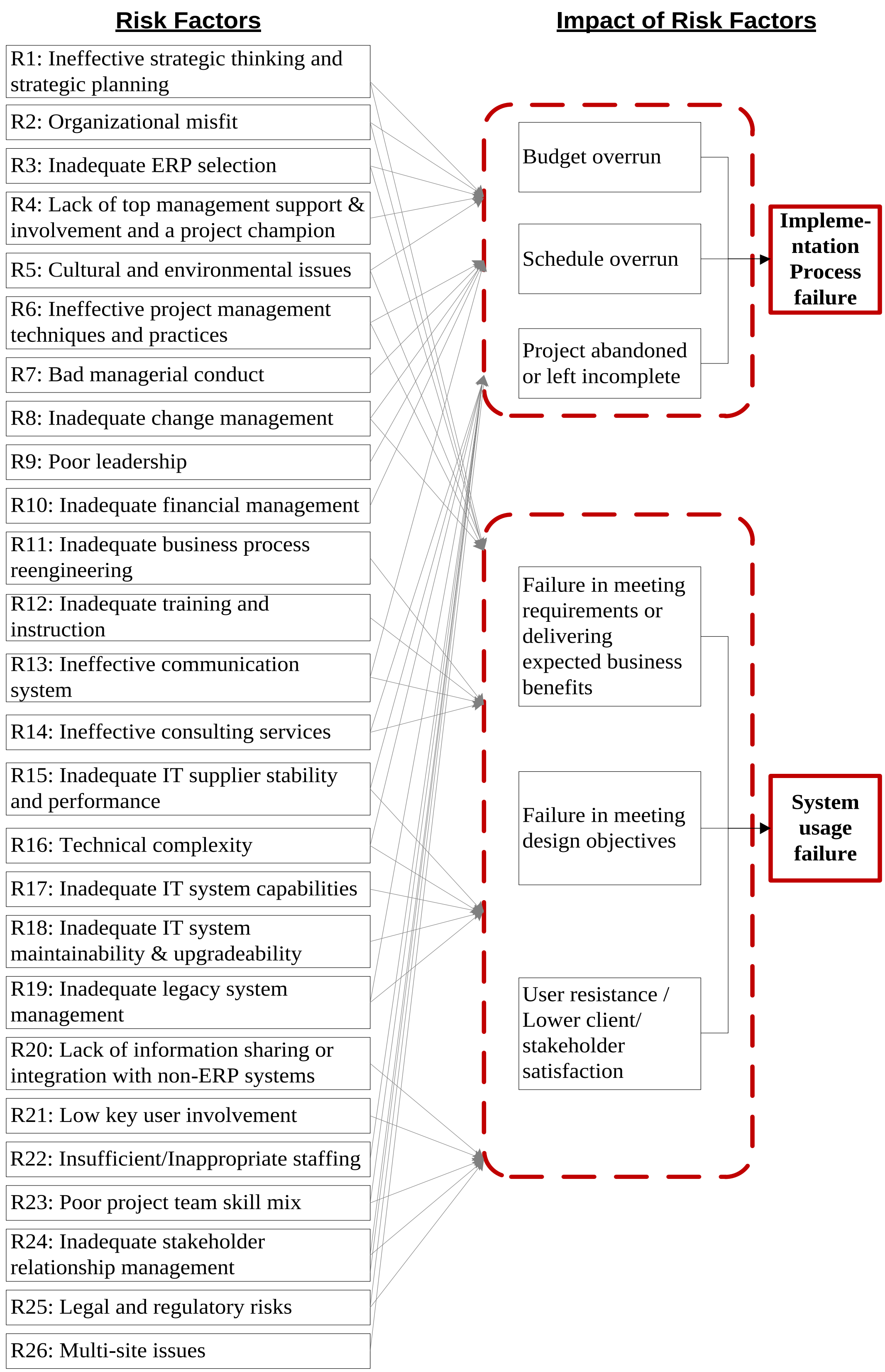


Figure 4.1 Risk Factors and Their Impacts

4.4 Qualitative Analysis of Risk Factors

4.4.1 Description of Risk Factors

The ERP risk factors identified above have mostly been mentioned and described in existing literature. The following sub-sections briefly describe each risk factor and its major source of references, except those factors already discussed in section 4.3.2.

4.4.1.1 Ineffective strategic thinking and planning

ERP implementation is very different from and far more complex than typical software installation. Considering the capital investment and resources required for ERP adoption and the impact its success – or failure – may have on the organization, it is too risky to simply treat it as normal software licensing and installation. The lack of strategic directions and planning has been repetitively cited as a critical issue in current IT investment practices (Lubbe & Remenyi, 1999; Nutt, 1999; Tallon, Kraemer, & Gurbaxani, 2000). Strategic thinking and planning require articulation of a business vision to the organization, alignment ERP implementation with corporate goals and business strategies, and definition of clear goals and objectives.

4.4.1.2 Inadequate ERP selection

Thorough evaluation and careful selection of an ERP vendor, ERP packages, modules, and services is the premise of successful ERP deployment. The better the ERP selection process, the greater the chance of success (Travis, 1999). If the wrong choices are made, and these choices have to be made very early on, the company faces either a misfit between ERP package and business processes and strategy, or a need for major modifications and customizations, which are time-consuming, costly and risky (Janson & Subramanian, 1996).

4.4.1.3 Low top management support & involvement and lack of a project champion

Sustained top management support is one of the most cited critical success factors in ERP implementation (Akkermans & Van Helden, 2002; Aloini, et al., 2007; Gargeya & Brady, 2005; Plant & Willcocks, 2007; Soja, 2006; Somers & Nelson, 2004; Umble, et al., 2003). In the early stage of ERP project, no single factor is as predictive of its success as the commitment of top management (Jarvenpaa & Ives, 1991; Somers & Nelson, 2004). A number of key activities, including establishing strategic directions, setting the goals, allocating necessary resources, and mediating among different interest groups etc., all are dependent on the support and participation of senior management. The need of a project champion is also frequently advocated (Finney & Corbett, 2007; Ngai, Law, & Wat, 2008; Somers & Nelson, 2004). A project champion, also called executive sponsor, is an individual who has the authority and influence to advocate the project and obtain valuable resources within or outside an organization for the completion of the project. The person usually comes from the rank of senior management, and performs the crucial functions of transformational leadership, facilitation and marketing the ERP project to users (Beath, 1991).

4.4.1.4 Ineffective project management techniques and practices

Project management refers to the management of the ERP implementation processes, from project planning, assignment of responsibilities to various players, scheduling of project tasks, definition of milestones and critical paths, to monitoring and controlling activities, and closing the project (Nah, Lau, & Kuang, 2001). Effectively utilizing various project management methodologies and tools and adopting good practices such as those recommended by PMI are essential for ERP project success, as the myriad of technical, organizational and human issues makes many ERP project huge and inherently complex. Besides project planning and controlling, a particular challenge is to properly manage the scope of ERP implementation to avoid scope creep caused by major customization (Somers & Nelson, 2001).

4.4.1.5 Bad managerial conduct

Effective project implementation requires a well-articulated business vision that establishes the goals and the business model behind the project (Holland & Light, 1999). The lack of clearly defined goals and objectives or the inclination to shift them now and again brings confusion and disruption the ERP implementation. Also, managing user and stakeholder expectations is a part of managerial challenge. In addition, while dedicated resources is indispensable for ERP success, there is a tendency to escalate projects because of social norms (e.g. to save face; for public companies, to avoid the negative impact of project failure on stock prices) and to keep pouring resources into a failing project (Keil & Montealegre, 2000; Sumner, 2000a; Willcocks & Margetts, 1994). Such kind of social commitments may augment risks and lead to more severe consequences should the project fail.

4.4.1.6 Inadequate change management

The adoption of ERP system is normally accompanied with changes in the way that an organization operates and its employees conduct their work. It also brings changes in corporate culture and the relationship of employees. Moreover, in light of the complexity of ERP system, numerous changes such as changing requirements, must be dealt with during the process of implementation. Therefore, effective change management is important for ERP success. Underestimating the effort involved in change management may result in project failure, especially in early stages (Aloini, et al., 2007).

4.4.1.7 Poor leadership

Strong and committed leadership, and under the leadership, open and honest communication, and a motivated and empowered implementation team are among the social enablers of successful ERP adoption (Sarker & Lee, 2003).

4.4.1.8 Inadequate financial management

ERP implementation is very expensive. Significant cost overrun may nullify the benefits in years that can be realized by the adoption of ERP and even cause the organization to go bankruptcy. A famous case is that FoxMeyer filed for Chapter 11 bankruptcy protection after spending millions of dollars in ERP implementation (I. Chen, 2001).

4.4.1.9 Inadequate business process reengineering

ERP packages are not always compatible with an organization's needs and business processes immediately off the shelf. Thus either software modification or business process reengineering is necessary, or both. As software modification and customization are expensive and plagued with uncertainties, and ERP packages are normally designed with generally accepted good practices and optimized processes, restructuring the business processes is regarded by some as a favorable option (Jarrar, Al-Mudimigh, & Zairi, 2000; Scheer & Habermann, 2000). Therefore, neglecting or downplaying business process reengineering is prone to risks (Aloini, et al., 2007; Finney & Corbett, 2007; Jarrar, et al., 2000).

4.4.1.10 Inadequate training and instruction

The role and importance of training and education to facilitate ERP or other software implementation have been well documented (Bronsema & Keen, 1985; Nelson & Cheney, 1987; Yetton, 2007). Lack of end-user training and understanding of changes in business processes is posited as responsible for many ERP implementation problems (Aloini, et al., 2007). As the adoption of ERP system bring changes in organizational structure and business process, the roles of some employees may need to be redesigned to reap the benefits of the new system.

4.4.1.11 Ineffective communication system

Clear and effective communication at all levels of an organization is necessary before and during the implementation of ERP (Parr & Shanks, 2000). Communication among various functions/levels (Mandal & Gunasekaran, 2003) and specifically between business and IT personnel (Grant, 2003) is especially important. A communication plan is required to ensure that open communication occurs within the entire organization (Finney & Corbett, 2007; V. Kumar, Maheshwari, & Kumar, 2002).

4.4.1.12 Ineffective consulting services

The use of consultants, usually external consultants from professional service firms, is common in ERP projects and regarded as a success factor (Aloini, et al., 2007; Somers & Nelson, 2001). Consultants are supposed to have experience in specific industries and comprehensive knowledge about certain ERP modules. Consultants may be involved in various stages of the implementation: performing requirements analysis, recommending a suitable solution, and participating in the implementation (Thong, Yap, & Raman, 1994). As consultants play a major role in diminishing ERP risks, choosing unqualified consultants or using their services ineffectively should be avoided.

4.4.1.13 Inadequate IT supplier stability and performance

The success of ERP implementation requires the support and involvement of ERP vendor(s). Also, post-implementation ERP use may necessitate further investment in upgrades and new modules with additional functionality. So the stability and performance of ERP vendor is a risk factor (Aloini, et al., 2007; Somers & Nelson, 2001).

4.4.1.14 Technical complexity

The number of modules to be implemented, the complexity of system architecture, and the extent of software customization and customization influence the technical complexity of ERP projects. As the number of modules increase, the project complexity is increased accordingly (Francalanci, 2001). System architectural consideration is important, particularly in the early stages. Without adequate system planning and architecture design, personalization and adaptation may cause problems (Markus, Axline, Petrie, & Tanis, 2000). Indeed, minimal customization has been frequently cited as a critical success factor for ERP success (Finney & Corbett, 2007; Nah, et al., 2001; Parr & Shanks, 2000; Somers & Nelson, 2001). Thus the scope of software modification and customization, if they cannot be avoided, should be carefully managed and controlled.

4.4.1.15 Inadequate IT system capabilities

Technical software capabilities must be studied before implementation matters and their impact on business processes assessed; questions such as these are pivotal for ERP success (Aloini, et al., 2007). They should also be routinely evaluated during the implementation process, especially in software customization and system testing. According to Aloini, et al. (2007), essential technical aspects are: all necessary functionality, user friendliness, portability, scalability, modularity, versioning management, flexibility, security, presence of a complete guide, a procedure manual to help users, and data accuracy.

4.4.1.16 Inadequate IT system maintainability and upgradeability

ERP maintenance activities are very important for continual use and benefit realization; they require continual capital spending. ERP upgrade may be necessary to introduce additional functionalities and keep pace with the development of technology; it, however, may turn out to be very expensive. Thus the maintainability and upgradeability of the system must be taken into account during ERP implementation.

4.4.1.17 Inadequate legacy system management

Legacy systems encapsulate the existing business processes, organization structure, culture, and information technology (Bennett, 1995; Holland & Light, 1999). Because the business, organizational and cultural aspects of legacy systems are mostly covered in other risk factors listed above, the risk factor related to legacy system management mainly copes with technical issues, especially the conversion and migration of important data, the treatment of legacy information system and transition strategies. Inadequate legacy system management might lead to the loss of valuable data and disruption to the business operations of the company.

4.4.1.18 Low key user involvement

Key user involvement is essential to gain users' confidence in the system, manage their expectations and extract users' requirements. While user training and instruction take place in the later stages of ERP implementation, key user involvement should be conducted earlier in the process.

4.4.1.19 Poor project team composition and skill mix

Sufficient and appropriate staffing for the project team is indispensable for ERP implementation success. It has been repeatedly mentioned that there is a critical need to put in place a solid, core implementation team that is comprised of the organization's best and brightest individuals (Finney & Corbett, 2007). The project team should also have a suitable and adequate combination of skills and experiences that is required by the implementation.

4.4.2 Further Classification of Risk Factors

The risk factors identified above can be further classified into sub-factors, or illustrated with a number of issues or instances. As such, a risk hierarchy is demonstrated in the following table, assuming a checklist approach. While the risk hierarchy aims to be as exhaustive as possible, it is noteworthy that some additional issues or instances may not be included, and overlaps might exist between different sub-factors or problems. It is also probable that different risk factors and sub-factors may be correlated to each other.

Table 4.3 Hierarchy of ERP Risk Factors

Dimension of Risks	Risk Factor	Sub-factors, Problems, or Instances
Organizational	Ineffective strategic thinking and strategic planning	• Lack of a clear vision (Davenport, 1998) • Lack of IS strategy (Lubbe & Remenyi, 1999; Nutt, 1999; Tallon, et al., 2000) • Absence of strategic analysis and planning • Ambiguous business needs (Yeo, 2002) • Misalignment between ERP and business strategies (Grant, 2003; Papp, 1999) • Little justification of ERP investment (Wang, 2006)
	Organizational misfit	• Low fit with organizational structure (Morton & Hu, 2008) • Low fit with process, data and user (Hong & Kim, 2002) • Lack of adequate technology infrastructure (Ewusi-Mensah, 1997; Sumner, 2000b) • Readiness for new technology (Keil, et al., 1998) • Insufficiency of resources (Barki, Rivard, & Talbot, 1993) • Extent of changes (Barki, et al., 1993) • Resistance to changes
	Inadequate ERP selection	• Inadequate evaluation and comparison of ERP packages and modules: use of proven methodologies, rigorousness of

		evaluation, involvement of key users and stakeholders • Inadequate evaluation and comparison of ERP vendor
	Low top management support & involvement and lack of a project champion	• Low top management support and commitment • Low top management participation • Low visibility of top management commitment to employees • Inconsistence of top management support • Top management permanently delegates its responsibilities to technical experts (Ewusi-Mensah & Przasnyski, 1991) • Lack of a steering committee (Somers & Nelson, 2001) • Lack of a project champion (Ngai, et al., 2008; Somers & Nelson, 2001) • Inadequate authority, influence, or skills of the project champion
	Cultural and environmental issues	• Differentiation of culture and customs • Language barriers • Lack of ownership (Al-Mashari & Zairi, 2000) • Fear of massive manpower reduction (Al-Mashari & Zairi, 2000) • Lack of IT readiness • Unstable organizational environment (Wallace, Keil, & Rai, 2004a) • Corporate politics with negative impact on project (Wallace, et al., 2004a)

Managerial	Ineffective project management techniques and practices	• Lack of project success criteria • Inadequate use of proven project management methodologies • Poor project planning • Poor project processes design and management • Poor estimation of required resources • Inadequate estimation of project schedules • Project milestones not clearly defined • "Preemption" of project by higher priority project: management unable to resolve conflicting schedule demands (Schmidt, Lyytinen, Keil, & Cule, 2001) • Unclear scope • Scope creep • Poor or nonexistent control: no sign-offs, no project tracking methodology, unaware of overall project status, project progress not monitored closely enough • Lack of focused and consistent performance measures (Umble, et al., 2003) • Inadequate project risk management
	Bad managerial conduct	• Lack of clearly defined and realistic goals and objectives • Goals and objectives not agreed upon • Frequently changing goals and objectives • Failure to manage user and stakeholder expectations

		• Social commitment (Keil & Montealegre, 2000; Sumner, 2000a; Willcocks & Margetts, 1994)
	Inadequate change management	• Underestimate the efforts involved in change management (Appleton, 1997; Somers & Nelson, 2001) • Poor design of organizational structure change • Lack of proper mechanism to manage changes • Ineffective use of change tactics: evolutionary vs. revolutionary
	Poor leadership	• Frequent turnover of managers • Lack of motivation • Lack of empowerment • Inadequacy of status, authority and influence of leaders • Lack of suitable skill sets and experiences • Technical mindset (Al-Mashari & Zairi, 2000)
	Inadequate financial management	• Poor budgeting and estimation • Ineffective cost control • Unavailability or instability of funding • Ignoring or underestimating hidden cost
Operational	Inadequate business process reengineering	• Large number of organizational units involved (Schmidt, et al., 2001) • Fragmented business processes • Failure to streamline key business processes

		• Failure to use proven business process reengineering methodologies
	Inadequate training and instruction	• Lack of a training plan • Insufficient training and re-skilling • Inadequate job role redesign
	Ineffective communication system	• Lack of communication planning • Lack of implementation promotion to all employees in the organizations (Soja, 2006) • Difficulty in inter-department/cross-functional communications • Ineffective use of appropriate communication media • Lack of face-to-face communications • Ineffective document control and reporting
	Ineffective consulting services	• Not using consulting services • Inadequate selection of consultants • Lack of appropriate skills and experiences • Lack of specific industry knowledge • Conflict of interests if consultants have close financial ties with vendors (Piturro, 1999) • Consultants assuming too much control and responsibility (Somers & Nelson, 2001)
	Inadequate IT supplier stability and	• Vendor overpromise

	performance	• Lack of partnership with vendor(s) (Willcocks & Sykes, 2000) • Failure to use vendor's development tools (Somers & Nelson, 2001) • Unstable vendor support • Low quality of vendor services
Technological	Technical complexity	• Large number of implementation modules • Large number of links to non-ERP systems • Complex system architecture • Large scope of software modification and customization
	Inadequate IT system capabilities	• Poor architecture planning (Feeny & Willcocks, 1998; Somers & Nelson, 2001) • Incorrect or unclear system requirements (Wallace, Keil, & Rai, 2004b) • Conflicting system requirements (Wallace, et al., 2004b) • System requirements not adequately identified • Continually changing system requirements • Misunderstood requirements • Difficulty in defining the inputs and outputs of the system (Wallace, et al., 2004b) • Failure to adhere to standardized specifications • Lack of integration among modules

		• Poor software development • Inadequate system testing and troubleshooting • Poor data management (Ngai, et al., 2008) • Issues with data accuracy (Umble, et al., 2003; Zhang, Lee, Zhang, & Banerjee, 2003)
	Inadequate IT system maintainability and upgradability	• Unsatisfactory of maintainability: high cost, complexity, etc. • Complexity and cost of upgradability
	Inadequate legacy system management	• Attempting to build bridge to legacy systems (Sumner, 2000a) • Inadequate data analysis and conversion • Loss of data integrity • Lack of effective transition strategy • Ineffective transition from legacy systems to new ERP system
	Lack of information sharing or integration with non-ERP systems	• Failure to incorporate the consideration of integration with non-ERP system into system design and requirement analysis • Lack of common data standard or effective data conversion tools
Human	Low key user involvement	• Lack of cooperation from users • Lack of motivation system rewarding user involvement (Soja, 2006) • Users resistant to change • Users not committed to the project • Lack of user involvement in business processes reengineering

		• Lack of user participation in requirements analysis • Conflict between users • Users with negative attitudes toward the project • Lack of full-time commitment to project activities
	Poor project team composition and skill mix	• Frequent turnover within the project team • Inappropriate staffing • Personnel shortfall • Excessive use of outside consultants (Schmidt, et al., 2001) • Lack of application knowledge (Ewusi-Mensah, 1997) • Lack of technical expertise (Ewusi-Mensah, 1997) • Poor teamwork
	Inadequate stakeholder relationship management	• Frequent conflicts between project team members • Lack of interdepartmental cooperation • Conflicts among different functional departments • Mistrust • Information hiding • Political risks • Lack of middle or lower level management support • Lack of control over consultants, vendors, and subcontractors (Schmidt, et al., 2001) • Failure to consider the requirements and expectations of external

<table>
<tr><td></td><td></td><td>stakeholder, particularly clients/customers
• Disruption to the ongoing projects or business relationships with external stakeholders during implementation</td></tr>
<tr><td rowspan="2">Miscellaneous</td><td>Legal and regulatory risks</td><td>• Poor contract specification
• Ineffective contract administration
• Arbitration and litigation
• Failure to consider regulatory requirements in requirements analysis
• Failure to consider legal implication in business process reengineering</td></tr>
<tr><td>Multi-site issues</td><td>• Organizational diversity (Gargeya & Brady, 2005)
• Local project team autonomy
• Different legacy practices across project sites or countries (Olson, Chae, & Sheu, 2005)
• Variance of user IT experiences (Olson, et al., 2005)
• Varying regulations (Olson, et al., 2005)
• Location-related functional requirements and interfaces
• Conflicts between process standardization and local optimization
• Differentiation of culture and customs
• Temporariness of project teams and sites
• Travel among different sites</td></tr>
</table>

4.5 Chapter Summary

This chapter provides a comprehensive identification and analysis of risks in ERP system implementation. While most of the risk factors are identified in generic ERP projects, they are considered to apply to project-based firms as well. Also, certain factors, such as organizational misfit, multi-site issues, stakeholder involvement and relationship management, and information integration with non-ERP systems especially technical software applications, are important to project-based firms. These factors comprise a taxonomy of ERP system implementation risk factors in project-based firms. Assuming a checklist approach, a variety of sub-factors, problems and/or examples of issues are listed. Overall, identifying and understanding various risk factors that might occur during the ERP implementation process and impact project and business performance is the premise of effective risk response and management.

5 ERP Risk Modeling and Assessment with Fault Tree Analysis

5.1 Introduction

While there are a large number of publications addressing risk management in ERP system implementation projects, most of them are focused on identifying and qualitatively analyzing the risk factors or critical success factors for ERP projects as a whole. However, few inquire into ERP risks through the failure of system components, and quantitative risk analysis has been rarely documented in extant ERP literature, although the relative importance of each factor has been studied now and again. Indeed, ERP system implementation project is so convoluted and subject to so many dependencies and uncertainties that it is very difficult to establish a quantifiable relationship between each risk factor and the ultimate project outcome, not to mention that most of the risk factors themselves are elusive and hard to measure. In this chapter, an approach is proposed and developed using fault tree analysis to analyze ERP implementation failures both qualitatively and quantitatively. Although fault tree analysis has been widely used as an effective tool for reliability analysis and safety engineering, its application in information system risk assessment has been seldom explored. The developed approach aims to help better understand how ERP system implementation fails and find out what risk factors are the root causes of the failure, and therefore, provides a tool for effective risk response and mitigation during the ERP implementation process.

5.2 Theoretical Foundation

5.2.1 A System Perspective on ERP

Both ERP system and ERP implementation projects can be viewed and analyzed with a system perspective. A system is defined as a set of interacting discrete components having well-defined (although possibly poorly understood) behavior or purpose (Magee & de Weck, 2004). In between one may define subsystems. Like ERP system implementation, systems are complex and dynamic in nature. The results produced by the system are not obtainable by the components alone. The components, also called elements or parts, are all things required to produce system-level results, which can include people, hardware, software, facilities, policies, and documents (INCOSE, 2010). In the system of ERP implementation project, components are the activities and tasks undertaken during the project life cycle. In the implemented ERP systems, components are the integral software modules, applications, databases, hardware and other IT devices, or any parts of them, acquired and deployed by the organization as a result of the implementation.

Intuitively, the failure of a system is caused either by the failure of one or more components, or by the failure of interconnections and interactions among components or between components and external environment. In fact, the effect imposed by various risk factors on the whole ERP project is a sum of their effects on different components of the system. As such, to figure out how components fail due to various risk factors and how the failure of components leads to system failure provides a foundation to understand the relationships between risk factors and the ERP project and the implemented system (Figure 5.2). This is different from the traditional approach that analyzes the impact of risk factors on the system as a whole, which are found in the majority of studies about ERP system implementation risk management (Figure 5.1).

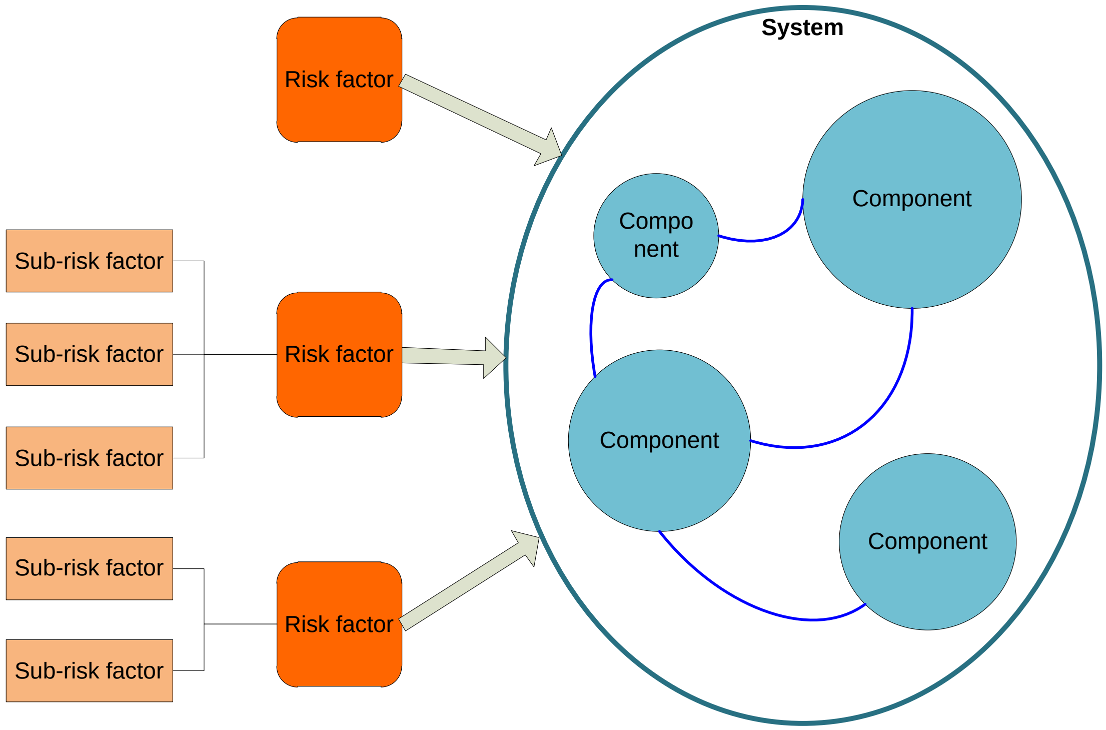


Figure 5.1 Impact of Risks on the Entire System

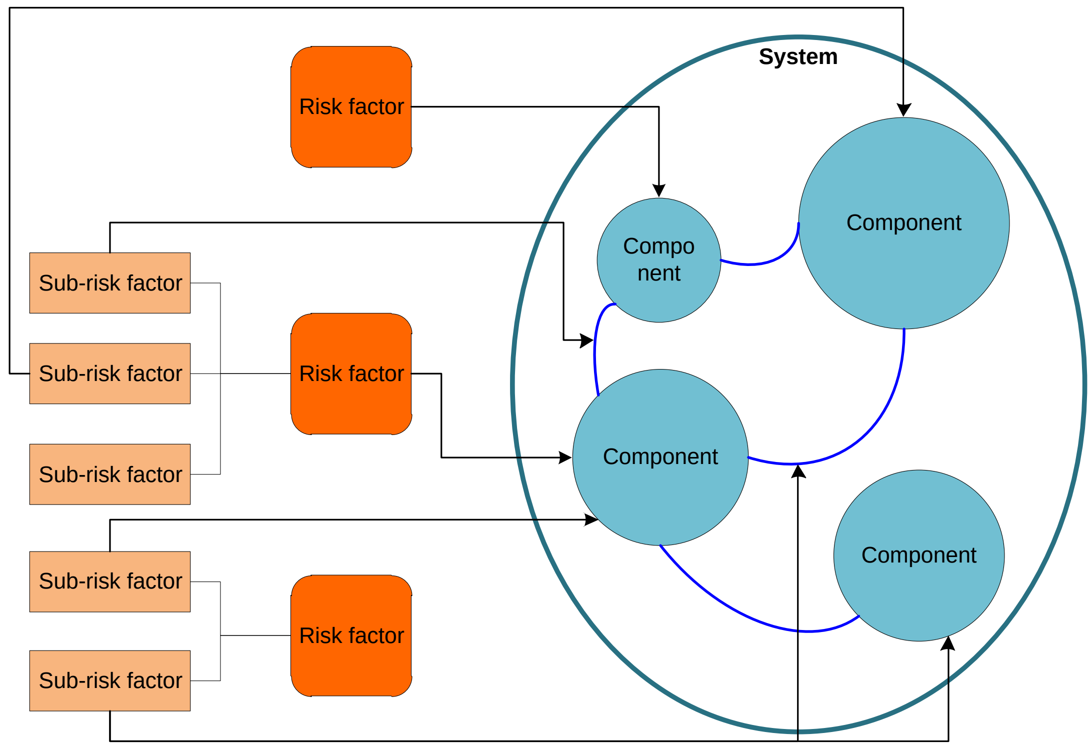


Figure 5.2 Impact of Risks on System Components

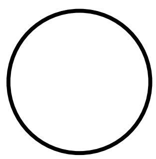
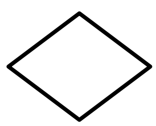
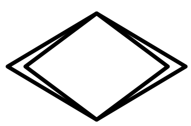
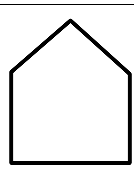
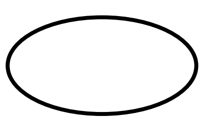
5.2.2 Fundamentals of Fault Tree Analysis

Fault tree analysis (FTA), is a formal deductive procedure for determining combinations of component failures and human errors that could result in the occurrence of specified undesired events or states at the system level (Geymayr & Ebecken, 1995). It is a logical and diagrammatic method to depict the relationships between component states and the system state (Tanaka, Fan, Lai, & Toguchi, 1983). This method can be employed to analyze the vast majority of industrial system reliability and safety problems (Geymayr & Ebecken, 1995). With the ability to model interactions between components or events, it can also be used as an effective risk estimation tool. Indeed, fault tree analysis is one of the most important logic and probabilistic techniques used in probabilistic risk assessment and system reliability assessment today (Stamatelatos et al., 2002).

Based on the idea that a problem may be traced backwards to its root causes, fault tree analysis uses "backward logic" (Bedford & Cooke, 2001). In other words, given a particular failure of a system, which is called the top event, one can seek the component failures or faults that contribute to the system failure. When the top event is the failure of a system, other events would be the failures, or faults, of the components in different levels of the system. The events are termed "faults" if they are initiated by other events and "failures" if they are basic initiating events (Stamatelatos, et al., 2002). Those events in the bottom of the constructed fault tree diagrams are called basic events; they are either risk events that cannot be described further at a finer level of detail, or the states of those elements that cannot be divided into small independent parts. All of the other events in between are intermediate events. The occurrence of the top event is described deterministically in terms of the occurrence or non-occurrence of other events (Bedford & Cooke, 2001). Different kinds of events are depicted as different graphical symbols shown in the Table 5.1.

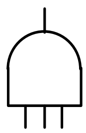
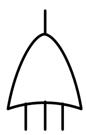
Fault trees are depicted as a Boolean expression to demonstrate the combination of identified basic events sufficient to cause the undesired top event. It is assumed that the top event and all basic events are binary, that is, true of false (Bedford & Cooke, 2001). Each level of the tree lists the lower level events that are necessary to cause the event in the above level. If the individual probabilities for all basic events are known, the probability of the top event can be calculated accordingly. However, it is often difficult or infeasible to know the exact probabilities of all basic events.

Table 5.1 Graphical Symbols and Description of Events

Graphical Symbol	Shape	Name	Description
	Rectangle	Top Event or Intermediate Event	Failure in the top or intermediate levels that can be further developed
	Circle	Basic Event, aka Elementary Basic Event	Failure at the lowest level with no further development necessary
	Rhombus	Undeveloped Event aka Non-elementary Basic Event	An event that is not developed further because there is no information available, or because it is not necessary
	Double Rhombus	Underdeveloped Event	An event that is considered to be basic in this step and will be analyzed later
	House	External Event aka House Event	An event that is normally expected to occur
	Ellipse	Conditioning Event	Specific conditions or restrictions that apply to a given logic gate

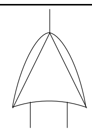
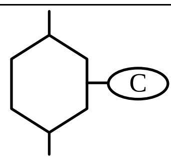
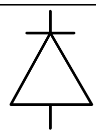
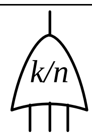
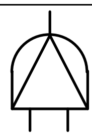
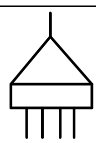
The fault tree uses logic gate (or named operator) as a basic symbol to depict and interrelate the relationships among events. Each gate has inputs and an output; the gate inputs are the lower events and the output is a higher fault event. Because backward logic is used, the tree is developed from higher level faults to the more basic faults or failures when a fault tree is drawn; that is, from outputs to inputs. The two basic types of gates are OR-gate and AND-gate, described in Table 5.2 (Limnios, 2007). Other types of gates related to this study will be introduced later.

Table 5.2 Fundamental Logic Gates

Graphical Symbol	Name	Description
	AND	The output event occurs if all of the input events occur
	OR	The output event occurs if at least one of the input event occurs

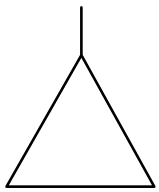
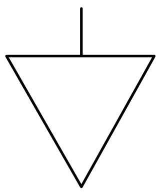
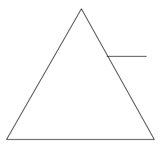
Special types of gates, which may be called dynamic gates, are developed in addition to the fundamental gates. Traditional static fault tree analysis using the AND and OR gates only is not able to capture the more complicated and dynamic relationships between the events. The dynamic behaviors of system failure mechanism may be characterized by sequence-dependent events, spares and dynamic redundancy management, priorities of failure events, and so on (Rao et al., 2009). The introduction of dynamic gates to the fault tree enhances the modeling power of fault trees and helps depicting and specifying complex system failure behaviors that depend on the sequence as well as combination of component failures. Table 5.3 illustrates a number of special logic gates (Limnios, 2007; Stamatelatos, et al., 2002). A few other types of dynamic gates are also introduced in Rao et al. (2009).

Table 5.3 Special Logic Gates

Graphical Symbol	Name	Description
	Exclusive OR	The output event occurs if and only if exactly one of the input events occur
	IF, aka Inhibit	The output event occurs if and only if the single input event occurs in the presence of a conditioning event
	No	The output event occurs when the input event does not occur
	Voting, aka k-out-of-n combination	The output event occurs if and only if at least k of the n input events occur ($1 \leq k \leq n$)
	Priority AND, aka sequential IF	The output event occurs if and only if all the input events occur in a given order
	Matrix	The output event occurs for certain combination of input events

There are also transfer triangle symbols, signifying a transfer of a fault tree branch to another location within the fault tree, see Table 5.4 (Limnios, 2007).

Table 5.4 Graphical Symbols and Description of Transfer Triangles

Graphical Symbol	Name	Description
	Identical transfer in	An identical part of the tree is developed further elsewhere. The place where the development takes place is indicated with a Transfer out symbol
	Similar transfer in	A similar part of the tree is developed further elsewhere
	Transfer out	Marks an identical or similar part of tree that is not otherwise resumed

5.2.3 ERP System Usage Failure vs. Process Failure

The risk management approach with fault tree analysis is proposed to analyze and manage the risks related to ERP system usage failure. As defined in Chapter 4, there other type of ERP implementation project failure is implementation process failure, which occurs in the forms of either cost or schedule overrun, or both. Based on empirical evidence, the importance of process success (cost and schedule) and system usage success of ERP implementation projects appears to be different in many hosting organizations. According to the results of two recent surveys that are illustrated in Figure 5.3 and 5.4 (Panorama, 2008, 2010), while the majority of ERP projects should have been judged failure in terms of their cost and schedule performance, a much smaller portion of executives and employees were unsatisfied (either very unsatisfied or fairly unsatisfied) about their ERP systems. Moreover, as the ERP implementation cost and schedule exceeding was reduced, possibly because of the efforts to cut IT budget and limit implementation scope in response to the weak economic conditions, the dissatisfaction rate increased considerably, from 19.0% to 35.5% (Panorama, 2010). An earlier study based on a survey of 117 firms in 17 counties finds that 34% of the organizations were very satisfied with the ERP systems they implemented, and 54% were somewhat satisfied (McNurlin, 2001). As a result, it can be inferred that, when project cost and schedule are within acceptable range, avoiding ERP system usage failure and ensuring the performance and benefit realization of ERP system in use is of more importance to the hosting organizations, and thus should be put more efforts in the ERP project risk management processes.

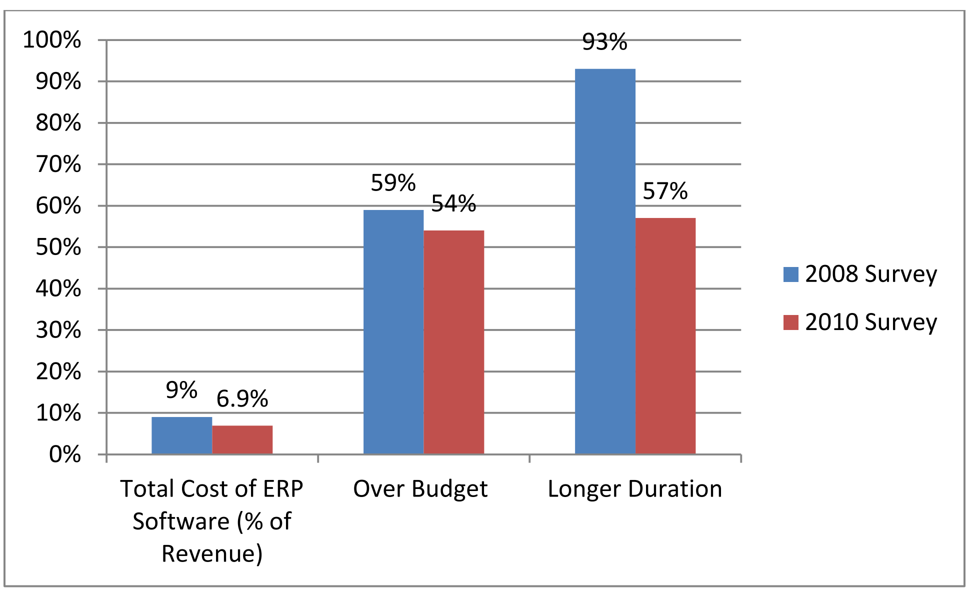


Figure 5.3 Percentage of ERP Implementation Process Failure

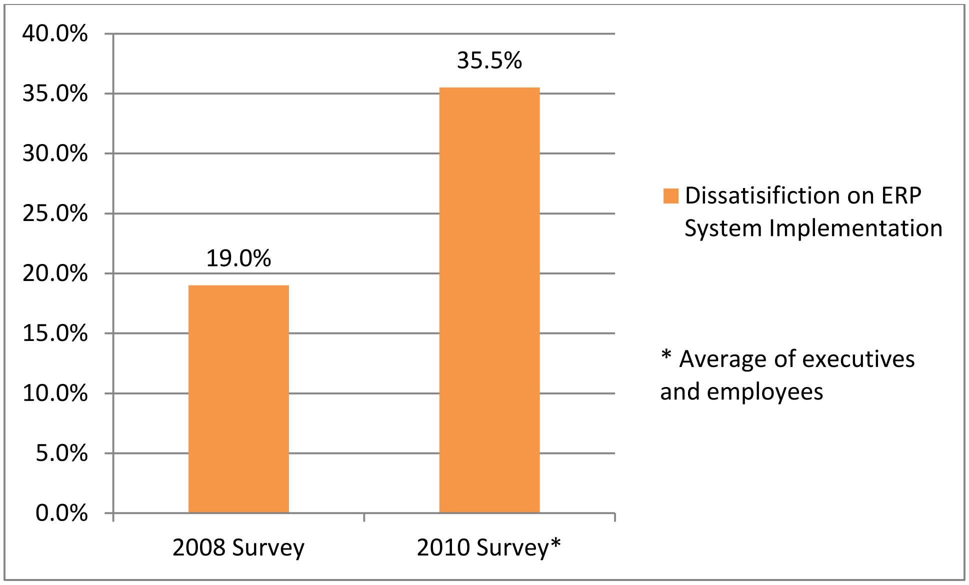


Figure 5.4 Percentage of Dissatisfaction on ERP System Implementation

Because the cost and duration of any implementation task (or activity) are nonnegative continuous variables, it might be problematic to model either the cost or the duration of a task as a binary variable determined solely by the success or failure of its sub-tasks, which are also continuous variables. Besides, the success of a task depends on how the task itself is carried out rather than the success or failure of prior activities. For these reasons, traditional fault tree analysis techniques and methods seem not be suitable for the modeling of ERP implementation process failure in their current forms. As a matter of fact, there are already a wide variety of project risk analysis methods available in literature that can be applied for ERP project cost and schedule risk management, among which is a recent study using Bayesian Belief Networks within a Monte Carlo simulation environment (Ordóñez Arízaga, 2007). In contrast, the state of an ERP system and its components in terms of delivering expected benefits, matching design specifications, and obtaining user satisfaction can be reasonably expressed as a binary variable. The determination of ERP usage success, by and large, depends on the perception and judgment of people in the hosting organization, which are basically subjective. Indeed, there is a lack of objective measurement for ERP usage performance and benefits in literature, so it is very difficult to put continuously distributed numerical values to characterize the state of ERP system and its components. Therefore, although the identified risk factors apply to different kinds of ERP system implementation failures, the focus of the proposed approach based on fault tree analysis is mainly on the risks related to ERP system usage failure.

5.2.4 Rationale of the Proposed Approach

Taking a system perspective, the proposed risk management approach assumes that ERP systems and their implementation processes comprise, and thus can be divided into, components of different segments and levels. As such, the effects of risk factors are imposed directly on these components or the interaction between components, and then reflected in the ultimate implementation outcomes. Risk factors impact the success of individual components and, if the impact is sufficiently negative, may trigger their faults or failures, which eventually influence the project outcomes (See Figure 5.5). Using a deductive approach such as fault tree analysis, one can trace system failure to the failure of individual component or combination of components, thus the relationship between specific risk factors and the system can be understood and established. Indeed, it is a common sense that the risk factors causing failure of a single ERP basic component are less in amount, narrower in scope, and thus much easier to identify than the those causing failure of the entire complex ERP system.

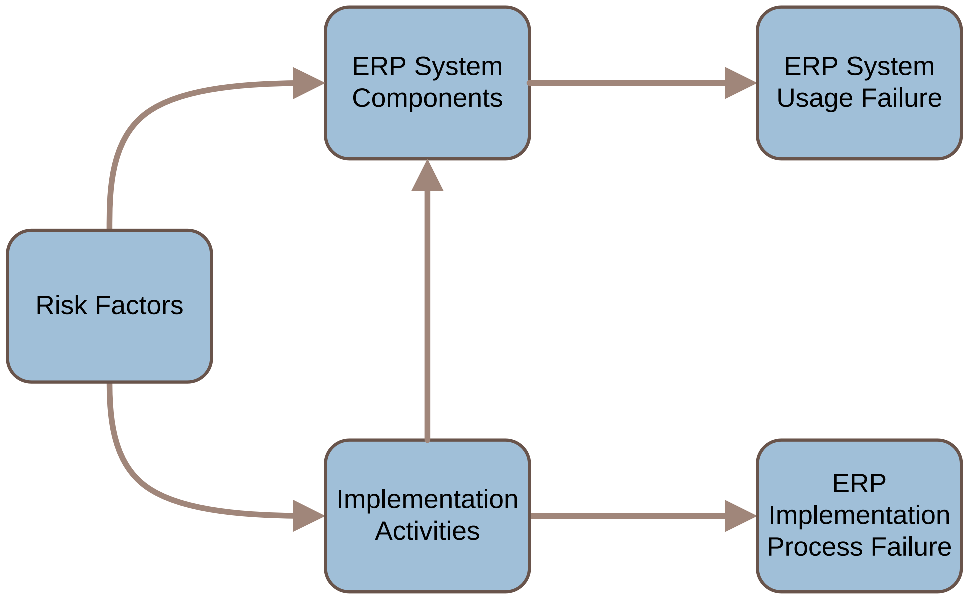


Figure 5.5 Risk Factors on ERP Projects

Certain assumptions are recognized in the proposed approach. 1) As stated above, an ERP system is regarded as a decomposable system. 2) The representation of a system is coherent, that is, the system as a whole cannot improve when one or more of its components (subsystems) fail (Bedford & Cooke, 2001). 3) The fault or failure of a component (an event) of any level is either caused or characterized by the fault or failure of a certain combination of its components in the immediate lower level, unless it has no lower level component. The number of components leading to the fault or failure of the component in the immediate upper level may range from at least one to all, and the sequence of component faults may matter. 4) The state of each component is binary – either success or failure; in other words, the event that a component fails has only two possible result – true or false. This, however, makes it difficult to model the situations where there are more than two possible states. 5) It is often assumed that components in the same hierarchical level of the systems and thus of the fault trees, are statistically independent from each other. If a component has interactions or connections with another component that are clearly understood and defined, such interactions or connections are treated as additional independent components. However, assumption 5) may be relaxed.

The process of the proposed approach for ERP risk management is illustrated in Figure 5.6. The diagram is a combination and adaptation of the processes described by Aloini, et al. (2007), Limnios (2007), Stamatelatos, et al. (2002), and so on. After relevant risks are identified and qualitatively analyzed within the context of ERP implementation, the ERP system and its usage failure can be decomposed into different components, according to preset criteria. All of the components that are related to system failure are identified and listed, and their hierarchies and interdependencies clearly established. It is critical to define the failure modes for each level of components, that is, the manner that component failures are recognized. With all components identified and their failure modes defined, the system can be reconstituted with these components. According to Limnios (2007), system specifications involve the definition of phases, which is referred to the different working modes of a system; boundary conditions, i.e., the interactions of the system with its environment; initial conditions; and other specific hypothesis regarding the system.

In order to conduct fault tree analysis successfully, certain steps should be carried out. The identification of objective seems obvious, so is the definition of top event, which is the event for which the failure causes will be resolved and the failure probability determined. The scope of the fault tree analysis indicates which of the failures and contributors will be included; the resolution is the level of detail to which the failure causes for the top event will be developed; and the ground rules include the procedures and nomenclature by which events and gates are named in the fault trees (Stamatelatos, et al., 2002). The construction of the fault tree needs to use the graphical symbols introduced above.

After the fault tree is constructed, both qualitative and quantitative evaluation can be performed, which is discussed in the next sections. The results from both qualitative and quantitative evaluations of the fault tree make it possible to identify the ERP components and implementation activities that are of critical importance. As a result, decision-makers are enabled to take either corrective or preventive measures to ensure ERP implementation success.

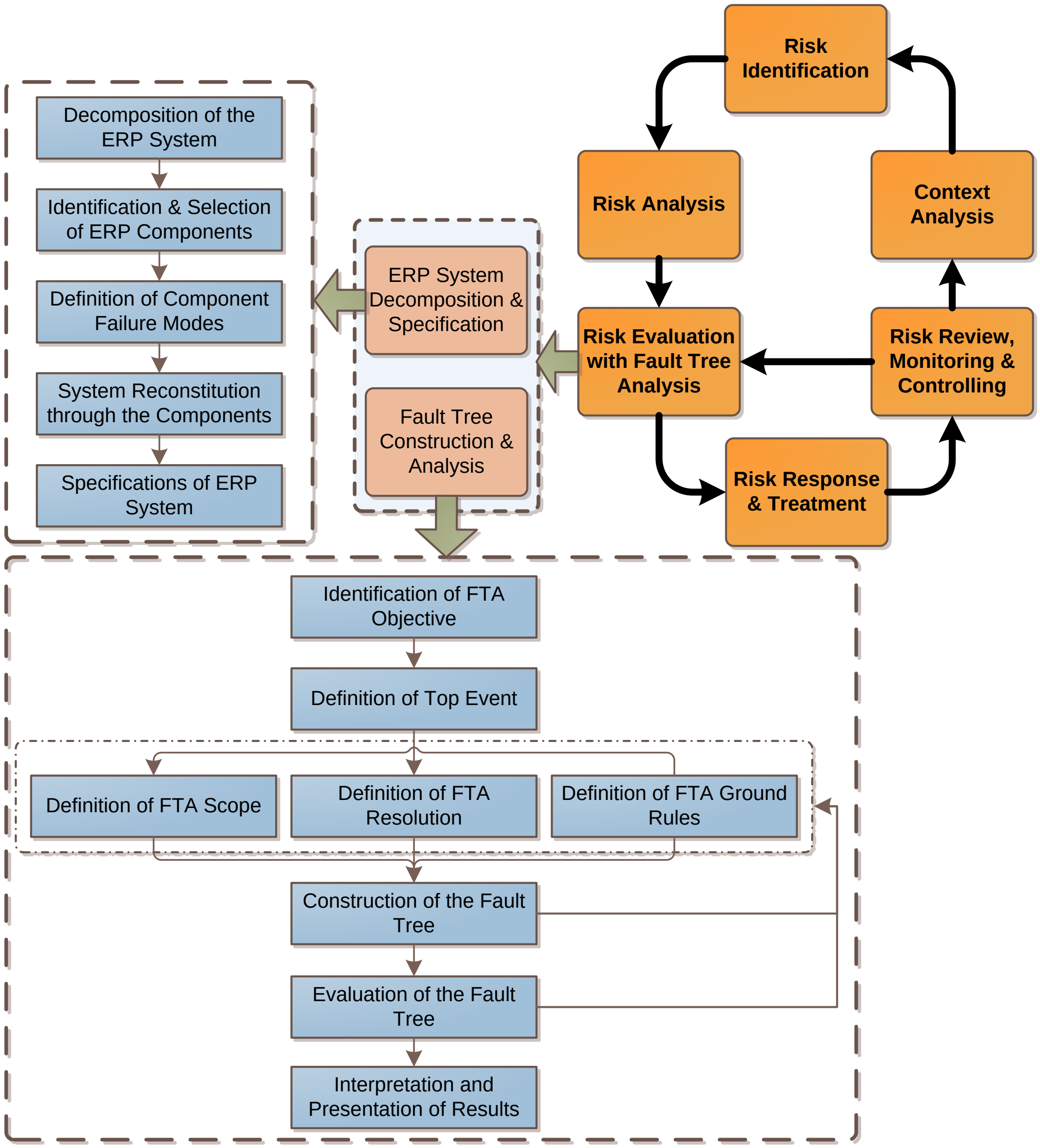


Figure 5.6 Proposed Risk Management Approach

5.3 ERP System Usage Failure Modeling

5.3.1 Decomposition of ERP System and Its Failure

ERP systems are designed to manage both internal and external resources of a whole organization and facilitate all the information flowing between different business functions. The all-encompassing purpose of ERP systems make them very complex in nature and large in size. In order to divide an ERP system into different components, one must establish certain criteria. Since an ERP system is made up of various different software modules, each performing a range of tasks to meet the business needs of a certain functional area, functionality is a natural criterion to be used to decompose the system, which may need to be complemented by other criteria. It is noteworthy that the additional software and hardware related to ERP implementation, such as database management system, security software, PCs, workstations, servers, networking infrastructures, etc., may also be included in the analysis provided it is relevant to the post-implementation ERP audit.

A modular view of a typical ERP system is illustrated in Figure 5.7. Although the nomenclature, scope and structure of similar modules and their components vary more or less, depending on the architectural design and product strategy of ERP vendors, one can loosely categorize these modules and divide them into different sub-modules or functional components. According to Kalakota & Robinson (2001), the multiple core applications comprising an ERP system (a standard ERP framework) are "themselves built from smaller software modules that perform specific business processes within a given functional area." As a result, the system decomposition process could be continued until the functionalities of the lowest level of components cannot be further divided, or it is more convenient or reasonable to evaluate the components with a holistic viewpoint, as long as the predetermined criteria of decomposition are met.

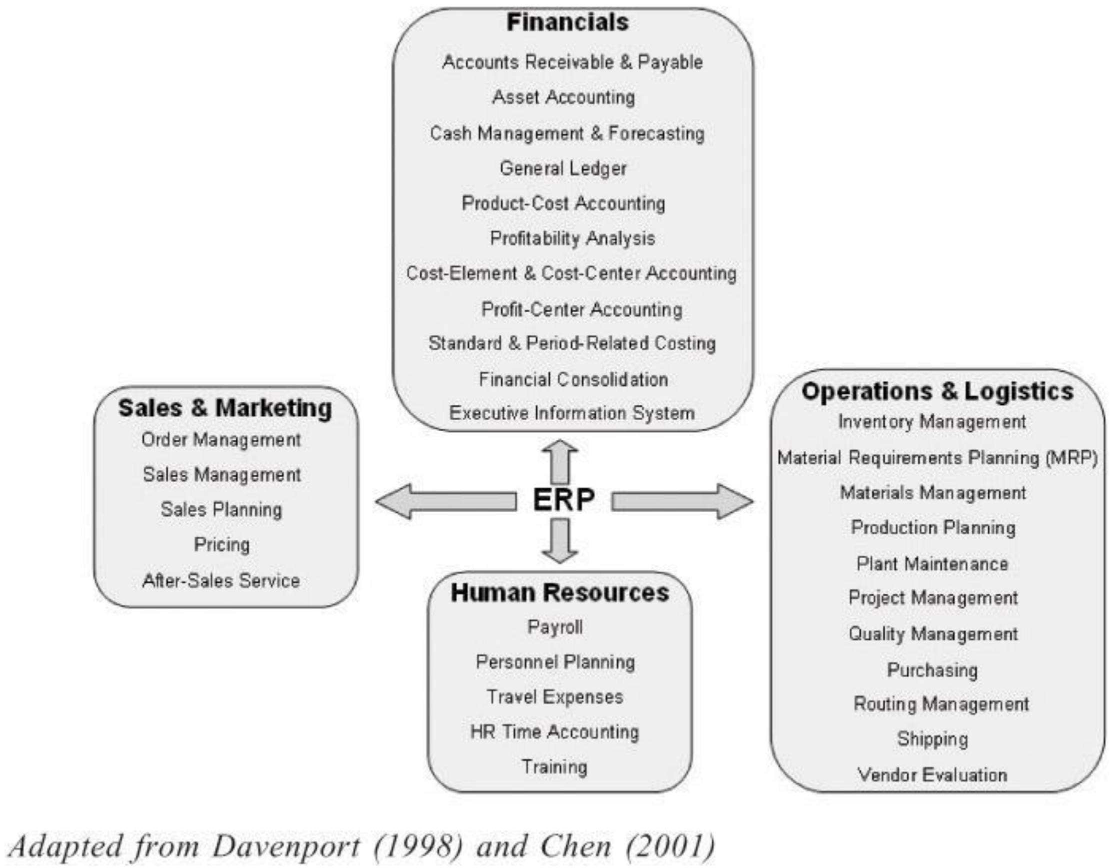


Figure 5.7 Modular Overview of Typical ERP Systems

Adapted from Davenport (1998) and Chen (2001)

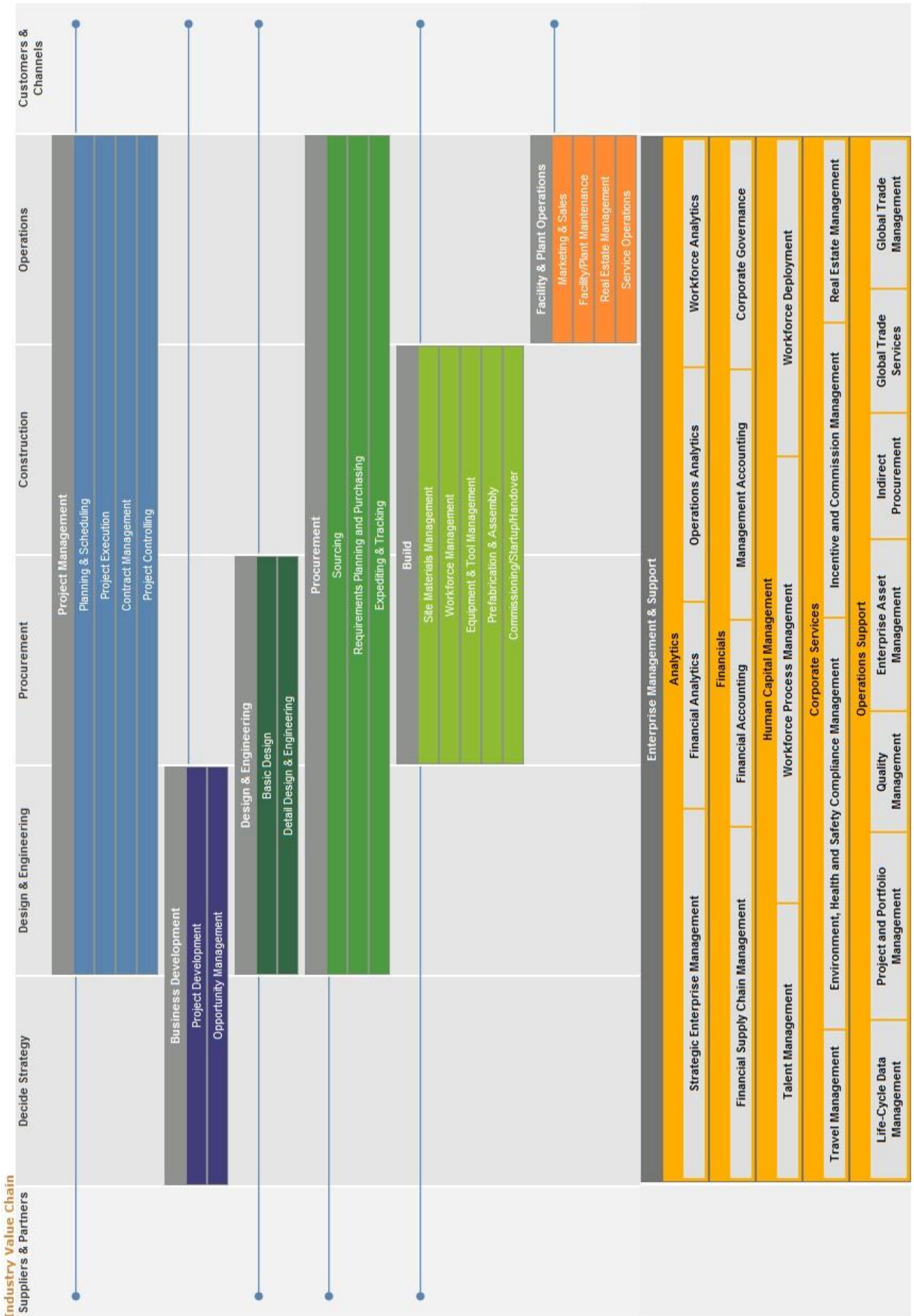


Figure 5.8 SAP Engineering, Construction & Operations Solution Map

Leading ERP vendors, such SAP, Oracle and Microsoft, have taken an industry specific approach to market their solutions, with some targeting project-based industries. The characteristics that distinguish ERP systems for project-based firms from other ERP systems are whether project management functionalities are included in the package, how important they are, and how the business processes of project-based organizations are dealt with in them. Figure 5.8 and 5.9 display the solution maps of SAP and Oracle for the Engineering & Construction industry, respectively (Chung, 2007; SAP, 2008). The solution maps provide an overview of the functionality composition of mainstream ERP systems for project-based industries. These ERP systems intend to cover the full range of business processes in project-based firms. The firms, however, do not have to implement all modules of the solutions; they can choose among various modules based on their specific needs and financial capability.

Streamline Opportunity Management	Drive Bid and Proposal Efficiently	Optimize Delivery of Pre-Construction Tasks	Control Project Changes and Enhance Execution	Manage Close-Out and Ongoing Operations
Sales - Sales - Project Costing **Customer Data Mgmt.** - Customer Data Hub - Customer Data Spoke - Cust. Data Librarian	**Proposal Management** - Proposals - Project Management - Project Collaboration - Project Costing - Project Contracts - CADView-3D - Adv. Project Catalog - Sourcing	**Project Planning** - Project Contracts - Project Management - Project Collaboration - Adv. Project Catalog - CADView-3D **Resource Management** - Project Resource Mgmt. - iProcurement - Purchasing - Service Procurement - iSupplier Portal	**Project Planning** - Project Management - Project Collaboration **Cost Management** - Project Costing - Time & Labor - Payroll - Advanced Benefits - Financials - Project Billing	**Accounting** - Financials - iReceivables - Project Costing - Project Billing **HR Management** - Human Resources - Self-Service HR **Facilities Maintenance** - Enterprise Asset Mgmt. - Self-Service Work Reqs. - Network Logistics

Performance Management	E-Business Intelligence, Balanced Scorecard, Enterprise Planning & Budgeting
Corporate Governance	Internal Controls Manager, Financials, Tutor, Learning Management
IT Infrastructure	Database Server, Applications Server, Systems Management, Development Tools, Collaboration Suite
Services	Consulting, On Demand, Education, Support

Figure 5.9 Oracle Solution Map for the Engineering & Construction Industry

While functional components are the primary units to construct fault trees and conduct the analysis, the interactions between them should be taken into account and treated as additional components, if these interactions affect the failure mode of any component. The interaction, typically the capability to transfer, share or integrate information between different functional areas, may be either unidirectional or bi-directional. A virtual component representing such an interaction is considered as an additional immediately lower-level component to the component whose failure may be caused by the interaction (see Figure 5.10 below). If it has impact on more than one component, duplicate components can be placed in different positions and levels in the fault tree.

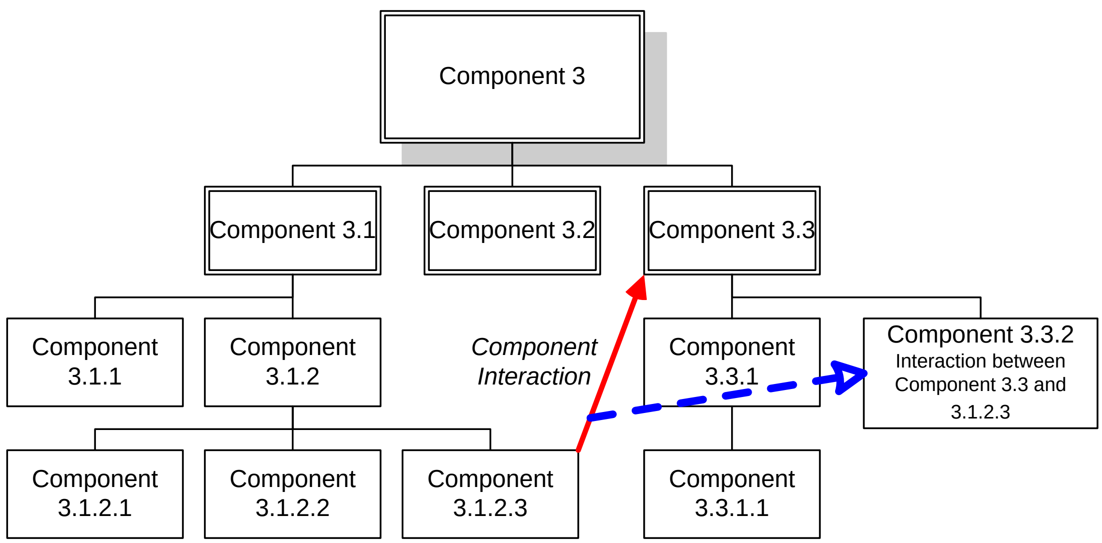


Figure 5.10 Modeling of Component Interactions as Separate Components

Although functionality is the principal criterion to identify ERP components, one must consider the causes to a functional component failure other than the failure of its underlying functional components. For example, a project scheduling application -

an intermediate component, is deemed failing only because the user interface is too unfriendly to allow the users to use it, even though it can meet all the original functionality requirements. As a result, virtual components should be created to represent the nonfunctional causes to failures in the fault tree. This is similar to the modeling of component interactions using new components.

While system decomposition according to functionality is intuitive and straightforward, there may be other kinds of criteria to decompose ERP systems, such as those based on business processes or from the perspective of end-users. Moreover, the selection of decomposition criteria is flexible and dynamic, in order to fully explore the causes of component failures. Besides, different criteria can be used together, as described by the cases of component interactions and user interfaces above.

5.3.2 Selection of ERP Components for Fault Tree Construction

No matter what criteria are used, the identification of components contributing to higher-level component failures must be as exhaustive as possible. However, not all components need to be included in the fault trees. Increasing the number of components under a single gate is likely to complicate the fault tree analysis afterwards and make it laborious. Thus screening ERP components is often necessary before constructing a fault tree. At first, those components whose faults are explicitly stated to have very little impact whatsoever on any other components or the whole system, either acting alone or together with other components, should be excluded from the analysis to avoid redundancy in the fault tree. This is to make sure that only the components that are relevant and/or important to upper-level component are modeled in the trees. Secondly, components whose probabilities of failure are extremely small, or several orders of magnitude smaller than other components under the same gate should be dealt with carefully and removed from consideration if appropriate. It is suggested, as a common sense rule, not to continue to model an input to an OR gate if there is information that assures its probability is significantly lower than the probability of one or more of the other inputs (Stamatelatos, et al., 2002). Also, including an input event with extremely small probability to an AND gate would essentially nullify other input events with high probability of failure. In particular, there is no need to chase higher order combinations of faults if there are lower order combinations already identified, thus the number of input events to an AND gate should be limited (Vesely, Goldberg, Roberts, & Haasl, 1981). Based on these two rules, more specifically defined rules can be set up. For example, a threshold of failure probability (e.g., 0.001) may be imposed to exclude the basic components with extremely low chance to fail. In order to simplify fault tree modeling and at the same time avoid biasing the fault tree towards some components, screening ERP components should be carried out consistently following predetermined rules. It is therefore reasonable to assume that the excluded components will be successfully deployed.

5.3.3 Failure Mechanisms and Modes of ERP System Components

As the components of an ERP system is identified, the key to fault tree analysis is to understand how the fault of a collection of components leads to the failure of higher level components in the ERP system. There is, however, a significant difference between physical systems and information systems, because the causal relationship between component failures in the latter is much more opaque and elusive. In physical systems such as nuclear reactors, the failure of a component is often physically caused, and preceded in time, by the faults or failures of other components in the lower level of the fault tree. In contrast, the failure of a functional component in an ERP system is recognized or judged because of certain kinds of faults or failures of its underlying components, where normally there is no lapse in time and it is often more like a whole-part relationship rather than a direct causal relationship. Therefore, how the failure of underlying components result in that of an upper-level component requires a clear definition from ERP users or the management in the hosting organization, and such a definition can be both objective and subjective. This makes the construction of a fault tree modeling ERP system usage failure dependent on the requirements and expectations of users and/or the management from the adopted ERP system rather than the system itself. As such, the fault tree analysis method in this study is modified and different from its traditional form.

As stated in the last chapter, ERP usage failure is a combination of three different types of information system failures: expectation failure, interaction failure, and correspondence failure (Lyytinen & Hirschheim, 1988). Thus the failure of basic components (basic events) can be evaluated from these three dimensions. While failing to attain a match between an ERP component and the planned objectives (correspondence failure) is relatively easy to find, expectation failure and interaction failure must be clearly defined and documented. For example, a project scheduling staff may have negative attitudes towards the scheduling component of the newly implemented ERP system, only because one of his/her colleagues gets laid off as a result of increased automation capacity of the component. It would not be suitable to declare an interaction failure in this case. Indeed, the measurement of expectation and interaction failure tends to be subjective, and the behavior or managerial issues that are outside of the ERP system should be excluded.

The concept of failure mechanisms, failure modes, and failure effects are important in determining the proper interrelationships among different events in constructing a fault tree (Stamatelatos, et al., 2002). Failure mechanisms show how specific failure modes occur; they are the means by which failure modes occur. Failure modes detail the exact aspects of component failure of concern, and failure effects indicate the effects of a component failure on another. In ERP system fault tree models, failure mechanisms are the combination, and possibly order, of immediate lower-level component failures or faults; failure modes are the type and details of component failure. In a word, failure mechanisms produce failure modes, which, in turn, have certain effects on the system (Stamatelatos, et al., 2002).

Because the purpose of the fault tree modeling is to prevent ERP system usage failure and ensure bottom-line implementation success, the definition of failure mode for each non-basic component should be carried out with an artificially imposed threshold. The threshold normally corresponds to the minimum acceptable success in the failure space (see Figure 5.11) proposed by Stamatelatos, et al. (2002); it could also be designated as the minimum anticipated success, if the requirement of the hosting organization on ERP success is strict. It is noteworthy that the failure mode should be defined realistically, by taking into account the project plan, particularly limited resources and time.

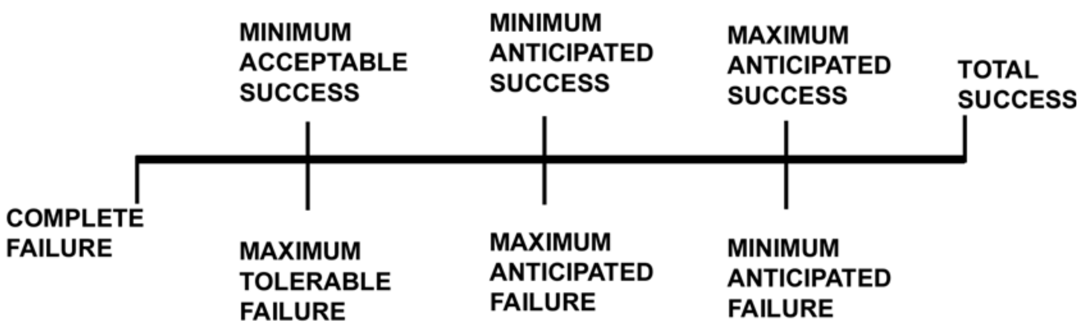


Figure 5.11 Failure Space vs. Success Space

5.3.4 Construction of the Fault Tree

After an ERP system is reconstituted with the identified components whose failure modes are also defined, one can select proper logic gates to capture the relationships between different components and construct a fault tree. While it is often straightforward to select fault tree gates to represent the failure mechanisms between ERP components based on objective information, it is not unusual that opinions of key stakeholders such as management and key users are needed to finalize the selection of gates. Eliciting these opinions must take into account the constraints of time and resources specified in the current project plan, in order to avoid wishing thinking and make the expectations or requirements realistic.

The top event is ERP system usage failure or the failure of specific ERP modules or application (subsystem) if the scope is narrowed down. Certainly, the faults or failures of all of the intermediate components are intermediate events in the tree. However, there are two approaches to model basic events. A straightforward one (the first approach in Figure 5.12) is to treat the failures of basic components as basic events, and exclude the causes of such failures from the fault tree. On the other hand, the second approach is to further analyze the failure mechanisms of these basic components, identify the risk events that cause their failures and model these risk events as basic events and thus the basic components as intermediate events; multi-level of causes can also be accommodated, starting from direct causes. The risk factors and their sub-factors listed in Chapter 3 are among the most frequently cited causes to ERP system and component failure, although other causes may need to be identified. The cause to basic component failure is also called risk event. A risk event is defined as a discrete occurrence of a risk factor that affects the ERP project. These two approaches that link ERP components and events in the fault tree are illustrated in the Figure 5.12. A mix of these two approaches constitutes a third one, as the causes to the failure of some components may not be fully identified or understood at the time of the analysis. Indeed, if a basic component itself is derived from the failure cause of another component and cannot be further divided, such as the failure of interaction between components mentioned above, it can only be treated as a basic event.

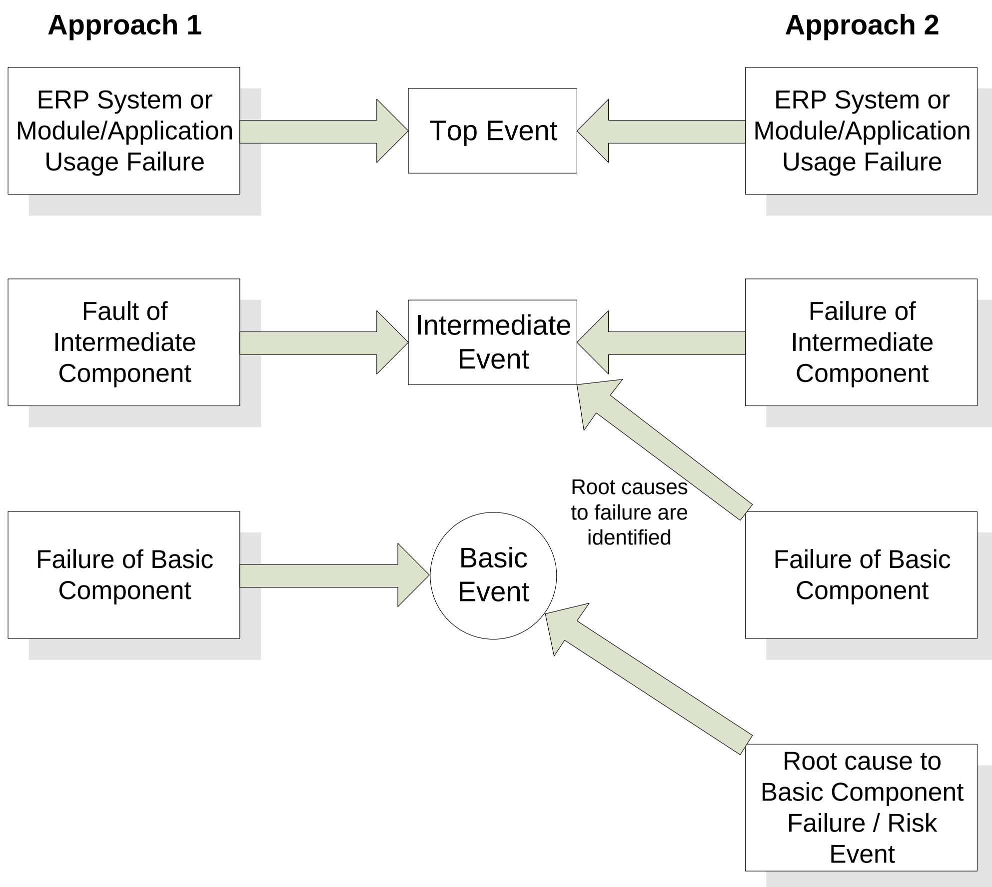


Figure 5.12 Conversion from Component Failures to Fault Tree Events

Certain types of logic gates are useful for ERP fault tree construction, including AND, OR, Voting (also named k-out-of-n combination or Voting OR), Priority AND (also called Priority or Sequential IF), and IF gates. With logic gates selected based on the relationships between component failures, one can use one of the above methods to convert ERP components failures into events, and connect them with gates, thus construct a fault tree corresponding to system failure.

5.3.5 Causal Relationship between Risk Events and Component Failure

As illustrated in Figure 5.12, the difference between the two approaches for ERP fault tree construction is the modeling of basic events. Ideally, the development of ERP fault tree could incorporate various risk events – occurrences of specific risk factors – that may cause basic ERP components to fail, thus those risk events resulting in ERP system usage failure can be pinpointed and resolved. Therefore, approach 2 in Figure 5.12 can be used, in which the causal relationships between risk events and basic ERP component failures are expressed explicitly and depicted using specific fault tree gates in the trees.

However, the risk events that cause the usage failure of basic ERP components might still be elusive to understand, although the scope has been significantly narrowed down in comparison to the identification of risk events that cause the entire ERP system usage failure. Even though these risk events are fully identified, their relationships with the pertinent basic ERP component failure may not be deterministically stated using pre-defined fault tree gates, because the causal relationship between risk events and basic component failure is often fuzzy. For example, if there are three events that lead to a component failure, one may still be uncertain to determine the exact combination of risk events that can sufficiently lead to the specific basic component failure. As a result, the top-down development of ERP fault tree model can be carried out to the basic ERP components rather than their associated risk events; in other words, approach 1 depicted in Figure 5.12 is used. Besides, in the case that the estimation of probabilities is easier to carry out or more reliable for basic component failure than for risk events, this approach will be a more suitable choice to construct ERP fault tree models.

The utilization of approach 1 entails further analysis after the fault tree evaluation is completed, in order to understand the connections between basic ERP components and risk events that cause the failure of the former. The causal relationships between risk events and some basic ERP component failures may be explicitly expressed in the form of fault tree gates and thus evaluated quantitatively. Otherwise, the primary risk events for each basic ERP component can still be identified, analyzed, and prioritized. Certainly, those risk events associated with ERP components more prone to failure should be handled with more attention and resources.

5.4 Fault Tree Evaluation and Probabilistic Assessment

5.4.1 Evaluation of Fault Trees with Boolean Algebra

The constructed fault tree itself is a qualitative illustration of the events and relationships that lead to the top event and provides significant insights and understanding into the cause of system failure (Stamatelatos, et al., 2002). The qualitative analysis is conducted from an algebraic point of view, also called logic analysis. Its principal purpose is to determine the structure function of the fault tree concerning the top event, primarily the minimal cut sets and minimal path sets. A cut set is a combination of basic events that can cause the top event; and thus a minimal cut set is the smallest combination of basic events that result in the top event (Vesely, et al., 1981). A path set (or a path) is a collection of basic events such that if none of these events occur then the top event will certainly not occur (Bedford & Cooke, 2001); and a path set that does not contain another path set is called a minimal path set. The minimal cut sets relate the top event directly to the basic event causes, thus provide significant amount of information about the vulnerability of the system.

Evaluation of a fault tree requires the application of Boolean algebra, as it is essentially a pictorial representation of a Boolean expression. In Boolean algebra, there are two binary operators, AND and OR, which correspond with the AND and OR gates in a fault tree, respectively. There is also a unary operator NOT. Let $\boldsymbol{Q}$ denote the output event of a specific gate, $\boldsymbol{G}$, and $\boldsymbol{A_i}$, $i=1,2,\dots n$, denote the input events. Thus for a AND operator, event $\boldsymbol{Q}$ will occur if and only if all of the $\boldsymbol{A_i}$ occur, thus the Boolean expression is:

$$\boldsymbol{Q} = \boldsymbol{A_1} \cap \boldsymbol{A_2} \cap \boldsymbol{A_3} \cap \dots \cap \boldsymbol{A_n}$$

or

$$\boldsymbol{Q} = \boldsymbol{A_1} \bullet \boldsymbol{A_2} \bullet \boldsymbol{A_3} \bullet \dots \bullet \boldsymbol{A_n} \quad (5\text{-}1)$$

For a OR operator with $\boldsymbol{n}$ input events, the Boolean expression is

$$\boldsymbol{Q} = \boldsymbol{A_1} \cup \boldsymbol{A_2} \cup \boldsymbol{A_3} \cup \dots \cup \boldsymbol{A_n}$$

or

$$\boldsymbol{Q} = \boldsymbol{A_1} + \boldsymbol{A_2} + \boldsymbol{A_3} + \cdots + \boldsymbol{A_n} \quad (5\text{-}2)$$

Regarding the NOT operator, not $\boldsymbol{A}$ can be expressed as $\boldsymbol{A'}$ or $\boldsymbol{A^c}$. Certain basic laws of Boolean algebra are summarized as follows (Bedford & Cooke, 2001; Limnios, 2007):

Commutative laws: $\boldsymbol{A} \bullet \boldsymbol{B} = \boldsymbol{B} \bullet \boldsymbol{A}$ (5-3)

$$\boldsymbol{A} + \boldsymbol{B} = \boldsymbol{B} + \boldsymbol{A}$$

Associative laws: $$\boldsymbol{A} \bullet (\boldsymbol{B} \bullet \boldsymbol{C}) = (\boldsymbol{A} \bullet \boldsymbol{B}) \bullet \boldsymbol{C} \quad (5\text{-}4)$$

$$\boldsymbol{A} + (\boldsymbol{B} + \boldsymbol{C}) = (\boldsymbol{A} + \boldsymbol{B}) + \boldsymbol{C}$$

Distributive laws: $$\boldsymbol{A} \bullet (\boldsymbol{B} + \boldsymbol{C}) = \boldsymbol{A} \bullet \boldsymbol{B} + \boldsymbol{A} \bullet \boldsymbol{C} \quad (5\text{-}5)$$

Idempotent laws: $$\boldsymbol{A}^{\boldsymbol{n}} = \boldsymbol{A} \quad (5\text{-}6)$$

$$\boldsymbol{n}\boldsymbol{A} = \boldsymbol{A} \; (\boldsymbol{n} \in \boldsymbol{N})$$

Absorption law: $$\boldsymbol{A} + \boldsymbol{A} \bullet \boldsymbol{B} = \boldsymbol{A} \quad (5\text{-}7)$$

Complementation: $$\boldsymbol{A} + \boldsymbol{A}' = \boldsymbol{\Omega} \quad (5\text{-}8)$$

De Morgan's laws: $$(\boldsymbol{A} \bullet \boldsymbol{B})' = \boldsymbol{A}' + \boldsymbol{B}' \quad (5\text{-}9)$$

$$(\boldsymbol{A} + \boldsymbol{B})' = \boldsymbol{A}' \bullet \boldsymbol{B}'$$

After a fault tree is depicted, the minimal cut set can be obtained by a direct method (Limnios, 2007), which will be illustrated in a case study. The method consists of three steps as follows:

1) Construction: construct the structure function that indicates the state of the top events, in terms of indicator variables describing the state of lower level events;

2) Development: develop the expression to the form only consisting of indicator variables of basic events; and

3) Reduction: simplify the expression of the structure function using basic laws of Boolean algebra.

In addition to the direct method above, there are other methods to find the minimal cut sets and path sets. One of the most widely used methods is descending (top down) substitution and decomposition of gates in the fault tree (operators) using the MOCUS algorithm, which is originally developed by Fussell & Vesely (1972). The MOCUS algorithm consists of initializing a matrix through the top gate and resolving it into its inputs. This involves a branching process: working from the top of the fault tree at an OR gate we branch and at an AND gate we list those events underneath (Bedford & Cooke, 2001). In contrast to the descending (top down) method, the ascending (bottom up) method proceed from the basic events, calculate the minimal cut sets at gates lower in the fault tree before moving upwards and calculating minimal cut set expressions for higher gates, eventually reaching an expression for the minimal cut sets of the top event. This method helps obtain minimal cut sets for each intermediate event instead of for the top event only, and save on calculation time (Bedford & Cooke, 2001).

Based on the definition of cut and path sets, it is apparent that there is a duality between them. The dual tree of a given fault tree is obtained by replacing all events with their complimentary events, all AND gates with OR gates, and all OR gates with AND gates (Limnios, 2007). Bedford & Cooke (2001) state, as a theorem, that a (minimal) path set for a coherent tree is a (minimal) cut set for the dual tree, and vice versa. As a result, the minimal path set of a fault tree can be obtained by applying the same methods to find minimal cut sets to its dual tree.

5.4.2 Probability Estimation for Basic Events

Estimating the probabilities of basic events is a prerequisite to conduct quantitative fault tree analysis. If approach 1 (Figure 5.12) is used, the probability of a basic event refers to the probability that the minimal accepted usage success cannot be achieved for the corresponding basic ERP component. If approach 2 (Figure 5.12) is used, the probability of a basic event is that a specific risk event occurs. The conventional approach has been the use of point probabilities for the analysis of the system, which is found in most available research in fault tree analysis (Haimes, 2009). This approach requires accurate data on the component failure rate along with a point distribution, which may not be available in ERP practices. Alternatively, an interval of uncertainty for the probability of the basic event of interest can be developed. In order to overcome the limitations imposed by the unavailability of relevant data, it has been suggested to approximate the available data (if any) and/or the subjective estimates of the basic event occurrence by a probability distribution, such as normal or lognormal distribution. However, when different probability distributions are used for basic events, existing analytical methods are either not applicable or very complex and difficult to adopt for large systems (Haimes, 2009). In that case, numerical simulation can be used to generate pseudorandom numbers to approximate the probability distributions of basic events and then calculate the probability of the top event.

There are a number of techniques to assess the probabilities of basic events for ERP system fault tree modeling; among them analysis on historical data and eliciting from expert opinions are the most widely cited. Historical data and documentation from past ERP implementations provide objective information for the probabilities of basic events. Lots of ERP vendors, consulting firms and perhaps some research organizations maintain detailed records regarding the ERP implementation projects in which they are involved. However, the accessibility, affordability and/or relevance of such data might be of concern. Expert judgments are subjective estimation based on the knowledge and experiences of subject matter experts. For example, ERP consultants are supposed to be experts in estimating the likelihood of ERP component failure or the occurrence of failure causes of basic components. It is suggested that the problem should be disaggregated sufficiently well so that experts can concentrate on estimating something that is tangible and easy to envisage (Vose, 2008). The decomposition of ERP system and its failure is exactly the disaggregation required for opinion elicitation. The probability estimation provided by expert judgment should be undertaken on the conditions of given project constraints, especially the resources and schedule in the project plan.

There are a number of methodologies to elicit expert opinions, such as brainstorming, interview, Delphi method and consensus group method (Vose, 2008). The PERT distribution is often used to model an expert's opinion, so that the expert need only provides estimates of the minimum, most likely and maximum values for the variable. Expert judgment suffers from heuristic biases and errors, however, including representativeness, adjustment, and anchoring.

5.4.3 Probabilistic Assessment of Fault Trees: Direct Method

The quantitative assessment of a fault tree aims to determine the probability of the top event and the importance of basic events. If a fault tree does not include any repeated events, the probability of the top event can be calculated directly using a simple bottom-up approach, starting from the probabilities of basic events and climbing up the fault tree. When a fault tree possesses repeated events, the direct bottom-up calculation approach is no longer applicable because it yields overstated results (Limnios, 2007). Certainly the probability of the top event is the primary focus of the analysis; meanwhile, the probabilities of any intermediate event can also be determined. The cut sets that contribute significantly to the top event probability are called the dominant cut sets (Stamatelatos, et al., 2002). While time-related probabilities can also be calculated, the failure of ERP system is barely dependent on time, which is different from the failures of physical systems such as machines, thus such calculations are normally not necessary.

The probability of the output event can be expressed in terms of the probabilities of input events. For a simple AND gate with only two input events (Figure 5.13), we have the following formula (Stamatelatos, et al., 2002):

$$\boldsymbol{P(Q) = P(A)P(B|A) = P(B)P(A|B)} \qquad (5\text{-}10)$$

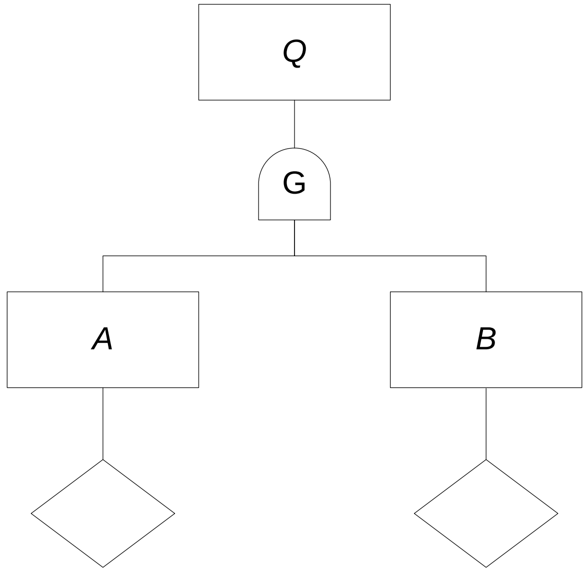


Figure 5.13 A Two-Input AND Gate

If the input events are independent from each other, for two input events we have

$$\boldsymbol{P(Q) = P(A)P(B)} \tag{5-11}$$

and for more than two input events, we get

$$\boldsymbol{P(Q) = P(A_1)P(A_2) \ldots P(A_n)} \tag{5-12}$$

It is assumed that in ERP systems, components of the same level and thus their failure are mutually independent. If they are not independent from each other, $\boldsymbol{P(Q)}$ may be significantly greater than the product of probabilities of the input events

For a OR gate with two input events, the probability of the output event can be expressed as follows (Stamatelatos, et al., 2002):

$$\boldsymbol{P(Q) = P(A) + P(B) - P(A \cap B)}$$

$$\boldsymbol{= P(A) + P(B) - P(A)P(B|A)} \tag{5-13}$$

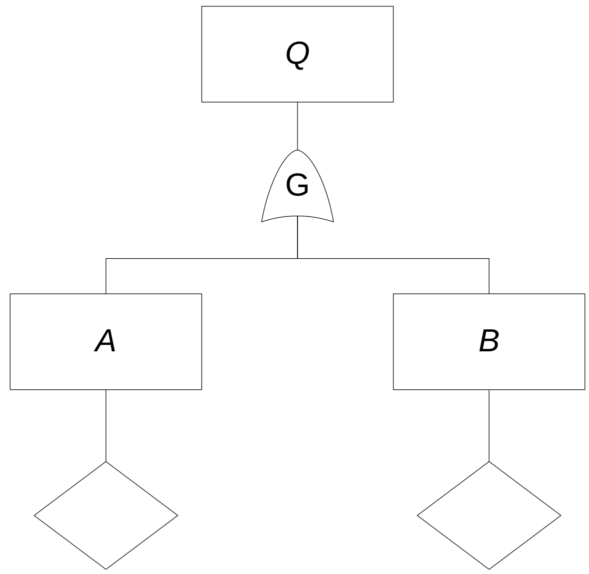


Figure 5.14 A Two-Input OR Gate

According to Equation 5-13, a few observations can be made (Stamatelatos, et al., 2002):

1) If the input events $\boldsymbol{A}$ and $\boldsymbol{B}$ are mutually exclusive, then $\boldsymbol{P(A \cap B) = 0}$ and $\boldsymbol{P(Q) = P(A) + P(B)}$;

2) If $\boldsymbol{A}$ and $\boldsymbol{B}$ are independent events, then $\boldsymbol{P(B|A) = P(B)}$ and $\boldsymbol{P(Q) = P(A) + P(B) - P(A)P(B)}$;

3) If event $\boldsymbol{B}$ is completely dependent on $\boldsymbol{A}$, i.e., $\boldsymbol{B}$ occurs whenever $\boldsymbol{A}$ occurs, then $\boldsymbol{P(B|A) = 1}$ and $\boldsymbol{P(Q) = P(B)}$.

In an Exclusive OR gate with two inputs, the output event $\boldsymbol{Q}$ occurs if and only if one of the input events occurs ($\boldsymbol{A}$ or $\boldsymbol{B}$), but not both. Thus the probability of the output event can be expressed as:

$$\boldsymbol{P(Q) = P(A) + P(B) - 2P(A \cap B)} \qquad (5\text{-}14)$$

In a Voting gate (k-out-of-n gate), the output event occur when at least $\boldsymbol{k}$ input events among $\boldsymbol{n}$ occur. If the input events have the same probability, i.e., $\boldsymbol{P(A_1 = A_2 = \ldots = A_n) = q}$, we have

$$\boldsymbol{P(Q) = \sum_{i=k}^{n} C_n^i q^i (1-q)^{n-i}}$$

(5-15)

The probability of output events connected with input events through other types of gates can also be expressed in specific terms of input event probabilities. This can be straightforward for some types of gates, such as the IF gate. However, for dynamic gates, e.g. Priority AND gate, the expression might be much more complex. In addition, while the analysis of probability for gates with two- or three-input events are relatively easy to carry out, it becomes more complex if the number of input events increases. To simplify the analysis, one can replace a gate that has many input events with an equivalent form which has different gates of different levels, each having less input events. For example, an OR gate with four input events can be equivalently converted into three OR gate in two levels each having two input events.

5.4.4 Probabilistic Assessment with Minimal Sets

After the minimal cut sets of a fault tree are found, the probability of top event can be obtained by calculating the probability of each minimal cut set and by sorting and summing up the probabilities of all cut sets (Stamatelatos, et al., 2002). Unlike physical systems, the judgment of ERP system and component success or failure is conducted during the implementation process, or from the post-implementation audit activities, thus it is essentially independent from specific time interval. As a consequence, the input data that must be supplied to the basic events are the probabilities of basic component failure or other related events, such as the cause to component failures.

Let $\boldsymbol{C_1}$, $\boldsymbol{C_2}$,…, $\boldsymbol{C_n}$, denote the minimal cut sets, and $\boldsymbol{T}$ denote the top event, we have

$$\boldsymbol{T = C_1 \cup C_2 \cup \ldots \cup C_n} \qquad (5\text{-}16)$$

According to the inclusion-exclusion principle (Vesely, et al., 1981), we obtain the probability of the top event shown as follows:

$$\begin{aligned} \boldsymbol{P(T)} &= \boldsymbol{P\left(\bigcup_{i=1}^{n} C_i\right)} \\ &= \boldsymbol{\sum_{i=1}^{n} P(C_i) - \sum_{i<j} P(C_i \cap C_j) + \sum_{i<j<k} P(C_i \cap C_j \cap C_k) - \ldots} \\ &\quad \boldsymbol{+ (-1)^{n+1} P(C_1 \cap C_2 \cap \ldots \cap C_n)} \end{aligned} \qquad (5\text{-}17)$$

From (5-17) above, we can get a upper bound and lower bound for $\boldsymbol{P(T)}$,

$$\boldsymbol{\sum_{i=1}^{n} P(C_i) - \sum_{i<j} P(C_i \cap C_j) \leq P(T) \leq \sum_{i=1}^{n} P(C_i)} \qquad (5\text{-}18)$$

Based on the assumption that the magnitude of likelihood that two minimal cut sets occur simultaneously should be smaller than the probability that only one of the two minimal cut sets occurs, the approximation of $\boldsymbol{P(T)}$ is given by (Bedford & Cooke, 2001):

$$\boldsymbol{P}(\boldsymbol{T}) \approx \sum_{\boldsymbol{i}=\boldsymbol{1}}^{\boldsymbol{n}} \boldsymbol{P}(\boldsymbol{C_i}) \tag{5-19}$$

This is called rare event approximation. When there is little overlap between the elements of different cut sets, the approximation is close to the accurate top event probability.

In addition to inclusion-exclusion development, there are other methods using minimal cut sets to calculate the probability of the top event in a fault tree, such as the disjoint products method (Abraham, 1979; Limnios, 2007). These methods assume that the probabilities of basic events are constant and independent of time. If this assumption is relaxed, that is, the basic events of a fault tree are described by underlying stochastic processes, and their probabilities are given depending on time, the Kitt (Kinetic Tree Theory) method (Vesely, 1970) and the method of factorization (Limnios, 2007) can be used to calculate top event probability without minimal cut set representation.

5.5 Interpretation and Use of ERP System Fault Tree Analysis Results

5.5.1 Critical ERP Components and Critical Risk Events

Based on the minimal cut set representation, one can discern that the importance of different components in the system vary considerably. If approach 1 is used for fault tree construction, there may be some components that have independent expression in the minimal cut set, which means that their failure directly lead to system usage failure; also, their probabilities linearly contribute to the probability of the top event. These components are called critical component. Similarly, if approach 2 is used for fault tree construction, we can detect the critical risk events, which are defined as discrete occurrences of corresponding risk factors. Because of their disastrous impact, the success of critical components must be assured, and critical risk events must be addressed, in order to avoid ERP system usage failure. This has significant implications on the treatment of risks, which will be discussed later. At the same time, other components or risk events (causes to basic component failures) should not be overlooked.

5.5.2 Fault Tree Modeling for ERP System Adoption Decision Making

While the proposed risk management approach in this study can never substitute ERP evaluation, either financial or technical, it can help in ERP adoption decision making from the perspective of risk aversion. A company that is evaluating ERP system adoption can, in a negative way, incorporate its requirements for ERP system usage success – minimum acceptable success or minimum anticipated success – into a fault tree model using a top-down approach. The probabilities of basic events are then estimated according to preliminary planning for the ERP project or based on the experiences drawn from previous implementations. Subsequently, the probability of entire system usage failure can be obtained through quantitative fault tree evaluation. The management is thus enabled to judge whether the level of risks is acceptable and the company should be committed to the ERP system implementation project. If there are different options (ERP vendors, packages, and collection of modules) to select, the procedures can be carried out for each option and the results are then compared against each other for decision making. In addition to computing the probability of system usage failure, the number of critical ERP components, the nature of critical risk events, and other important information revealed by the constructed fault tree model may also need to be taken into account.

5.6 Chapter Summary

Based on the established theoretical foundation, this chapter introduces the rationale and describes the processes and methods to assess the risks of ERP system with fault tree analysis. Through constructing fault trees to represent an ERP system or a specific module or application within the system, one can obtain insights into how system failure takes place as a consequence of the failures of its components, which are caused by the risk factors discussed in Chapter 4. The evaluation of fault trees enables ERP implementation practitioners to locate and understand certain components with ERP systems that have relatively more importance in system success (or failure) and more exposure to risks, and to identify, or at least narrow down the range of, risk factors that may lead to component failures. In a word, the results gained from fault tree analysis on ERP system usage provides significant information for managers and practitioners to develop strategies and take corresponding actions to actively manage the risk of ERP implementation.

6 Case Studies

6.1 Design of Case Study

The purpose of the case studies is to calibrate and verify the developed risk management approach using fault tree analysis in corporate settings. Although the use of fault tree analysis for probabilistic risk assessment in physical systems has been widely accepted, its application in information system project risk management is scarce. The proposed risk management approach is derived from well-established theoretical principles, but its applicability and usefulness has yet to be tested and verified in real world context. An ideal scenario would be using the approach to conduct risk assessment and management for a currently ongoing ERP project from initialization to completion, which is, however, hardly feasible in reality. It is not necessary, either, because the structure of an ERP system to be implemented rarely change after the system and its modules are selected and committed by the top management of the firm. Hence it suffices to place the case studies in firms that have completed ERP system implementation. There is also a case study that is carried out in a firm which considered and evaluated ERP system implementation but did not initialize the project eventually. Due to requirement from the firms on confidentiality, their names are substituted with codes in the study.

The case study at first involves solicitation, collection, review and analysis of archived materials related to the ERP implementation project, in addition to the collection of corporate background information from public sources such as websites. One of the important records is the architecture of ERP system and its modules, in the form of solution maps, graphs or descriptive texts. It helps understand the composition of the system and the relationships among different ERP components. The firm's business process reengineering effort and work breakdown structure for the ERP project, it documented, also provide useful information. After the related documentations are reviewed, a semi-structural interview is carried out with the leading professionals of the ERP project team, either management or technical. They are considered experts in practice for the ERP implementation project. The interview is intended to investigate the ERP system implementation processes and outcome in the company, and examine the failure modes of each level of ERP components. The aversion of the firms to different types of failures is discussed; and the importance of component success (or failure) in the whole ERP implementation project can be inferred. For interviewees located in the area, the interview takes a face-to-face form; for interviewees outside of the country, it is undertaken over the phone and/or Internet. After the interview, the experts are asked to fill a questionnaire to retrospectively estimate the likelihood of occurrence for different risk factors based on the experiences in their firms. Further questions and requests for additional materials may follow up by email correspondence. The information obtained from the case study is then organized and summarized as descriptive texts, followed by an attempt to construct a fault tree model for the ERP project in the firm, which is subsequently evaluated to find out the vulnerabilities of the ERP project.

6.2 Case Study A

6.2.1 Overview of Company A

Company A is a public engineering and construction company principally engaged in the construction and design of civil engineering and buildings, including public facilities, parking lots, residential buildings, office buildings, school buildings and factories. The company also involves in the distribution of pre-mixed mortar and construction materials. Headquartered in Taipei, it operates its businesses primarily in Taiwan, and maintains presence in the mainland Chinese market as well. It is a strong matrix organization with all major business organized in the form of projects. With about 500 full-time employees (excluding sub-contractors and temporary staff), the company generates an annual revenue of about 200 million US dollar in the latest fiscal year, most of which were obtained from construction business.

6.2.2 Description of the ERP System Implementation in Company A

Company A decided to revamp its information technology infrastructure with ERP system in order to resolve the so-called problem "islands of automation in construction", a term coined by Matti Hannus (Hannus, 1998) to characterize the information fragmentation in the industry, and achieve better integration among different divisions of the company and with the legacy system. The company selected SAP as its sole ERP vendor, and acquired the licenses of 10 SAP ERP modules for the project (see Table 6.1 and Figure 6.1). It also planned to adopt three additional modules in the future - SCM and CRM are also considered as separate information systems or extensions to ERP, which were deemed as a new project.

Table 6.1 SAP ERP Modules

Abbreviation of SAP ERP Module	Module Name
SD	Sales and Distribution
PS	Project Systems
PP	Production Planning
MM	Materials Management
QM	Quality Management
FI	Financial Accounting
TR	Treasury
CO	Controlling
AM	Asset Management
PM	Plant Maintenance
HR	Human Resources
CRM	Customer Relationship Management
SCM	Supply Chain Management

Company A invested about 3.1 million US dollars in ERP system implementation project, slightly over the original budget. This was not the total cost of ERP ownership, as some costs including internal staff expenses seemed not to be counted. The company formed a team devoted to the project on a full-time basis, which is composed of nearly 30 internal staff and about 10 consultants from an external consulting firm. The project was completed almost on schedule, taking about 12 months.

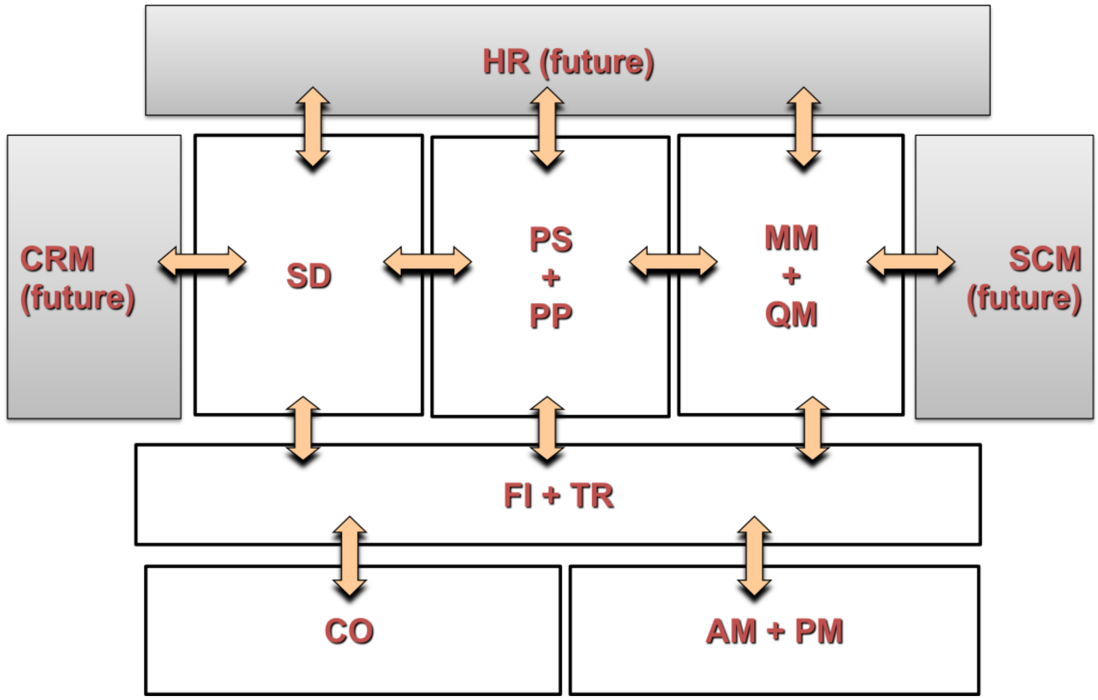


Figure 6.1 Implemented SAP Modules in Company A

In general, the project has been considered as a success. The end users were resistant to the new system in the beginning, but as system usage normalized, their attitude towards the ERP system evolved to somewhere between neutral and satisfied. The senior management of the company was very supportive during the implementation process, and basically satisfied with business benefits brought by the ERP systems, which were described to include significant reduction of redundant and repetitive data entry, integration with the legacy system that remained in use, transparent information, and improved business performance in the company.

6.2.3 ERP Implementation Process and System Decomposition

In order to smooth the transition from legacy system to new ERP system, the company adopted a combination of parallel implementation and phased rollout from one module to another. The legacy information system continued to be used for currently ongoing engineering and construction projects, while new projects were initialized with the new ERP system. Both systems co-existed in the company for an extended period even after the ERP implementation project is completed; some of the legacy systems have been continually maintained and updated to complement the functionalities of ERP systems to date. By this means, the company avoided disruptions to the execution of its ongoing projects and daily business operations. It was estimated that 40% to 50% of the features of the modules were somehow customized in the implementation, in order to make the system fit with the organization. Some of the previous business processes were also redesigned to adapt to the ERP system, either because of the determination of the management to align the company's business processes with the best practices defined by ERP, or because of the perceived difficulty to make further modifications to the software.

Due to the complexity of the ERP system, it is phased in by module, and its modules were further divided for customization and modification, primarily based on functionalities. The hierarchy of system components is shown in Figure 6.2. This is still a decomposition of middle to high level, as most components may be further divided. An example is the decomposition of the financial accounting module to a lower level, which is displayed in Figure 6.3. The decompositions in Figure 6.2 and

6.3 are based on both the system information at Company A and the information available from SAP. There are also some components of the ERP system that are not depicted in the figures. These include the components regarded as the foundation to the whole ERP system such as ABAP programming and runtime environment, ABAP workbench, database interface, database platform, middleware, security, communication interface, documentation and translation tools, and so on. Also, there are cross-application components such as cross-application time sheet, data transfer application, document management, employee self-services, CAD interface, etc. These cross-application components can be deployed either as an independent component (e.g. CAD interface) or as a lower-level component within the module it belongs to (e.g. FI/SD credit management and risk management component in Figure 6.3). In company A, unit testing was performed for each individual unit of the modules to ensure that code meets its design objectives and behaves as intended. Integration testing was carried out later to verify that the interfaces between components meet software design, followed by the system testing on the completed and integrated ERP system to evaluate the system's compliance with its specified requirements.

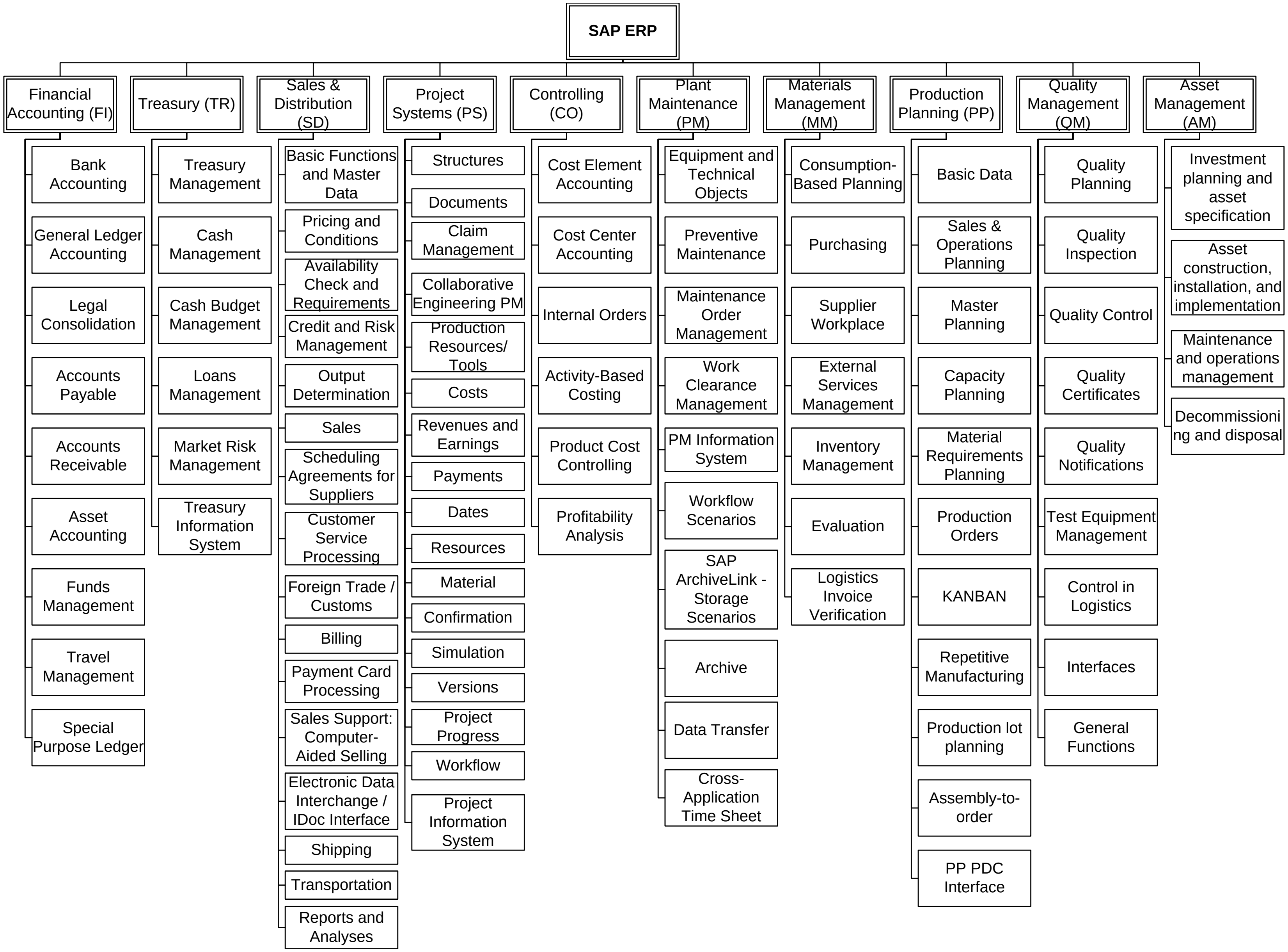


Figure 6.2 Hierarchical Overview of SAP ERP System Major Components

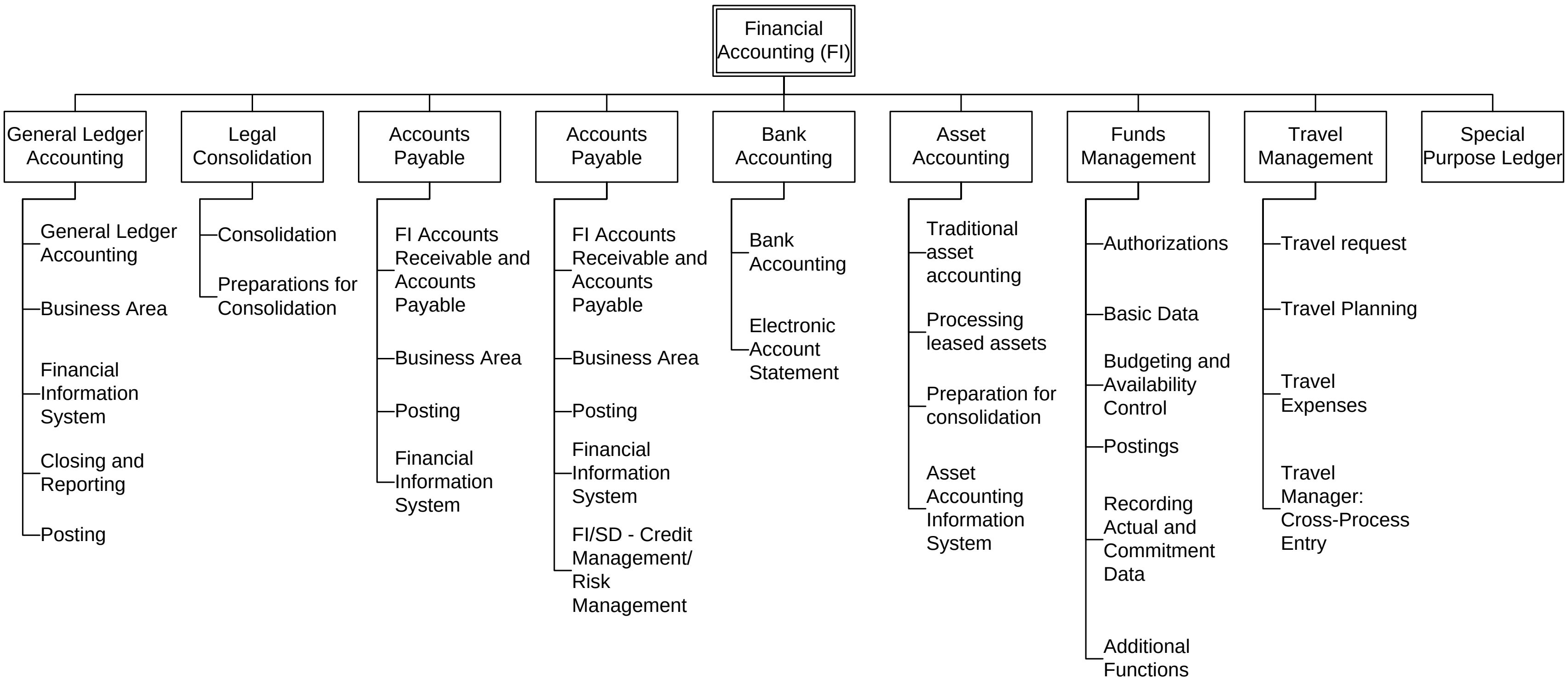


Figure 6.3 Decomposition of the Financial Accounting Module

6.2.4 Fault Tree Modeling and Analysis

The company can follow the general principles stated in Chapter 5 or establish its own criteria to screen ERP system components for fault tree modeling. Indeed, not all ERP system components need to be included in the fault tree model for risk assessment. Since some components are designed for general purpose, they may even not be useful in the company, for example, the shipping component in the SD module. If there is a close fit between a component and the current business practices in the related department of the company, the need for software customization, business process reengineering, and user training may be limited to a minimal level, thus renders the probability of component failure to be very small. In these cases, the component may be excluded from the fault tree modeling. After screening the components of ERP systems, a fault tree model is constructed as displayed in Figure 6.4. It is simplified for the purpose of the study and could be substantially expanded to include many lower level events. The selection of gates is based on the company's aversions to ERP system usage failures. Please note that G2 is a k-out-of-n (2 out of 4) gate, that is, the output event will be true if 2 of the 4 input events occurs.

The probabilities of basic events are roughly estimated according to the original project plan with specified timeframe and resources. The probabilities of component failures are shown in Table 6.2.

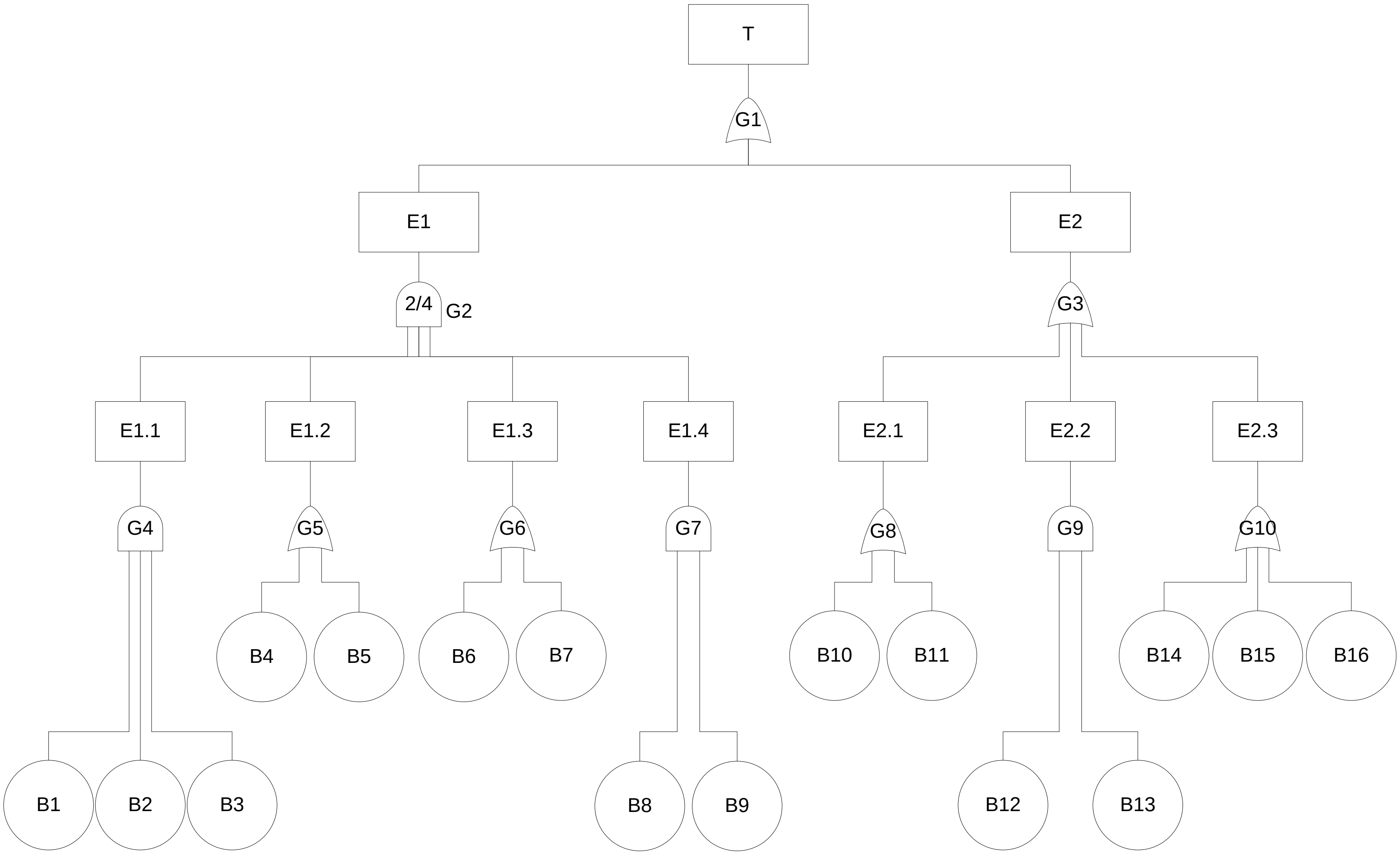


Figure 6.4 Fault Tree Modeling of SAP ERP in the Company A

Table 6.2 List of Events and Probability Estimates for Figure 6.4

Code in the fault tree	Event: *Failure of Component*	Probability of Occurrence
T	ERP System	
E1	Combination of E1.1 to E1.5	
E1.1	CO module	
B1	Cost center accounting	0.02
B2	Activity-based costing	0.10
B3	Profitability analysis	0.05
E1.2	SD module	
B4	Pricing and conditions	0.10
B5	Billing	0.05
E1.3	QM module	
B6	Quality inspection	0.02
B7	Quality control	0.10
E1.5	PP module	
B8	Capacity planning	0.05
B9	Materials requirements planning	0.30
E2	Combination of E2.1 to E.3	
E2.1	FI module	
B10	General ledger accounting	0.01
B11	Legal consolidation	0.05
E2.2	MM module	
B12	External service management	0.10
B13	Inventory management	0.20
E2.3	PS module	
B14	Claim management	0.05
B15	Resources	0.02
B16	Workflow	0.10

Let G_i , i = 1,2,…,11, denote the output at gate **G1**, **G2** to **G11**, E_j denote the state indicator variable of event **Ej**, and B_k denote the state indicator variable of basic event **Bk**, k = 1,2,…,16,. From the fault tree in Figure 6.4, the top event can be represented by:

$$\boldsymbol{T} = \boldsymbol{G_1} = \boldsymbol{G_2} + \boldsymbol{G_3}$$

$$= \text{at least 2 gates out of } (\boldsymbol{G_4}, \boldsymbol{G_5}, \boldsymbol{G_6}, \boldsymbol{G_7}) + (\boldsymbol{G_8} + \boldsymbol{G_9} + \boldsymbol{G_{10}})$$

$$= (\boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3}) \bullet (\boldsymbol{B_4} + \boldsymbol{B_5}) \bullet (\boldsymbol{B_6} + \boldsymbol{B_7})' \bullet (\boldsymbol{B_8} \bullet \boldsymbol{B_9})'$$

$$+ (\boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3}) \bullet (\boldsymbol{B_4} + \boldsymbol{B_5})' \bullet (\boldsymbol{B_6} + \boldsymbol{B_7}) \bullet (\boldsymbol{B_8} \bullet \boldsymbol{B_9})'$$

$$+ (\boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3})' \bullet (\boldsymbol{B_4} + \boldsymbol{B_5}) \bullet (\boldsymbol{B_6} + \boldsymbol{B_7}) \bullet (\boldsymbol{B_8} \bullet \boldsymbol{B_9})'$$

$$+ (\boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3}) \bullet (\boldsymbol{B_4} + \boldsymbol{B_5})' \bullet (\boldsymbol{B_6} + \boldsymbol{B_7})' \bullet (\boldsymbol{B_8} \bullet \boldsymbol{B_9})$$

$$+ (\boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3})' \bullet (\boldsymbol{B_4} + \boldsymbol{B_5}) \bullet (\boldsymbol{B_6} + \boldsymbol{B_7})' \bullet (\boldsymbol{B_8} \bullet \boldsymbol{B_9})$$

$$+ (\boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3})' \bullet (\boldsymbol{B_4} + \boldsymbol{B_5})' \bullet (\boldsymbol{B_6} + \boldsymbol{B_7}) \bullet (\boldsymbol{B_8} \bullet \boldsymbol{B_9})$$

$$+ (\boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3})' \bullet (\boldsymbol{B_4} + \boldsymbol{B_5}) \bullet (\boldsymbol{B_6} + \boldsymbol{B_7}) \bullet (\boldsymbol{B_8} \bullet \boldsymbol{B_9})$$

$$+ (\boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3}) \bullet (\boldsymbol{B_4} + \boldsymbol{B_5})' \bullet (\boldsymbol{B_6} + \boldsymbol{B_7}) \bullet (\boldsymbol{B_8} \bullet \boldsymbol{B_9})$$

$$+ (\boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3}) \bullet (\boldsymbol{B_4} + \boldsymbol{B_5}) \bullet (\boldsymbol{B_6} + \boldsymbol{B_7})' \bullet (\boldsymbol{B_8} \bullet \boldsymbol{B_9})$$

$$+ (\boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3}) \bullet (\boldsymbol{B_4} + \boldsymbol{B_5}) \bullet (\boldsymbol{B_6} + \boldsymbol{B_7}) \bullet (\boldsymbol{B_8} \bullet \boldsymbol{B_9})'$$

$$+ (\boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3}) \bullet (\boldsymbol{B_4} + \boldsymbol{B_5}) \bullet (\boldsymbol{B_6} + \boldsymbol{B_7}) \bullet (\boldsymbol{B_8} \bullet \boldsymbol{B_9})$$

$$+ (\boldsymbol{B_{10}} + \boldsymbol{B_{11}}) + (\boldsymbol{B_{12}} \bullet \boldsymbol{B_{13}} \bullet \boldsymbol{B_{14}}) + (\boldsymbol{B_{15}} + \boldsymbol{B_{16}})$$

The expression is made very complicated because of the introduction of voting (k-out-of-n) gate; otherwise it would be much simpler. Using a bottom-up direct method and assuming mutual independence among basic events, we can calculate the probability of the top event (ERP system usage failure) as follows:

$$P(\boldsymbol{T}) = \mathbf{0.022+0.06+0.02+0.17 = 0.272}$$

Through disaggregating the probability of the top event, we can quantify and differentiate the impacts of individual components on ERP system usage failure. The critical components for the ERP system implementation in the company are identified as the general ledger accounting and legal consolidation component within the Financial Accounting module and claim management, resources, and workflow components within the Project Systems module based on the analysis. Additional components such as material requirement planning and inventory management are also worth attention due to their high likelihood to fail.

6.2.5 Top ERP Implementation Risk Factors in Company A

The company's aversion to different types of ERP system implementation failures is elicited and ranked in the semi-structural interview. The failure to deliver expected business benefits is the most unacceptable; the second one is low user satisfaction, followed by budget exceeding and project delay; the failure to meet system design objectives or requirements was ranked the fifth, and project abandonment was considered the least disastrous among these negative outcomes.

According to the completed questionnaire, the top risk factors in the ERP implementation project are listed and ranked in Table 6.3. For those risk factors that were considered to have a severe impact on the ERP implementation success, most of them did not occur frequently in the project. Moreover, the risk events that have high likelihood of occurrence, their negative impacts were viewed as insignificant or moderate. This fact may have contributed to the success of the ERP implementation project in company A.

Table 6.3 Top Risk Factors: Company A

Grade	Likelihood of risk occurrence in the ERP project of the company	Severity of negative impact to cause ERP system implementation failure
1	Inadequate IT system maintainability and upgradability	Low top management support & involvement
	Inadequate legacy system management	Inadequate training and instruction
	Organizational misfit	Ineffective communication system
	Low key user involvement	Inadequate IT system maintainability and upgradability
	Technical complexity	Inadequate financial management
2	Inadequate ERP selection	Inadequate legacy system management
	Inadequate IT supplier stability and performance	Ineffective strategic thinking and strategic planning
	Ineffective communication system	Organizational misfit
	Lack of information sharing or integration with non-ERP systems	Low key user involvement
		Technical complexity
		Lack of information sharing or integration with non-ERP systems
		Cultural and environmental issues

6.3 Case Study B

6.3.1 Overview of Company B

Company B is a large financial service firm in Brazil; it is a major player in the consigned credit (repayments debited directly from salaries) business sector in the country. In 2007, the company had a portfolio of 1.5 billion Brazilian reals (about 810 million US dollars), over 600,000 active customers, and 850 full time employees. Although the company underwent change of ownership due to acquisitions, it still operates as an independent entity. The company is viewed as a weak or balanced matrix organization where projects do not have a dominant role. Despite the company has many branches across the region, its decision making is highly centralized. Regarding the use of IT in the company, 90% of the businesses were run with licensed software packages and 10% with add-on systems developed in-house.

6.3.2 Description of ERP System Implementation in Company B

Company B deployed an ERP system as its core information system. The ERP system was provided by a domestic vendor called TotalBanco, which is now a part of TOTVS, one of the largest enterprise management software companies in Brazil. Unlike most ERP implementations, the system was phased in by ERP module through a series of projects rather than a single one, as the company had a constant and evolving need to develop, maintain, refine, and upgrade its information system. The cost of the whole ERP system implementation was even not budgeted separately, but rather counted as a part of the regular IT budget of the company; the cost for ERP software acquisition was estimated to be around 1 million US dollars. Also, the major parts of the ERP system implementation took more than 2 years to complete, and further process remodeling/improvement and product delivery continued. The company employed a group of full-time IT staff, and hired consultants from both the ERP vendor and external IT consulting firms including Accenture to work on site for the implementation. The ERP project team consists of key users, business process analysts, system analysts, software developers, and project/product managers.

6.3.3 ERP System Decomposition and Implementation Process

The architecture of the ERP system implemented in the company is shown in Figure 6.5 (TotalBanco, 2007). The system is highly modular and scalable, and there are six major modules: Basics, Legal, Management Control, Credits, Business Systems and Integration with External Systems. The major components and flow and integration of information are displayed in Figure 6.6.

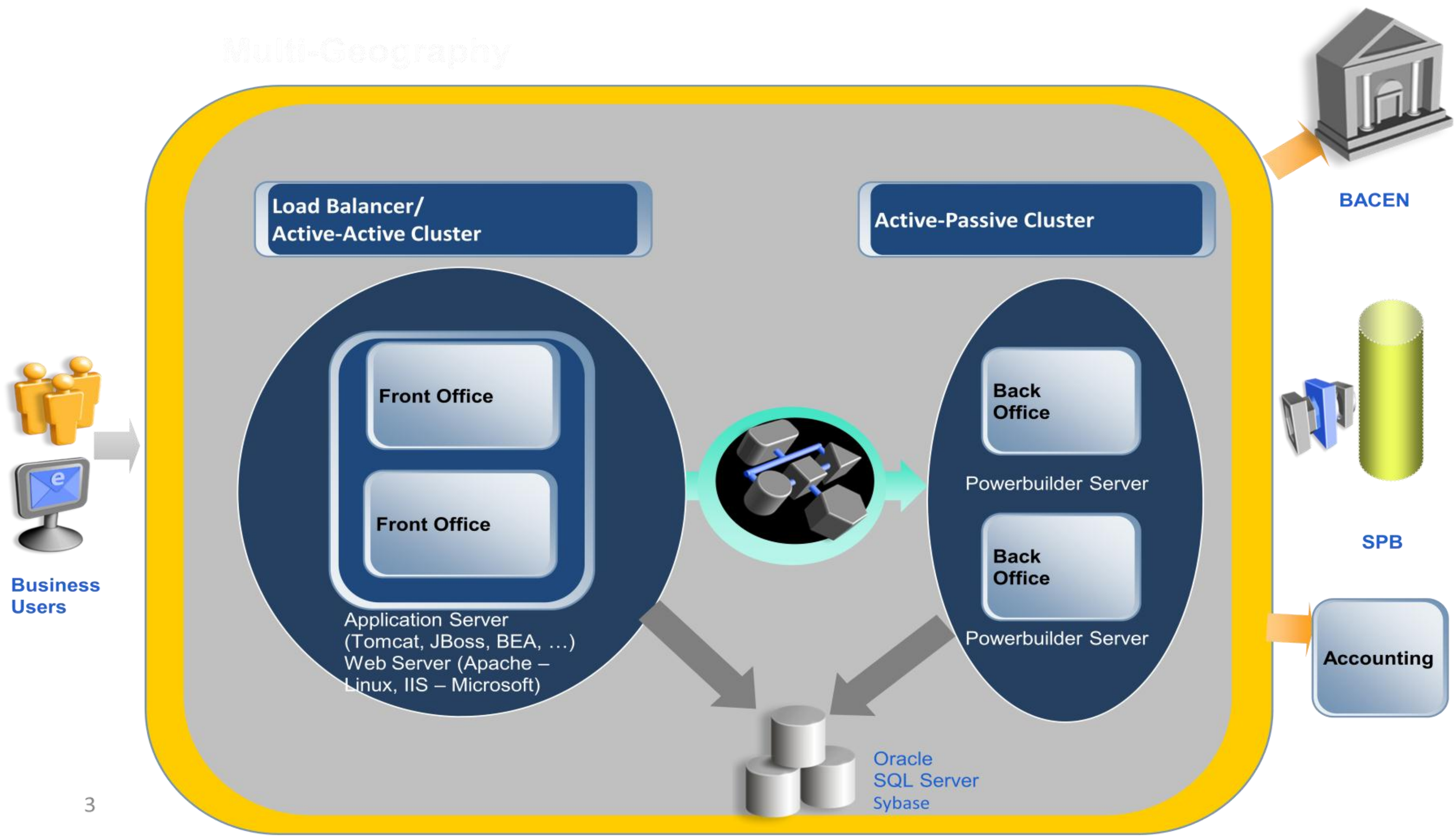


Figure 6.5 Architecture of the ERP System

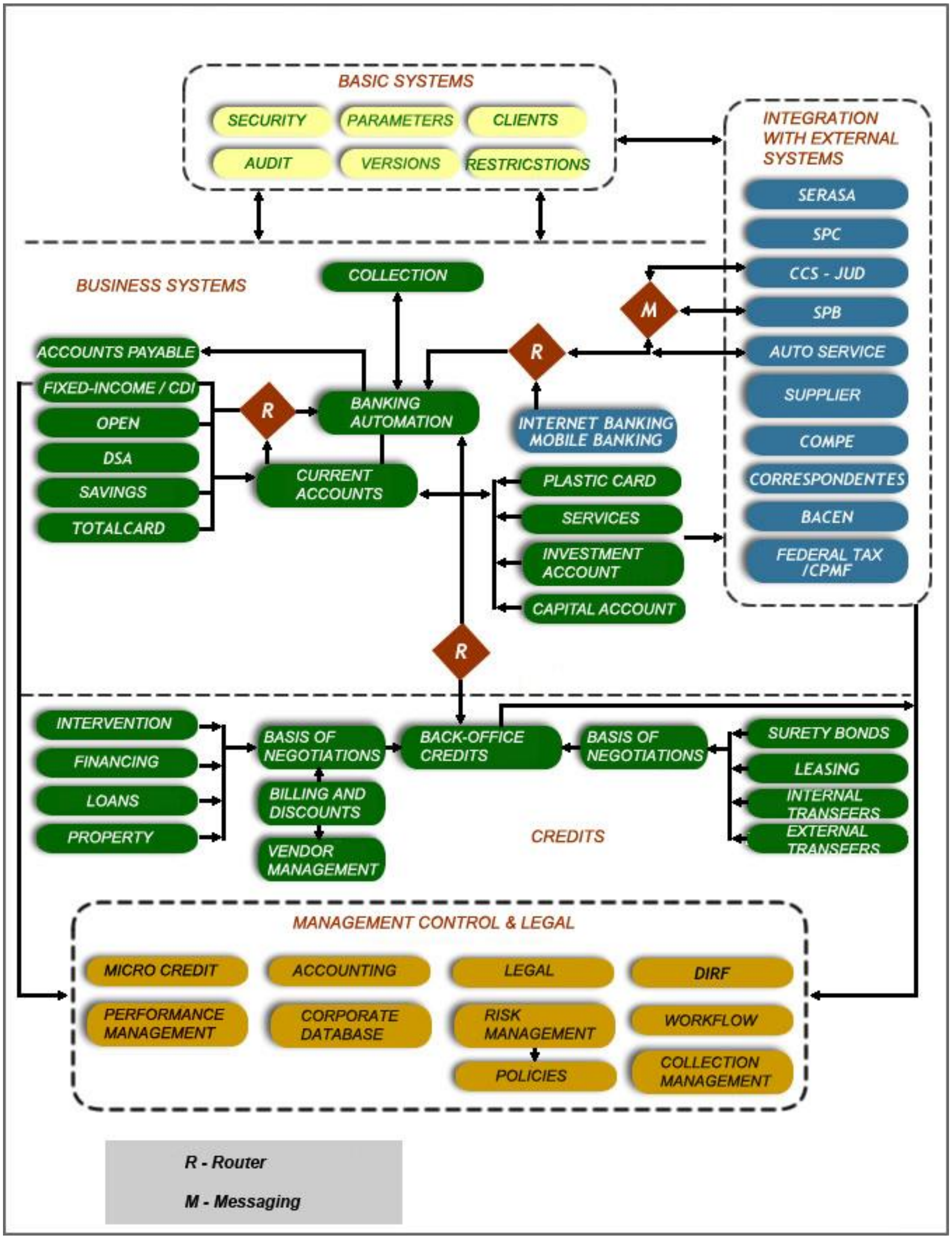


Figure 6.6 ERP System Components and Information Flow

Company B opted to roll out the ERP system by modules. The selection of this implementation strategy was based on the assessment of risks and impacts to the business operations of the company. The importance of reliable and accurate information to a financial service firm was said to be rarely overrated, as any error or loss of information might bring about a huge impact to its customers. Thus the company took extraordinary caution to implement the new system. It established a change committee to review and approve of proposed changes to its current business processes, and define the priorities to deploy different ERP system components. The percentage of software customization was less than 20%, and most of the customization was more parameterization than modifications. Because the ERP vendor was specialized in delivering ERP systems for the banking industry in Brazil, the assumptions defined in the prepackaged system had a good fit for company B, therefore business processes change was also modest. Moreover, vigorous testing was undertaken before new features went alive.

A few approaches were adopted in the company to break down the ERP system into different parts for deployment. Some of the decomposing was carried out by functionality, considering the architecture of the system, as shown the figures above. Others were business processes oriented, particularly in the extensional development after the major implementation project, each business process redesign and implementation was considered as a separate project. An additional way for ERP system decomposing took into account the risks associated with the deployment of each component, and the people who have the ability to tackle the risks. Either way, the ERP system implementation can be structured in such a way that each basic component corresponds with specific risks, stakeholders and delivery requirements, which makes it possible to construct a fault tree for risk assessment. While the modular structure of the ERP system can help construct a fault tree model, due to the lack of more detailed information, the step of fault tree analysis is not furthered for this company.

6.3.4 Top ERP Implementation Risk Factors in Company B

Company B had strongest aversion to the failure of the ERP system to deliver expected business benefits and meet specific design objectives, both of which were ranked the No. 1 must avoidable failure. Failure to lead to higher client/customer satisfaction was considered the third most unacceptable, because the system were planned to better serve and retain its customers as well. The fourth were project completion over the budget or behind the schedule, which were tied. Failure to lead to high user satisfaction was a less concern, and abandoning an ERP project was the least unacceptable result compared with others. Among the risk factors, there are 7 risk factors were considered to have very severe impact (highest ranking) to lead to ERP implementation failure, which are listed at Table 6.4. The probability of occurrence of various risk factors had certain dependencies, including the organizational maturity to adopt ERP and implementation methodology (or strategy) assumed by the vendor and used in practice. Those factors that are more probable to occur are shown in Table 6.5.

Table 6.4 Top Risk Factors by Severity of Negative Impact: Company B

Grade of severity	Risk factor
1	Ineffective strategic thinking and strategic planning Organizational misfit Ineffective project management techniques and practices Ineffective consulting services Inadequate IT supplier stability and performance Inadequate IT system capabilities Low key user involvement
2	Poor leadership Inadequate training and instruction Ineffective communication system Inadequate IT system maintainability and upgradability Poor project team composition and skill mix

Table 6.5 Top Risk Factors by Likelihood of Occurrence: Company B

Grade of likelihood of occurrence	Risk Factor
1	Organizational misfit Low top management support & involvement and lack of a project champion Low key user involvement Ineffective strategic thinking and strategic planning
2	Ineffective project management techniques and practices Inadequate IT supplier stability and performance Inadequate IT system capabilities Inadequate IT system maintainability and upgradability Inadequate legacy system management Lack of information sharing or integration with non-ERP systems

6.4 Case Study C

6.4.1 Overview of Company C

Company C is a private medium-size general contractor located in the mid-Atlantic area of the United States. It has about 120 employees, dispersed at 2 branches and 4 site offices (at the time of ERP adoption evaluation), and generating 40 million US dollars annually. Like the majority of construction businesses, the organizational structure of the company is almost purely projectized, that is, projects are the dominant organizing form. Due to its size and concentration on the regional markets, decision making in the company are normally centralized. The legacy information system of company C was highly fragmented. It used a variety of software applications provided by different vendors, to meet the different needs for information technology in its business. These standalone software applications had little, if any, integration among each other.

6.4.2 Description of the Attempted ERP System Implementation

The top management of company C evaluated an initiative to adopt an ERP system to overcome the fragmentation of information and business processes in the company. There were two modules that are of interest to the company: accounting/financials and project management. The company then narrowed its choice of ERP vendors to two leading players in the market – SAP and JD Edwards (a subsidiary of Oracle Corporation) and requested for proposals and quotations. The company was asked by the ERP vendors to at least commit 240,000 US dollars for software licensing of the two modules, while other costs were not considered yet.

If the ERP adoption was finally approved and initiated, the company planned to carry out the implementation using both parallel and phased rollout. In other words, it would simultaneously use the new ERP system and part of the legacy system that was intended to be substituted eventually for some time, and phase the ERP system in from one branch to the other, and to new site offices as well. The company intended to rely solely upon its small in-house IT staff and the support from the selected ERP vendor, without resorting to the service of external consultants. It did not plan any software customization, either. As a result, it would have to undergo extensive changes to its current business processes. The company also scheduled to complete the implementation within 18 months, 6 of which would be spent on parallel operations.

However, the initiative of ERP system adoption was not approved by the top management in the end. Based the decision-making model proposed by Negahban (2008), there are a number of prohibitive criteria that may hinder the adoption of ERP systems: cost, time, functionalities, and security. For the attempted ERP implementation project in company C, the primary prohibitive factor was the cost that was viewed too high, as the company had limited capital for IT spending. Besides, according to the interview, while the company expected lots of benefits from the ERP system, mostly intangible benefits such as increased efficiency of data entry and reporting and probably improved productivity, it had no specific measurement to evaluate the benefits against the cost. Due to numerous reports that ERP system implementation project were over the budget more than often, the top management of company C was hardly assured or convinced that the project, if approved, would be completed with the budget goals met.

6.4.3 Perception of ERP Risks in Company C

Among a few ERP system implementation outcomes, completion within budget was considered to be the most important to company C, followed by benefit realization, on-time delivery, and user satisfaction. When asked about the aversion to different failures, failure to deliver expected benefits and complete within budget are ranked the NO. 1 and NO. 2 most unacceptable result, respectively, followed by failure to meet system design requirements, delay in completion, and failure to gain user satisfaction. Again, project abandonment was viewed as the least concern compared with other types of failure.

Because the company did not proceed with the implementation, only the perceived severity to cause ERP system implementation failure was assessed for different risk factors. They are shown in Table 6.6. Among the list of top risk factors, lack of top management support & involvement was considered as the one that has the most significant impact to the approval and initialization of the ERP project, and should the project was approved, it would be the critical factor that may impede the ERP system implementation from success.

Table 6.6 Top Risk Factors by Severity of Negative Impact: Company C

Grade of severity	Risk factor
1	Low top management support & involvement and lack of a project champion Inadequate financial management
2	Inadequate change management Poor leadership
3	Ineffective strategic thinking and strategic planning Bad managerial conduct Inadequate business process reengineering Ineffective communication system Low key user involvement Poor project team composition and skill mix

6.4.4 ERP Adoption Decision Making with System Usage Risk Assessment

As aforementioned, the primary reasons against ERP system adoption in company C were the relatively high cost compared with the limited financial resources of the company, the low confidence in benefit realization, and the concerns about budget exceeding. Simply put, it was benefits versus costs. Despite the method proposed by Murphy & Simon (2001) to use cost benefit analysis for ERP project evaluation, a large amount of the benefits brought by the adoption of ERP systems are neither tangible nor quantifiable (Skibniewski & Zeng, 2010). The difficulty to capture and measure ERP benefits makes it rarely feasible to calculate the return on investment (ROI) in ERP system adoption using traditional financial techniques. The observation that over 60% of ERP system implementation projects did not achieve the return on investment identified in the project approval phase by Ptak & Schragenheim (2004) indicates the high rate of ERP failure based on this particular criterion on one hand, but also implies that return on investment may not be relevant or applicable as a criterion to judge ERP success on the other hand. Lucas (1999) hence points out that "Not all investment in IT should be expected to show a measurable return, and investment can have value to an organization even without demonstrable financial return." This is particularly true for strategic IT like ERP system.

Since company C is most concerned at the benefit delivery of the ERP system, we can use the proposed risk management approach with fault tree analysis to calculate the probability of system expectation failure, which is a proxy of the failure to deliver business benefits. The company planned to limit software customization to a minimal extent, and it aimed to substantially reengineer its current business processes to accommodate the ERP system. Thus the business benefits would be realized primarily through the improvements in work efficiency, effectiveness, and productivity associated with the new functionalities provide by ERP system and the changes in business processes and practices. After obtaining detailed information about the modules and their functionalities to deploy, the management of the company can have realistic expectations on the upcoming changes and improvements, which are embodied in, or brought by, various ERP components. They can then decide the minimum acceptable success for each level of components, considering the cost of ERP implementation. The ERP system is decomposed to a level where the changes and improvements should be evaluated independently but not further separated. As a result, a fault tree model can be constructed to assess ERP system expectation failure.

In order to proceed with the calculation, it is necessary to estimate the probabilities of basic component failures (assume the 1st approach is used for fault tree modeling). The company needs to establish specific metrics to judge the success or failure of basic component in delivering business benefits. For example, if the ERP vendor promised the payroll application of the system can shorten the duration of payroll processing for the whole company from 3 days to 2 hours, which became the expectation of the management (anticipated success), it may turn out that 4 hours were necessary with some minor data entry. This would still be acceptable. However, if it took 8 hours, which exceeded the bottom line of the management's expectation of 6 hours (minimum acceptable success), the component would be considered to encounter expectation failure. Therefore, estimating the probability of basic component expectation failure should be conducted with the predefined metrics kept in mind.

6.4.5 ERP System Decomposition in Company C

As mentioned above, company C considered two ERP vendors, one of which was SAP. An ERP system that is marketed by SAP for project-based firms in the Engineering & Construction industry is modeled using fault tree analysis (SAP, 2010). Due to the limited IT budget of company C, it only considered two ERP modules for implementation: accounting/financials and project management. These two modules are indeed indispensable to the information needs of project-based firms. Each module is decomposed into a few levels of functional component. Moreover, only those components that are considered important and relatively prone to failure are listed. Some other components, such as cost elements, labor and time data recording, and document management, are not included in the fault tree analysis based on the assumption that the magnitudes of their failure probabilities are much smaller. The system is illustrated in Figure 6.7. The decomposition may be further refined, as long as the components can be evaluated independently. For example, the project scheduling component should include a variety of application tools that enable end-users to choose from different scheduling techniques, such as Critical Path Method, Gantt chart, and so on. But the present form is sufficient for fault tree analysis, as the methods required to conduct fault tree analysis depend on the types of gates and structure of the fault tree rather than how detailed the system is decomposed.

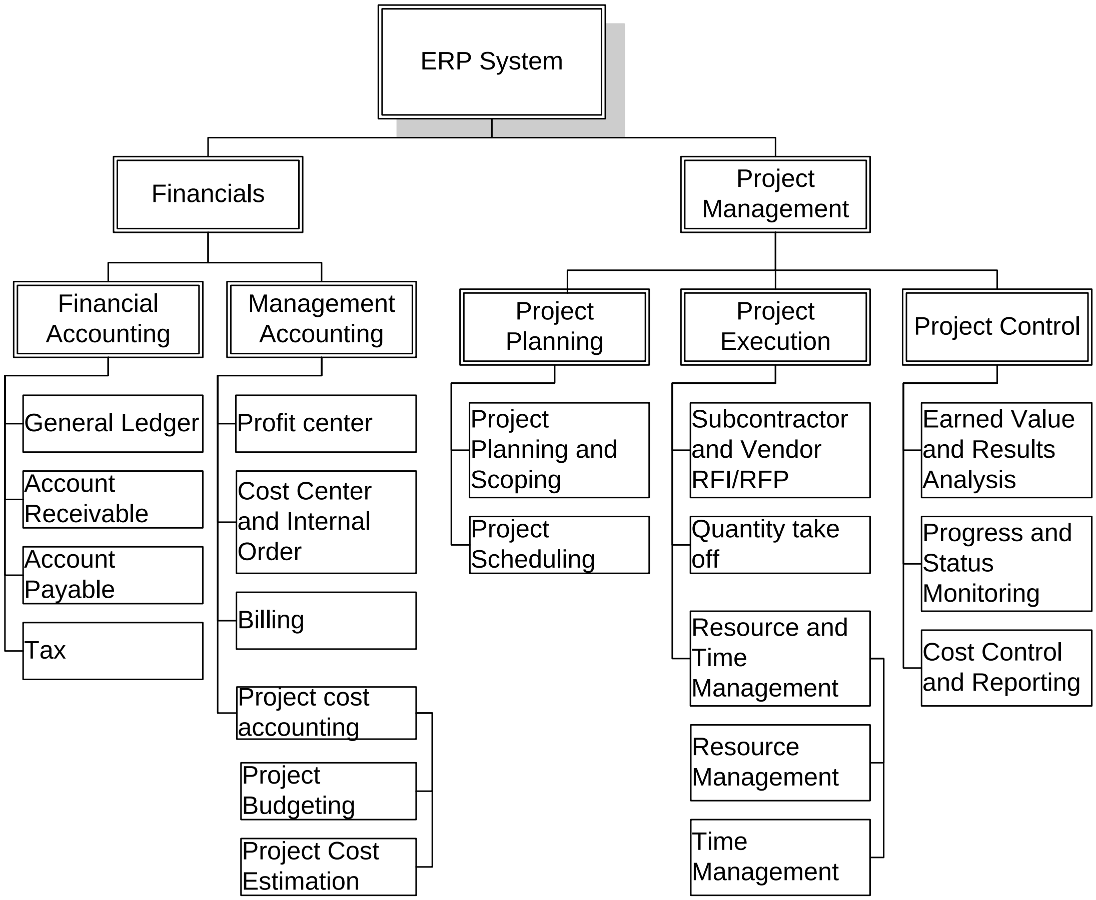


Figure 6.7 ERP Components for Fault Tree Construction and Analysis

6.4.6 Fault Tree Construction and Evaluation

The 1st approach demonstrated in Figure 5.12 is used to convert ERP component failure into fault tree events. There are connections between different components in the ERP system. For example, the component of project cost control and reporting needs data from generated by the project budgeting component. Thus, if the cost control and reporting is further decomposed, it should include its interaction with the project budgeting component. However, it is treated as a basic component in the study, and its failure causes are not fully identified yet, thus the interaction is not taken into account in the fault tree construction, unless it results in the failure of an intermediate component rather than a basic component.

Based on the system decomposition results, we can select appropriate gates to construct a fault tree. The selection of gates depends on the requirements and expectations of the hosting organization from the implemented ERP system. In this study, because both the financials module and the project management module are essential for project-based firms, an OR gate is used under the top event; that is, the system cannot be successful when either of the modules fails. The same rationale applies to the underlying components of the project management module. In the lower levels, the definition of component failure differs, which is also reflected on the selection of gates as both AND and OR gates are mixed. In fact, the AND and OR gates are the most commonly used gates. The fault tree diagram for the ERP system is depicted in Figure 6.8. In the figure, **T** represents the top event – ERP system usage failure, **E** means intermediate events, and **B** stands for basic events. Table 6.7 lists the codes and their corresponding events in the fault tree.

Table 6.7 List of Events in the Fault Tree

Code in the Fault Tree	Event: *Failure of Component*	Probability of Occurrence
T	ERP System	
E1	Financials Module	
E1.1	Financial Accounting	
B1	General Ledger	0.05
B2	Account Receivable	0.05
B3	Account Payable	0.05
B4	Tax	0.10
E1.2	Management Accounting	
E.1.2.1	Combination of B5, B6 & B7	
B5	Profit Center	0.05
B6	Cost Center and Internal Order Accounting	0.05
B7	Billing	0.10
E.1.2.2	Project Cost Accounting	
B8	Project Budgeting	0.10
B9	Project Cost Estimation	0.25
E2	Project Management Module	
E2.1	Project Planning	
B10	Project Planning and Scoping	0.05
B11	Project Scheduling	0.10
E2.2	Project Execution	
B14	Subcontractor and Vendor RFI/RFP	0.10
B15	Quantity Take-off	0.15
E.2.2.1	Resource and Time Management	
B12	Resource Management	0.05
B13	Time Management	0.10
E2.3	Project Control	
B16	Earned Value and Results Analysis	0.10
B17	Progress and Status Monitoring	0.05
B18	Cost Control and Reporting	0.02

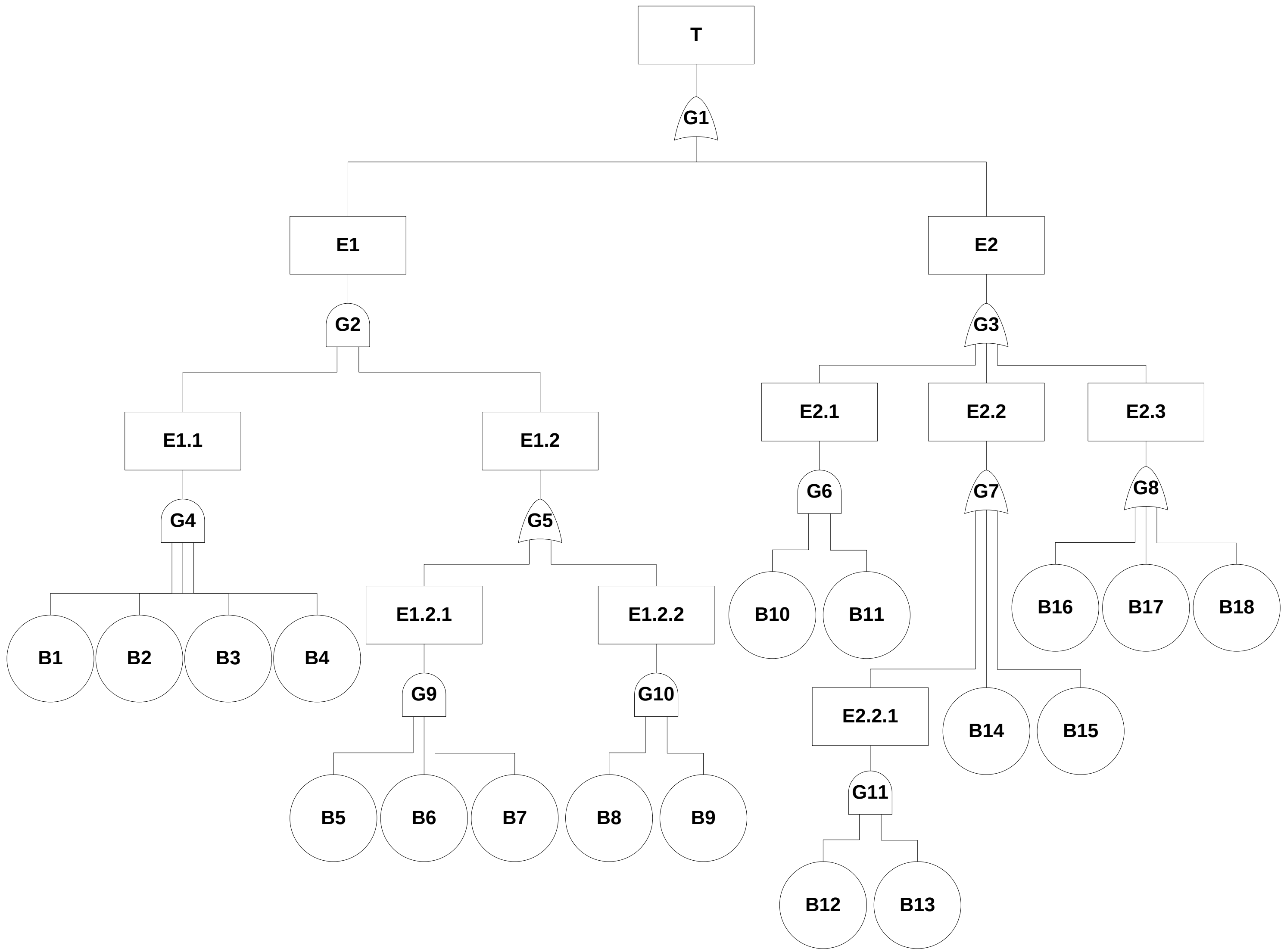


Figure 6.8 Fault Tree Modeling for ERP System Adoption

Let $\boldsymbol{G_i}$, $\boldsymbol{i}$ = 1,2,…,11, denote the output at gate **G1**, **G2** to **G11**, $\boldsymbol{E_i}$ denote the state indicator variable of event **Ei**, and $\boldsymbol{B_i}$ denote the state indicator variable of basic event **Bi**. From the fault tree in Figure 6.8, the top event can be represented by:

$$\boldsymbol{T} = \boldsymbol{G_1} = \boldsymbol{G_2} + \boldsymbol{G_3} = (\boldsymbol{G_4} \bullet \boldsymbol{G_5}) + (\boldsymbol{G_6} + \boldsymbol{G_7} + \boldsymbol{G_8})$$

$$= (\boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3} \bullet \boldsymbol{B_4}) \bullet (\boldsymbol{G_9} + \boldsymbol{G_{10}})$$

$$+ [(\boldsymbol{B_{10}} \bullet \boldsymbol{B_{11}}) + (\boldsymbol{G_{11}} + \boldsymbol{B_{14}} + \boldsymbol{B_{15}}) + (\boldsymbol{B_{16}} + \boldsymbol{B_{17}} + \boldsymbol{B_{18}})]$$

$$= (\boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3} \bullet \boldsymbol{B_4}) \bullet (\boldsymbol{B_5} \bullet \boldsymbol{B_6} \bullet \boldsymbol{B_7} + \boldsymbol{B_8} \bullet \boldsymbol{B_9})$$

$$+ [(\boldsymbol{B_{10}} \bullet \boldsymbol{B_{11}}) + (\boldsymbol{B_{12}} \bullet \boldsymbol{B_{13}} + \boldsymbol{B_{14}} + \boldsymbol{B_{15}}) + (\boldsymbol{B_{16}} + \boldsymbol{B_{17}} + \boldsymbol{B_{18}})]$$

Applying the Boolean logic rules, we can obtain the minimal cut set representation as follows:

$$\boldsymbol{T} = \boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3} \bullet \boldsymbol{B_4} \bullet \boldsymbol{B_5} \bullet \boldsymbol{B_6} \bullet \boldsymbol{B_7} + \boldsymbol{B_1} \bullet \boldsymbol{B_2} \bullet \boldsymbol{B_3} \bullet \boldsymbol{B_4} \bullet \boldsymbol{B_8} \bullet \boldsymbol{B_9} + \boldsymbol{B_{10}} \bullet \boldsymbol{B_{11}}$$

$$+ \boldsymbol{B_{12}} \bullet \boldsymbol{B_{13}} + \boldsymbol{B_{14}} + \boldsymbol{B_{15}} + \boldsymbol{B_{16}} + \boldsymbol{B_{17}} + \boldsymbol{B_{18}}$$

Provided that the probabilities of basic events are known, we can calculate the top event probability either using the direct method to climb up the gates along the fault tree, or using rare event approximation because the minimal cut sets has been identified and these basic events can be assumed to be independent from each other. Apparently, the latter is less laborious to carry out. As mentioned above, the probabilities of basic events need to be determined beforehand. Table 6.7 gives the probabilities of the occurrence of all basic events.

Given the assumption that there is no correlation between different basic events, the probability of the top event can be calculated as follows:

$$\boldsymbol{P(T) = \sum_{i=1}^{7} P(C_i)}$$

$$= \boldsymbol{P(B_1 \cap B_2 \cap B_3 \cap B_4 \cap B_5 \cap B_6 \cap B_7) + P(B_1 \cap B_2 \cap B_3 \cap B_4 \cap B_8 \cap B_9) + P(B_{10} \cap B_{11}) + P(B_{12} \cap B_{13}) + P(B_{14}) + P(B_{15}) + P(B_{16}) + P(B_{17}) + P(B_{18})}$$

$$= 0.453$$

From the calculation above, one can find that even though the project cost estimation component has the highest probability to fail, the minimal cut set it belongs to contributes little to the top event. In contrast, the component of quantity take-off, despite less prone to fail than the project cost estimation and earned value analysis components, is critical for the whole system. Hence, the calculation of top event probability not only helps understand the risk of the system, but also makes it possible to analyze the impact of each basic event to the top event, in other words, to identify the vulnerabilities of the system.

6.5 Summary & Common Findings of the Case Studies

6.5.1 Aversion to ERP System Implementation Failure

A common finding from the case studies is that these companies were most averse to the failure of ERP system to deliver expected benefits. Among the mentioned benefits were integration within the whole organization, reduction or elimination of duplicate data entry, and possible improvement of corporate performance. However, there seemed to be a lack of detailed definition of ERP benefits, particularly about the improvements of performance and productivity, and there was little, if any, specific measurement of benefits after the implementation was completed. Project abandonment was considered the least unacceptable failure among the list, and other types of ERP project failures were in the middle, in which failure to meet planned design objectives or requirements were viewed as more unacceptable than cost exceeding and delay of completion. These findings suggest that, while completing an ERP system implementation project on time and at budget is important, ensuring the quality of the implemented system so that it functions as designed and delivers the benefits as expected should be the focus of the ERP system implementation project. That is exactly what the proposed risk management approach aims to address.

6.5.2 Top ERP Implementation Risk Factors

The case studies confirm top management support and involvement as one of the most significant factors, or just the most important one in the early stage, in ERP system implementation projects, which is documented in numerous studies, such as Akkermans & Van Helden (2002), Jarvenpaa & Ives (1991), and Somers & Nelson (2004). Lack of top management commitment is indeed the foremost factor that made the strategic initiative of implementing an ERP system aborted in company C; it was also among the top risk factors in the ERP implementation in company A and B. Its importance is mainly due to the severity of impact to cause ERP implementation failure. Without sustained top management support and involvement, the ERP project may not be able to secure sufficient resources and dedicated involvement from key users, nor may it assure interdepartmental communication and cooperation. Further, it makes it more difficult to ensure adequate strategic thinking and planning for the ERP project, and to introduce changes to entrenched business processes and practices. In other words, lack of top management support and involvement can be regarded a major root cause to other risk factors in ERP system implementations. However, it would be unwise to suggest that top management is omnipotent in guaranteeing ERP implementation success. Middle management and other staff, especially key users, are at least as important, but they will play different roles (Akkermans & Van Helden, 2002). Moreover, it is found in the case studies that the likelihood that sustained top management support and involvement are not in place varies from company to company. As the significance of top management commitment and active involvement is ubiquitously documented in literature and increasingly known to practitioners, the question shifts from whether they are in place to how to make sure they are in the right place at each stage of the ERP project so as to bolster the chance of ERP implementation success.

A second critical risk factor that is common in the case studies is inadequate financial management. Even though company B does not rank it as a top risk factor, the lack of a separate budget and active monitoring of ERP project cost itself is a demonstration of inadequate financial management. It is found in all of the three companies that the focus of budgeting and cost controlling is put on software acquisition and licensing, which only a portion of the total ERP project cost. In addition, the hidden cost of ERP system implementation, such as disruption to business operations and temporary decline in productivity, was seldom recognized and recorded. Inadequate financial management can directly cause implementation process failure rather ERP system usage failure, thus it is of less concern in ERP fault tree modeling to avoid system usage failure.

Based on the case studies, we can further identify additional risk factors that have relatively more severe adverse impact on ERP system implementations. Among them are ineffective strategic thinking and planning, ineffective communication system, low key user involvement, followed by inadequate training and instruction, organizational misfit, and inadequate IT system maintainability and upgradability. It must be noted that the sample size is too small to generalize the findings, which is the limitation of the case study method.

Compared with the survey results by Akkermans & Van Helden (2002), poor project team composition and skill mix and ineffective project management techniques and practices appear to have less severe impact as project-based firms are specialized in project team building and execution. In addition, external stakeholder relationship management is not considered critical because the ERP system is mostly targeted for internal use; legal and regulatory risks and multi-site issues are also of least concern to the companies.

One important finding is that, in general, non-technical risk factors have more severe negative impact on ERP system implementation outcomes than technical (or technological) factors. This corroborates the notion that ERP system implementation is, first and foremost, a management concern, before it becomes a technical concern. Indeed, technical mindset is cited as one of the sub-risk factors under "poor leadership" (Al-Mashari & Zairi, 2000).

It is found in the case studies, especially the one in company A, that risk factors with severe negative effects do not necessarily have higher probabilities to take place in reality. Many studies on ERP risks management to date appears to have evaluated and ranked the risk factors based on the degree of importance (Akkermans & Van Helden, 2002), which is semantically more aligned with the severity of impact rather than the likelihood of occurrence, although this is often not clarified. As the degree of risk is determined not only by the severity of negative impact but also the probability of occurrence, the finding that risk factors with severe negative impact may not have high probabilities to occur has significant implications. It suggests that determining their threats, or "criticality", of various risk factors to cause ERP implementation failure, and subsequently devising risk response strategies, must consider both of the severity of impact and their probabilities.

6.5.3 Decomposability of ERP System and Its Failure

The case studies confirm the decomposability of ERP systems, which is the ability to be broken down into various parts or components for the purpose of design, customization, coding, testing, and training, though this may not apply to installation. It is a common practice to break down an ERP system for implementation, as different applications are designed to work for different functional departments, business processes, and end users. The modular and hierarchical architecture of ERP systems also makes it a natural choice to decompose the system and its possible usage failure for risk analysis and evaluation.

6.5.4 Component Selection for Fault Tree Modeling

As stated in Chapter 5, not all of the ERP system components need to be selected for fault tree modeling. While this is still valid, it is found in the case studies that, if the ERP components screening takes place before the failure mode of each non-basic component is defined in the form of component failures on its lower level, the management would be inclined to overstate its aversion to risks. For example, if an intermediate ERP component has 10 lower level components, but only 2 are chosen for fault tree construction and the other 8 are deemed nearly impossible to fail, the company may tend to judge either one of the 2 selected components' failure as a failure of the component on the upper level - an OR gate would be assigned, if they are the only components that are brought for judgment. In contrast, if all of the 10 components are presented, the management would have full recognition of the stakes and make more realistic requirements. Indeed, the definition of failure mode for each non-basic component, to some degree, depends on the expectations and requirements of the company to achieve ERP system usage success under the constraint of project plan, particularly subject to the given timeframe and limited resources.

6.5.5 Validation of the Proposed Risk Management Approach

The proposed risk management approach was put into practical use in the case studies. While the approach was new to practitioners, the underlying ways of thinking were understandable, because they had to break down the ERP system into different pieces for implementation. It is also sensible to estimate the probabilities of basic components with taking into considerations the conditions, such as available resources, scheduled deadlines, and technical complexities, etc. However, a discrepancy was found in these cases between ERP system decomposition and the Work Breakdown Structure (WBS) of the same project. In spite of many overlaps, the development of work breakdown structure and subsequent project schedule were not always in line with the way that the ERP system was decomposed, for example, by functionality or by business process. Besides, the number of breakdown levels may differ for the same module or application. For example, a module may have five lower levels of components, but it is only broken down to the second in the WBS and subsequent project scheduling. As a consequence, the mismatch between ERP system decomposition and Work Breakdown Structure (WBS) may make it difficult to estimate the probabilities of basic component failures as the conditions are uncertain.

Because of uncertain conditions resulting from the above described mismatch and the difficulty to fully replicate the details of historical EPR implementations, a simplified approach was assumed in the case studies in order to construct fault tree models for the ERP projects. The ERP system decomposition was undertaken on middle to high levels, and only approach 1 (see Figure 5.12) was used to treat basic component failures as basic events in the fault tree. After detailed explanations about the rationales, the procedures to utilize the proposed risk management approach were followed to complete the construct fault tree models, and the probabilities of ERP system usage failure were obtained with the input basic event probabilities estimated. Overall, the construction and depiction of fault trees were based on the experiences of ERP system implementations in the companies. The results of the fault tree evaluation gave both qualitative and quantitative interpretations for the vulnerabilities of the ERP system implementations and established direct connections between ERP components and risks. Particularly, the identification of critical components was considered very helpful to direct limited resources of the company to deal with risks in a more effective manner. In sum, the applicability of the proposed risk management approach has been verified in the case studies, and its usefulness in practice has also been demonstrated and recognized. However, there are still certain limitations to use the proposed approach in practice, which will be discussed in the last chapter.

7 ERP System Implementation Risk Management Strategies in Project-Based Firms

7.1 Introduction

The risk factors identified and described in Chapter 4 and the proposed approach to assess the impact of component failure on the whole system using fault tree analysis in Chapter 5 provide a foundation for active risk management in real-world ERP implementations. The efforts of risk analysis, assessment and evaluation help understand the origination, likelihood of occurrence, and severity of risks that may cause failures in ERP components and implementation activities, and thus enable practitioners to make effective use of limited resources and take appropriate measures to deal with these risks. This chapter presents a number of practical strategies to prevent, mitigate, and minimize the risks of ERP implementations in project-based firms. While the principles of risk management strategies are found in existing studies, they are elaborated in the settings of ERP implementation projects. Moreover, the ERP risk response and treatment strategies directly rely upon the results of fault tree modeling and analysis of ERP risks, and also maintain close and dynamic interaction with the latter.

7.2 Guidelines for Application of ERP Fault Tree Analysis in Practice

The case studies reveal that lots of corporate IT and/or ERP practitioners have little knowledge about fault tree analysis. Therefore, it is necessary to establish basic guidelines for the application of the proposed approach in the practice of ERP implementation risk management, as complements to the principles and processes of the approach detailed in the previous chapters.

7.2.1 Bottom-line vs. Maximal ERP System Usage Success

The risk management approach is proposed to ensure the bottom line of ERP system implementation, that is, to prevent ERP system usage failure. This should be distinguished from the effort to achieve maximal ERP system usage success. The success or failure of ERP projects, like the majority of other IT or engineering projects, are more than often measured in terms of cost and schedule performance. The underlying assumption for such measurement is that the required quality of work is eventually fulfilled. As a consequence, the high rate of ERP project failure in the forms of cost and schedule overrun that are reported in different statistics implies that, given the planned time frame and budget, the tasks in the ERP projects cannot be fully completed, or the system usage performance does not meet the minimal requirements. Thus only after the ERP system usage failure is avoided, maximizing ERP implementation success is made possible.

7.2.2 Alignment between WBS and ERP Decomposition

It is found in the case studies that there may be a misalignment between ERP system decomposition and Work Breakdown Structure (WBS) of the ERP project. The criteria for ERP decomposition and project work breakdown may differ from each other, and ERP decomposition might be carried out to a level lower than the lowest of WBS, which means that the ERP components are not planned separately and thus makes it more difficult to obtain reliable probability estimation for fault tree analysis. In order to resolve this issue, it is necessary to align the development of WBS with the decomposition of ERP system. Such alignment not only helps the project team to undertake thorough project planning and scheduling for ERP system implementation, but also assures that the estimations of basic event probabilities are made with sufficient information.

7.2.3 Dedicated Resources for ERP Risk Management

Because of the complexity of fault tree analysis and its unfamiliarity to lots of IT practitioners, it is suggested that the ERP project team should commit dedicated resources that are knowledgeable of the principles and processes of the proposed approach to conduct ERP risk management. Specific training may be required. Risk management should be included in the whole process of ERP system implementation, especially in the early stages. Because the proposed approach not only requires the inputs of the ERP project team, but also those from important stakeholders such as functional management and key users that are outside of the project team, risk management using this approach should be carried out formally by the dedicated resources and well communicated throughout the organization.

7.2.4 Consistence in Fault Tree Modeling

ERP fault tree must be developed with consistence assured. Because the proposed approach is as good as the input data, the selection and screening of ERP components and their failures, the selection of fault tree gates, and the estimation of probabilities for basic events should follow the same preset ground rules and proceed with due diligence to the same degree for different ERP components. For example, while there are a number of techniques to elicit the practitioners' opinions on probabilities of basic events, it is recommended that a single technique should be used for the modeling of the entire ERP fault tree as possible as one can.

7.3 Implications of ERP Fault Tree Analysis Results

The results of fault tree analysis of ERP system implementations can be interpreted at two levels. At the system level, the probability of the entire ERP system usage failure can be obtained by quantitative evaluation of the fault tree, thus make it possible for executives of the hosting organization to make informed decisions on ERP project initiation, termination, and high-level system requirement changes. At the component level, the implications of fault tree analysis depend on the approach that was adopted in fault tree construction. As described in the last chapter, there are two basic approaches, which a third one is the mix of them. The difference in these two approaches is that the second requires one to incorporate the risk events to component failures into the fault tree and thus directly assess the impact of these risk events on system failure, while the first approach indicates that the causes are either too elusive to be included in the fault tree or will be identified on a later stage. If approach 1 is used, the root causes to ERP system usage failure can be traced back to individual components, and the relative importance of different components in system implementation can be measured in an objective manner. As a result, the components whose failures have more severe impact and higher probability of occurrence on the whole system would draw more attention from management and thus secure necessary resources to ensure their success. The next step would be to identify the causes to component failures, followed by appropriate treatment of these causes. In case that it is difficult to pinpoint the direct causes to possible component failure, one can still make sure that the implementation of key ERP components is carefully planned, adequately staffed, and vigilantly monitored. If approach 2 is used, that is, the direct causes (risk events) to component failures are listed and analyzed in the fault tree, one can identify and rank the most risky causes to ERP system failure, and thus take corresponding actions either preventing the occurrence of these causes or mitigating their impacts.

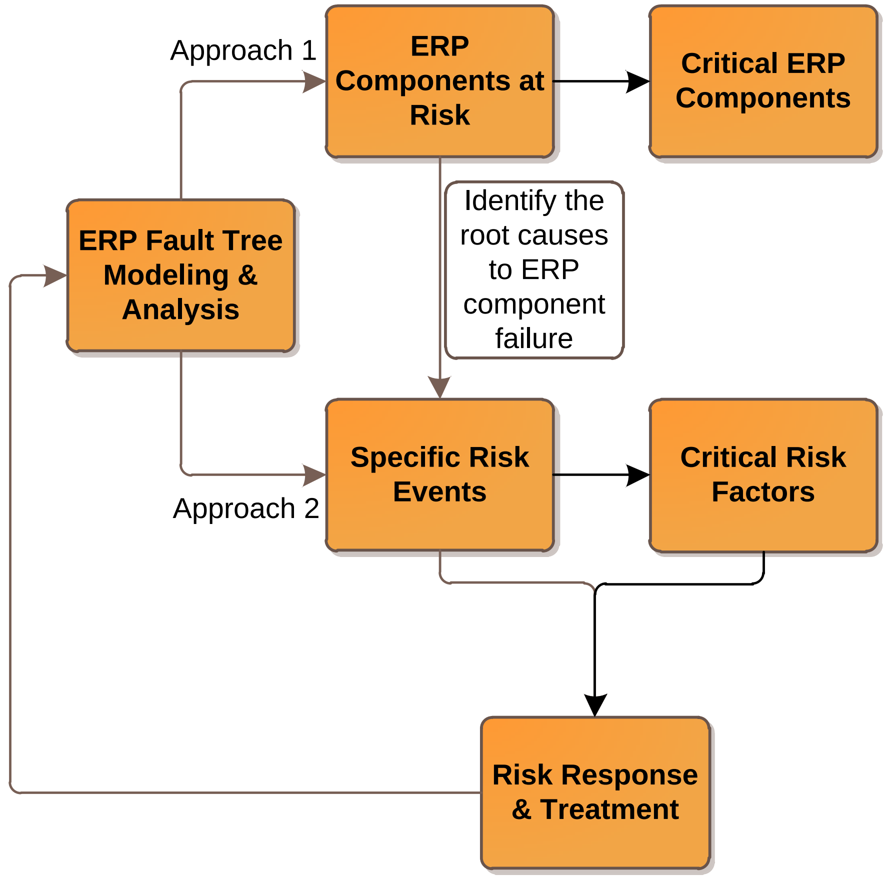


Figure 7.1 Connection between ERP Fault Tree Modeling and Risk Response

7.4 ERP Risk Response and Treatment Strategies in Project-Based Firms

7.4.1 Scheme of Risk Management Strategies

Based on the results of risk analysis and evaluation, one can formulate suitable strategies to respond to and treat ERP implementation risks. The purpose of such strategies is to either decrease the likelihood that risk events would occur or reduce the potential severity of loss - especially financial loss - as much as possible should the risk events take place, or both. They may also involve monitoring and controlling the risks until the completion of the ERP project. These strategies must be developed in accordance with the specific nature and consequence of each risk factor, and thus for different risks they may differ more or less. The formulation and implementation of these strategies must also take the organizational characteristics of the firms into account.

There are a number of risk response and allocation strategies that are described in lots of studies on risk management (Al-Bahar & Crandall, 1990; Baker, Ponniah, & Smith, 1999; Haimes, 2009): risk retention, risk avoidance, risk reduction, and risk transfer. These strategies are discussed in the following sections. Additional approaches such as insurance and financial derivative instruments, although commonly used in risk management practices, are likely to be not applicable in ERP system implementation in project-based firms due to the lack of counterparty.

7.4.2 Risk Avoidance

Risk avoidance, also known as risk elimination, literally means that the activities associated with the risks are not carried out to completely avoid the risk exposure. As an ERP system is disaggregated into diverse components for the purpose of adoption, if fault tree analysis concludes that the implementation of a component has a significant negative impact on system failure, one may simply drop the component from the ERP project. Thus the scope of the project would be changed. In an extreme case, the entire ERP project might be determined to be too risky to initiate. This passive approach to reduce the scope of the ERP project may be neither desirable nor practical in many circumstances because the elimination of risks must come up with the loss of potential rewards or gains that may be derived from assuming that exposure. More often, one can avoid specific risk exposure by improving and optimizing the implementation processes based on the result interpretation of fault tree analysis. For example, if modifying a functional component turns out to be very difficult, one can redesign the corresponding part of business process or job roles of employees instead to circumvent the exposure. Another example is that language barriers can be totally avoided by selecting ERP modules that are prepackaged in local language. However, the number of risks whose exposure can be fully avoided without compromising related potential benefits or bringing about new issues might be limited in reality.

7.4.3 Risk Retention

Risk retention is sometimes referred to risk acceptance; it indicates that the practitioner take no specific measures to deal with the foreseen or unforeseen risks. There are two risk retention methods: active and passive (Carter & Doherty, 1974). Active retention is a deliberate management strategy after a conscious evaluation of the possible losses and costs of alternative ways to handle risks(Baker, et al., 1999). It may also include active risk monitoring. Passive risk retention, in contrast, implies the inability to identify risks, ignorance, negligence, or simply absence of decision and action. As such, the hosting organization must bear the consequences of these risks by itself. There are many risk factors identified in this study, and their impact on different ERP system component and implementation activities differ considerably. Therefore, it would be neither necessary nor feasible to cope with all risks. The risks suitable for retention are those that would produce small losses and occur less than frequently. It is suggested that even those risks occurring frequently but only having small losses are suitable for retention as well (Baker, et al., 1999). If approach 2 is applied in ERP fault tree modeling, one can directly determine the risks to accept. When approach 1 is used, if the contribution of a single component to ERP system failure (the top event) is negligible or very limited, the component can be implemented according to the original plan with its inherent risks retained.

7.4.4 Risk Transfer

It is common in risk management practices to shift specific risks to other parties. Risk transfer can take two different forms: (1) the property or activity is retained, and the financial risk transferred by the means of insurance, warranties, or derivative instruments; (2) the property or activity is transferred (Thompson & Perry, 1992). While insurance is widely used in various projects, there is no counterparty to insure the risks of ERP implementation in the marketplace, nor is there any established method to set a premium for the policy associated with the risks. In other words, risks in ERP implementation are hardly insurable. Thus risk transfer is often undertaken in the form of transferring the risky activities from the hosting organization to a third party that has the specialized expertise and resources to minimize and control the risks, which are consulting firms and ERP vendors in this case. If a part of the ERP system implementation is totally independent from others, it may even be outsourced.

Contractual arrangements are critical to ensure reasonable risk allocation among different parties. If a certain party is the sole source, and thus has complete control of a specific risk, it should be obliged to prevent the occurrence of the risk or mitigate its negative impact. This way of risk transfer can be explicitly stated in contractual agreements, or reached through mutual understanding in an informal manner. For example, the risk of inadequate IT supplier stability and performance may be transferred from the hosting organization to the ERP vendor by including appropriate binding clauses in the purchasing agreement through negotiation in the initialization stage of the ERP project. Besides, the performance of external ERP consultants could be improved by specifying detailed metrics for the service they provide. Some of the risks in ERP project may also be transferred from the ERP project team to the functional departments associated with the risks.

7.4.5 Risk Reduction

Risk reduction is sometimes considered as an extension to risk retention, in that risks are retained but actions are taken to mitigate its potential adverse effect. It takes places when risk avoidance is undesirable and there is no effective way to transfer the risks to other parties, and complete risk acceptance may bring about material loss. In ERP system implementation projects, the majority of risks may have to be treated and mitigated rather than eliminated, transferred or fully retained, thus risk reduction is normally the centerpiece of the overall risk management process.

Risk reduction is achieved either by decreasing the likelihood that the risk events would occur (risk prevention) or by mitigating the severity of losses should they happen (loss reduction), or both. If there are certain conditions that may lead to the presence of the risk, one can prevent its occurrence or at least reduce the probability by removing or containing these conditions. While the maintenance and improvement of physical devices is essential for risk prevention in engineering systems, managerial, technical, educational, and other non-physical adjustment and enhancement in ERP system implementations are more relevant. For each identified risk, one can devise specific counter measures to reduce its likelihood of occurrence, or even avert it entirely. As an example, if the cooperation from a functional department is seen as a potential hazard to the implementation, one can set up meetings in advance and even leverage the support of senior management to ensure the needed cooperation. Moreover, the ERP project team can reallocate resources according to the level of risks and importance of different ERP components.

Loss reduction requires corrective measures to be carefully planned in case of possible risk events and swiftly put into action once they occur. These corrective measures are prepared to resolve the problems caused by corresponding risk events, such as disruptions, misalignments, and errors. The ERP system implementation is either brought back on track according to the original plan, or proceeds with a refined course. Moreover, a contingency plan is often created to provide a buffer against the effects of risks, which mitigates the negative consequence of the risks with a purpose of limiting the losses within an acceptable level. For risks with mild impact that need treatment, detailed risk reduction plans may not be in place, and thus appropriate reactive actions would be required from the ERP project team.

7.5 Implementation of ERP Risk Management Strategies

7.5.1 Selection of Response Strategy for Risk Factors

The determination of risk response strategy at first depends on the nature and characteristics of the risk itself. Whether the risk is avoidable, transferrable, or treatable would limit the choice the ERP project team may have in dealing with it. Also, the probability and severity of potential loss are the two most important variables in choosing risk response and treatment strategies. Figure 7.2 illustrates that the magnitude of risk depends on the combination of these two variables. While the probability of risk is a positive number between 0 and 1, the severity of loss could be negative, which indicates that the risk event would be beneficial to the project.

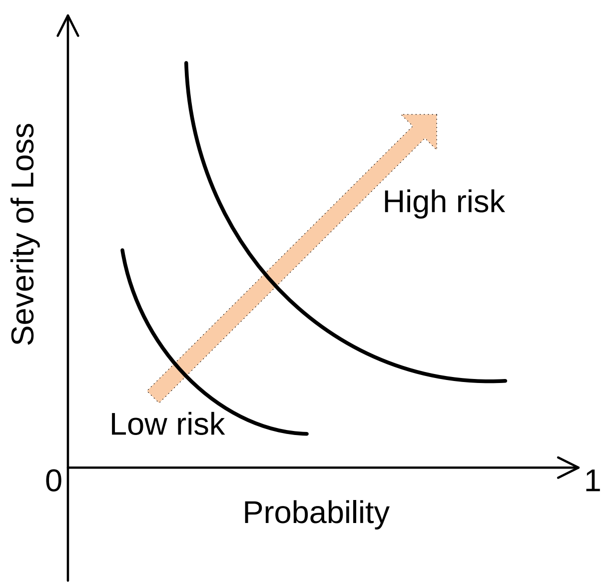


Figure 7.2 Magnitude of Risks

Table 7.1 shows a typical framework for choosing risk response strategies in ERP projects, depending on the probability of occurrence and severity of loss. The framework is helpful for the ERP project team to deal with risk events in ERP system implementations if the severity of loss caused by the risk events can be quantified or approximated. While insurance is mentioned to be a likely unavailable option, it would be highly desirable if the risk is insurable and the loss might be severe, so it is included in the table. The table is an illustration partially adapted from Flanagan & Norman (1993) and Baker, et al. (1999), and the strategies to handle risks will change from project to project.

Table 7.1 A Typical Framework for Determining Risk Response Strategy

Severity of Loss	**Likelihood of Occurrence**				
	Improbable	Rare	Possible	Probable	Very Likely
Negligible	Retention	Retention	Retention	Retention	Retention
Small	Retention	Retention	Partial Transfer	Partial Transfer	Partial Transfer, Reduction
Moderate	Retention	Partial Transfer, Reduction	Transfer, Reduction	Transfer, Reduction	Transfer, Reduction
Large	Transfer (Insurance)	Transfer, Reduction	Transfer, Reduction	Transfer, Reduction	Transfer, Reduction, Avoidance
Disastrous	Transfer (Insurance)	Transfer (Insurance)	Avoidance	Avoidance	Avoidance

7.5.2 Selection of Risk Response Strategy for ERP System Components

If approach 2 is used in ERP system fault tree modeling and the critical causes to component failures are not yet enumerated, one can decide the strategies to manage the risks associated with basic ERP components based on the probability of component failure and its impact on system failure. The minimal cut set representation obtained from Boolean algebraic calculations in the fault tree analysis provides analytical insights into the relationship between each possible component failure and system failure. There are three different forms that a basic component failure (basic event of the fault tree) may be included in the minimal cut set:

- A component might not be included in the minimal cut set, or even excluded from the fault tree construction. Hence, its impact to system failure is minimal, but certainly its success is still desirable. This kind of component is of least concern for ERP system implementation risk management.
- A minimal cut set may represent a sole critical component or critical risk event (cause to component failure), thus the probability of component failure directly augments the likelihood of ERP system usage failure. In other words, this component is critical to ERP system success and its associated risks should be carefully managed and vigilantly monitored.
- A component may have to be combined with other components in the minimal cut set representation through the AND operator. The expression normally takes the form $\boldsymbol{B_i} \bullet \boldsymbol{B_{j_1}} \bullet \ldots \bullet \boldsymbol{B_{j_n}}$, where $i \neq j_1 \neq \cdots \neq j_n$. The

risk of the component to system failure is reflected in the collective impact of the combination. If a component's probability of failure ($\boldsymbol{B_i}$) is large but those of other components $\boldsymbol{B_{j_1}}$,…, $\boldsymbol{B_{j_n}}$ are very small, the product of these probabilities would still be small, which indicates that the threat posed by the failure of these components to ERP system success is limited. Risk response among these combined components should be focused on those with relatively large probabilities.

The following two tables show typical frameworks to deal with individual component risks so as to reduce the probability of system failure. Again, they are for illustration purpose and the actual risk management strategy should be devised on a case-by-case basis.

Table 7.2 Risk Response Strategy for Basic Component

Form in the Minimal Cut Set	**Probability of Basic Component Failure (Basic Event $\boldsymbol{B_i}$)**				
	Improbable	Rare	Possible	Probable	Very Likely
Excluded	Retention	Retention	Retention	Transfer, Reduction	Reduction, Avoidance
Independent (Critical component)	Retention	Retention, Transfer, Reduction	Transfer, Reduction, Avoidance	Reduction, Avoidance	Avoidance

Table 7.3 Risk Response Strategy for Combined Basic Component*

Probability of Combination $B_i \bullet B_{j_1} \bullet \ldots \bullet B_{j_n}$	**Probability of Basic Component Failure (Basic Event B_i)**				
	Improbable	Rare	Possible	Probable	Very Likely
Improbable	Retention	Retention	Retention	Retention, Reduction	Transfer, Reduction
Rare		Transfer, Reduction	Retention, Transfer, Reduction	Transfer, Reduction	Transfer, Reduction, Avoidance
Possible			Transfer, Reduction	Transfer, Reduction, Avoidance	Avoidance
Probable				Transfer, Avoidance	Avoidance
Very Likely					Avoidance

* This is for basic event $\mathbf{B_i}$ only.

7.5.3 ERP Project Planning for Risk Management

As discussed in Chapter 5, the probabilities of ERP system component failures and occurrence of their direct causes are estimated given the resources committed to the deployment of the component, particularly human resources with specialized skills. They are also dependent on the scheduled duration according to ERP project plan. While other activities, such as communication planning, in the project planning phase may also be relevant with the probabilities of ERP component failures, project schedule and resources allocation are the two major activities that must be given to conduct probability estimation and may need adaptation now and again. Therefore, ensuring adequate resource and realistic project scheduling would help reduce some of the probabilities of failure. Also, the results of fault tree analysis can help make adjustments to the project plan and optimize the utilization of available resources. For example, if the probability of failure for a specific ERP component can be decreased with the scheduled duration of related implementation activities extended, the ERP project team can adjust and improve project scheduling reflecting the need for risk reduction. Also, the project team may shift some resources from components of low risk to those with high risk exposure. Figure 7.3 below illustrates the interaction between project scheduling and resource allocation in the project planning phase and probability estimation, which is essential to ERP fault tree modeling.

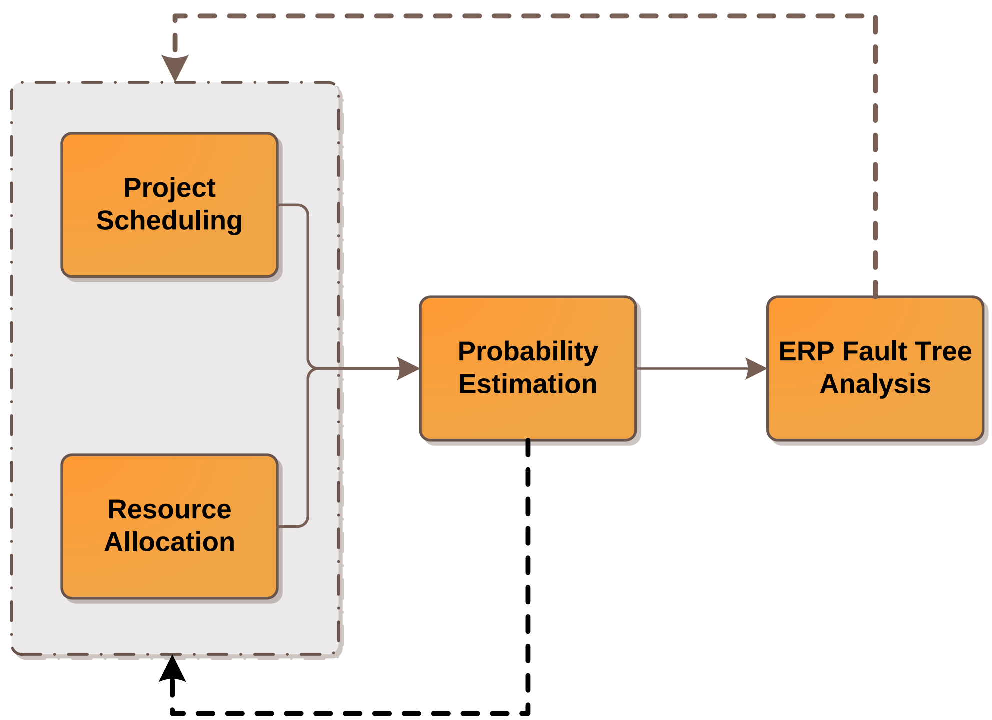


Figure 7.3 Interaction between Project Planning and Risk Management

7.5.4 Key ERP Implementation Decisions Associated with Risks

There are a number of important decisions in ERP projects that are essential to the processes and ultimate outcome of ERP system implementations. These decisions are made either by senior management of the hosting organization or by the ERP project team. They are closely associated with the sources of major ERP risks. As a result, it is very helpful for ERP risk management to ensure that the key decisions are wisely made and carefully executed.

The first key decision is the selection of ERP vendors and modules that fit the strategic goals and business needs of the hosting organization. Adopting an ERP system means much more than purchasing software: the hosting organization must, for the most part, accept the vendor's assumptions about management philosophy and business practices that are embedded in the ERP system and change existing processes and procedures to conform to them (Umble, et al., 2003). Without adequate organizational fit, the ERP system implementation might turn out to be disastrous. In addition, since ERP consultants play a crucial role in the implementation process, it is also important to recruit consultants with specialized expertise.

Second, the choice of implementation strategies is important to ERP system implementation success. There are a number of major ERP implementation strategies: Big Bang (direct cutover), phased implementation, parallel implementation, and pilot implementation (Schniederjans, Hamaker, & Schniederjans, 2004). Big Bang indicates that the implementation takes places in a single instance, with the existing system removed totally and the new ERP system installed. Phased rollout means the new system is phased in by module, by business unit, or by location, and users move onto the new system in a series of steps over an extended period of time. Parallel implementation indicates that the legacy system and the new system operate simultaneously until the new system is fully functional and the legacy system can be discontinued. Pilot implementation refers to that the new system is implemented in one part of the business operation as a trial. According to a recent survey, phased rollout, Big Bang and the combination of both were used by 89% of ERP implementations projects (Neal, 2010). Adapted from Eason (1988), Table 7.4 illustrates the difference among the implementation strategies, in which pilot implementation is not included, and "critical mass" means that the ERP system givens little benefit until a large number of functionalities or users has been achieved.

Table 7.4 Implementation Strategy Matrix

	Revolution	⟶	*Evolution*
Strategy / Criteria	Big Bang	Parallel Implementation	Phased Rollout
Need for "critical mass"	Big	⟶	Small
Need for risk control	Low	⟶	High
Need for facilitation of change	Low	⟶	High
Pace of changeover	High	⟶	Low
Local design needs	Low	⟶	High
User adaptation	Difficult	⟶	Easy

In addition, as stated above, the level of software customization and the extent of business process reengineering (or called business process customization) are two major determining factors on the magnitude of risks associated with the ERP system and its components. Table 7.5 shows a framework of customization options, which is proposed by Luo & Strong (2004) .

Table 7.5 Options for Software Customization and Business Process Change (Luo & Strong, 2004)

		Process Customization Options		
		No Change	**Incremental Change**	**Radical Change**
Technical Customization Options	**Module customization**	**No customization** Business process fits the system process, no customization necessary	**Process Adaptation** System process is ideal and business process is close to it.	**Process Conversion** System process is ideal and business process is far from it
	Table customization	**Fit System to Process** Business process change not necessary Fit system process to business process	**Mutual Adaptation** Mutual adjustment: system process and business are close, minor modification to both can achieve fit	**Fit Process to System** Minor system process changes, redesign business process to system process
	Code customization	**System Conversion** Business process change not desirable, Customize system process to business process	**System Conversion and Process Adaptation** Minor business process changes are desirable customize system process to business process	**System and Process Reengineering** Total redesign of business and system processes

7.6 Chapter Summary

This chapter describes the practical strategies that can be used in ERP system implementation risk management in project-based organizations. There are a number of risk response and treatment strategies that aim to avoid, transfer, reduce or fully retain the risks. They must be formulated and implemented based on the probability and consequences of their occurrences, with the nature of risks associated with ERP system implementations taken into account. Since the probabilities of risk event occurrences are dependent on the project plan, adjusting and optimizing the project plan in the form of schedule change and resource allocation can help reduce the probability of high-impact risk events or component failures, thus mitigate the risk to cause ERP system usage failure.

8 Conclusion and Discussions

8.1 Summary of the Study

8.1.1 Identification and Qualitative Analysis of ERP Risk Factors

Despite its potential to bring tremendous benefits, the implementation of ERP systems is prone to failure, as having been reported in numerous studies. This is one of the major reasons for the low adoption of ERP systems in project-based firms. Two different types of ERP system implementation failures are defined: implementation process failure and system usage failure, the latter of which is the focus point of this study.

The study provides a comprehensive identification of risks inherent in ERP system implementations within project-based organizations. Since there have been few studies that specifically address the ERP system implementation risks in project-based firms, most of the risk factors that have been documented in literature for generic ERP system implementations are considered to apply to project-based firms. Additional risk factors, such as organizational misfit, multi-site issues, stakeholder involvement and relationship management, and information integration with non-ERP systems, are identified considering the often fragmented nature and distributed work practices of such firms. The risk factors are qualitatively described, and their potential impacts to cause ERP system implementation failures are analyzed. Moreover, the 26 risk factors are categorized into 6 dimensions, and each of them are further broken down with sub-factors or related problems listed, using a checklist approach. The list of risk dimensions, factors, and sub-factors or problems constitutes a taxonomy of ERP risks, which could be used to help fully enumerate the risks in real world ERP system implementations and provide a premise for effective risk management.

8.1.2 Fault Tree Analysis for ERP System Implementations

The proposed risk management approach takes a system perspective on ERP systems and related implementation projects, as ERP systems are modular in structure and often hierarchical. Its underlying rationale is that the effects of risks are imposed on ERP system components, and the accumulation or specific combination of component failures lead to usage failure of the entire ERP system. Therefore, the fault tree analysis method, which is widely used in physical system probabilistic risk assessment, is introduced and modified to model the ERP system and analyze the impacts of risks to cause system usage failure.

The proposed approach at first requires ERP system decomposition to a level where the component can be evaluated independently or to the risk events that cause basic ERP component failures. The components are screened for fault tree construction as some components may not need to be included for analysis. The failures of each non-basic component is defined in the form of component failures on its immediate lower level, primarily depending on the minimum acceptable success required by the management of the hosting organization. There are two approaches to construct a fault tree: one of them turns basic component failures into basic events, and the other one incorporates the causes (risk events) to basic component failures as basic events. Then the probabilities of basic events can be estimated on the conditions of available resources and planned schedule, probably with other factors such the extent of changes and technical complexity taken into account as well. As a result of the completed construction of a fault tree model, one can calculate the probability of the top event and obtain the minimal cut set representation. Further, one can identify the critical components and/or critical risk events to ERP system usage failure, and provide both qualitative and quantitative interpretations about the risks in the ERP system implementation project.

Through case studies in practical settings, the applicability and usefulness of the proposed approach have been verified. With a main purpose to prevent ERP system usage failure and ensure the bottom-line success of ERP systems, the proposed approach can be used as an effective tool to manage the risks in ERP projects.

8.1.3 Aversion to ERP Failure and Top ERP Implementation Risk Factors

It is found in the case studies that the hosting organizations are more averse to ERP system usage failure than to implementation process failure, particularly the failure to meet system requirements and deliver expected business benefits are considered most unacceptable. This suggests that the focus of risk management for ERP implementation projects should be shifted from meeting cost and schedule objectives, which is found in most previous studies, to achieving ERP system usage success that leads to benefit realization.

The case studies also confirm that ERP system implementation is at first a management concern, before it becomes a technical concern; indeed, non-technical risk factors have more severe adverse impact on the outcome of the ERP project than technical factors. Based on the severity of impact, low top management support and involvement and inadequate financial management are regarded as top risk factors, followed by ineffective strategic thinking and planning, ineffective communication system, low key user involvement, inadequate training and instruction, organizational misfit, and inadequate IT system maintainability and upgradability, etc. Furthermore, the risks in ERP implementation projects should be assessed based not only on their severity of negative impact, but also on their probabilities to take place in reality. It is found that risk factors with severe adverse impact may not have high probabilities to occur. Both attributes are taken into account and conjointly assessed in the proposed risk management approach based on fault tree analysis.

8.1.4 Risk Management Strategies based on Fault Tree Analysis

Based on the developed risk management approach with fault tree analysis, one can formulate appropriate strategies to tackle the risks in ERP system implementations. The formulation and implementation of such strategies primarily depend on the probabilities of risks, and on the connection between specific risk events, component failure, and system usage failure. Critical components and critical risk events should be the priorities of risk management. The form of critical ERP components and critical risk events in the obtained fault tree representations, especially in the minimal cut set, provides significant information about the vulnerabilities of the ERP implementation project. In general, the purpose of the strategies is to avoid, transfer, fully retain or reduce the risks. Since the probabilities of component failures or risk events are estimated on certain conditions, a natural choice to reduce such probabilities is to change these conditions, normally in the form of securing sufficient time and resources, which involves revision of the project plans.

8.2 Contributions of the Study

8.2.1 Contribution to the Body of Knowledge

While fault tree analysis method has been widely accepted and used in the probabilistic risk assessment related to physical systems such as nuclear reactors, its application in information system risk management has been rarely documented, nor has its potential been discussed. This study is one of the first attempts, if not the first, to apply the fault tree analysis method to information system risk management.

During the past years, there are a large number of publications addressing risk management issues in ERP system implementations. However, most of the current literature is confined to identifying and discussing the critical success factors or risk factors related to ERP system implementations. An ERP system implementation project is often treated holistically; how the success or failures of different ERP system components are affected by risk factors have been seldom explored. As a result, many existing methods for ERP implementation risk management suffer from an inability to capture the relationship among risk factors, ERP components, and the whole ERP system, and thus a lack of applicability in real-world ERP projects. Moreover, most of extant literature is focused on qualitative analysis of critical factors; quantitative assessment is hardly found. This study thus fills a gap in literature by establishing an approach to explore and evaluate the relationships among system usage failure, component failures, and risk factors, by both qualitative and quantitative means.

In addition, the majority of project risk management researches so far are focused on cost and schedule risks, despite that quality is also an important project constraint defined in PMBOK (PMI, 2008). Since ERP system usage is mostly overlapped with the quality of ERP implementation project, this study can become an addition to the body of knowledge in information system project risk management in quality as well.

8.2.2 Contribution to the Practice of Information System Risk Management

The study provides decision makers and practitioners with a knowledge base and an effective tool to conduct risk management in ERP system implementations in practical contexts. The proposed risk management approach makes it possible to quantify the impact of specific component failures or risk events on system usage failure, and thus help identify critical components and critical risk events. Therefore, the hosting organization can detect the vulnerabilities in the ERP system and its implementation efforts; it can further optimize the allocation of limited resources to tackle the critical risks and prevent the risks from causing implementation failure. Besides, the proposed approach can also help the management of the hosting organization to make better informed decisions on ERP system adoption and the selection of ERP packages and modules. It is noteworthy that, although the proposed risk management approach is developed and tested within project-based firms, its utilization could be extended to other forms of organizations, and to the implementations of some other types of enterprise-wide information systems such as SCM and CRM, as long as they can be broken down into diverse components for implementation and evaluation.

8.3 Limitations of the Study

Although the risk management approach developed in this study is theoretically sound and practically useful, it has several limitations, which are discussed as follows:

- Conversion of continuous variables to binary variables. The success (or failure) of each component and the entire ERP system is in essence a continuous variable, but it was converted to a binary variable in the proposed risk management approach with a threshold (namely the minimum acceptable success) imposed. This is reasonably justified because there appears to be no objective measurement in literature to properly express the state of an ERP system or component in the form a continuous variable. For example, it is hardly possible to put a dollar amount on the benefit that may be brought by an ERP component because it is often intangible and unquantifiable. Besides, there should be a break point when an ERP system or component is judged for success or failure. It is also necessary simplification for the purpose of developing fault tree models. However, the simplification of the state of ERP system and its components might be problematic, as the judgment of a component's state with a holistic view might be different from that obtained by the combination of its lower level components.

- Over-reliance on expert judgment for probability estimation. Probability estimation is crucial in order to obtain valid and useful results from the fault tree analysis. However, there seems to an over-reliance on expert judgment to estimate probabilities of basic events, as demonstrated in the case studies. Historical data about the issues related to major components may be available with ERP vendors and consultants, but such information may not be disclosed. Furthermore, the implementation of ERP systems has seldom been standardized, thus the conditions for the implementation of an ERP component may differ from historical deployment of the same component, which makes the historical statistical information less relevant. Because expert judgment might be biased, it is very important to make sure that the experts have sufficient knowledge and experiences to provide reliable probability estimates, and the process is completed with vigor and consistence.
- Unfamiliarity to practitioners and need of training. As encountered in the case studies, the proposed risk management approach is not familiar to practitioners, thus the utilization of this approach for risk assessment must be preceded by adequate training about its principles and procedures.

8.4 Discussion of Further Studies

It is of both theoretical and practical significance to continue the improvement of risk management in the high-stake strategic information system projects such as ERP system implementations. Following the risk management approach developed in this research, further studies will be undertaken in the two directions outlined below:

- The fault tree analysis method has been introduced and modified to assess ERP implementation risks leading to system usage failure in project-based firms. It can also be used to analyze and assess the risks related to ERP implementation process failure, that is, budget and schedule exceeding. However, since cost and time are continuous variables with well-established measurement, the method must be further revised to incorporate this important nature.
- There are other probabilistic risk assessment techniques that are widely utilized in physical system risk management, especially event tree analysis. Unlike fault trees, event trees are graphical representations constructed using forward logic. It provides an inductive approach that identifies and quantifies the possible outcomes following an initiating event. Event tree analysis can be used for information system risk analysis and management.

The future studies outlined above are natural extensions to this study; they will become meaningful additions to the body of knowledge and further improve the understanding and capability of decision makers and practitioners to successfully implement ERP systems and other types of strategic information systems in business organizations.

Appendices

<u>*Appendix 1: Letter to Request a Case Study*</u>

Date

Name of the Contact
Department, Organization
Address, City, State/Province, Zip Code
Country

Dear *** *(Name of the contact),*

The e-Construction Group, part of the Center for Excellence in Project Management at the University of Maryland, College Park, U.S.A., is conducting a research study on risk management during Enterprise Resource Planning (ERP) systems implementations. We are conducting a number of case studies with ERP systems practitioners who have direct knowledge of and experience with the deployment of such systems in project-based organizations. Thus, we are writing to request your help with a case study based on the experiences of your firm with your ERP system implementation efforts.

The case study involving your firm solicits information about the ERP implementation processes, particularly on how your firm's ERP system has been structured into diverse components for deployment, and how different risk factors are perceived and estimated in terms of their likelihood of occurrence and potential impact. The case study will be conducted in the form of a semi-structured interview over the phone with a simultaneous use of Google Documents online (or face-to-face for local interviews). An estimated time needed for the interview is approximately 90 minutes or less. If necessary, additional questions may follow by email.

Your input will be invaluable to our research effort and our results will be shared with you when the study is complete. Any sensitive information you provide will be kept in strict confidence and used only for the purposes of our analysis. If you kindly agree, please share with us the name and contact information of your organization's leading practitioners in ERP implementation.

Many thanks in advance; we look forward to hearing from you very soon. For correspondence, please use the contact information listed below.

Sincerely yours,

Mirosław J. Skibniewski, Ph.D.
A. James Clark Chair Professor of Construction Engineering & Project Management
Dept. of Civil & Environmental Engineering
A. James Clark School of Engineering
1188 Glenn L. Martin Hall
University of Maryland
College Park, MD 20742-3021, U.S.A.

Yajun (Alex) Zeng
Research Assistant
Tel: 1-301-405-8215
Email: yzeng@umd.edu

Appendix 2: List of ERP Project Archived Materials

The following materials are requested, collected and reviewed before the interview, subject to the availability and the willingness of the firm to share:

- Hierarchical structure (architecture, solution map, breakdown, or other equivalent name) of the ERP system and its modules.
- List of important functionalities for each module of the ERP system implemented in the firm.
- Business process reengineering charts, graphs, and documents.
- ERP implementation project risk management plan.
- Work Breakdown Structure (WBS) of the ERP implementation project.
- ERP implementation project schedule.
- Other documentations that deemed to be important to the implementation.

Appendix 3: Questions for the Case Study Interviews

Date of the Interview

Personal Information of the Interviewee

1. Name of Interviewee

2. Title and Role

3. Involvement in the ERP decision making and implementation

   ☐ Executive sponsor of the ERP project

   ☐ ERP project leader or manager

   ☐ ERP project team member

   ☐ ERP consultant

   ☐ ERP expert or researcher

   ☐ Other - please specify:

Firm Information

Most of the information below is obtained from web search rather than the interview, unless not available from public sources.

1. What is the name of your firm (firm name will NOT be disclosed)?

2. What is the main business of the firm?

3. How many employees do you have in the company?

4. Where is the firm located? Does it have different branches? How many?

5. How much is the annual revenue of the firm?

6. Please briefly describe the organizational structure of the firm. Projectized, strong matrix, balanced matrix, weak matrix, functional?

7. Please briefly describe the decision making system in the firm (centralized, decentralized – corporate, divisional, project levels, mixed…).

ERP System Implementation Processes and Results

8. Please indicate the involvement of the following groups of stakeholders in ERP system implementation in your organization?

2.1 ERP adoption decision making and vendor/module selection

☐ Top management ☐ IT head/director

☐ ERP project manager ☐ ERP project team member

☐ Manager in functional departments/divisions/business projects

☐ Key users of ERP system

☐ ERP consultant

☐ External stakeholder – key clients/customers, suppliers, etc

☐ Other, please specify:

2.2 ERP implementation processes

☐ Top management ☐ IT head/director

☒ ERP project manager ☒ ERP project team member

☐ Manager in functional departments/divisions/business projects

☐ Key users of ERP system

☐ ERP consultant

☐ External stakeholder – key clients/customers, suppliers, etc

☐ Other, please specify:

9. Which of the following ERP implementation strategies is used?

- ☐ Big Bang (Direct cutover)
- ☐ Parallel implementation
- ☐ Phased implementation:
  - ☐ Phased in by modules
  - ☐ Phased in by divisions, plants, or geographies
- ☐ Pilot implementation
- ☐ Other, please specify:

10. If the firm has multiple branches, do you use a one-site or a multi-site structure?

11. What is the ERP system customization percentage (or estimate)? Why is the customization necessary?

12. Please describe the extent of business process reengineering (BPR) to fit ERP system and the percentage of time and budget dedicated to BPR.

13. Do you conduct risk management in ERP system implementation? If yes, what is the general approach?

14. Compared with the original ERP project budget, the total ERP implementation cost in your organization was:

☐ Over budget by 100%+

☐ Over budget by 50~100%

☐ Over budget by 25~50%

☐ Over budget by 5~25%

☐ Almost at budget by ±5%

☐ Under budget by 5~25%

☐ Under budget by 25~50%

☐ Under budget by 50%+

ERP project Budget (estimate):

Alternatively, please provide the budget and actual cost, if available:

ERP project Budget:

Actual total ERP project cost:

15. What are major causes to the difference between the budget and the actual total cost?

16. Please provide the planned and actual duration of the ERP project:

Planned duration of ERP project:

Actual total duration of the ERP project:

17. What are major causes to the difference between the planned and actual ERP project duration?

18. How do you measure the business benefits of ERP systems?

What is the approximate percentage of business benefits that is achieved after the ERP system goes live?

19. Please rate the level of satisfaction on the implemented ERP system:

Corporate executives:

☐ Very satisfied ☐ Satisfied

☐ Neutral

☐ Unsatisfied ☐ Very unsatisfied

End users:

☐ Very satisfied ☐ Satisfied

☐ Neutral

☐ Unsatisfied ☐ Very unsatisfied

ERP Implementation Expectation and System Decomposition

20. Does your organization have clearly defined measure to evaluate the outcome of ERP system implementation?

☐ Yes, please select:

☐ The implemented ERP system meets system design objectives or requirements

☐ The ERP project is completed on time

☐ The ERP project is completed within budget

☐ The implemented ERP system delivers expected business value/benefits

☐ The implemented ERP system leads to high user satisfaction

☐ Other, please specify:

☐ No

21. Please rank the importance to the firm of the following ERP system implementation outcomes:

***1** – most important to the firm*

____ The implemented ERP system meets system design objectives or requirements

____ The ERP project is completed on time

____ The ERP project is completed within budget

____ The implemented ERP system delivers expected business value /benefits

____ The implemented ERP system obtain high user satisfaction

Other, please specify:

22. Please rank your aversion to the following ERP implementation failures:

1 – the firm wants to avoid the most, in other words, the most unacceptable

The implemented ERP system fails to meet system design objectives or requirements

The ERP project fails to complete on time

The ERP project is abandoned

The ERP project fails to complete within budget

The implemented ERP system fails to deliver expected/required business value/benefits

The implemented ERP system fails to lead to high user satisfaction

Other, please specify:

23. ERP system vendor (select all that apply):

☐ SAP

☐ Oracle (including E-Business Suite, PeopleSoft, Siebel, JD Edwards)

☐ Microsoft Dynamics

☐ Sage Group ☐ Epicor

☐ Infor Global Solutions (including SSA Global Technologies, Baan)

☐ Lawson ☐ IFS

☐ QAD ☐ CDC Software

☐ Other - please specify:

24. Does your organization integrate the ERP system with other systems or include the following as ERP system modules?

- ☐ Customer Relationship Management (CRM)
- ☐ Supply Chain Management (SCM)
- ☐ Business Intelligence (BI)
- ☐ Building Information Modeling (BIM)
- ☐ Web-based project management system
- ☐ Other - please specify:

25. ERP system modules / high-level sub-systems implemented or to be implemented:

- ☐ Accounting/Financials
- ☐ Project Management
- ☐ Human Resources Management
- ☐ Sales and Distribution Management
- ☐ Production Management
- ☐ Plant Management
- ☐ Materials Management
- ☐ Other - please specify:

26. Please describe the critical implementation activities of the ERP project, referring to the work breakdown structure (WBS).

27. How do you break down ERP modules into different components/pieces for design, customization, and deployment? By functionality, business process, targeted user or other criteria?

28. Based on the hierarchical overview (provided beforehand and depicted) of your firm's ERP system and after the ERP system is decomposed and assuming that all lower level of components unlisted are deployed successfully, please describe how each level of ERP component is deemed to fail in terms of the failures of lower level of components, using a top-down approach. In other words, what is the minimal acceptable success for each component in terms of lower-level component success?

29. Please list (and if necessary, briefly describe) the major causes to possible failure of the basic components.

30. If the causes to basic component failure are evasive to enumerate, are you able to estimate the probability of basic component failure, given the original project plan? Please give an estimate.

Appendix 4: Questionnaire for Likelihood & Severity Estimation of Risk Factors

Please rate the likelihood of occurrence of the following risk factors and their impact on ERP implementation outcome, in a scale of 0-9: 0 – Unlikely to occur / no impact on system implementation outcome, 9 – certainly to happen / most severe negative impact on implementation.

Dimension of Risks	**Risk Factor**	Sub-factors, Problems, or Instances	Likelihood of Occurrence	Severity of Negative Impact to Implementation
Organizational	**Ineffective strategic thinking and strategic planning**	• Lack of a clear vision (Davenport, 1998) • Lack of IS strategy (Lubbe & Remenyi, 1999; Nutt, 1999; Tallon, et al., 2000) • Absence of strategic analysis and planning • Ambiguous business needs (Yeo, 2002) • Misalignment between ERP and business strategies (Grant, 2003; Papp, 1999) • Little justification of ERP investment (Wang, 2006)		
	Organizational misfit	• Low fit with organizational structure (Morton & Hu, 2008) • Low fit with process, data and user (Hong & Kim, 2002) • Lack of adequate technology infrastructure (Ewusi-Mensah, 1997; Sumner, 2000b) • Readiness for new technology (Keil, et al., 1998)		

		• Insufficiency of resources (Barki, et al., 1993) • Extent of changes (Barki, et al., 1993) • Resistance to changes		
	Inadequate ERP selection	• Inadequate evaluation and comparison of ERP packages and modules: use of proven methodologies, rigorousness of evaluation, involvement of key users and stakeholders • Inadequate evaluation and comparison of ERP vendor		
	Low top management support & involvement and lack of a project champion	• Low top management support and commitment • Low top management participation • Low visibility of top management commitment to employees • Inconsistence of top management support • Top management permanently delegates its responsibilities to technical experts (Ewusi-Mensah & Przasnyski, 1991) • Lack of a steering committee (Somers & Nelson, 2001) • Lack of a project champion (Ngai, et al., 2008; Somers & Nelson, 2001) • Inadequate authority, influence, or skills of the project champion		
	Cultural and environmental issues	• Differentiation of culture and customs • Language barriers • Lack of ownership (Al-Mashari & Zairi, 2000) • Fear of massive manpower reduction (Al-Mashari & Zairi, 2000) • Lack of IT readiness • Unstable organizational environment (Wallace, et al., 2004a) • Corporate politics with negative impact on project (Wallace, et al., 2004a)		
Managerial	**Ineffective project**	• Lack of project success criteria • Inadequate use of proven project management methodologies		

	management techniques and practices	• Poor project planning • Poor project processes design and management • Poor estimation of required resources • Inadequate estimation of project schedules • Project milestones not clearly defined • "Preemption" of project by higher priority project: management unable to resolve conflicting schedule demands (Schmidt, et al., 2001) • Unclear scope • Scope creep • Poor or nonexistent control: no sign-offs, no project tracking methodology, unaware of overall project status, project progress not monitored closely enough • Lack of focused and consistent performance measures (Umble, et al., 2003) • Inadequate project risk management		
	Bad managerial conduct	• Lack of clearly defined and realistic goals and objectives • Goals and objectives not agreed upon • Frequently changing goals and objectives • Failure to manage user and stakeholder expectations • Social commitment (Keil & Montealegre, 2000; Sumner, 2000a; Willcocks & Margetts, 1994)		
	Inadequate change management	• Underestimate the efforts involved in change management (Appleton, 1997; Somers & Nelson, 2001) • Poor design of organizational structure change • Lack of proper mechanism to manage changes • Ineffective use of change tactics: evolutionary vs. revolutionary		

	Poor leadership	• Frequent turnover of managers • Lack of motivation • Lack of empowerment • Inadequacy of status, authority and influence of leaders • Lack of suitable skill sets and experiences • Technical mindset (Al-Mashari & Zairi, 2000)		
	Inadequate financial management	• Poor budgeting and estimation • Ineffective cost control • Unavailability or instability of funding • Ignoring or underestimating hidden cost		
Operational	**Inadequate business process reengineering**	• Large number of organizational units involved (Schmidt, et al., 2001) • Fragmented business processes • Failure to streamline key business processes • Failure to use proven business process reengineering methodologies		
	Inadequate training and instruction	• Lack of a training plan • Insufficient training and re-skilling • Inadequate job role redesign		
	Ineffective communication system	• Lack of communication planning • Lack of implementation promotion to all employees in the organizations (Soja, 2006) • Difficulty in inter-department/cross-functional communications • Ineffective use of appropriate communication media • Lack of face-to-face communications • Ineffective document control and reporting		

	Ineffective consulting services	• Not using consulting services • Inadequate selection of consultants • Lack of appropriate skills and experiences • Lack of specific industry knowledge • Conflict of interests if consultants have close financial ties with vendors (Piturro, 1999) • Consultants assuming too much control and responsibility (Somers & Nelson, 2001)		
	Inadequate IT supplier stability and performance	• Vendor overpromise • Lack of partnership with vendor(s) (Willcocks & Sykes, 2000) • Failure to use vendor's development tools (Somers & Nelson, 2001) • Unstable vendor support • Low quality of vendor services		
Technological	**Technical complexity**	• Large number of implementation modules • Large number of links to non-ERP systems • Complex system architecture • Large scope of software modification and customization		
	Inadequate IT system capabilities	• Poor architecture planning (Feeny & Willcocks, 1998; Somers & Nelson, 2001) • Incorrect or unclear system requirements (Wallace, et al., 2004b) • Conflicting system requirements (Wallace, et al., 2004b) • System requirements not adequately identified • Continually changing system requirements • Misunderstood requirements • Difficulty in defining the inputs and outputs of the system (Wallace, et al., 2004b)		

		• Failure to adhere to standardized specifications • Lack of integration among modules • Poor software development • Inadequate system testing and troubleshooting • Poor data management (Ngai, et al., 2008) • Issues with data accuracy (Umble, et al., 2003; Zhang, et al., 2003)		
	Inadequate IT system maintainability and upgradability	• Unsatisfactory of maintainability: high cost, complexity, etc. • Complexity and cost of upgradability		
	Inadequate legacy system management	• Attempting to build bridge to legacy systems (Sumner, 2000a) • Inadequate data analysis and conversion • Loss of data integrity • Lack of effective transition strategy • Ineffective transition from legacy systems to new ERP system		
	Lack of information sharing or integration with non-ERP systems	• Failure to incorporate the consideration of integration with non-ERP system into system design and requirement analysis • Lack of common data standard or effective data conversion tools		
Human	**Low key user involvement**	• Lack of cooperation from users • Lack of motivation system rewarding user involvement (Soja, 2006)		

		• Users resistant to change • Users not committed to the project • Lack of user involvement in business processes reengineering • Lack of user participation in requirements analysis • Conflict between users • Users with negative attitudes toward the project • Lack of full-time commitment to project activities		
	Poor project team composition and skill mix	• Frequent turnover within the project team • Inappropriate staffing • Personnel shortfall • Excessive use of outside consultants (Schmidt, et al., 2001) • Lack of application knowledge (Ewusi-Mensah, 1997) • Lack of technical expertise (Ewusi-Mensah, 1997) • Poor teamwork		
	Inadequate stakeholder relationship management	• Frequent conflicts between project team members • Lack of interdepartmental cooperation • Conflicts among different functional departments • Mistrust • Information hiding • Political risks • Lack of middle or lower level management support • Lack of control over consultants, vendors, and subcontractors (Schmidt, et al., 2001) • Failure to consider the requirements and expectations of external stakeholder, particularly clients/customers • Disruption to the ongoing projects or business relationships with external stakeholders during implementation		
Miscellaneous	**Legal and**	• Poor contract specification • Ineffective contract administration		

	regulatory risks	• Arbitration and litigation • Failure to consider regulatory requirements in requirements analysis • Failure to consider legal implication in business process reengineering		
	Multi-site issues	• Organizational diversity (Gargeya & Brady, 2005) • Local project team autonomy • Different legacy practices across project sites or countries (Olson, et al., 2005) • Variance of user IT experiences (Olson, et al., 2005) • Varying regulations (Olson, et al., 2005) • Location-related functional requirements and interfaces • Conflicts between process standardization and local optimization • Differentiation of culture and customs • Temporariness of project teams and sites • Travel among different sites		

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