



**Reacting to Risks with Real Options:  
Valuation of Managerial Flexibility in IT Projects**



# **Reacting to Risks with Real Options: Valuation of Managerial Flexibility in IT Projects**

**Reageren op Risico's met Reële Opties:  
Waardering van Managerial Flexibiliteit in IT Projecten**

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**Cornelia Alijda Richarda Hilhorst**

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Promotores: Prof.dr. P.M.A. Ribbers  
Prof.dr.ir. H.W.G.M. van Heck

Copromotor: Dr. M.T. Smits

Overige leden: Prof.dr. J.A. Bartoli  
Prof.dr. W.E. Berghout  
Prof.dr. H. Krmar

Tilburg University/Faculty of Economics and Business Administration

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## **Preface**

This dissertation is the result of intellectual curiosity, creativity but most of all perseverance. It is the product of a large personal investment in which I tried to be flexible by staging the project in order not to run the risk of abandonment of the project altogether. As such, I am grateful to many people who have helped me during the last five years.

My Ph.D. would not have started if Prof. Dirk van Dalen, my former master thesis supervisor, had not underlined that ‘doctoranda’ means ‘she who has to become doctor’. I want to thank him for stimulating me to pursue an academic career in the first place.

Of course, the by far most important contributors to this thesis I want to thank are Prof. Pieter Ribbers, Prof. Eric van Heck and Martin Smits who have made it possible for me to write this dissertation and who have given me the freedom to find my own research path, step by step. Over the years we have had many discussions about the papers I worked on and those discussions have very much improved the overall quality of the research presented in this dissertation.

At PricewaterhouseCoopers I received important support from many colleagues. It has been a huge pleasure to realise that we work for a firm with people possessing so much knowledge as well as enthusiasm to help out. Most importantly, without the full support from Adri de Bruijn it would not have been possible to combine a full-time job with scientific research and to be able to write up in France. Furthermore, it was a pleasure to see how my colleagues at PricewaterhouseCoopers spent time and made knowledgeable efforts to help me sharpen the field experiment instrument and questions and in conducting the ‘guinea pig’ experiments. I am especially indebted to Hans Luijendijk who provided me with data from senior IS/IT executives, and Jacques de Swart and Jan Wille to help me interpret the experimental data. Additionally I would like to

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I want to thank students and faculty of the ECIS 2006 Doctoral Consortium for their feedback and for providing me with the confidence regarding the direction of my research. Throughout the course of my research I have benefited from the help of many academics whom I asked for advice. I especially would like to thank Bert Bettonvil for helping me on several occasions.

During the final year of my PhD, I spent two-and-a-half months at l'Institut d'Administration d'Entreprises in Aix-en-Provence. My advice for anyone who ever needs to write a thesis or a book: go there! Even with the rainy karma of Piet surrounding me in the South of France, it was a wonderful experience and I want to thank Jacques-Andre Bartoli for having me over to work on my dissertation.

And of course, my close friends and special women in my life deserve special mentioning: Erica, Elfi (my 'thesis-victim-in-crime'), Ieke, Rebecca, Simone, Esther, Nikki and my sister Claire. Each of you supported me in her own way in difficult times as well as in less difficult times. I enjoy your company very much and hope that our relationships will continue to strengthen in the future.

My mother, Ida, and father, Kees, have given me all the attention I needed and they have tried their best to keep up with the academic customs and my progress.

I will not forget the adorable question my father posed me one day: 'Will your whole class be defending their theses at the same day?' They are definitely the proof that flexibility comes with age.

Cokky

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# Chapter 1

## Introduction

Risk is at the heart of most large information technology (IT) capital investments (Keen 1991). From large software applications (e.g., ERP, tailor-made applications) to infrastructure technologies (e.g., networks, security systems), a common element is uncertainty about whether the project will achieve its goals, and if so, what payoffs can be expected (Fichman et al. 2005). Due to the risk involved, IT projects are notoriously difficult to manage and too many of them end in failure. Research shows that project failures are occurring with alarming frequency. Data shows that a 30 percent failure chance is not unusual (The Standish Group 2001) and as many as 80 percent of all IT projects run over their budgets (Walkerden and Jefferey 1997). Hence it is no surprise that avoidance of failure is a dominant theme in the information systems (IS) literature.

One explanation for the high failure rate is that managers are not taking prudent measures to assess and manage the risks involved in these projects. Since a large proportion of the causes for late, over-budget delivery of software are management-related (Van Genuchten 1991), the search for appropriate managerial action to solve this problem has been intense. As managers have considerable flexibility in how they approach and structure their IT projects (Fichman 2004), using this flexibility to manage risk is among recently advocated methods for improving IT project value (Kumar 2002, Benaroch 2006).

This research aims at increasing our understanding of the role and impact of risk and managerial flexibility on IT project valuation.

## 1.1 Why Should We Study this Topic?

Since risk is a central fact of life, it is important that decision-makers know how they should respond to risk and which countermeasures are effective in managing risk. In practice, given the potential for major losses on IT projects, organisations exhibit a defensive posture towards IT projects (Fichman et al. 2005). One manifestation of this posture is downplaying the level of risk. When managing IT projects, risk is often overlooked, underplayed, and dismissed, especially organisational risk (Fichman et al. 2005). Another manifestation is applying an appearance of predictability to IT projects by demanding rigidity in project planning and execution. A final manifestation is that managers do not acknowledge that abandoning IT projects can be inherent in the process of undertaking risky ventures. By hiding instead of highlighting risk, these approaches can increase an organisation's exposure to unnecessary risk (Fichman et al. 2005).

In research, considerable hopes in improving the performance in software development have been placed in techniques and guidelines that identify, analyze and tackle IT risks (Leavit 1964, Boehm 1989, 1991, Davis 1982, McFarlan 1982, Schmidt et al. 2001, Wallace et al. 2004). Research on dealing with IT risk has primarily focused on crafting guidelines for specific tasks (Lyytinen et al. 1998). This has led to a number of problems. Firstly, we have little empirical evidence of the practical usefulness of managing risk. Secondly, approaches for management of risk shape the attention and guide the actions of managers in quite different and ad hoc ways (Lyytinen et al. 1998). Thirdly, risk management approaches have, until more recently in work developed by Wallace et al. (2004) and Du et al. (2007), largely ignored the organisational environment in which they are used and their impact on management performance and IT project value (Benaroch 2002). Overall, the area seems to lack theories that help to explain risk management approaches.

When there is high risk, flexibility has value. An important aspect in dealing with risk in IT project management decision-making is the presence of flexibility in IT projects. This flexibility can take two basic forms (Fichman 2004). The first dimension is flexibility in the *result*, i.e., what the system offers for future uses and enhancements. Organisations can – although at a certain cost and effort - enhance flexibility by making systems more generic, modular, interoperable, and scalable, and so to apply them to a variety of business processes or products (Fichman et al. 2005). The second dimension of flexibility on IT projects concerns the *process* by which IT systems are delivered. IT can be suited to a variety of opportunities for incremental project commitment, such as developing simulations, prototypes, pilots, and various forms of staged implementation (Benaroch 2002, Fichman 2004). This type of flexibility is promoted by managerial decisions to for example decompose, scale down, or stage projects. Allowing managers to wait prior to committing to a risky outcome is the key difference in decisions with flexibility (Miller and Shapira 2004). This managerial flexibility, which is the focus of our research, gives managerial decision makers the possibility to adjust project resources in ways that avoids potential losses while preserving potential gains. Managerial flexibility provides managers the ability to alter the operating strategy, or the course of a single project, by acting in response to the resolution of uncertainty over time. A flexible project may allow for downside protection against unfavourable conditions, e.g. by abandoning a project or by shrinking its scale; but as it may also endow the manager with the possibility of profiting from growth opportunities in case of favourable conditions, e.g. by expanding the scale or scope of a project. Therefore, when facing risk, a project with embedded managerial flexibility to respond to contingencies can be more valuable than one without.

In recent years, a large body of research has been dedicated to the application of real options theory in IS management. In our research, we will use real options theory to research the valuation of managerial flexibility in IT projects in practice.

A project embeds real options when managers have the opportunity but not the obligation to adjust the future direction of the project in response to external or internal risks. Examples of these different types of real options include deferring the project, switching the project to serve a different purpose, changing the scale of the project, implementing a project in incremental stages, abandoning the project, or using the project as a platform for future growth opportunities.

As real options theory proposes, managerial flexibility can have value in risky projects. Real options theory allows an organisation to assess uncertain IT investments and more importantly, it offers a framework that assumes that decision makers take a proactive stance to manage risk on IT projects by actively creating and extracting value. As real options theory proposes, promoting flexibility in the IT project *process* or *result* creates a quantifiable value, and this value exists whether or not an organisation actually attempts to quantify it (Fichman et al. 2005). Therefore, effective options reasoning requires that managers do three things well (Fichman et al. 2005):

- *recognize* and enhance opportunities to create options with IT,
- *value* these options, and,
- *manage* projects to fully extract this value.

We will use these three aspects of recognizing, valuing and managing flexibility to answer our overall research question.

## **1.2 Overall Research Questions and Theoretical Issues Addressed**

This dissertation raises the following overall research question:

### **Overall Research Question:**

*How do real options, as a response to risks, impact IT project valuation?*

The dissertation will attempt to answer this question by conducting three separate studies. Although each study has its own specific research question, they all will be (partly or fully) investigated using the particular real options lens.

The first issue we will explore is whether managerial flexibility in IT investment decisions is *recognized* in practice. As we will explain, flexibility is a crucial factor to gain competitive advantage as a firm. Nowadays, managers of most companies seem to be aware of the benefits of being flexible. Since flexibility is a critical success factor in relation to the management and design of IT investments (Kim and Saunders 2003), and understanding flexibility is a difficult issue, it is important to explore how firms build flexibility into their IT investment decisions. Therefore, this will be the purpose of the first study. This initial study looks at decision-making at a strategic firm level and explores the linkages between strategic flexibility, IT infrastructure capabilities, and managerial flexibility in IT project decision-making.

In the second part of our research we investigate how managerial flexibility in IT projects can be *valued*. Real options theory values managerial flexibility by finding an optimal balance between risk and returns from a financial perspective. However, the value of managerial flexibility in IT projects will not rely on real options value alone. IT projects can typically result in non-financial benefits such as intangible performance improvements (Remenyi et al. 1993). Unlike cost, such benefits primarily impact processes inside an organisation and are seldom easily translatable into cash flow. Therefore, their value is predominantly dependent on (individual) judgement and not on market prices. When finding a balance between risk and IT project benefits to determine the value of managerial flexibility, ignoring this value may negatively impact the insight in the total value of managerial flexibility of the IT project. We develop a theoretical decision-making model which deals with both financial and non-financial criteria. We make a literature investigation and propose decision criteria that should be taken into account to optimally configure an IT project both from a financial and from a

non-financial perspective. The model captures risk regarding the variability of the project's financial value as well as risk regarding non-financial judgments. We show that the developed decision-making model can generate valuable information for decision-makers required to select from competing IT project configurations using sensitivity analysis. We also will go into the fundamental requirements that need to be met when combining real options analysis with decision analysis.

The third part of our dissertation takes a qualitative perspective on the *management* of managerial flexibility in relation to IT project risk. Since real options are not inherent in IT projects, they usually must be planned and intentionally embedded in an IT project in order to control specific risk factors (Benaroch 2002). Several researchers have proposed effective combinations of risk and real options to embed in IT projects in order to optimally control risk and maximize IT project value (Benaroch 2002, Kumar 2002). Recognizing which managerial flexibilities to embed in an IT project as a response to risk is one of the main steps that has to be taken by management for deciding whether or not the flexibility as offered by real options is relevant for a specific IT project. In this research, we empirically test the effects of specific risks on the valuation of real options in IT project decisions. The aim is to investigate whether the proposed link between risk management and real options is in line with the intuition managers have. Our approach is to use a field experiment, including a pre-test, to examine how different risk factors and real options embedded in an IT project affect managers' perceptions of project value. We will test the proposed risk-options relations and investigate possible biases that may exist in the valuation of risk-real options relations.

### **1.3 Research Contribution of the Dissertation**

The main contribution of this research is to offer new insight to real options and risk management literature. While earlier research has shown that managers



understand that the flexibility offered by real options has value (Benarch et al. 2006, Tiwana et al. 2006), our research tries to give insight in the fact that this valuation is actually driven by the presence of different types of risk. We intend to investigate whether the proposed option based risk management reasoning as proposed in earlier research generally corresponds with the intuition of managers. This would suggest that managers understand that the value of managerial flexibility offered by different types of options in IT projects can serve as an effective risk countermeasure. Also, we intend to investigate possible biases that may exist in the managerial valuation of real options in the presence of different types of risk. Our study hopes to extend the theoretical literature in which mappings are suggested between different types of risk and the managerial flexibility as offered by different types of options (Micallizi and Trigeorgis 1999, Benaroch 2002, Kumar 2002, Bräutigem et al. 2003). This insight is particularly important since it would suggest that real options theory can be used to study risk management from an economic perspective by linking risk, flexibility, and economic value. Therefore, real options theory may be used as a complementary theory to study risk management behaviour.

The second contribution of this research is to support the insight that - when changing the operating strategy of a project - the number of choices an organisation possesses, the likelihood of the change as well as the ease of change depend on both financial and non-financial criteria which cannot be provided for by real options analysis alone. Many IT project benefits are seldom associated to goods or services sold on an outside market. When decision-makers ignore these benefits in the valuation of managerial flexibility in IT projects, they will ignore vital information in the selection of the most viable type of flexibility to embed in an IT project. This may negatively impact the total value of the IT project. Whilst previous research studies have valued multi-stage investments using real options analysis, they have ignored the multi-dimensional nature of IT project decisions. We develop a decision model to value managerial flexibility in a way that takes

account of the multi-dimensional nature of IT projects by combining real options analysis and decision analysis. We intend to offer a contribution to real options theory and decision theory, by giving an insight in the main theoretical hurdles that have to be taken into account when combining real options theory and decision theory.

Of course, additional research is necessary to give insight in how managers perceive IT project value and which biases they demonstrate in valuing IT projects. This insight is particularly important, since it may give insight in their decision-making rationale when making IT project selection and management decisions at a tactical and strategic level.

#### **1.4 Implications for Practice**

Our research has several implications in practice. The major practical implication of our study will be based on our finding whether the managerial valuation of the different types of real options follows real options based risk management reasoning. However, the experimental results will only indicate whether the valuation of different types of real options is taken into account *implicitly*. The intuitive managerial valuation of real options in the face of risk will be of little practical consequence unless managers become explicitly aware of the value of managerial flexibility. There is no free lunch in managing flexibility; managing and valuing flexibility can be costly when resources are limited, and flexibility may have a negative effect on project commitment. Therefore, mechanisms have to be put in place to maximize real options reasoning in practice. These mechanisms include several aspects.

Firstly, management may actively and explicitly identify and select operational options to manage risk at the offset of IT projects. This can be achieved by identifying the most important risks that affect the project's success. By using a simple checklist, the most viable options to manage the risk can be selected. Of course, the flexibility may not need to be valued in all projects. It may be viable

only in projects with competing scenarios or in projects in which the uncertainty is high or the time-frame is long. The most obvious candidates for the valuation of managerial flexibility are projects that are managed in fast moving environments or projects that are large and complex. The flexibility can be valued using for example real options analysis or decision tree analysis. As is implied by our research, financial analysis tools may be complemented by non-financial decision analysis tools to take into account the full benefits of the embedded flexibility. In projects where valuation of flexibility is not necessary, for example due to reasons of insufficient skills or resources, rules of thumb or experience may be used to 'value' flexibility.

Secondly, management may be committed to actually exercising options when appropriate. Project management practices to continuously track the evolving value of options could be employed. Of course, the degree to which these project investment and planning capabilities can be successfully developed and implemented depends on the maturity and culture of the organisation, the maturity of the IT department and the skills of its staff, but most importantly, on the adequacy of the organisation's and project's governance structure. This includes the mandate to actively embed and manage flexibility to fully extract its value, but also the mandate to terminate or abandon projects if they do not deliver their expected value. To overcome personal and organisational biases, managers may take steps to change the elements of organisational culture and procedures, for example by defining and implementing 'exit strategies' when making the IT project investment. In any case, management may need to explicitly define and communicate decision rules and triggers to be able to manage and control the embedded flexibility during the course of a project, including conditions under which a project can be abandoned.

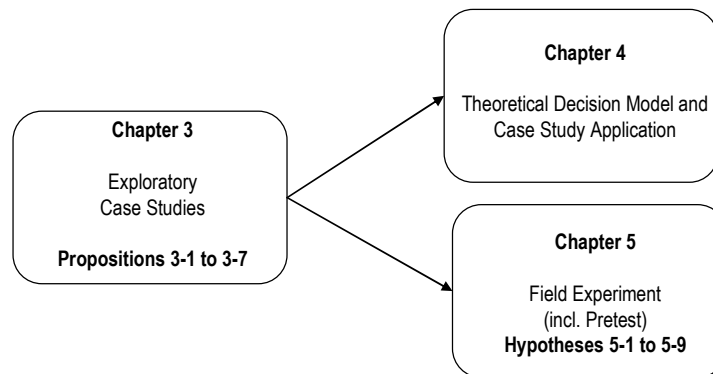
Another practical implication of our research is that practitioners may invest in different types of IT infrastructure capabilities (Weill et al. 1998) when aiming for different types of strategic flexibility needed at the business side. They may

identify the necessary IT infrastructure capabilities and the accompanying IT infrastructure investments, by actively and explicitly searching for strategic growth options, since these may represent a large part of the IT infrastructure investments value. Since the strategic growth options are mainly business driven, both IT and business can be involved when searching for growth options.

A practical contribution of this research is to provide for a model that relates risk, managerial flexibility and IT project value at different decision-making levels. To our knowledge, this is the first decision-making model that links risk, managerial flexibility and IT project value at a strategic, tactical and managerial decision-making level.

## **1.5 Research Design: a Multimethod Multilevel Approach**

In this dissertation, a multimethod research approach is selected to address the overall research question. Multimethod research aims to strengthen the validity of the research by using multiple methods, whereby the methods are chosen to complement each other's strengths and weaknesses. Multiple methods can be used in a simultaneous or sequential form (Brewer et al. 1989). In a simultaneous form, the researcher uses multiple methods in the same study to measure the same phenomenon (Mingers 2001). In sequentially using multiple methods, the results of one method are the basis for a new study of the same concept using a different method. The sequential multimethod approach is taken in our overall research (see Figure 1-1). As Figure 1-1 shows, the different research methods we use are (exploratory) case study research and field experiments.



**Figure 1-1.** Sequential multimethod approach in our research

A multimethod approach is advocated (Mingers 2001) for different reasons. Firstly, a multimethod approach can be an effective way of dealing with the full richness of the phenomena studied. It encourages creativity of the researcher by ‘discovering fresh or paradoxical factors that stimulate further work’ (Mingers 2001). Since a study is rarely a single event but often a longer process, different methods may yield different insights during the study of the whole process. Secondly, the use of different research methods increases the internal and external validity<sup>1</sup> of the research, thereby possibly increasing the generalizability of the research. Scandura & Williams (2000) identify three dimensions to rate a research method. These are generalizability of the results, precision of measurement, and realism of context. Table 1-1 shows how our two methods score on each of these three dimensions.

---

<sup>1</sup> Internal validity refers to the extent to which cause-and-effect conclusions can validly be made in a study and requires that alternative explanations of the results can be eliminated (Yin 1994). External validity refers to the extent to which a study’s findings can be generalized to people beyond those in the specific study. It requires good construct validity, establishing correct operational measures for the concepts being studied, and content validity, to the extent to which a measure represents all facets of a given social concept (Yin 1994).

Research method dimensions	Case Study	Field Experiment
External validity	High	High
Precision of measurement	Low	High
Realism of context	High	Low

**Table 1-1** Dimensions of our research methods (Scandura and Williams 2000)

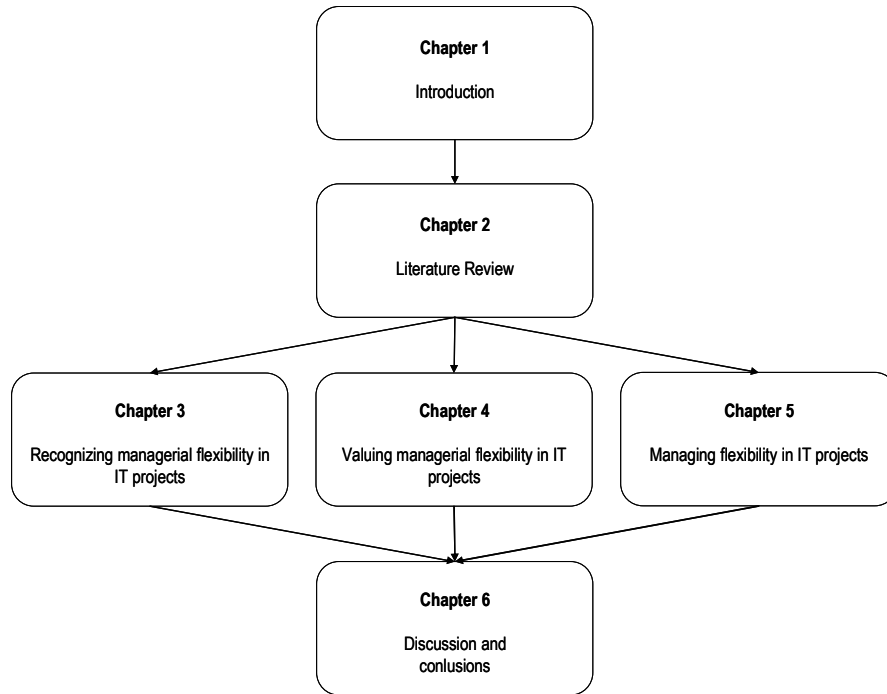
Our sequential multimethod research approach enables us to score high on each of the three dimensions of a research design. The advantage of field experiments is that they create a tightly controlled environment that allows a researcher to establish causality and increase the internal validity (Shadish et al. 2002). Field data have the strength of high external validity. Case study research scores high on external validity and realism of context. Combining the above methods should lead to robust conclusions compared with a single method study. Replicating studies using a different research method challenges the researcher to assess whether the operationalisation made in one study can be replicated or refined to accommodate this new setting while staying consistent with the previous study. By combining analysis from different research methods, we aim at giving a fuller and richer understanding of how risk and managerial flexibility impacts IT project value.

To study IT decision-making, different levels of analyses can be taken. A multilevel approach aims at explaining macro level outcomes using micro level inputs, or vice versa. This research is concerned with organisational decision-making. Organisational decisions are inherently multilevel, since they are taken at various organisational levels (Keuning and Eppink 1979), and either by individuals or by groups. In our research we look at IT decision-making at a firm level (strategic and tactical decisions, that concern the organisation and its external environment and the internal structure of the organisation), at a project level

(tactical level, that concerns the internal structure of the organisation), and at the level of an individual decision-maker (tactical level, that concerns the internal structure of the organisation). In chapter six we conclude by presenting a conceptual model which relates the researched constructs at the different decision-making levels.

## **1.6 Structure of the Dissertation**

After this introduction, chapter two provides a literature overview. The chapter introduces the detailed research questions that will be the focus of the empirical research chapters. In the following three chapters, we address the research questions by presenting our empirical research. The chapters are relatively independent of each other: each chapter addresses a specific research question. However, the three chapters jointly cover the topic of how the valuation of managerial flexibility impacts IT decision-making. Chapter three focuses on the recognition of managerial flexibility from a firm-perspective. Chapter four addresses the theoretical and practical valuation of managerial flexibility in a specific IT project when dealing with risk. In chapter five we present empirical findings on the managerial valuation of real options in risky IT projects. Finally, in chapter six we discuss our results and conclusions. We discuss the generalizability of our findings, highlight the managerial relevance and discuss implications for future research. Figure 1-2 illustrates the structure of the dissertation.



**Figure 1-2.** Structure of the dissertation



## Chapter 2

### Literature Review

In this chapter we will review current knowledge on IT project decision-making, risk and flexibility. The literature reviewed in this chapter mainly follows the course of our empirical research as presented in chapters three to six. This research has evolved from doing exploratory research on flexibility by taking a broad perspective on the management of IT infrastructures when facing environmental uncertainty, to a detailed study of dealing with different types of IT risk and managerial flexibility when evaluating IT projects. Therefore, the literature review in this chapter will deal with these topics in a more general overview. In this chapter, we define the main concepts that are used in the subsequent empirical chapters. This provides part of the theoretical background for the studies in the subsequent chapters.

This chapter is structured as follows. In section one, we explain why flexibility is important in gaining competitive advantage when investing in risky IT projects. In section two, we explore the concept of flexibility. In section three, we present different theoretical perspectives on risk management and explain how managerial flexibility can play an important role when dealing with risk. In section four we introduce the valuation of managerial flexibility using real options theory. In the last section we explain the use of real options reasoning in IT risk management.

## **2.1 Flexibility as a Priority in Gaining Competitive Advantage**

In this section, we shortly discuss the concept of competitive advantage and we discuss its link to IT investments. We investigate how the concept of flexibility has become a key priority in gaining competitive advantage.

### **2.1.1 Competitive Advantage and IT**

Practitioners of strategic management in organisations are constantly on the lookout for resources that can bring their firms competitive advantage. The concept was popularized by Porter (1985), who states that competitive advantage grows from the value a firm is able to create that exceeds the firms cost of creating the product or service. Sustained competitive advantage flows from organisational capabilities and resources that are rare, valuable, non-substitutable, and imperfectly imitable (Barney 1991).

Over the past decades, information technology (IT) has been promoted as one of the resources that organisations could use to gain a competitive advantage (Byrd et al. 2001, Charette 1989, Clemons 1986, Kemerer et al. 1991). As IT operates at the core of modern organisations, the efficiency and flexibility with which IT capabilities – hardware, software, skills and expertise – are developed and embedded in the organisation, is business critical (Byrd et al. 2001, Rockart et al. 1996). Although during the 1980s and 1990s, the competitive value of IT was thought to come from the so-called strategic information systems (Reich et al. 1990, Clemons 1991), researchers rationalised that complementary assets or organisational characteristics are needed to keep these systems proprietary to the firm and keep these systems gain competitive advantage (King et al. 1989, Rockart et al. 1996). Nowadays, the search for competitive advantage from IT has shifted much more from strategic information systems to the strategic value of IT infrastructure. Research has shown that the success of companies really is derived from long-term, well-planned investments in networks, databases, and skills,

which are components of the organisations' IT infrastructure (Weill 1993, Davenport et al. 1994).

In this research we use a general definition of IT as given in Boynton et al. (1994):

*"The organized combination of hardware, software, data resources and communication networks as well as the knowledge, skills and methods, used for enabling electronically-based information collection, transformation and dissemination."*

In our research we make a distinction between IT projects and IT investments. Although the two terms are often used interchangeably, we refer to IT investments as any use of resources intended to increase future production output or income with the use of IT (derived from Buckley et al 1998). With an IT project we refer to a sequence of activities undertaken to accomplish a temporary endeavour (with a defined completion date) to create a unique product or service over time using IT (derived from Loch et al. 2006). We make a further distinction between different aspects of the general concept of IT (Weill 1993, Weill et al. 1998):

- The physical IT infrastructure consisting of hardware, communication networks and basic software such as operating systems and database management systems, including applications that are standard across the firm, such as email applications.
- The information systems as applications of IT, to solve specific business problems.
- The management-oriented capabilities for an effective provision and use of information resources. These include for example the management of the infrastructure and its relationships with the business, the core policies that govern the use of the infrastructure and determine the future development, and research and development of the IT infrastructure.

One reason for making the above distinction is that decisions planned for each of the mentioned aspects of IT are different in nature, thus requiring the application of different decision logics, different competencies of the decision-maker and the involvement of different people in the decision-making process (Mocker et al. 2006). The concept of IT infrastructure emphasizes the standardization of systems and data throughout the corporation, on the one hand, and the distribution of systems and applications on the other (Benjamin et al. 1984). Many IT infrastructure investments are not business problem specific and thus should not only be seen as serving specific information systems. Weill and Broadbent (1998) confirm this view by stating that IT infrastructure is “shared by multiple business areas and [...] used by several different applications”. Thus, IT infrastructure investment decisions are concerned with building a “strategic IT platform [...] that not only responds to immediate needs but also provides escalating benefits over the long term” (Rockart et al. 1996). Parker, Benson and Trainor (1998) recognize the specifics of IT infrastructure decisions in that they state that “traditional cost-benefit approaches don’t work well in areas of investment unrelated to specific development projects”. In contrast, each information system addresses a specific business problem or need. The corresponding strategic decisions are made on the basis of so called “business cases” that justify how well these specific business needs are fulfilled.

In a more recent debate on IT, Carr (2003) takes the view that as computer technology becomes more standardized, businesses will have a harder time gaining a competitive edge over their rivals through IT investments. However, in the fierce debate following the article, the main reactions contend that competitive advantage is not the result of standardized desktops, but the result of effective management and use of IT by skilled and highly motivated people (Carr 2003). Firms using identical technologies and spending comparable amounts on IT display an enormous variability in profitability (Strassman 1997).

### **2.1.2 Flexibility in IT Projects as a Critical Success Factor in Gaining Competitive Advantage**

There is widespread recognition that IT investments are surrounded by uncertainty. Uncertainty facing IT investments arises from many sources—for example, the increasing integration of technologies within and across organisations or the increasing emphasis on using IT to support innovative products and customer-facing processes with hard-to-predict market appeal. There are two fundamental types of uncertainty that play a role when making IT investments: exogenous and endogenous uncertainty (Pindyck 1988). Exogenous uncertainty refers to market and environmental uncertainty, whereas endogenous uncertainty refers to uncertainty that is IT project related and caused within the organisation. Due to sources of endogenous and exogenous uncertainties, IT projects are widely regarded as notoriously risky<sup>2</sup> (Keen 1981).

Since the existing business environment is characterized by augmented uncertainty and risk, flexibility is regarded as an essential competence for organisations in a rapidly changing and unpredictable world. An organisation should be flexible enough to handle both the unexpected threats and the opportunities posed by an uncertain future and unstable environment. Given the increase in uncertainty and risk, companies that recognize the value of flexibility and that build a degree of flexibility into their IT investments are likely to be at a significant advantage in the future, relative to companies that fail to take account of flexibility in the design and evaluation of IT projects (Baldwin 1987).

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<sup>2</sup> In decision theory and practice it is common to make a distinction between risk and uncertainty. If each of the possible actions leads to a set of outcomes with known probability the decision is made in an environment of risk. If decision-making is concerned with a number of possible scenarios that can actualize with unknown probability, decisions are made in an environment of uncertainty. The term uncertainty refers to the degree to which future states cannot be anticipated and accurately predicted (Pfeffer and Salancik 1978). Since the terms risk and uncertainty differ only by the degree with which probabilities of outcomes can be defined, it is not surprising that they are mostly used interchangeably in literature and practice (Hertz and Thomas 1983). In this thesis, we will mainly refer to the concept of risk, although probabilities may not always be explicitly assigned to a set of outcomes.

Although flexibility is a core concept in theory and practice, understanding and defining flexibility is a difficult issue as the term is manifold and used in heterogeneous contexts. A growing number of terms is used to refer to flexibility such as agility, adaptability, or resilience. Also, flexibility is used in relation to different concepts such as organisations, IT (infrastructure or information systems), and decision-making. Evans (1991) shaped the expression “polymorphy of the concept flexibility”. For this reason it is important to clarify what types of flexibility are discussed in this work and to define the term flexibility for the purpose of this thesis.

## **2.2 The Concept and Value of Managerial Flexibility**

In this section, we investigate the different perspectives on flexibility and explain why and when flexibility has value in IT projects.

### **2.2.1 What Does Flexibility Mean?**

Different dimensions and definitions of flexibility within companies can be found in today’s literature. In psychological terms, a flexible person is open-minded and adaptable, whereas an inflexible person is unable to deal with ambiguity and uncertainty (Anastasi 1990). This is a good starting point for defining flexibility in an economic or a business environment. Flexibility is generally understood as the ability or characteristic of a system to activate or enable a change potential when the demand for change arises either from the environment or from within the system (Gronau 2003). It refers to smooth alterations in practices and policies in the event of unexpected or changing conditions. In Table 2-1 several definitions and references are given of flexibility.

Flexibility definition	Application area	Reference
The ability to raise funds in adverse capital markets.	Strategic management	Bernstein 1978
Firm's ability to reposition itself in markets, change its game plan or dismantle its current strategies.	Strategic management	Harrigan 1985
The ability to rapidly introduce new parts and to change the production mix to respond to short-run fluctuations.	Manufacturing	Hutchinson et al. 1989
The ability of a system to cope with changes effectively.	Manufacturing	Verter et al. 1992
The ability to support a wide variety of technologies that can be easily diffused into the overall platform, to distribute any type of information and to support a heterogeneity of business applications.	IT infrastructure	Byrd et al. 2001
The reach and range of an IT platform, where reach represents the locations to which a platform can link, range represents the connectivity of information across systems.	IT infrastructure	Keen 1993
The capacity for input flexibility within a part of the organisation, it is the part's ability to withstand variability in input conditions.	IT functionality	Knoll et al. 1994
The ability to recognize opportunities and exploit relationships.	IT use	
The ease and variability of technology modification through process flexibility.	IT modification	

**Table 2-1** Definitions of flexibility and their application domain

A shortcoming of these definitions is that flexibility in particular functions may be emphasized, while the overall influence of flexibility is overlooked. Chapter three provides a good example of this, where a firm in one of the cases implements an IT platform to enable a multi-channel strategy. This gives the firm the flexibility to quickly respond to changes in aggregate customer demand and customize a product or service to suit an individual customer. However, as one business manager explicitly states, it makes the firm more inflexible from a business unit perspective, since working in multidisciplinary teams makes projects more complex and defining products in one channel takes more time.

Because of such problems, and because the research on flexibility is fragmented across many disciplines, creating confusion and misunderstanding regarding the term's meaning, some authors tried to find a common way to unify the various interpretations of flexibility.

Volberda (1998) divided flexibility in two types, namely internal flexibility, which is viewed as the capacity of organisations to adapt to the demands of the environment, and external strategic flexibility, which describes the capacity of organisations to influence their environment and thereby reduce their vulnerability. This definition involves the strategy of adaptation to the environment as well as the one of influencing the environment itself. We will use part of this definition in our research in chapter three.

Several authors (Koornhof 1998, Ku 1995) stated that the meaning of flexibility is too multi-faceted to give a single formal definition of it. Koornhof (1998) contends that a definition of flexibility should delineate the space in which a more detailed analysis can take place and exclude other spaces, but without creating a completely unique space for itself. Therefore, it is essential to define flexibility for a special purpose, without violating the broader meaning of flexibility. In line with this, in our research we use the definition as given by Trigeorgis (1993), who defines flexibility as:

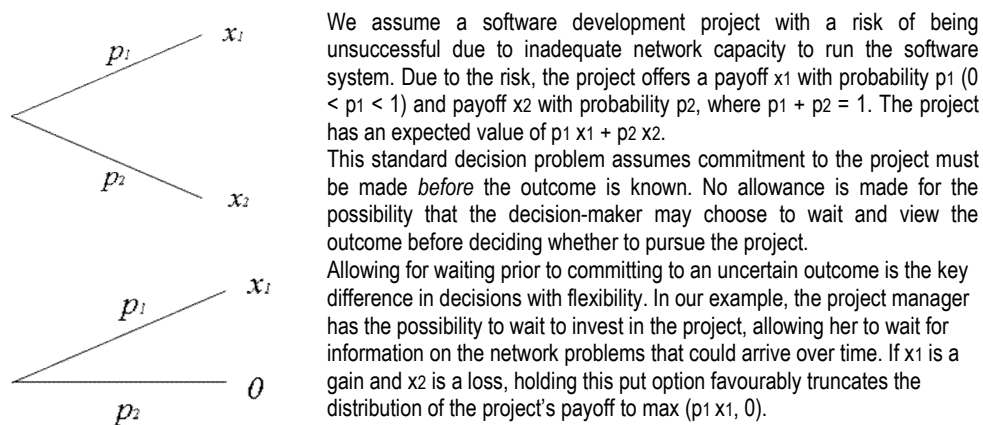
*“the ability of management to alter its operating strategy, or the course of a single project, by acting in response to the resolution of uncertainty over time in order to capitalize on favourable future opportunities or to mitigate loss.”*

We refer to this type of flexibility as managerial flexibility. This definition emphasizes the option character of an IT investment or project, as flexibility in this context implies for a manager the right but not the obligation to change the project settings according to uncertain conditions.



## 2.2.2 The Importance to Value Managerial Flexibility in IT Projects

Since the flexibility in IT investment opportunities represents value, it is evident that valuing flexibility in a management environment is an important topic to master, not only for a single decision maker, but for the firm as a whole. Failure to give the right value to an IT project could lead a firm to reject investment opportunities that would be worthwhile. In this manner, a firm could easily lose revenues. The value of managerial flexibility can be motivated from the risky choice problems commonly found in microeconomics (Neumann et al. 1944), as shown in Figure 2-1, derived from Miller and Shapira (2004). If the built-in managerial flexibility in this example is ignored, a decision maker would miss important investment value.



**Figure 2-1** A risky decision problem without flexibility vs. with flexibility

Although organisations know they must innovate (at least occasionally) to thrive, it can still be difficult to decide which IT projects to adopt, when to adopt them, and how to manage the implementation process to realize business value. Nowadays, managers of most companies seem to be aware of the benefits of being flexible (Busby et al. 1997). For this reason, it is surprising that the methods that

are adopted to value flexibility are mostly ad hoc, rather than trying to use a comprehensive, systematic and structured approach.

### 2.2.3 Different Types of Managerial Flexibility in IT projects

Managers have considerable flexibility in how they approach IT investments. This flexibility can take two basic forms: flexibility in the *process* or *course* of delivering the new system, and flexibility in the *result*, i.e., what the system offers for future uses and enhancements (Fichman 2004). Flexibility in the former is promoted by managerial discretion in how projects are decomposed and staged, while flexibility in the latter is promoted by proactive steps to make systems more generic, modular, multipurpose, interoperable, and scalable. This type of flexibility of the functions in the delivered system can also create (or frustrate) variations of process flexibility. For example, if a firm implements a web site using HTML scripts instead of Java, this might limit its ability to expand the web site to handle more traffic and functions if future circumstances justify expansion of the scope or scale of the project.

Many authors provide a clear understanding of the different types of managerial flexibility that management possesses to structure the course of an IT project. To make a first introduction to managerial flexibility in relation to the theory of real options, in Table 2-2 different types of managerial flexibility (real options) as categorized by Trigeorgis (1993) are presented.

Option type	Description
Switch use	Management can decide to switch the use of a project, when a project is put to a different purpose from that for which it was originally intended (Trigeorgis 1993). Over time, the relative value of alternative uses becomes more apparent and only uses with positive payoffs are pursued.
Change Scale	Management can decide to change the scale of a project, allowing the resources allocated to a project to be <i>contracted</i> or <i>expanded</i> in order to change the scope or the scale of the application (Kumar 2002, Pindyck 1988). The organisation can increase the scale of a project (and thus the range of potential benefits) if circumstances are favorable; or it can reduce the scale (and thus potential losses) if circumstances are

Option type	Description
	unfavorable.
Stage	Management can stage a project by structuring a project as a series of incremental outlays that allows the project to be terminated if business conditions become unfavorable. As each stage is completed the ambiguities about the net payoffs from subsequent stages are resolved; value is created by only pursuing stages with positive payoffs.
Abandon	Management can abandon a project by discontinuing the project prior to completion and redeploy remaining project resources (Hubbard 1993). As a project unfolds actual costs and benefits become more clear, and losses can be curtailed by terminating the project.
Strategic Growth	A growth option is embedded in a project when an initial baseline investment opens the door to pursue a variety of potential follow-up investments, not all of which can necessarily be foreseen (Trigeorgis 1993). Over time, the relative value of follow-up investments becomes more apparent and only investments with positive pay offs are pursued.
Defer	The initiation of a project can be delayed without risking foregoing a valuable opportunity (Benaroch et al. 1999, Hubbard 1994). The firm avoids investing in what is destined to be a losing proposition, while chances are increased of making the right choice on a crucial project decision.

**Table 2-2** Classification of different types of managerial flexibility (real options)

#### **2.2.4 Risk as a Key Value Driver of Managerial Flexibility**

If there is no purpose to play out flexibility, there is no reason for having or creating it, and thus flexibility will be of no value (Ku 1995). To remain transparent and give a clear message about the value arising from flexibility, a decision maker must decide which type of flexibility is more relevant for an actual project. Besides the augmented clarity in communication of flexibility's value, there are other reasons which enforce limiting the amount of flexibility to be examined. Barnett (2005) for example, states that looking for strike signals for exercising the managerial flexibility is costly and resources are limited. Busby and Pitts (1997) notice that having flexibility can also have negative effects, in as far the commitment of the organisation to a proposed plan can be undermined. Also, Ku (1995) points out that too much flexibility, i.e. too many options, may be harmful

in as far as they can complicate the analysis and confuse the decision maker. Bräutigam et al. (2003) observe that since flexibility represents the ability to react to a state of resolved risk, this risk is the key presence of flexibility. Mapping flexibilities to risks should be one of the core concepts for decision-maker to decide whether or not managerial flexibility is relevant for a specific IT project.

## **2.3 IT Risks and Theoretical Perspectives on Risk**

As we have described above, managerial flexibility has value in the presence of risk. Therefore, we describe the different types of risk in IT projects and we explain the different definitions of risk and the attitudes towards risk as defined in decision theory and behavioral theory. We will describe the real options perspective on risk, a theory that is used to study the phenomenon of managerial flexibility.

### **2.3.1 Risk in IT projects**

Work on IT project risk management has focused on the identification and categorisation of critical risk factors in IT projects, developing checklists, propose frameworks and risk dimensions (Barki et al. 2001, Boehm 1989, McFarlan 1997, Wallace et al. 2004). The major stream in research on IT risk includes work concerned with firm-specific risk arising in software development projects (Barki et al. 2001, Copeland et al. 2000, Benaroch et al. 2000). Research initially identified technical execution risk factors such as IT personnel skills, project size, technical complexity, and a continuous stream of requirement changes (Boehm 1989), and additionally identified such risk factors as user involvement, top management commitment, and conflicts between user departments (Barki et al. 1993, Keil et al. 1998, Wallace et al. 2004). The second stream of research focuses more on IT risks arising outside the scope of software development and implementation (Clemons 1986, Clemons 1991, Kemerer et al. 1991). This work identifies additional forms of risk that can generally be referred to as competitive risks and market risks, which

are especially relevant in the context of strategic information systems. The forms of IT risk can be placed into three categories (Benaroch 2002):

- *Firm-specific risks* are due to uncertain endogenous factors. These factors affect the ability of the firm to successfully realize an IT project. Firm-specific risks can be subdivided in financial risk, project execution risk, scope and requirements risk and organisational risk (see also chapter five).
- *Competition risks* are the result of uncertainty about whether a competitor will make a pre-emptive move, or simply copy the project and improve on it. These risks give rise to the possibility that the investing firm might lose part or all of the project opportunity.
- *Market risks* are due to uncertain exogenous factors that affect every firm considering the same project. These factors can affect the ability of the investing firm to obtain the payoffs expected from a realized project opportunity (see chapter five).

### **2.3.2 Risk and Attitudes towards Risk in Decision Theory and Behavioral Theory**

In classical decision theory, risk is most commonly defined as reflecting variation in the distribution of possible outcomes, their likelihoods, and their subjective values (Arrow 1965). The idea of risk is embedded in the larger idea of choice as affected by the expected return of an alternative. Risk is measured by the variance of the probability distribution of possible gains and losses associated with a particular alternative (Arrow 1965). In this formulation, a risky alternative is one for which the variance is large.

According to the behavioural view of risk, the managerial perspective on risk differs from classical decision theory. Firstly, although managers regard possibilities for gain as being of primary significance in assessing the attractiveness of alternatives (MacCrimmon et al. 1986), they see 'risk' as associated with the negative outcomes. Secondly, managers see risk not primarily

as a probability concept, but rather define it in terms of the magnitude of possible bad outcomes. Thirdly, though quantities may be involved in assessing the level of risk, most managers show little desire to reduce risk to a quantifiable construct. According to Lyytinen et al. (1998), IT project risk management approaches focus on ambiguous losses (Boehm 1989). In the literature dealing with IT project risk, risks are both defined following the decision theoretic view (Boehm 1989, Charette 1989), and following the managerial view in which risk is associated with a negative outcome (Keil et al. 1998, Wallace et al. 2004). Yet, most risk management approaches deal solely with negative outcomes and how to avoid them. In this way, the central insight of the decision theoretic view (the importance of considering the whole distribution of possible outcomes) becomes obscured.

Regarding attitudes towards risk, virtually all theories of choice assume that decision makers prefer larger expected returns to smaller ones, provided all other factors (e.g., risk) are constant (Lindley 1971). In general, they also assume that decision makers are risk averse. When faced with one alternative having a given outcome with certainty, and a second alternative which is a gamble but has the same expected value as the first, an individual will choose the certain outcome rather than the gamble (Pratt 1964, Arrow 1965, Ross 1981). Thus, expected value is assumed to be positively associated, and risk is assumed to be negatively associated with the attractiveness of an alternative. Risk averse decision makers prefer relatively low risks and are willing to sacrifice some expected return in order to reduce the variation in possible outcomes (March and Shapira 1987). Risk seeking decision makers prefer relatively high risks and are willing to sacrifice some expected return in order to increase variation (March and Shapira 1987). The decision theoretic view implicitly considers that decision makers normally have to be compensated for variability in possible outcomes. It also assumes that decision makers are passive in managing risk. It assumes that all alternatives are given, their features cannot be changed to affect risk and decision makers deal with risk

by first calculating and then choosing among the available alternative risk-return combinations (Yates 1992).

The behavioural view of risk has several implications for this classical decision theoretic view of risk management. Firstly, when risk involves great losses, managers act in a loss-averse manner instead of a rational manner as predicted by the traditional theory (Kahneman and Tversky 1982). They make fast decisions to avoid risks, negotiate uncertainty absorbing contracts, or just delay decisions if possible (MacCrimmon and Wehrung 1986). Secondly, managing risks is not seen as gambling, but as mastering the environments so as to bring the risks under control. Management seeks to modify risks, rather than simply accept them, and they assume that risk is controllable and manageable (MacCrimmon and Wehrung 1986). Bringing risk under control is seen as entailing the active mastering of the environment. Thirdly, managers neither understand, nor care to use precise probability estimates: crude characterizations are used to exclude certain possibilities from the decision (Fischhoff et al. 1981) and thus make the managerial process a sequential pruning exercise instead of a one-shot decision.

According to Lyytinen et al. (1998) the behavioural perspective on risk (March and Shapira 1987) seems more appropriate in explaining current practices of managing IT project risks than the classical decision theoretic view on risk management.

### **2.3.2 Real Options Theory and IT Risk Management**

An important aspect that forms a foundation for the research in our empirical chapters is the use of real options reasoning. Real options reasoning can represent a valuable theoretical foundation for studying IT risk management for several reasons. Firstly, real options theory views risk as a trait of a project or of its contextual environment that affects the degree of variation in both negative and positive expected outcomes (Benaroch 2006). The IT risk management focus on

avoiding the negative outcomes of risk may neglect the opening up to future expansion opportunities as a response to positive risk, which are regarded as specifically valuable (Benaroch 2002, McGrath 1997). Secondly, although the behavioural view shows us that managers neither understand, nor care to use probability estimates, the attitude towards risk in the options perspective is more in line with the behavioural than with the decision theoretic perspective. Real options based risk management suggests that management should proactively manage strategic investments, by creating opportunities for mid-course corrections to investment strategies (Teece 2006). The real options approach assumes that strategy is a path of related options and there is no well thought-through overall strategy. By using managerial flexibility to deal with risk, managers can avoid risk or bring it down to acceptable proportions, for example by delaying decisions, transferring risk to a third party or by redirecting the course of the project. So the real options perspective may represent a promising complementary theory to existing theories by offering an economic perspective on risk management logic as observed in practice.

## **2.4 The Valuation of Managerial Flexibility in IT Projects using Real Options Theory**

As real options theory represents a promising candidate for studying risk management in IT projects, in this section we will introduce the core concepts of real options theory. We will introduce the two main real options research streams in the IS field and briefly review real options critique.

### **2.4.1 Real Options Theory and Managerial Flexibility**

Using real options theory, decision-makers are able to evaluate managerial flexibility using the value of an investment and its risk profile (Kulatilaka et al. 1996). A real option, by definition, gives the holder the right, but not the obligation, to take ownership of an underlying asset at a future point in time. Real



options theory considers the risk firms face due to technical, organisational and environmental factors (Tallon et al. 2002). If future events remove or otherwise reduce the key sources of risk to some satisfactory level, the firm may exercise its option to invest (Tallon et al. 2002). Using real options, a project may allow for downside protection against adverse risk, e.g., by deferring the project or by reducing its scale. But it also endows a manager with the possibility of profiting from growth opportunities in case of favourable conditions, for example by expanding the scale or the scope of the project.

Three conditions are prerequisite to using real options concepts to structure the evaluation and management of technology investments, and all three conditions hold strongly for IT projects.

- Uncertainty regarding net payoffs: as we have described earlier, net payoffs in IT projects are typically uncertain.
- Irreversibility in project costs. Irreversibility is defined as the impossibility to reverse or correct a decision with no cost. Regarding the condition of irreversibility, the adoption of an IT project is essentially an investment in a new organisational capability, and such investments are largely irreversible due to the tight coupling of technology and organisation (Kogut et al. 2001). While a portion of expenditures for hardware and software can be reversed in some cases, other direct costs associated with organisational learning and adaptation cannot be reversed. These costs include expenditures for training, hiring experienced workers and consultants, engaging in learning by doing, developing new policies and procedures, and absorbing losses in productivity during the transition from old to new (Fichman 2004).
- Managerial flexibility regarding how projects are structured (Dixit et al. 1994). As described earlier, managers have considerable flexibility in how they approach IT projects. This flexibility can take the form of flexibility in the configuration of a project, for example through staging or incremental development.

Different types of real options may be present in IT projects, as described in Table 2-1 (Trigeorgis 1993). A distinction can be made between operating real options and strategic real options. *Operating real options* relate to the operational aspects of the project (timing, scale, scope, etc.) and allow to flexibly change investment configuration features. These options are the option to defer, the option to change scale, the option to switch use, the option to abandon and the option to stage. *Strategic growth options* spawn new investment opportunities and refer to the opportunity to grow the project's scope beyond what was initially anticipated through follow-up investments (Benaroch 2002). Strategic flexibility options are especially interesting in case of IT infrastructure investments, as we shall see in chapter three, since their value is derived from follow-up investments.

In the information systems research field, there are two main streams of research with regard to real options theory. One stream focuses on *real options analysis* (Benaroch and Kauffman 1999, Benaroch 2000), and is high on rigor and the technical aspects of valuing investments using real option analysis. However, it often overlooks the complexities of applying real options to the kind of projects IT managers actually face. The other stream focuses on *real options reasoning* or *real options thinking* (Fichman 2004, Fichman et al. 2005, Tiwana et al. 2006, Tiwana et al. 2007), a strategy focus concerned with the articulation of managerial heuristics and reasoning processes based on the real options logic. This stream recognizes the complexities of applying real options in practice. It typically offers no rigorous approach to configuring the various real options that could be embedded in real projects.

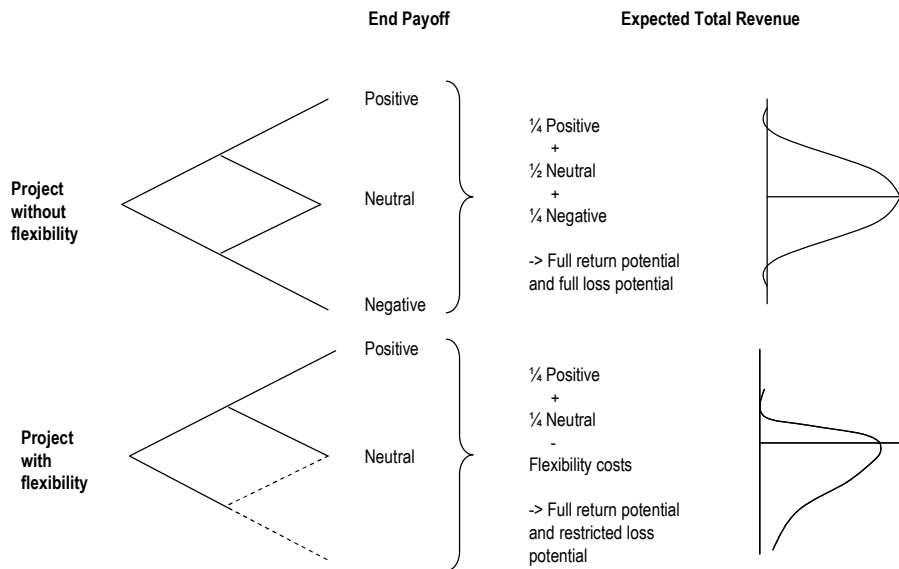
The focus of our research is mainly directed to the options reasoning research, as we show in chapter three and five. In chapter four we will use a real options analysis to compare the real options value with other valuation techniques. We will first discuss real options analysis, as its core concepts represent the basis for options reasoning. In the next section we present real options reasoning and its relation to the management of risk.

## 2.4.2 Real Options Analysis

In capital budgeting theory, the value of an asset (or an entire company) equals the discounted present value of its expected future cash flows. Cash flows are the cash inflow and cash outflow of the organisation. Normally, the legal boundary of the company is taken as the 'border'. This net present value (NPV) is exactly the same as the increase in shareholders' wealth (Buckley et al. 1998). Hence, companies contemplating investments in capital projects should use the NPV rule. That is, take the project if the NPV is positive but reject it if the NPV is negative or zero. The attractiveness of an IT investment project is then calculated by the summation of the associated cash flows. In formula (Copeland et al. 2001):

$$NPV = \sum (CF_t / (1 + k)^t) - I_0, \quad \text{for } t = 1, \dots, n$$

$CF_t$  stands for the sum of cash flows in year  $t$ . The cost of capital is  $k$ .  $I_0$  stands for the initial investment (cash flows) at the beginning of the project. NPV stands for net present value, the sum of the discounted cash flows of the investment. The NPV rule assumes that no decision or action will be taken in the future once the project starts to take place; that is, it assumes that all expected cash flows are precommitted. As we have argued earlier, this is typically not the case with IT projects. Therefore, the NPV rule is argued to represent the lower bound of an ongoing project's actual value to the firm (Taudes et al. 2000). The difference in the valuation of an investment without flexibility as opposed to an investment with flexibility is shown in Figure 2-2.



**Figure 2-2:** IT project value with and without managerial flexibility (Scialdone 2007)

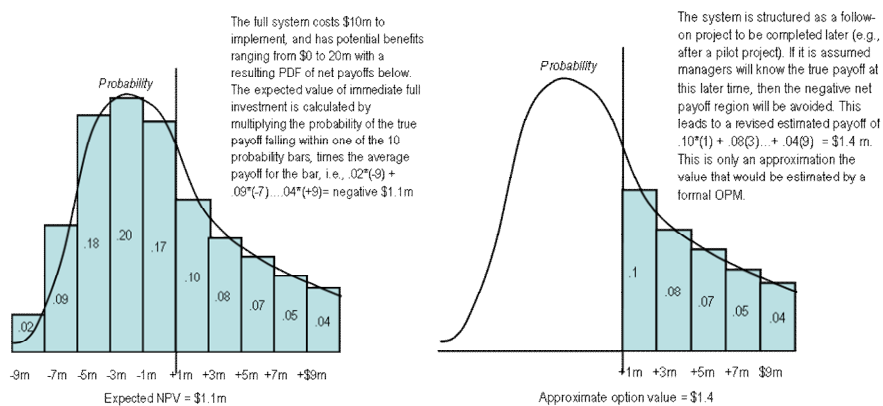
Let us assume that a project's outcome can either go up or down in both time periods. The upper decision tree in the figure represents the project without flexibility. The outcome at the end of period two can be either positive (i.e. two times up), neutral (one time up and one time down) or negative (two times down). The middle outcome is twice as likely as the other two outcomes because it can be reached in two different ways. This will result in a normal distribution of the project's expected cash flow. The lower project investment incorporates managerial flexibility, considering the possibility to skip the negative outcomes (depicted in dotted lines). This results in an asymmetrical distribution of the project's payoff. Therefore, Fischer (2002) concluded that the NPV on its own is unsuitable for valuing projects as it represents the lower bound of project value under high uncertainty.

The goal of a real options analysis is to determine the active net present value (NPV) of a project. The traditional NPV estimates do not consider the value of the

opportunity for managers to intervene across the project's trajectory. The so-called 'active' NPV is equal to the traditional, or passive NPV plus the value of the embedded real options (flexibility) (Benaroch 2002). Thus,

$$NPV_{Active} = NPV_{Passive} + f(\text{value of real options embedded in the project})$$

The option perspective assumes that the exposure to positive and negative payoffs of a project is asymmetric. This follows directly from the assumption of managerial flexibility underlying real options analysis, and is visualized in Figure 2-2 and explained in detail in Figure 2-3 (Fichman 2004). It is assumed that managers will have the discretion to refuse to exercise options (flexibility) for which the updated estimates of investment costs exceed those for the benefits. To put this graphically, it is assumed that managers are only exposed to the positive payoff region of the investment, as shown in Figure 2-3 (b). This fact contradicts the NPV view, which assumes all initiated projects are brought to completion, i.e., firms are exposed to the whole payoff region in Figure 2-3(a).



**Figure 2-3 (Fichman 2004) (a): NPV Approach (b): Real Options Approach**

To calculate real options value, the NPV represents the starting point for valuing flexibility using real options, since the present value of the project without flexibility represents the base case in a real options valuation as we show in chapter four. To calculate a project's option value, one needs the project's NPV, the time in years until the expiration of the option and the volatility of the project, which represents an estimate of the variance of project returns. It measures the risk associated with the project in terms of fluctuations in the cash flow during the course of the project.

There are different types of real option valuation models, such as the Black Scholes model or the binomial option model. A treatment of these models and their specific underlying assumptions is outside the scope of this research.

### **2.4.3 Real Options Analysis Critique**

There are limitations in applying options analysis to emerging technology investments. Financial options models rely on several core assumptions to arrive at an option price, where different models have been developed that have different underlying assumptions. To generate a comprehensive overview of the arguments against the use of real options, they will be briefly mentioned in this section. However, it should be noted that we will not go into the arguments against real options analysis and its counterarguments too deeply, since they also depend on the options model and this is beyond the scope of the present study. In Table 2 the arguments against the use of option pricing and the counterarguments are described (Benaroch et al. 2000, Fichman 2004, Kumar 2002, Scialdone 2007).

Challenge	Counter Argument/Remedy
There is a lack of transparency in options models.	When transparency is important, analysts can use the binomial option model or even more transparent approaches, such as a decision tree, which can give a rough approximation of option value.
Absence of a traded market for IT assets makes it difficult to estimate the expected value of future cash flow of a project.	The NPV of the project itself can be regarded as the best estimation for the value of the project as if it were traded on the market. Managers must estimate the future expected cash flows of a project even under the NPV approach, and options valuation is no more sensitive than NPV valuation to misestimates of project cash flows.
Option valuation uses a risk-neutral approach.	Option valuation is the same in the risk-neutral world and our everyday risk-averse world as long as it is possible to build a portfolio of assets that tracks the risk characteristics of the investment. In the event of not being able to build a tracking portfolio, option valuation may still be a good approximation that captures flexibilities of the investment decision that are not considered by NPV.
Absence of a traded market for IT assets makes it difficult to estimate the volatility (uncertainty) of the value of a project (another key option model parameter) and may raise concerns that analysts might "fudge" this parameter.	Analysts can do a sensitivity analysis to determine whether a project is justified under different sets of assumed levels of volatility. Analysts can use conservative values for uncertainty until they have gained more experience.

**Table 2-3** Summary of real options critique

While practical challenges exist in the valuation of managerial flexibility in IT projects, in many cases these challenges will be manageable (Copeland et al. 2001), and where they are not, managers can use other techniques to support options reasoning, such as decision tree analysis, qualitative scoring models, or general project management heuristics. While a formal options model is not needed to apply options reasoning, it is often worthwhile to employ such models, especially on major projects or in situations with competing investment scenarios.

Following the economist Adam Smith, Scialdone (2007) states that it is important to keep in mind that specialization and concentration of workers in

their special single subtasks leads to better skill and greater productivity. He contends that there is a need to separate the two aspects of recognizing and managing the value of managerial flexibility by decision makers and technically valuing the flexibility by mathematicians. In the next section, we will address the more interesting issue of the recognition and management of flexibility by decision-makers.

In our opinion, the main issue we should focus on in this research is the fact that real options theory recognizes that managerial flexibility has value and that managers can actively use this value to deal with risk when investing in IT projects. There will be many circumstances where embedded options resist precise quantification, due to high levels of ambiguity surrounding the impact of these options on the firm and its competitive environment (Fichman 2004) and the related impossibility to quantify the needed variables necessary to actually perform the option valuation. We believe it is worthwhile that managers place a value on flexibility in some (either quantitative or qualitative) way and apply real options logic in a systematic way when managing IT projects.

#### **2.4.4 Non-financial Criteria to Value the Potential of Managerial Flexibility**

Obviously, managerial flexibility to alter the operating strategy of a project depends on the number of choices there are, the likelihood of the change (Mandelbaum 1978) and the ease of change (Scialdone 2007). When determining the value of managerial flexibility to optimally configure an IT project, both the real option and the NPV approach derive their measure for managerial flexibility from the financial consequences of an IT project. However, although economists often define value in terms of strict monetary equivalent, Remenyi et al. (1993) have a non-financial definition of value, being 'the amount of some commodity, medium of exchange, etc. which is considered to be an equivalent for something else; a fair or adequate equivalent or return'.



IT projects can typically result in non-financial benefits such as intangible performance improvements (Remenyi et al. 1993). Unlike cost, such benefits primarily impact processes inside an organisation and are seldom easily translatable into cash flow. Their value is, therefore, predominantly dependent on (individual) judgement and not on market prices. When finding a balance between risk and IT project benefits to determine the value of managerial flexibility, ignoring this value may negatively impact the insight in the total value of managerial flexibility of the IT project. When changing the operating strategy of a project, both the number of choices an organisation possesses, the likelihood of the change as well as the ease of change can heavily depend on non-financial criteria. These non-financial criteria are, for example, the availability of resources for making a change possible, or the presence of multiple interested parties which makes changes not desirable, or the internal process benefits that are affected by adding flexibility to a project.

There are several techniques available for decision-making under uncertainty, such as multiple attribute decision-making and scenario planning. Taking into account other aspects than financial criteria to value managerial flexibility in an IT project can lead to very different considerations and outcomes in the valuation process as we shall show in chapter four.

## **2.5 Real Options Reasoning and IT Risk Management**

Researchers have stressed the importance of recognizing that real options analysis is first and foremost a way of reasoning. In this section we present real options thinking and its relation to the management of risk. We address the issue of the recognition and management of flexibility by decision-makers.

### **2.5.1 The Managerial Valuation of Real Options in Practice**

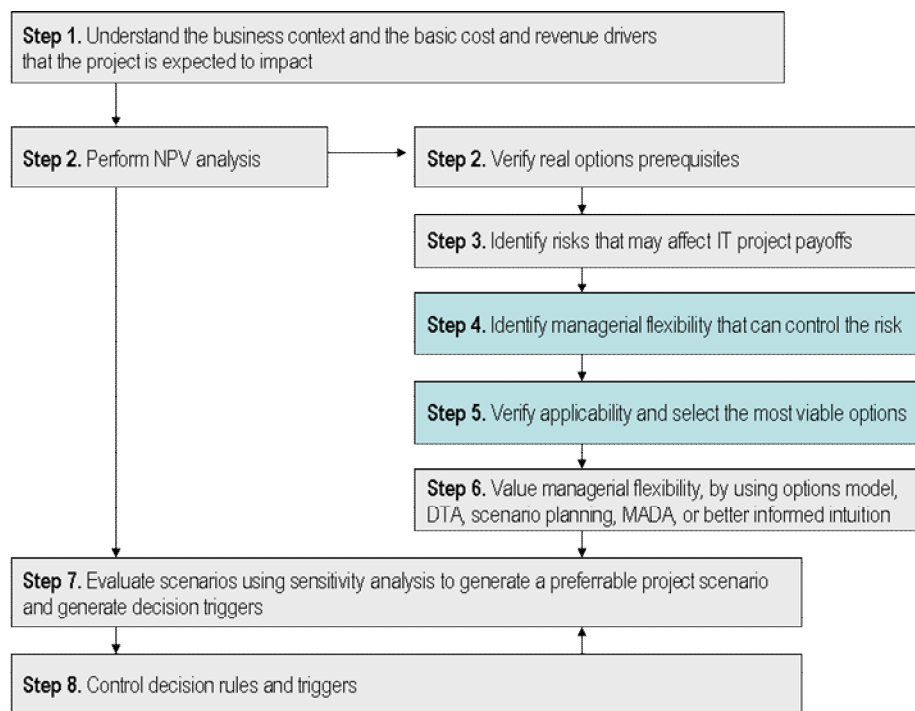
In practice real options are not pre-existent in IT projects and have to be actively embedded and managed by decision makers (Benaroch 2002). Even though it may be difficult to precisely calculate the value of real options, it is plausible that managers motivated by the prospect of producing a positive economic return recognize the value of real options and ascribe a higher value to a project with one or more embedded options than they would to the same project without any embedded options (Tiwana et al. 2006).

However, there is little evidence on the valuation of real options by managers. The little evidence we have at present shows that the real options logic may well explain some of managerial decision-making. Busby and Pitts (1997) found that managers' intuitions agreed with the qualitative prescriptions of real options theory. In one of the few laboratory experiments to date on real options valuation, Howell and Jäggle (1997) found that the NPV rule is a poor description of how managers empirically value growth options when presented with decisions on a series of investment case studies, and they found a weak correspondence between management's intuition and real growth option theory.

More recently, Tiwana et al. (2007) found that managers ascribe a higher value to a project with embedded options than they do to the same project without any embedded options. Especially, managers value growth options higher than operational options. The perceived added value of the options is found to influence IT project continuation decisions. In a more recent article, Tiwana et al. (2007) found that managers intuitively value real options when a project's easily quantifiable benefits are low, but are highly vulnerable to being oblivious to them when the project's quantifiable benefits are high. So, in summary, there is some, but still little, evidence that managers intuitively value real options in project investment decisions.

## 2.5.2 The Managerial Valuation of Real Options in IT Risk Management

Using real options to study risk management is based on the recognition that managerial flexibility is not only valuable; it is also a way of *dealing* with risk. Bräutigem et al. (2003) observed that since flexibility represents the ability to react to a state of resolved risk, this risk is the key presence of flexibility. Recognizing which managerial flexibilities to embed in a project as a response to risk should be one of the core concepts for deciding whether or not a real option analysis is relevant for a specific IT project. We show this in Figure 2.4, as derived from (Benaroch et al. 2007, Bräutigem 2003).



**Figure 2-4:** Project investment configuration framework, derived from (Benaroch et al. 2007, Bräutigem 2003)

Obviously not every single risk factor may be tied in a clear manner to a single specific real option, or vice versa. However, Micalizzi and Trigeorgis (1999),

Kumar (2002) and Benaroch (2002) have shown how different real options can be related to a specific risk to capture the inherent value of active management of a specific risk factor. They find a matching type of real option which could respond to a given risk that affects the IT project's outcome.

Of course, from a managerial perspective it is interesting to find out whether IT decision makers follow real options logic in risk making decisions. Do they recognize the value as offered by different option types when facing different types of risk, and which biases do they show in intuitively valuing managerial flexibility when facing risk? This is especially relevant considering that a manager is informed about the risk that may be encountered during the IT project's lifecycle, and also about the possible flexibilities that she possesses to change the operating strategy of the project. The manager has to make the preliminary decision of properly determining the potential real options inherent in a project in the face of risk. We will present and test the logic behind the mapping as proposed by Benaroch et al. (2006) in chapter five.

## **2.6 Detailed Research Questions**

As we have contended above, flexibility is a crucial factor to gain competitive advantage as a firm. Nowadays, managers of most companies seem to be aware of the benefits of being flexible. Since flexibility is a critical success factor in relation to the management and design of IT investments (Kim and Chung 2003), and since understanding flexibility is a difficult issue, it is important to explore how firms build flexibility into their IT investment decisions. Therefore, in chapter three, we will focus on the following research questions:

**Detailed Research Question 3-1:**

*How do firms develop IT infrastructure capabilities<sup>3</sup> and what is the role of the needed strategic flexibility?*

**Detailed Research Question 3-2:**

*How do firms recognize and value different types of managerial flexibility?*

While a formal options model is not needed to apply options reasoning, it may be worthwhile to employ such models, especially on major projects or in situations with competing investment scenarios. However, non-financial benefits can form a large part of a project's value, and therefore the value of managerial flexibility in IT projects will not rely on real options value alone. In chapter four, we will focus on the following research questions:

**Detailed Research Question 4-1:**

*How can managerial flexibility in an IT project be evaluated so that different types of risk, and financial and non-financial information can be taken into account?*

Recognizing which managerial flexibilities to embed in an IT project as a response to risk should be one of the core concepts for deciding whether or not the flexibility as offered by real options is relevant for a specific IT project. Of course, now the obvious question to investigate is our last detailed research question, as we will present in chapter five.

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<sup>3</sup> Since IT infrastructure investments address shared organisational goals as connectivity or compatibility (e.g., through standardization) rather than needs of specific lines of business, it is a central concept in research on organisational flexibility. Therefore, in chapter three we focus on IT infrastructure investments.

### Detailed Research Question 5-1:

*How do different types of risk influence the relative value that managers intuitively ascribe to different types of real options?*

Table 2-4 summarizes the detailed research questions, the research methods, the level of analysis and the studies' corresponding chapters.

Research Question	Level of Analysis	Research Method	Chapter
RQ3-1	Firm perspective	Exploratory case studies	3
RQ3-2			
RQ4-1	Project perspective	Decision model and case study application	4
RQ5-1	Individual perspective	Field experiment (incl. pretest)	5

**Table 2-4:** Summary of the research design

<sup>4</sup> Since IT infrastructure investments address shared organisational goals as connectivity or compatibility (e.g., through standardization) rather than needs of specific lines of business, it is a central concept in research on organisational flexibility. Therefore, in chapter three we focus on IT infrastructure investments.

## Chapter 3

### **A Resource Based and Real Options Perspective on Strategic Flexibility and IT Infrastructure Capabilities: an Exploratory Case Study Analysis**

In this chapter, we are interested in exploring the linkages between strategic flexibility, IT infrastructure capabilities, and flexibility in IT investment decision-making. The research presented in this chapter has two purposes. The first purpose of this chapter is to explore whether different types of needed flexibility at the organisational level ask for different types of IT infrastructure capabilities, and how firms build flexibility into their IT investment decisions. To meet the research objective, we used the literature review leading to a general research framework<sup>5</sup> to guide the explorative case studies<sup>6</sup>, as described in chapter two. We took a closer look at the important constructs and the relationships between them. In this chapter, we report on the empirical study, and present the findings. Using these findings, we present propositions and improvements for a more detailed research framework that will guide us in future research. The second purpose of the research in this chapter is to frame the scope of the remaining research as presented in the subsequent chapters. Therefore, we explicitly emphasize the explorative character of the research presented here.

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<sup>5</sup> An earlier version of the literature study and the conceptual framework was presented at the *European Conference on Information Systems 2004*, C.A.R. Hilhorst, M.T. Smits, 'A resource based and real option perspective on IT infrastructure investment aiming for strategic flexibility', June 2004, *European Conference on Information Systems*, Turku Finland, 2004

<sup>6</sup> A previous version of the case study analysis in this chapter was presented at the *European Conference on Information Systems 2005*, C.A.R. Hilhorst, M.T. Smits, E. van Heck, 'IT infrastructure investment and strategic flexibility: empirical evidence in two case studies', May 2005, *European Conference on Information Systems*, Regensburg Germany, 2005.

This chapter is structured as follows. In section one, we introduce the literature on investments in IT infrastructure and strategic flexibility. In section two, we introduce the literature on IT infrastructure capabilities and we introduce a conceptual framework that we use in the exploratory case study research. In section three, we present the case study data. In section four, the analysis of the empirical findings is presented and we present our propositions. In section five, we discuss the limitations of our study.

### **3.1 Strategic Flexibility and IT Infrastructure Investments**

The degree in which organisations in a turbulent environment can respond to competing demands while being in control is referred to as strategic flexibility. The business imperative of strategic flexibility is posing requirements on the firm's IT capabilities. Recent research (Duncan 1995, Byrd et al. 2001, Weill et al. 2002, Ross 2003) has focused on how to structure the IT infrastructure assets and resources when aiming for strategic flexibility.

A firm's needed degree of flexibility is dependent on the turbulence of a firm's environment, which is formed by its competitive forces and can be measured in terms of dynamism, complexity and predictability (Volberda 1998). An organisation's flexibility is the degree to which an organisation possesses a variety of actual and potential procedures, and the speed at which they can be activated, to increase the control capacity of management and improve the controllability of the organisation (Volberda 1998, Byrd et al. 2000). Confronted by a dynamic, complex, and unpredictable environment, firms need strategic flexibility. Strategic flexible firms possess the ability to easily and quickly change key aspects of business strategy, thereby improving their potential for a favourable competitive position (Hitt et al. 1998, Volberda 1998).

Strategic flexible firms can have a fast response to: (1) changes in aggregate customer demand, (2) customize a product or service to suit an individual customer, (3) new product or service launches by competitors, (4) introduce new



pricing schedules in response to changes in competitors' prices, (5) expansion in new markets or regions, (6) adopt and apply new technologies to produce faster, better and cheaper products and services, (7) fundamentally renew products, (8) cooperate or easily switch in co-makership, co-design or just-in-time purchasing to avail of lower costs, better quality or improved delivery times.

Strategic flexibility poses requirements on the IT capabilities to provide cost-effective, scalable IT infrastructures that enable the organisation to design and implement new business process applications to respond to emerging business opportunities. Weill and Broadbent (1998) define IT infrastructure as the base foundation for building business applications, which is shared throughout the firm as reliable services. They have found that firms have to be leading in certain infrastructure capabilities, depending on the type of business initiative a firm wants to implement in their aim for strategic flexibility. These types of business initiatives are characterized by: (1) their position on the value net (supply, internal or demand initiative), (2) the type of exchange (B2B or B2C) and (3) the position on the value net (new market or new product initiative). The capabilities of IT infrastructure are some of the most critical issues IT managers are facing. However, there is still little empirically based research with a focus on IT infrastructure capabilities and the specific strategic flexibility that these capabilities support. Also, there is little research on how organisations identify and manage these investments when dealing with a turbulent environment. In the next sections we will introduce a conceptual model to address this topic.

### **3.2 Theoretical Framework**

To help underpin the research on strategic flexibility and IT infrastructure, we draw insight from two theoretical frameworks: the resource based theory and the real option theory. Using resource based theory, one can explain how organisations structure their technological assets and resources to take advantage in a competitive market environment. Options theory suggests how firms can

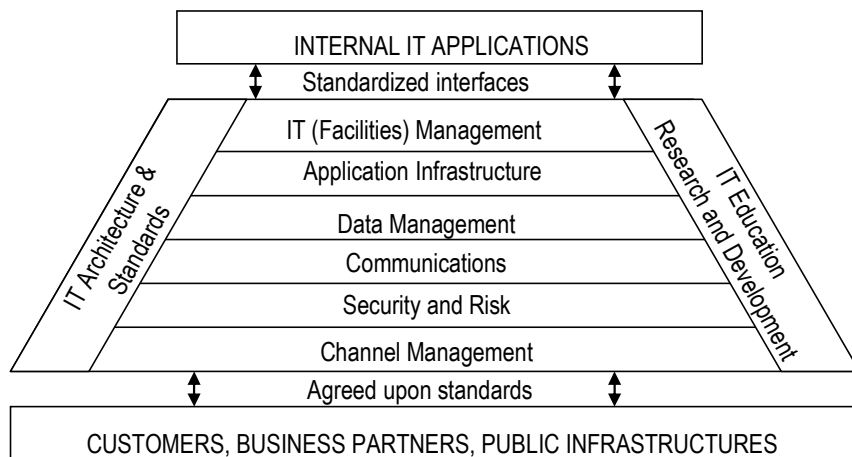
capitalize on their strategic options in a fast and changing business environment (Amran et al. 1999). A combination of these frameworks will provide in-depth knowledge on how organisations structure and use their IT infrastructure assets and resources given the uncertainty and irreversibility of their IT infrastructure investments.

### **3.2.1 Resource Based View and IT Infrastructure Capabilities**

The crucial requirements of the resource-based view are that the relevant resources, whatever their nature, are specific to the firm, rare and not capable of easy imitation by rivals (Barney 1991, Clemons 1991, Mata et al. 1995). A distinction can be made between resources and capabilities. While resources serve as basic units of analyses, capabilities are repeatable patterns of action in the use of resources to create, produce, or offer value to a market.

Weill et al. (2002) identify ten IT infrastructure capability clusters (see Figure 3-1). The clusters comprising the *physical* layer of IT infrastructure capability are: (1) channel management, electronic channels firms need to link to customers and partners, (2) security and risk-management services, which provide protection for the firm's brand, reputation, data, equipment and revenue stream, (3) communication services, through which electronic interactions with customers and partners occurs, (4) data-management services, which provide for management of data assets, (5) application infrastructure services, applications that are standard across the firm and (6) IT facilities management services, which coordinate and span the physical infrastructure layers and add value by integrating the five other physical layers. In addition to these clusters that constitute a firm's physical IT infrastructure capabilities, there are several clusters representing *management-oriented* capabilities, among which: (7) IT management services, which coordinate the integrated infrastructure and manage its relationships with the business units, (8) IT architecture and standards services, which comprise the core policies that govern the use of information technology

and that determine how future business will be done, (9) IT-education services, which includes training in the use of specific technologies and education for management on IT investment to create business value and (10) the IT Research and Development services, which includes the firm's search for new ways to use IT to create business value.



**Figure 3-1.** An integrated IT infrastructure with 10 capability clusters according to Weill et al. (2002)

In our research we use this capability view to investigate the IT infrastructure capabilities that firms develop when aiming for strategic flexibility. Resource based theory offers us a lens through which we can examine the distinguished IT infrastructure capabilities and analyze how these capabilities differ in the extent of strategic flexibility they provide.

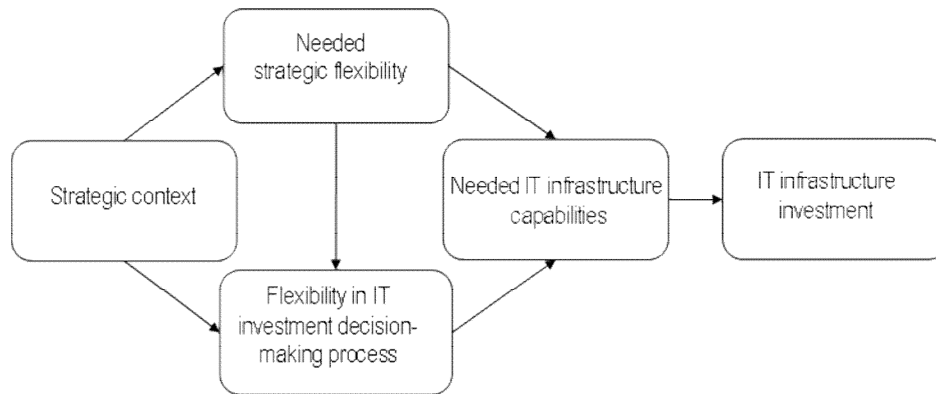
### **3.2.2 Real Options Theory and Flexibility of IT Investments**

Resource based theory favours investments that minimize the current level of uncertainty and performance variance (Peffer et al. 1978). Real options theory is used in situations involving irreversible decisions under high uncertainty. A real option, by definition, gives the holder the right, but not the obligation to take ownership of an underlying asset at a future point in time. Option models have been shown to be applicable to making IT investments (e.g., Benaroch et al. 1999, Taudes et al. 2000). Although there are limitations in applying options theory to emerging technology investments, option researchers and innovation scholars agree that real options are useful in understanding the adoption of emerging IT and stress the importance of recognizing that real options analysis is first and foremost a way of thinking about how technology investments can be structured and managed (Amran and Kulatilaka 1999, Jarvenpaa and Tiller 1999, McGrath and McMillian 2000, Fichman 2004).

Since flexibility is synonymous with the creation of real options (Benaroch et al. 1999), an increase in flexibility when investing in IT infrastructure can have a positive influence on the value of IT investments. Promoting flexibility in the investment or systems development process creates a quantifiable value, and this value exists whether or not an organisation actually attempts to quantify it using an options pricing model (Fichman et al. 2005). Also, promoting flexibility in the result of the investment (i.e., the connectivity or accessibility of the IT infrastructure) can open up future opportunities, for example to support the ability to change the scale of an investment. Fichman et al. (2005) distinguish between different types of real options that commonly exist in IT investment decision-making processes, and show how the options create value: (1) stage investments (i.e., projects can be divided into distinct stages), (2) to abandon investment, (3) defer initiation of investment, (4) to create growth opportunities based on an initial investment, (5) to change the scale of investment, and (6) to switch assets created by the investment to another use. We will use these different

types of options to analyse the extent of flexibility in the IT infrastructure investment decision-making process. A distinction can be made between operating real options and strategic real options. *Operating real options* relate to the operational aspects of the project (timing, scale, scope, etc.) and allow for the flexible changing of investment configuration features. These options are the option to defer, the option to change scale, the option to switch use, the option to abandon and the option to stage. *Strategic growth options* spawn new investment opportunities and refer to the opportunity to grow the project's scope beyond what was initially anticipated through follow-up investments. Real options theory offers us a lens through which we can examine whether and how organisations identify, track and actively increase flexibility in the IT infrastructure investment process and result.

We propose a conceptual framework based on the elements described above to guide the field study and the data collection of this study (see Figure 4-2). We define strategic context as the degree of environmental turbulence, and it is measured in terms of dynamism, complexity and predictability (Volberda 1998). Depending on the strategic context, firms need specific strategic flexibility, which is defined according to Volberda (1998). The need for specific types of flexibility leads to IT infrastructure resource investment, which leads to different IT infrastructure capabilities, which are operationalized and categorized according to Weill et al (2002) (see appendix A). Depending on the environmental turbulence, firms may need flexibility in their IT investment decision-making process, which will be operationalized by the different types of options according to Fichman et al. (2005).



**Figure 3-2.** Conceptual framework for the explorative case study research

The model in Figure 3-2 raises the following research questions, which will lead the investigation:

- How do firms develop IT infrastructure capabilities and what is the role of the needed strategic flexibility?
- How do firms recognize and value different types of managerial flexibility?

### 3.3 Field Study

To further explore the relationships between the strategic context, strategic flexibility, IT infrastructure capabilities and flexibility in the IT investment process, we conducted a multiple explorative case study. We selected two firms in different industries and in different strategic contexts. We selected cases with firms where the needed types of strategic flexibility differed. Within these firms we selected IT infrastructure investments that are complex, strategic or innovative. One firm is a Dutch nationally operating bank, which operates in a complex, dynamic but predictable environment. The other firm is a Dutch internationally operating lithography company that is operating in a complex, dynamic, and highly unpredictable environment.

The cases were studied from May to August 2004, and encompass in-depth semi-structured interviews with the CIO, a business manager, an IT architect and, in one case, an external IT-supplier. A set of open questions was used to roughly guide the interviews. Archival data based on internal documents, industry publications, and other written material were used. The cases will be described in more detail in the following section.

### **3.3.1 The Case of the Dutch Bank**

#### *Strategic Context*

The Dutch bank is a business unit of a banking and insurance group with approximately 6000 employees. The bank and the other business units of the group operate quite independently from one another. The bank has its own internal IT organisation which employs about 250 people. The bank is one of the five large banks in the Netherlands, and has its focus on the national retail market. The bank's environment can be described as dynamic, complex but predictable.

#### *Needed strategic flexibility*

The bank started a strategic reorientation in 2000, which resulted in a choice for product leadership, by striving to offer innovative products among different channels with a short time to market that can quickly respond to changes in customer preferences and changes in competitors' actions. Strategic flexibility is needed to offer a fast response to: (1) changes in aggregate customer demand, (2) customization of products or services to suit individual customers and (3) new product launches by competitors.

#### *IT Infrastructure Resource Investment*

In early 2000, the IT department began the process of aligning the information infrastructure with the new corporate strategy by uniting all of its retail distribution channels into a common technical strategy. In 2001, the IT department

started with the implementation of a new strategic infrastructure platform, an IBM WebSphere<sup>7</sup> platform. With this platform, the banks main goal was to invest in the development of an internal foundation to meet the strategic objectives.

#### *IT Infrastructure Capabilities*

The WebSphere implementation project started as an architecture project. The platform must fulfill an integral part of the bank's future IT architecture at business unit level. The platform provides for channel management capabilities: it is intended to be the strategic application development platform and to support applications for all different labels ('brand names') and channels (which include the offices, the call-centre, the Internet, intermediaries and electronic applications like cash-machines). By choosing a platform based on open standards, it is expected that future technologies will be added relatively easily. The platform provides for application infrastructure capabilities: it supports back-office application integration to improve communication between the front-office and back-office systems and makes application development cheaper. Before the investment was made, the application functionality and interfaces between applications in the front- and back-office can be represented as shown in Figure 3-3a. For each distribution channel, front-office functionality is developed independently per label and per distribution channel. This leads to redundant functionality in the front-office and a 'spaghetti' of interfaces with the back-office, giving a lack of maintainability.

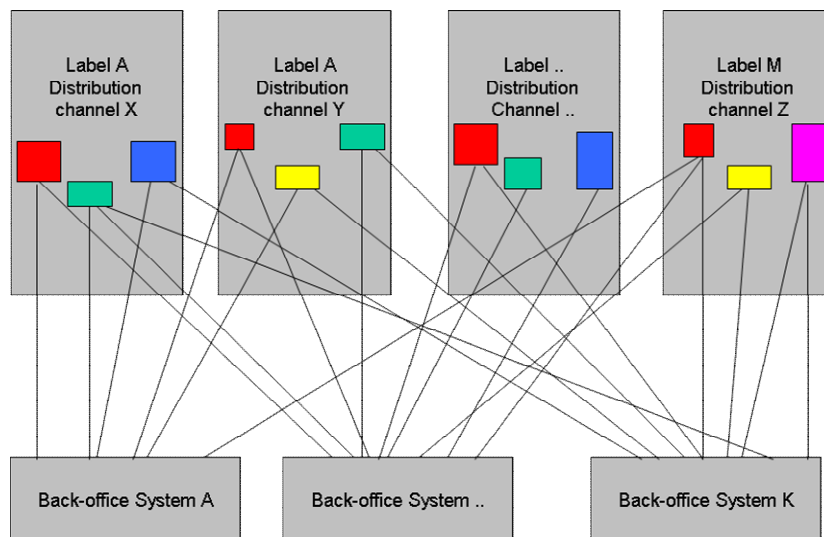
The future application functionality and the interfaces between applications in the front- and back-office can be represented as shown in Figure 3-3b. Front-office functionality will be shared among labels and distribution channels whenever possible. This is expected to lead to a reduction of the number of interfaces between the front-office and the back-office. In the future, the reusability of

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<sup>7</sup> The following WebSphere products were tested: WS Visual Age for Java, WS Application Server, WS Business Components Composer, WS Bank Business Teller Components. The first three products



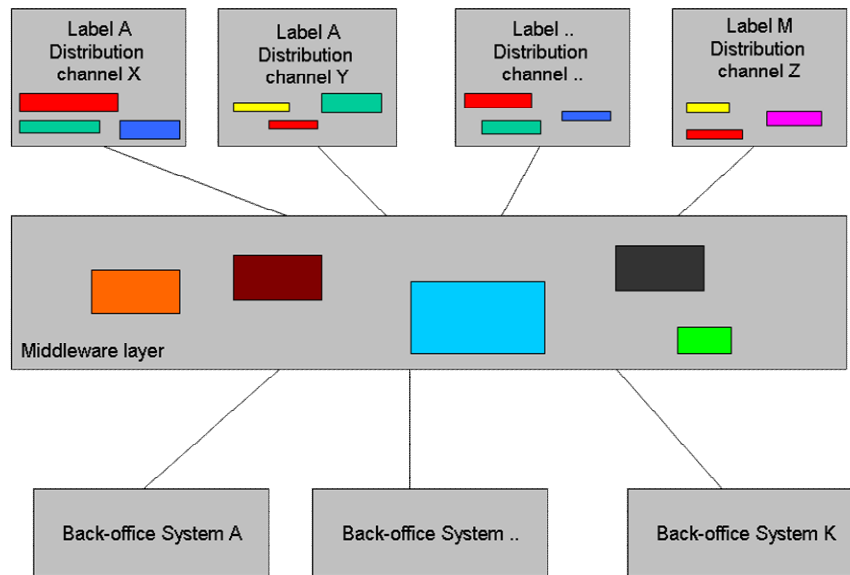
transactions over different front-office channels is expected to lead to reduced maintenance costs and to simplified application management. Central data management services at business unit level heavily facilitated the platform implementation. Easy access to centrally stored client data at business unit level has prevented discussions about adjusting data definitions and data quality issues. This made it relatively easy to implement projects at the demand side, such as implementing Internet-banking, Internet-saving-accounts and i-mode applications.



**Figure 3-3a.** A conceptual representation of the IT infrastructure before the investment

Strongly developed IT management capabilities such as strategic planning capabilities, lead to the IT platform investment in the first place; the business first was reluctant to the implementation. However, the IT management board considered the platform to be an essential investment for fast response in future were finally purchased.

demand side initiatives. By specifying architecture guidelines for the way IT applications will be used and integrated, the IT architecture and standards capabilities matured.



**Figure 3-3b.** A conceptual representation of the IT infrastructure after the investment

*Flexibility in the IT Investment Decision-Making Process*

In general, the bank has a relative advantage in the efficiency and effectiveness of its IT decision-making as opposed to competitors, by its relatively small size and its centrally organized IT department. The IT investment decision cycle for large projects has recently been brought back from a one-year-project-planning-cycle, to a one-year-project-planning-cycle with a revision of the project planning every quarter, thereby allowing to respond faster to opportunities that arise. A special project committee has been installed to prioritize projects and to advise the CIO and the board of directors. The bank allows for small investments in strategic

experiments to keep up with competition. IT investment decisions are based on a ROI business case and valued on a diversity of additional criteria, among which the extent to which a project can be deferred. Flexibility is explicitly taken into account in the investment process by looking at scalability, the openness of the solution and the possibilities for reusability.

The system development and implementation process for the platform investment comprises several stages: (1) an architecture phase of one month, (2) an implementation phase of four-and-a-half months, consisting of the development and implementation of a working application and the development and implementation of the needed organisational methods and techniques. After this project, the bank's largest 16-bits front office application consisting of 3,000 transactions was rebuilt into new reusable functionality, taking several years to complete.

*"This application is one of the major justifications for implementing the platform, which every business unit will use either totally or partially. If we can realize savings by reusing every form of transaction, in fact we will have profited 3,000 times." Project manager*

This project, that would have taken approximately 45 man-years to complete, could be completed in approximately 25 man-years due to the platform investment and has been completed in 2004. This project was not explicitly valued in the business case for the platform implementation, but was implicitly taken into account. The two initially developed applications supported by the new platform comprised two applications that were built to improve and refine existing solutions to support structured, transaction processing activities. The bank scheduled two additional near future projects to renovate the way the bank interacts with its customers. One project aims at building an application that supports assisted-investing, by which customers can invest with self-assistance

through the web instead of with bank-office support. Another project aims at further developing middle-layer application integration, which helps to create a complete customer profile to enable the new multi-channel applications to provide customers with all account information at once.

The development of new product releases is more complex, as it asks for a more multidisciplinary view on software maintenance.

*"We have won in flexibility if we want to launch new products among multiple channels. But this gain in flexibility has a downside: on the whole, things have become more complex because of working in multidisciplinary IT and business teams. Also, if we want to launch a product in one channel only, these projects take more time." Business manager*

Although productivity rates are managed strongly, a loss in productivity when implementing new functionality due to learning-time is noticed on the business side and is compensated for by the IT department. On the organisational side, extra time is needed when accommodating requests among channels; business people are obliged to work in cross-channel teams.

### **3.3.2 The Case of the Dutch Lithography Firm**

#### *Strategic Context*

The global lithography firm operates in the chip technology business with a client base consisting of large high-tech international firms. One of the basic characteristics of the firm is that it finds itself in a market with highly volatile demand; global economic changes are very well sensible and periods with high and low sales rates are swift. Despite this environmental turbulence, the firm is the leading technology provider in its industry. It has approximately 5,000 employees among which are production employees, engineers and machine software-developers. It owns an internal IT department with about 400 employees.

Because of fluctuations in demand, the firms' employee base fluctuates accordingly. The acquisition of a U.S. corporation made clear that the integration of the two firms would become an issue.

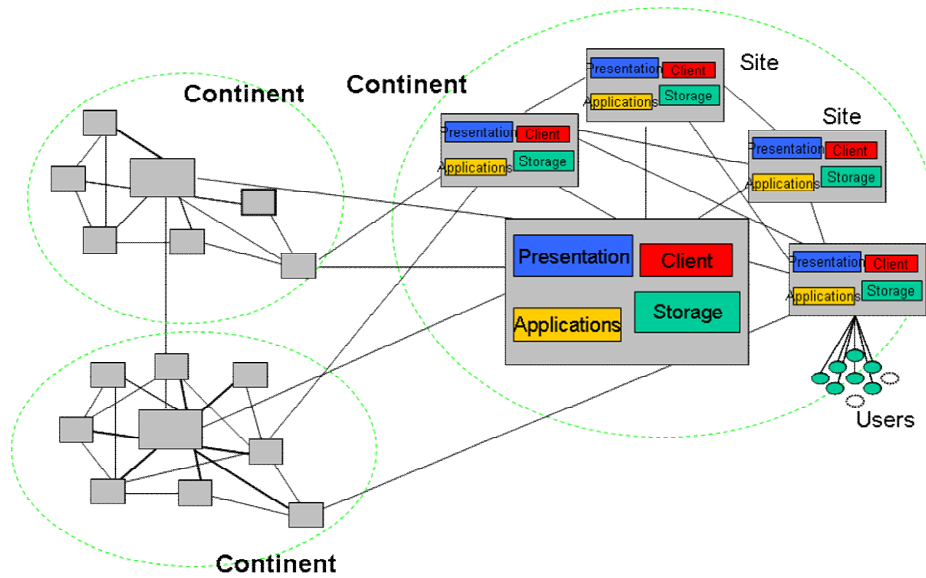
#### *Needed Strategic Flexibility*

To respond to the changing markets, the firm works closely with suppliers and other third parties. Communication and information form the backbone for the highly integrated chains, including products and manufacturing-chains at the customer site. IT support for strategic flexibility in terms of fast cooperation and communication with external partners has to improve. The development of three months forecasts with external partners to respond to the changing market has to be supported by a flexible and consolidated technical IT infrastructure. Also, the global application of new technologies has to be made easier by implementing firm-wide architecture standards.

IT infrastructure support for strategic flexibility to globally scale workforce capacity up and down, also has to become easier. The expansion in new markets or regions and the integration of acquisitions has to improve. Easy global services access of new user groups (e-mail, et cetera) has to be supported by the new infrastructure.

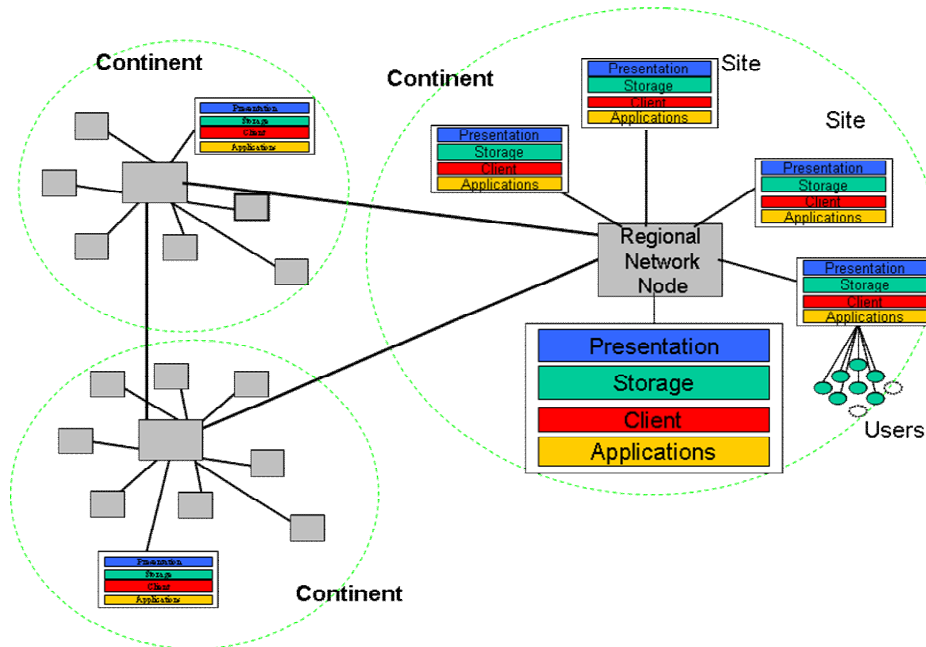
#### *IT Infrastructure Resource Investment*

The firm's management intends to keep meeting its customer needs, to keep improving mobility of its workforce and to keep the ability to work closely with third parties and partners. It therefore decided to invest heavily in IT infrastructure, where IT infrastructure adaptability, availability, flexibility and connectivity were considered essential future assets. Since 2000 the scattered and departmentally optimized IT-environment (see Figure 3-4a) was transformed to a centralized environment having the ability to provide for global enterprise-wide services and to improve the data and application landscape.



**Figure 3-4a.** A conceptual representation of the IT infrastructure before the investment

The three layers that form the technical fundament of these services are: (1) the data centers, (2) the network layer and (3) the connectivity layer. Upon this fundament, the firm is building the following services: (1) the storage layer, (2) the application and computer layer, (3) the presentation layer, and (4) the client layer (see Figure 3-4b).



**Figure 3-4b.** A conceptual representation of the IT infrastructure after the investment

#### *IT Infrastructure Capabilities*

The new IT infrastructure vision has been translated into IT infrastructure investments that connect continental network and services nodes to local sites, where the continental nodes are connected by a backbone. The network nodes are the central continental connectivity points for connections and access of service nodes. The service nodes provide continental, global or local services to the attached network available for users, customers and suppliers, like applications, email services, storage etc. Combining Internet access with the network-nodes allows for a more central security management by central management of firewall services and disaster planning. IT management considers both development according to architectural principles and building the network layer as essential parts of building a flexible IT infrastructure and gaining support for strategic flexibility.

*“Flexibility can only be solved by architecture thinking: thinking in modularity, scalability, in maintainability. For flexibility in technical IT infrastructure the architecture choice is absolutely essential.” Director IT infrastructure*

The development of these communication services, security and risk-management services and IT facilities management capabilities by setting (communication) technology standards are seen as a first stage in building a global IT infrastructure. The provided global IT infrastructure services serve as the foundation for building future data management and application infrastructure capabilities. The data storage function has been improved by offering storage as a firm-wide service. In the future the applications landscape will be differentiated in three layers: (1) global services that need to be centrally managed and which are difficult to distribute and synchronize, e.g. SAP, (2) continental services located at the three differentiated continents, e.g. mail and storage services and (3) local functions including heavy applications with large amount of data.

The firm has developed a network and connectivity concept that can support a globally working company, and new sites all around the globe can easily be added to the firm’s infrastructure.

*“Because of the acquisition in the U.S. the time to configure the software built in collaboration by programmers in the Netherlands and the U.S. was shortened, augmenting the software storage problems already encountered. By defining our new global storage concept, which is supported by the new network structure, this service can now be provided for and is scalable in case of future changes.” IT Architect*

The development of three months forecasts with external partners to respond to the changing market is now supported by a flexible and consolidated technical IT



infrastructure. The firm works a lot with external suppliers and third parties who source the firm's services. By implementing network attached storage it is easier to communicate with partners. Mobility is improving worldwide and third parties can get access to (a dedicated part of) the firm's network. Thin client technology that only requires a browser, will be used as a platform to connect external parties and customers to the firm's network and provide them with a dedicated working environment. In this way, the standard global and continental services can be delivered. This will provide gain in speed and flexibility to provide services to temporary locations and workplaces. Clients and partners have access to the ERP through the Internet. Global connection of new sites to the infrastructure has improved. Implementation of new technologies will be easier by implementing firm-wide architecture standards.

#### *Flexibility in the IT investment Decision-Making Process*

The IT management board of the centrally organized IT department consists of the CIO and several directors. The board decides upon budgets for a cluster of activities. These budgets can be allocated to different projects. In general, IT investment decisions are based on a business case and are valued on ROI. The flexibility of the IT infrastructure is explicitly taken into account in the investment process.

*"In our projects IT infrastructure flexibility are hard criteria, how to be scalable, how scalable should it be for the upcoming three years. Budgets are adjusted to this." IT architect*

Although decision-making is formalized using business cases, responding to emerging issues appears to provide the investment agenda, *"sometimes combined with vision"* (IT architect). By looking at day-to-day problems and future possible developments, IT capabilities that are necessary for supporting the business are

defined and standards are set to develop these capabilities. For example, one of the main triggers that lead to a firm-wide vision on the network-concept was a major storage issue due to an annual data growth of 80%. There is no explicit formalisation in terms of planning and budget for experimentation initiatives. New technologies are most of the time introduced bottom-up by the technicians and architects and by talking to clients.

The department responsible for application development projects is a strong supporter for ERP solutions. New ERP solutions, which are built tailor-made, are hardly scalable or generic and hamper integration with other systems, including integration with the ERP-system itself. Application development projects are conducted using classical system development methods, leading to long analysis and development phases. Centrally developed applications are mostly built using an ERP solution. These tailor-made ERP solutions are hardly scalable or generic and allow for a very exploitative use. In the production process these solutions are found to support the process very well, also allowing for flexibility needed in the production process to scale production extremely up and down. However, several examples were given where a locally built, flexible application has been rebuilt in the ERP system, which takes out the necessary variation, flexibility and innovation of the organisational processes. This loss of flexibility is made worse by the long application development projects that are needed to build these systems. Despite the recent investments in the IT infrastructure, this is strongly felt to hamper strategic flexibility.

*“The flexibility of the technical infrastructure is paying off. Now we bump into inflexibility of applications. People want to collaborate, work in teams, exchange documents. One can build this using SAP, but this represents an old culture, of legacy systems, big consultancy teams. I want to translate scalability to functional applications and offer flexible functionality in within say two weeks to these people.” Director IT infrastructure*

At the organisational level, local, non-formalized applications and IT solutions are developed to deal with processes having a more explorative nature.

### 3.4 Analysis of Empirical Findings

Both described cases focus on specific IT infrastructure investments that are intended to support future strategic flexibility. Both firms invested in different IT infrastructure capabilities to support this need in flexibility.

Case	Needed strategic flexibility	IT infrastructure investment	IT infrastructure capabilities
Dutch bank	Quick response to: - changes in aggregate customer demand - customize a product or service to suit an individual customer - new product or service launches by competitors	IT platform to enable a multi-channel strategy	- Channel management - Application infrastructure services  - IT architecture and standards
Lithography firm	Improve global ability to: - easy expansion in new markets or regions - cooperate or easily switch in co-makership, co-design to avail of lower costs, better quality or improved delivery times	Development of global IT infrastructure services	- Communication services - Security and risk-management services - IT facilities management services  - IT architecture and standards - IT management services (global)

**Table 3-1:** Needed strategic flexibility, IT infrastructure investment and developed IT infrastructure capabilities in both cases

As is indicated in the case of the bank, a quick response to changes in customer demand and quick response to competitors' new product launches are supported by standardization of data, applications and processes across channels. Shared IT infrastructure investments serve as the foundation for building electronic links to their customers (channel management capabilities) and building reusable applications that are standard across the firm (application infrastructure

capabilities). By standardizing across multiple channels and by allowing for reusability of software modules, changes in the application software can be realized in a short time period. Obviously, to share these applications and data across channels, a firm needs to develop a central architecture and standards capability across channels. Therefore, we propose:

**Proposition 3-1:** *Strategic flexibility to quickly respond to changes in customer demand (either aggregate customer demand or to customize a product or service to suit an individual customer) asks for IT channel management capabilities, IT application infrastructure services and IT architecture and standards capabilities.*

**Proposition 3-2:** *Strategic flexibility to quickly respond to new product or service launches by competitors asks for IT channel management capabilities, application infrastructure services and IT architecture and standards capabilities.*

At the moment of the case study research, decentralized management at the lithography firm led to the departmental application silo architecture and the firm is moving to offering central, enterprise-wide, standardized technology services. To lay the global core infrastructural foundation, the lithography firm specifically focused on developing communication services and security and risk-management services, which are a necessary foundation for interacting with partners and costumers in new markets occurs. IT facilities management capabilities and standards are needed to coordinate and span the global (integration of) physical infrastructure layers. The provided global IT infrastructure services serve as the foundation for building future data management and application infrastructure capabilities. Therefore, we propose:

**Proposition 3-3:** *Strategic flexibility to easily expand in new markets or regions globally asks for global IT communication services, IT security and risk-management services, IT facilities management services, IT management services and IT architecture and standards capabilities.*

**Proposition 3-4:** *Strategic flexibility to globally cooperate or easily switch in co-makership asks for IT communication services, IT security and risk-management services, IT facilities management services and IT architecture and standards.*

We have also tried to analyze how firms invest in IT infrastructure flexibility, how firms identify, track and actively increase the extent of flexibility in the IT infrastructure investment process. As for flexibility in the decision-making process, in both cases fast response to changing market conditions is formalized by short decision-cycles.

Different non-financial criteria are explicitly used to prioritize and to make flexible IT infrastructure investments. In the case of the bank these criteria take into account the IT infrastructure flexibility in terms of scalability, reuse and open standards for the applications. The lithography firm uses criteria as scalability, availability, accessibility and connectivity. In one case the IT infrastructure flexibility is also interpreted as the ability to scale back IT services, reflecting the up- and downturns in business activity as a result of economic cycles.

**Proposition 3-5:** *Under conditions of risk, both financial and non-financial criteria will be necessary to capture the value of managerial flexibility in IT investments.*

We have researched whether firms recognize and value different types of options in the IT infrastructure investment decision-making process. The cases

indicate that flexibility in the process of IT infrastructure investment decision-making is implicitly taken into account.

In the case of the bank thinking in real options was implicitly used to structure the IT projects. The platform implementation was staged, where the value of a single stage was not dependent on pursuing a subsequent stage (option to stage). Also, the bank invests in strategic experiments to deploy new technology. Abandonment of these specific investments is explicitly taken into account, although we did not find evidence that project abandonment is actually exercised (option to abandon). The extent to which a project can be deferred is an explicit criterion in the bank's decision-making process (option to defer). However, managerial flexibility that arises from these options was not explicitly valued and common valuation techniques (e.g., ROI) were not integrated with uncertainty modeling so as to capitalize on the value of flexibility. In the case of the lithography firm option thinking could be identified but is not formalized. Operational options are recognized in building the network, storage and computing layer. The ability to change the scale of business are strong drivers for the infrastructure investments (option to change scale). Lack of options thinking in the ERP applications development projects strongly hampers flexibility needed at the business level. Experiments are technology-driven, bottom-up initiated search processes, whereas in the case of the bank, there is a formal budget for these experiments and abandonment is accounted for. So, in both cases, management does not explicitly assess different types of managerial flexibility (real options) that are present in IT infrastructure investments. However, management does recognize and value the presence of managerial flexibility (real options) in IT infrastructure investments implicitly. Therefore we propose:

**Proposition 3-6:** *Under conditions of risk, managers will recognize and implicitly associate different types of real options with IT investment value.*

In both the bank and the lithography firm, the developed IT infrastructure capabilities serve as the foundation for building future data management and application infrastructure capabilities and the future opportunities are implicitly regarded as a justification for the development of IT infrastructure capabilities and the resulting IT infrastructure investments (strategic option to growth). For example, the bank invested in the IT platform knowing that the investment could lead to large savings on future application implementations. This value is implicitly taken into account when justifying IT infrastructure investments. The studies indicate that the different types of IT infrastructure capabilities which are needed to support different types of strategic flexibility are selected and identified *through* the identification of strategic real options. Thus, we propose:

**Proposition 3-7:** *Different types of IT infrastructure capabilities which are needed to support different types of strategic flexibility are selected and identified through the identification of strategic real options.*

### **3.5 Conclusions**

This chapter, in which the relationship between strategic flexibility and IT infrastructure investments is investigated, provides four contributions. Firstly, in a detailed literature review two perspectives (the resource based view and the real option theory) provided a general conceptual model that will shed light on the relationships between environmental turbulence, IT infrastructure capabilities, IT infrastructure flexibility and strategic flexibility. Secondly, the two case studies show how these two companies link their strategic flexibility with the different aspects of IT infrastructure capabilities. The studies indicate that different types of strategic flexibility are supported by different types of IT infrastructure capabilities *through* the identification of strategic real options. Thirdly, the cases indicate that when firms face risks, both financial and non-financial criteria are

necessary to capture the value of managerial flexibility in IT investments. Fourthly, the cases indicate that real options reasoning in the IT infrastructure investment decision-making is implicitly taken into account.

As for the limitations in our research, firstly, based on the empirical evidence in these exploratory case studies we suggest that future research should use a more refined research framework. More refined measurements of the constructs need to be developed in order to empirically test and validate the research model. For example, we did not use a scale to measure the extent in which the IT infrastructure capabilities are developed. This improves the external validity of the findings. Secondly, as opposed to the presented model, IT business value as a construct can be added. Thirdly, in the presented cases, we studied two well-performing firms in different industries. Future research should include research in these same industries in firms that differ in their extent of strategic flexibility, to study differences in investment behavior.

From a practitioner's perspective, the intent of the research is to identify best practices for firms in searching for and managing IT infrastructure capabilities when aiming for strategic flexibility. One implication of our study is that practitioners should invest in different types of IT infrastructure capabilities when aiming at different types of strategic flexibility needed at the business side. It is also indicated that as a necessary condition for providing IT infrastructure support for strategic flexibility, practitioners should organize their management-oriented IT infrastructure capabilities centrally.

Also, the research tries to identify best practices for the incorporation of managerial flexibility in IT investment decision-making in order to increase ability to change business strategy. Although the exploratory case studies implicate that managerial flexibility is highly appreciated and is valued implicitly, where specifically growth options are highly valued in relation to IT infrastructure investments, this will be of little practical consequence unless mechanisms are put in place to make real options reasoning explicit in practice. These mechanisms



include identifying and actively increasing the extent of flexibility when making IT project investment decisions. Project planning capabilities should be augmented by incorporating, communicating and in some way valuing the options in the IT investment justification and planning phase. Also, project management practices to continuously track the evolving value of options should be employed and commitment should be made to actually exercise options when appropriate. Of course, the degree to which these project investment and planning capabilities can be successfully developed and implemented may depend on the maturity and culture of the organisation, the maturity of the IT department, the amount of project risk and the size of the projects involved.



## Chapter 4

### Using Dempster-Shafer Theory and Real Options Theory to Assess Competing Strategies for Implementing IT Infrastructures: A Case Study

This chapter<sup>89</sup> discusses the selection of a preferred strategy for implementing an IT infrastructure from a range of competing alternatives. The model presented here combines the use of an evidential reasoning approach based on the Dempster-Shafer theory of belief functions with real options analysis. It can capture both risk and uncertainty about the variability of the project's financial value, as well as various uncertainties such as probabilities and vagueness in subjective judgments. We discuss the combined use of both theories and show that combining the Dempster-Shafer theory with real options analysis can generate valuable information for decision-makers required to select from competing implementation strategies. This combination provides flexible support that takes account of the multi-dimensional nature of implementation decisions. We also go into the fundamental requirements that need to be met when selecting a strategy for implementing an IT infrastructure. We conclude by outlining a number of the model's limitations.

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<sup>8</sup> A previous version of this chapter was presented at the European Conference on Information Systems 2006 in Sweden. C.A.R. Hilhorst, E. van Heck, P.M.A. Ribbers, M.T. Smits, 'Combining options valuation and multiattribute decision analysis with uncertainty: defining a favourable infrastructure implementation strategy', *European Conference on Information Systems*, Göteborg, Sweden, 2006

<sup>9</sup> This chapter is published as: Hilhorst, C.A.R. Van Heck, E., Ribbers, P.M.A., Smits, M.T. 'Using Dempster-Shafer Theory and Real Options Theory to Asses Competing Strategies for Implementing IT infrastructures: A Case Study. *Decision Support Systems* 46, pp.344-355, 2008.

## 4.1 Introduction

The consolidation of IT infrastructures in large organisations can result in development and implementation projects in which separate organisational units are required to work with the same system. This may result in complex technology development and implementation projects costing millions of euros. Since significant organisational change is required across all organisational units, and since such projects often involve the use of complex technology, they face serious risks that may result in unrealised benefits, high costs or overruns. The preferred strategy for developing and implementing such projects therefore needs to reduce the degree of uncertainty and risk, and also create managerial flexibility so as to maximise the project's benefits.

Multi-attribute decision analysis is a field of research in which various techniques have been developed to make 'preference decisions (such as evaluation, prioritisation, selection and so on) over the available alternatives that are characterised by multiple, usually conflicting, criteria' (Belton and Stewart 2001). One of the more recent developments in multi-attribute decision analysis is the use of an evidential reasoning approach based on the Dempster-Shafer theory of belief functions (Srivastava et al. 1999, Sun et al. 2006, Wang et al. 2006). The Dempster-Shafer theory models risk by using the notion of the plausibility of a negative outcome, and by capturing both precise data and various types of uncertainties (Sun et al. 2006).

Where the degree of uncertainty is high and the costs are irreversible, there is a consensus that real options theory can be applied to capture the financial value of managerial flexibility in IT infrastructure projects. By giving managers the ability to 'wait and see' in the event of uncertainty, real options analysis can help to identify the most favourable staging of investments, and can also create scope for additional learning about future payoffs before a final decision is made (Neely and De Neufville 2001).

In recent years, a growing volume of research has been performed into IT investments and real options (Benaroch and Kauffman 1999, Bardhan et al. 2004, Kim and Saunders 2002, Taudes 1998) and IT investments and the use of multi-attribute decision analysis to account for uncertainties (Petkov et al. 2006, Salling et al. 2006, Sun et al. 2006). Nevertheless, to our knowledge, no attempt has been made to date, as far as we are aware, to synthesise the findings of research on real options and multi-attribute decision analysis to support complex IT infrastructure investment decisions in conditions of uncertainty.

A vital issue in determining the practical value of both analytical methods is how to combine real options analysis with multi-attribute decision analysis, so as to incorporate different types of uncertainties and risks, as well as quantitative and qualitative information. Consequently, the goal of this chapter is to develop formal support for defining a favourable strategy for implementing an IT infrastructure that takes different types of uncertainty and risk into account. We combine real options theory and the Dempster-Shafer theory of belief functions to model risk. This allows us to analyse a fundamental problem in the implementation of IT infrastructure systems: what is the best strategy for balancing the risks and benefits from both financial and non-financial perspectives?

We compare the combined use of real options theory and Dempster-Shafer theory with the use of:

- (1) traditional net present value (NPV) analysis,
- (2) real options analysis,
- (3) Dempster-Shafer theory and NPV analysis.

We discuss the theoretical assumptions underlying and the limitations of combining real options theory and an evidential reasoning approach based on the Dempster-Shafer theory. Using real data from a large European-based service-provider, we use this combined model to define a favourable multi-stage strategy for developing and implementing a human resource management application. We

show that the combined use of these two approaches can generate important information for making a selection from competing strategies, and that this combined model takes full account of the multidimensional nature of IT investment decisions. We also offer a set of minimum decision-making criteria for IT infrastructure implementation projects that is consistent with prior work.

The proposed combined model covers a range of IT infrastructure projects in which a selection needs to be made from competing implementation scenarios in a setting where there is a project risk. The model provides flexible decision support that can be adapted to the specific domain in question.

The rest of the chapter is organised as follows. In the next section, we take a closer look at decisions which can be modelled with the aid of an evidential reasoning approach based on the Dempster-Shafer theory of belief functions. We also introduce real options theory, present a combination of the two theories and discuss the underlying theoretical assumptions. We then describe the background to the problem and outline the decision attributes that are relevant in defining an IT infrastructure implementation strategy. The application of the model in a case study is then presented, in which we use data from a large European-based service-provider to define a favourable strategy for implementing a human resource management system. Next we compare the decision-making models and discuss their limitations and we conclude with a summary of the study's main findings and suggest a number of possible topics of further research.

## **4.2 Theoretical Background**

A project for developing and implementing an IT infrastructure stands more chance of being successful if it is structured to fit the demands imposed by the risk inherent to the project (Galbraith 1974). Both financial and non-financial aspects play an important role in the investment process. In order to make a selection from competing implementation strategies in a situation where there is a project

risk, both qualitative and quantitative decision attributes and different types of risk have to be taken into account.

One means of structuring decision-making is presented by an evidential reasoning approach based on the Dempster-Shafer theory of belief functions (Yang 2001, Yang and Singh 1994), which models both quantitative and qualitative information in a situation of risk. After discussing this approach, we then introduce the Net Present Value (NPV) method and the valuation of multi-stage options using real options theory. To calculate the option value of alternative strategies, we use the binomial options model proposed by Cox, Ross and Rubinstein (1991). This model has frequently been used in prior research to value multi-staged investment scenarios. However, researchers have not paid much attention to the way in which non-financial aspects of the investment scenario affect the choice of a strategy for implementing an IT infrastructure. We show how we combined the use of real options analysis and the Dempster-Shafer theory and discuss their underlying theoretical assumptions.

#### **4.2.1 The Evidential Reasoning Approach Based on the Dempster-Shafer Theory of Belief Functions**

The evidential reasoning approach based on the Dempster-Shafer theory of belief functions can be used to deal with multi-attribute decision-making problems of both a quantitative and qualitative nature, in conditions of risk. There is growing support for the use of the Dempster-Shafer theory of belief functions for analysing multi-attribute decisions (Sun et al. 2006, Yang and Singh 1994, Wang et al. 2006). The approach has a number of important characteristics, which we discuss here.

In its traditional definition, risk is measured as the probability of a negative outcome of an event or situation (Sun et al. 2006). However, risk may also be conceptualised as an uncertain condition or event that has either a negative or a positive effect on the achievement of an objective (Sun et al. 2006). The Dempster-Shafer theory of belief functions allows us to incorporate both these above notions

of risk. Support for a hypothesis indicates the amount of belief that directly supports a given hypothesis, because there is no evidence that would contradict the hypothesis. Using belief functions we can withhold belief from a proposition without according that belief to the negation of the same proposition. This allows us to model the level of residual uncertainty or ambiguity that remains after the available evidence has been considered. Using belief functions allows us to model a lack of data, probabilities or vagueness in subjective judgments.

Using the Dempster-Shafer theory of belief functions, risk can be modelled by applying the notion of the plausibility (i.e. risk) of a negative outcome. To illustrate this, consider the situation where we have belief that the *implementation time* of a proposed IT implementation strategy (which may be subject to considerable uncertainty) could be 30% good and 20% not good, and 50% ignorance indicating we do not know whether the implementation time will be good or bad, based on what we know about the presence of threats and available countermeasures. In this case, 'Good' and 'Not Good' denote distinctive evaluation grades, and the percentage values of 30 and 20 are degrees of belief, indicating the extents to which the corresponding grades are assessed. This may be expressed as:

$$S(\text{Implementation time}) = \{(\text{Good}, 0.3), (\text{Not Good}, 0.2)\} \quad (1)$$

where  $S(\text{Implementation time})$  is the implementation time of the implementation strategy and the figures 0.3 and 0.2 stand for the degrees of belief. In this case, the plausibility that the implementation time is not good is 70%, based on the available information. So, we have 70% risk that the implementation time is not good. As illustrated, belief in a statement represents the total belief that the statement is true. Belief of zero in a statement means lack of evidence in support of the statement, unlike representing impossibility in probability.

The evidential reasoning approach uses an extended decision matrix, in which each attribute of an alternative is described by a distributed assessment. It employs a belief function based on the Dempster-Shafer theory of belief functions



to represent an assessment of an attribute as a distribution of a set of evaluation grades. Suppose there are  $K$  alternatives,  $O_j$  ( $j = 1, \dots, K$ ), to choose from and  $M$  attributes,  $A_i$  ( $i = 1, \dots, M$ ), to consider. Using a set  $H = \{H_i \mid i = 1, \dots, N\}$  of evaluation grades, we can represent the assessment of an attribute  $A_1$  on an alternative  $O_1$ , denoted by the expectation  $S(A_1(O_1))$ , using the following belief structure:

$$S(A_1(O_1)) = \{(H_1, \beta_{1,1}), (H_2, \beta_{2,1}), \dots, (H_N, \beta_{N,1})\},$$

$$\text{where } 0 \leq \sum \beta_{n,1} \leq 1 \text{ for } n = 1, \dots, N \quad (2)$$

where  $\beta_{n,1}$  denotes the degree of belief that attribute  $A_1$  is assessed to evaluation grade  $H_n$ . The expectation  $S(A_1(O_1))$  reads that attribute  $A_1$  at an alternative  $O_1$  is assessed to grade  $H_n$  to a degree of  $\beta_{n,1} \times 100\%$  ( $n = 1, \dots, N$ ). An assessment may be regarded as being complete if the sum of the degrees of belief for all  $n$  is 100%. In the evidential reasoning framework, a multi-attribute decision analysis problem with  $M$  attributes  $A_i$  ( $i = 1, \dots, M$ ),  $K$  alternatives  $O_j$  ( $j = 1, \dots, K$ ) and  $N$  evaluation grades  $H_n$  ( $n = 1, \dots, N$ ) for each attribute is represented using an extended decision matrix with  $S(A_i(O_j))$  as its element in the  $i$ th row and  $j$ th column.

In a utility-based evidential reasoning approach to multi-attribute decision analysis, an attribute can have its own set of evaluation grades that may differ from those of other attributes (Yang 2001). Rule-based or utility-based techniques can be used to devise a systematic procedure for transforming various types of information into a unified format, so that there is consistency between qualitative and quantitative information. It differs in this respect from traditional multi-attribute decision analysis approaches, most of which aggregate average scores. Instead of aggregating average scores, an evidential reasoning algorithm uses decision theory and the evidence combination rule of the Dempster-Shafer theory (Shafer 1976) to aggregate belief degrees. The logic behind the algorithm is that, if an object has a good (or bad) attribute, then that object must be good (or bad) to a certain extent. The extent is measured both by the relative weight, denoted by  $\omega$ , that decision-makers assign to the attribute and by the degree to which the

attribute belongs to the good (or bad) category. Appendix B provides details on the evidential reasoning algorithm.

The evidential reasoning approach is capable of accommodating numerical data and subjective judgments of various formats, as well as incomplete and imprecise information. In the presented analysis in section 4.4, we use a window-based software tool called *Intelligent Decision System* (IDS) (Yang 2001) to support the evidential reasoning approach based on the Dempster-Shafer theory of belief functions.

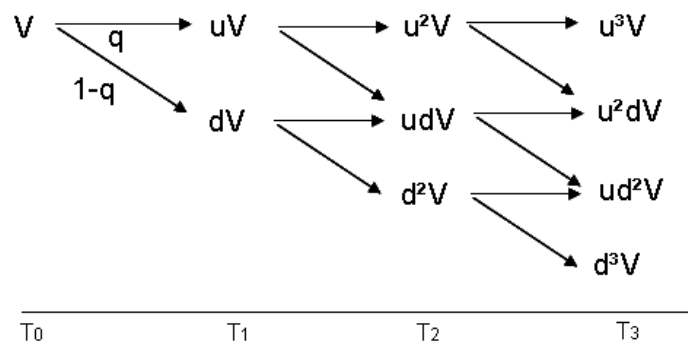
#### **4.2.2 The Valuation of Multi-stage IT Investments using the Binomial Options Model**

Researchers have used real options analysis as a capital budgeting approach that takes explicit account of the value of flexibility in IT investment decisions (Taudes 1998, Benaroch and Kauffman 1999, Taudes et al. 2000, Bardhan et al. 2004). It assumes that decision-makers can intervene if the projected level of cash flow is not realised due to resolved uncertainty, and that managers can actively maximise the upside potential of the investment or limit the downside loss. From an options perspective, risk is defined as the upward and downward variation in expected outcomes. Options analysis allows us to decide which implementation strategy results in the greatest managerial flexibility, by calculating the optimum outcome for project risk and financial return. The traditional NPV approach discounts the estimated cash flow of an investment to its present value, using a time value of money as the discount rate commensurate with the market expectations of the project risk. It assumes that initiation of a project entails a complete commitment to the cash flow specified. This assumption is not correct whenever the probability distribution of the returns is asymmetric, as is usually the case (Neely and De Neufville 2001).

However, IT infrastructure development and implementation projects may involve a different range of options. This chapter focuses on stage options. Stage

options create value by providing an opportunity to alter or terminate a project before each new stage of funding, based on updated information about costs and benefits, thus enabling project managers to learn or gather information during the investment process. As a stage is completed, the ambiguities about the net payoffs from subsequent stages may be resolved and value is created by only pursuing subsequent stages with positive payoffs.

In order to calculate the optional value of the different IT implementation alternatives, we use the binomial options model devised by Cox, Ross and Rubinstein (1991). This values the real options in discrete time using a binomial lattice and allows for the transparent and custom-tailored modelling of multi-stage investment decisions (Benaroch and Kauffman 1999). The binomial options model assumes that, starting at  $t_0 = 0$ , the value of the risky underlying asset  $V$  may increase to  $uV$  or decrease to  $dV$  by time  $t_1 = t_0 + \Delta t$ . In this case  $V$  is the value of an IT infrastructure investment. The probability that value  $V$  will rise is assumed to be  $q$  and the probability that value  $V$  will fall is  $1 - q$ , where  $d < 1$ ,  $u > 1$  (See Figure 4-1).



**Figure 4-1:** Underlying project value binomial tree for a four-stage implementation strategy

The up and down movements in the lattice follow the equations

$$u = \exp(\sigma\sqrt{t/n}) \quad d = \exp(-\sigma\sqrt{t/n}) \quad (3)$$

where  $n$  is the number of steps in the binomial lattice and one time period  $\Delta t$  is defined as the time to expiration of the option divided by the number of steps in the binomial lattice. In the option calculation, the volatility  $\sigma$  represents an estimate of the variance of project returns. It measures the risk associated with the project in terms of fluctuations in the cash flow during the course of the project.

For an explanation of how to calculate a call option using a binomial lattice, see extensive descriptions of the model in prior literature (Cox et al. 1991, Benaroch and Kauffman 1999). We can use the binomial options model to optimise the balance between implementation risk and benefits from a financial perspective.

#### 4.2.3 Real Option Analysis and the Dempster-Shafer Theory of Belief Functions

In the context of the evidential reasoning approach, quantitative data can be transformed to a unified format using utilities which can be estimated explicitly using the decision-maker's preferences. In this way, a quantitative basic attribute can be transformed to an equivalent expectation so that the quantitative attribute can be aggregated in conjunction with other qualitative attributes. In order to incorporate the generated option value in the cost attribute of the evidential reasoning framework, we assume a linear marginal utility function. This assumption cannot be relaxed, as is explained below. The utility of the financial attribute is normalised as follows. As the option value  $C$  is a cost and benefit attribute, the highest option value is preferred. Given a linear utility function, we assign  $u(C_{max}) = 1$  and  $u(C_{min}) = 0$ . Then a value  $C_j$  on an attribute  $A_i$  may be represented using the following equivalent expectation:

$$S_i(C_j) = (h_{n,i}, \beta_{n,j}), \quad \text{for } n = 1, \dots, N_i \quad (4)$$

where

$$\begin{aligned} \beta_{n,j} &= (u(h_{n+1,i}) - u(h_j)) / (u(h_{n+1,i}) - u(h_{n,i})) \quad \text{and} \\ \beta_{n+1,j} &= 1 - \beta_{n,j} \\ &\text{if } u(h_{n,i}) \leq u(h_j) \leq u(h_{n+1,i}). \end{aligned} \quad (5)$$

This transformation from a quantitative assessment to equation (4) is equivalent with regard to the underlying utility and rational in terms of preserving the features of the original assessment (Yang 2001). In particular, as shown in Yang (2001) the completeness of an assessment is preserved in the transformation process. We can use this quantitative data transformation technique to incorporate the financial valuation in the evidential reasoning framework.

#### **4.2.4 Combining the Use of Real Options with the Dempster-Shafer Theory of Belief Functions**

Combining real options with the Dempster-Shafer theory of belief functions appears attractive from a practical viewpoint, since it allows us to make a selection from competing implementation strategies in a situation where both qualitative and quantitative decision attributes and different types of risk have to be taken into account. However, both theories rest on certain assumptions that lead to a lack of theoretical elegance.

In the first place, Goodwin and Wright (2005) have already pointed out that converting NPV to utilities requires clear assumptions about the decision-maker's preferences. For example, the NPV assumes a constant rate of trade-off for sums of money between the same pair of years, irrespective of the amount of money which is transferred from next year to this (Goodwin and Wright 2005). From the viewpoint of the evidential reasoning approach, if this assumption is seriously violated, the NPV will not accurately represent the decision-maker's preference between sums of money arriving at different points in time.

In addition, real options analysis uses the volatility of a portfolio of securities that exactly replicates the project's payoffs as if they were traded on the market, assuming complete and perfect markets. The value of the project is indicated by the market value of this replicating portfolio. Furthermore, real options analysis assumes risk-neutral investors. Clearly, the decision-maker's probabilities and utility function for describing its preference for cash flow over time may well be

different from this perspective. According to Smith and Nau (1995) however, the option pricing method is a simpler and more direct way of computing the project value and determining the best project management strategy than trying to define the decision-maker's probabilities and utility function for the project's NPV. Based on these theoretical assumptions of risk neutrality and perfect markets it is not meaningful from a real options perspective to use a non-linear utility function to impose the decision-maker's risk attitude into the cost-benefit attribute when translating the option value into an evidential reasoning framework.

Despite these objections to the combined use of theories, when estimates of future cash flows and volatility are carefully considered, an identification of the options and an understanding of the value of flexibility can help managers to identify and abandon failing IT investments before they escalate out of control.

The main advantage of the combined model is that it effectively and comprehensibly combines both option analysis and the evidential reasoning approach into a practical means of accurately valuing projects. A thorough sensitivity analysis – both of the weights assigned to the criteria in the evidential reasoning approach and of the volatility in the real options analysis – generates information from a number of different perspectives. This gives us a practical advantage over the realistic alternatives of either not valuing or systematically undervaluing the different investment options associated with new products and projects (Neely and De Neufville 2001).

### **4.3 Attributes for IT Infrastructure Strategies**

In deciding on the most favourable implementation strategy, managers seek to learn about uncertainties to reduce risks and increase benefits. For example, a system may need functional flexibility to support differently organised business processes, or the organisation may need to respond to organisational changes during the course of implementation. The implementation strategy may also be a source of risk in itself; obviously, a big bang-type implementation across all

organisational units is a riskier undertaking than a project staged in multiple phases. An important step in the evidential reasoning approach is defining the relevant decision-making attribute hierarchy. The set of measurable attributes for modelling benefits and risks is obtained from prior research on IT project risk and on the justification of IT investments.

In an attempt to deal with the continuing problem of information system failures, researchers have tried to systematically organise critical risk factors in IT projects (Barki et al. 2001, Keil et al. 1998) and have identified IT project implementation risk factors (Applegate et al. 2005). Borenstein et al. (2005) identify a minimum set of attributes for the justification of general IT investments with operational, tactical and strategic attributes on costs, business change and risks, based on previous research studies (Robert and Weitzman 1981, Clemons 1991, Segars and Grover 1998). These attributes and risk factors lead to the formulation of three basic criteria:

1. *costs and benefits*: the costs of implementation in relation to the monetary benefits,
2. *project implementation risk*: the reduction of exposure to organisational or system failure or to budget overshoots or time overruns,
3. *business change*: the ability of the IT infrastructure to create opportunities for business transformation.

To these three main attributes we can add the *learning effects* attribute, which is the ability of the implementation strategy to support learning about the implementation of the system. With the exception of the *cost and benefit attribute*, all attributes address evidence for the competing implementation strategies that cannot be quantified financially at the time of making a decision. In total, the attribute hierarchy consists of four first-level attributes, fourteen second-level attributes and eleven third-level attributes. Table 4-1 summarises the attribute hierarchy, including a brief description of the attributes. The set of attributes to cover the minimum dimensions relevant to the selection of an implementation

strategy may be expanded, depending on the characteristics of the specific situation.

Attribute	
Label	Description
<b>(e1) Costs and benefits</b>	<b>The costs of the implementation related to the monetary benefits</b>
(e1a) Costs of the implementation	The costs of the system implementation
(e1b) Benefits of the implementation	The monetary benefits of the system implementation
<b>(e2) Project implementation risk</b>	<b>Reduction of exposure to organisational or system failure, or to higher-than-expected costs or time</b>
(e2a) Project size	The size of the project, measured in number of departments involved and the estimated project implementation time
(e2a1) Implementation time	Estimated project implementation time
(e2a2) Number of departments involved	Number of departments involved with implementing the system
(e2b) Experience with technology	The project team and organisations' familiarity with the systems technology
(e2b1) New hardware	The extent to which the hardware is new to the organisation
(e2b2) New software	The extent to which the software is new to the organisation
(e2b3) User IT knowledge	The extent to which the user is knowledgeable in the area of IT
(e2b4) Project team knowledge	The extent to which the project team is knowledgeable in the proposed application area
(e2c) Project structure	The nature of the task complexity the project faces, measured in changes that are needed to implement the system and the commitment to the system
(e2c1) Replaced functions	The percentage of existing functions that are replaced on a one-to-one basis
(e2c2) Procedural changes	The severity of user-department procedural changes caused by the proposed system
(e2c3) Structural changes	The degree of needed user-organization structural change to meet requirements of the new system
(e2c4) User attitude	The general attitude of the user towards the IT solution
(e2c5) Management commitment	Commitment of upper-level user management to the system
<b>(e3) Business change</b>	<b>The possibility of the IT implementation to provide opportunities for business transformation</b>
(e3a) Improvement in consumer service	Changes associated with the IT which positively influence the relationship with clients
(e3b) IT aligned with business strategy	Level to which the IT supports the strategy of the business
(e3c) Improvement of organisational image	The extent to which the IT use will positively influence the image of the organisation from the clients point-of-view
(e3d) Improvement of strategic positioning	The impact of the IT to open up opportunities for new business changes



Attribute	
Label	Description
(e3e) Improved efficiency and control of internal processes	The impact of the IT to foster monitoring of internal processes
<b>(e4) Learning effects</b>	<b>The possibility of the IT implementation strategy to support learning about the system implementation</b>
(e4a) Functional flexibility	The extent to which learning is supported about the functional flexibility of the system to support differently organised business processes
(e4b) Technical scalability	The extent to which learning is supported about the technical scalability of the system to support different user groups
(e4c) Technical compatibility	The extent to which learning is supported about the technical compatibility of the system to be successfully implemented in the different departmental infrastructures
(e4d) Improved implementation processes	The quality of the implementation process by having less implementation problems

**Table 4-1:** Attributes for defining an IT infrastructure implementation strategy

#### 4.4 The Case: Implementation of a Human Resource Management System

We used the combined model comprising the Dempster-Shafer theory and real options theory presented above to analyse a development and implementation investment decision of an IT infrastructure using data from a European-based service-provider. An organisation employing over 30,000 FTEs<sup>10</sup> developed a human resource management system (HRMS) to help the organisation match its staff complement to changing external and internal demands as effectively and efficiently as possible. The organisation consisted of 18 autonomous departments, ranging in size from small to large. The HRMS needed to support strategic high-level planning to justify capital expenditure, tactical management of human resources to meet demand, and operational scheduling and individual time registration. The HRMS implementation was a large and complex project affecting

<sup>10</sup> Due to reasons of confidentiality we do not provide the exact number of employees in the organisation. We also adjusted, without loss of generality, the number of departments of the service-provider and the name of the information system.

all the organisation's employees to a lesser or greater degree. After the development of the HRMS, 18 separate application implementation projects were planned for the 18 different departments. The business objective was cost reduction; the benefits were to consist of internal organisational benefits derived from the deployment of the system.

#### **4.4.1 The HRMS Project Risks**

The HRMS implementation project was associated with a high degree of risk due to organisational, technological and functional uncertainties. The project was affected by several organisation-specific and IT project implementation risks. These were due to endogenous factors and affect the organisation's ability to successfully implement the system.

Monetary risks were caused by reasonable doubts as to whether the estimated financial benefits of the development and implementation of the HRMS were valid and realisable, given that the organisation had a long history of failed or delayed IT projects. There was uncertainty about the clarity of scope, since the autonomous departments differed in their organisational structures and in the way they had organised their business processes. The new IT application needed to contain the features required to support all the various departments.

Risks concerning infrastructural stability and compliance, as well as adequate infrastructural support, arose from the fact that the departmental infrastructures used different technical platforms, different shared applications and different types of data. The application needed to be scalable to the larger departments and had to be compatible with departmental IT infrastructures. If the risks relating to the clarity of scope and infrastructural stability were not adequately addressed, the projected monetary benefits and opportunities for business transformation might not be realised in all the departments.

Project implementation risks, such as those relating to project size and project structure, arose from the absence of sufficient project capabilities such as

supportive senior management and access to key resources to effectively deploy the system during and after implementation. Insufficient project capabilities resulted from the large number of diverse departments that had to be supported during implementation. These project implementation risks could affect the success of implementation and hence the organisation's ability to achieve business change in all departments, eventually leading to a lack of monetary benefits.

#### **4.4.2 Application of the Evidential Reasoning Approach Based on the Dempster-Shafer Theory**

The case study analysis was carried out from February to October 2005. The analyses included in-depth interviews with various people working on the project, namely the IT project manager, line managers, interviews with employees from the 18 departments (both large and small) and interviews with project team members. We used open questions to roughly guide the interviews. The data provided by these interviews plus archival data based on internal documents and other written material was used to define and analyse the research problem. The data needed for the cost-benefit analysis was based on a system development and implementation estimation supplied by external consultants working on the project and was also obtained from internal project documents.

The process of defining a preferred implementation strategy using the evidential reasoning approach based on the Dempster-Shafer theory consisted of five stages:

- (1) specifying the decision-making goal and the alternatives taken into consideration
- (2) specifying the decision-making attributes (as presented in section 4.3)
- (3) assessing the attributes, including the cost-benefit analysis of the alternatives, and assigning weights to the attributes
- (4) aggregating the individual assessments into an overall assessment
- (5) performing a sensitivity analysis of the weights assigned.

Having identified the specific risks affecting the project, we will now present our findings relating to the individual stages.

#### **4.4.3 Outline of the Alternative Implementation Strategies for the HRMS Project**

The first stage involved specifying the decision-making goal and the alternatives. The goal of the decision is to define the best possible strategy for implementing an IT infrastructure that balances the risks and benefits from both a financial and a non-financial viewpoint.

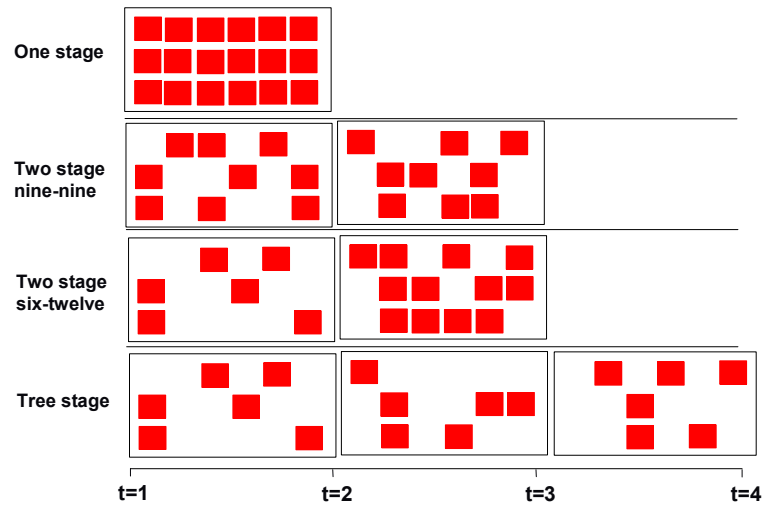
In order to define the alternative implementation strategies, we needed to make certain assumptions. Firstly, the development of the HRMS would last one year. This assumption was based on the project planning documents for the software development phase. Secondly, each implementation stage would take one year. Moreover, due to the scarcity of resources, each implementation stage had to be completed before a new one could start. Thirdly, the maximum duration of the entire HRMS implementation project was three years. If this deadline was not observed, the departments might diverge too widely in their organisational directions. We therefore decided that there should be a maximum of three one-year implementation stages. Although the costs and benefits of the HRMS could vary from one department to another, we assumed that the implementation had fixed costs and benefits in all departments.

Another important assumption was that the department implementation projects did not have correlated risk profiles in the real options analysis. The risks associated with the development and implementation of one IT project may impact other projects as well. This may result in a significant level of positive correlation of the organisational, technological and functional risks associated with implementation of projects with similar capabilities and dependent on similar skills. As a consequence, the valuation of a portfolio incorporating risk may be different from the sum of the valuations of individual projects if the firm is

risk averse (Bardhan et al. 2004). Although system implementation risks could change during the course of implementation as a result of learning (for example, whether the system supports different ways of working or whether it is technically scalable), we assumed that uncertainty about the organisational benefits depended on departmental efforts and therefore are not correlated. Additionally, we did not have data on the correlation between risks in this case. Instead, we added the *learning effects* attribute, which is the ability of the implementation strategy to support learning about the implementation of the system. The assumption on the correlation of risk profiles in the real options analysis could be loosened if data is available. Depending on the source of the correlated risk, this may influence the relevance of the added *learning effects* attribute, which can easily be adjusted.

In the light of these assumptions, we defined four alternative development and implementation strategies. These were as follows:

- (1) a one-stage implementation, where, after a development stage at  $t=0$ , the organisation implements the HRMS in all 18 departments at once (i.e. in the form of a 'big bang') at  $t=1$ ;
- (2) a two-stage, nine-nine implementation, where, after the development stage, the implementation is divided into two stages with nine departments in each stage;
- (3) a two-stage, six-twelve implementation, where the implementation is divided into two stages at  $t=1$ , with six departments in the first stage and twelve departments in the second stage;
- (4) a three-stage implementation, where implementation is divided into three stages after development, with six departments in each stage (see Figure 4-2).



**Figure 4-2:** The different development and implementation scenarios: from 'Big Bang' to staged implementation

Thus far, we have defined the decision-making goal, distinguished the alternatives and specified the decision-making attributes (see section 4.3). The next section assesses and represents the evidence strength, including a cost-benefit analysis of the alternatives.

#### 4.5 Assessment of the Different Implementation Strategies

To assess the attributes, we started by performing a cost-benefit analysis of the alternatives. We evaluated the cost-benefit attribute for the four development and implementation strategies. First, we calculated the NPVs of the implementation scenarios without flexibility (section 4.5.1). We then determined the best implementation strategy using the real options theory (section 4.5.2). The next step was to assess the non-financial attributes and assign weights to the attributes (section 4.5.3). We incorporated the results of the traditional NPV and real options theory into a multi-attribute decision analysis framework for evaluating the

implementation strategies. After aggregating the individual assessments into an overall assessment for the four strategies, we performed a sensitivity analysis on the assigned weights. We then compared the combined use of Dempster-Shafer theory and real options theory with the use of:

- (1) NPV analysis,
- (2) real options theory,
- (3) Dempster-Shafer theory and NPV analysis.

#### **4.5.1 Implementation without Flexibility: the NPV Analysis**

We conducted a standard NPV analysis, based on the cash flows estimation during development and implementation. We calculated the NPVs of all four strategies, i.e. one-stage, the two-stage nine-nine, two-stage six-twelve and three-stage implementation. These values were all different, since implementing the project in stages defers both costs and savings.

The project costs consist of personnel and non-personnel expenses, i.e. the costs pertaining to the project development environment (such as housing, workstations, hardware and application packages). The training costs comprise the investments made in training staff who were to work with the system. Management and maintenance costs consist of ongoing investments in IT infrastructure and maintenance. Since the organisation is a government body, we estimated a relatively low cost of capital ( $k = 10\%$ ), involving a risk premium of 6% above the risk-free rate ( $r = 4\%$ ).

As we have already mentioned, the project was designed to reduce costs. This means that the benefits consist of internal organisational benefits derived from using the system. There are two sources of financial benefits: lower labour costs and productivity gains. Labour costs can be lowered as the new HRMS supports the pro-active management of variable personnel expenses, leading to a reduction in overtime, picket costs, special duty costs, etc. We assumed that the reduction in labour costs consisted of an average of seven FTEs worth €40,000 a year in each

department, resulting in an average reduction of approximately 0.2% per annum in the cost of labour. The total benefits of the lower labour costs, once all departments are operational, would be €5 million per annum.

Development and One-step Implementation									
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013
<b>COSTS</b>									
Internal staff	800	2.184							
External staff	3.512	3.427							
Exploitation and maintenance		3.020	3.020	3.020	3.020	3.020	3.020	3.020	3.020
Training		721							
Non personnel	100	45	45	45	45	45	45	45	45
<i>Subtotal</i>	<i>4.412</i>	<i>9.398</i>	<i>3.065</i>	<i>3.065</i>	<i>3.065</i>	<i>3.065</i>	<i>3.065</i>	<i>3.065</i>	<i>3.065</i>
<b>BENEFITS</b>									
Reduction of labour costs			875	1.750	2.625	3.500	3.500	3.500	3.500
Productivity improvement			1.250	2.500	3.750	5.000	5.000	5.000	5.000
<i>Subtotal</i>	<i>0</i>	<i>0</i>	<i>2.125</i>	<i>4.250</i>	<i>6.375</i>	<i>8.500</i>	<i>8.500</i>	<i>8.500</i>	<i>8.500</i>
<b>Net cash flow</b>	<b>4.412-</b>	<b>9.398-</b>	<b>940</b>	<b>1.185</b>	<b>3.310</b>	<b>5.435</b>	<b>5.435</b>	<b>5.435</b>	<b>5.435</b>

**Table 4-2a:** Summary of cash flows (cost and benefits) for the one-stage implementation of the HRMS (in €1000)

The new HRMS would also improve staff productivity, as fewer planning mistakes would be made. The assumption here was that computerised support of capacity planning would lead to a productivity gain of one and a half percent per annum. The total benefits of productivity improvement once all departments were operational would be €3.5 million per annum. In both cases, we incorporated a learning effect for the estimated project benefits, assuming that 25% of the total estimated benefits would be realised in each department in the first deployment year, 50% in the second year, 75% in the third year and 100% as from the fourth year.



Table 4-2a shows the NPV analysis for the one-stage implementation project over the next eight years (i.e. until 2013), which is the expected lifespan of the HRMS. Including the development stage and a one-step implementation in all departments, the project results in a positive NPV of €1,183,678. We then performed the same calculation for the other implementation strategies, leading to an NPV of €929,329 for the two-stage nine-nine implementation, €844,546 for the two-stage six-twelve implementation and €690,395 for the three-stage implementation. In the case of the different two-stage and three-stage implementations, whilst implementing the system in a large number of departments earlier augments the NPV because of the earlier payback of larger benefits, the NPV is nonetheless not higher than in the case of a one-stage implementation strategy. Table 4-2b shows the NPV analysis for the two-stage nine-nine implementation as an example.

Development and Two-stage Nine-nine Implementation										
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
<i>COSTS</i>										
Internal staff	800	1.092	1.092							
External staff	3.512	1.714	1.714							
Exploitation and maintenance		1.510	3.020	3.020	3.020	3.020	3.020	3.020	3.020	1.510
Training		361	361							
Non personnel	100	23	45	45	45	45	45	45	45	23
<i>Subtotal</i>	<i>4.412</i>	<i>4.699</i>	<i>6.232</i>	<i>3.065</i>	<i>3.065</i>	<i>3.065</i>	<i>3.065</i>	<i>3.065</i>	<i>3.065</i>	<i>1.533</i>
<i>BENEFITS</i>										
Reduction of labour costs			438	1.313	2.188	3.063	3.500	3.500	3.500	1.750
Productivity improvement			625	1.875	3.125	4.375	5.000	5.000	5.000	2.500
<i>Subtotal</i>	<i>0</i>	<i>0</i>	<i>1.063</i>	<i>3.188</i>	<i>5.313</i>	<i>7.438</i>	<i>8.500</i>	<i>8.500</i>	<i>8.500</i>	<i>4.250</i>
<b>Net cash flow</b>	<b>4.412-</b>	<b>4.699-</b>	<b>5.169</b>	<b>122</b>	<b>2.247</b>	<b>4.372</b>	<b>5.435</b>	<b>5.435</b>	<b>5.435</b>	<b>2.717</b>

**Table 4-2b:** Summary of cash flows (cost and benefits) for the two-stage nine-nine implementation of the HRMS (in €1000)

Traditional investment valuation methods would therefore suggest that the project is an attractive investment and that the system should preferably be implemented in a single stage. Of course, this analysis does not include risk and does not take accurate account of the embedded option value of a staged implementation.

#### **4.5.2 The Real Options Analysis: using the Binomial Real Options Model**

We also performed a real options analysis using the binomial real options model including a sensitivity analysis. In order to calculate the values of the different implementation scenarios, we needed to know, for each call option in the lattice, the expected present value of the incremental cash flows,  $V_t$  and the investment  $I_t$  made to acquire the option, where  $t$  is the expiration time of the option. We also needed to know the volatility  $\sigma$  at each step.

In the option calculation, the volatility  $\sigma$  represents an estimate of the variance of project returns. A representation of the project volatility is the standard deviation of the rate of change in project returns over one time period (Dos Santos 1991, Taudes et al. 2000). It measures the risk associated with the project in terms of fluctuations in the project's cash flow during the course of the project. Although a good estimate of volatility  $\sigma$  may be based on historical data (Dos Santos 1991), in our case the IT infrastructure was implemented in 18 autonomous, decentral departments, where no historical data were available. Instead, as in (Bardhan et al. 2004, Taudes et al. 2000), different cash flow scenarios for the investment (i.e. worst-case, base-case and best-case scenarios) were produced for the various project stages and the variance was computed using the percentile estimate for the normal distribution. As we have previously explained, the base-case scenario is based on an average labour reduction of seven FTEs per department per annum and a productivity gain of one and a half percent per annum. In the worst-case

scenario, the reduction in labour costs is worth five FTEs per department per annum, whereas the best-case reduction is nine FTEs per department per annum. In the worst-case scenario, the productivity gain is half that achieved in the base-case scenario, whereas the best-case gain is double that in the base-case scenario. We then calculated the standard deviation of the rate of change in project returns in the worst-case, base-case and best-case scenario over one time period, representing the volatility values for the different implementations stages. We subsequently calculated option values for each project implementation strategy as summarised in Table 4-3.

Implementation strategy	Volatility per stage	Option value per implementation strategy
One stage implementation		4,411,823
Stage one (18 departments)	18,41	
Two stage nine-nine implementation		2,566,928
Stage one (nine departments)	6,66	
Stage two (twelve departments)	6,05	
Two stage six-twelve implementation		2,487,099
Stage one (six departments)	4,44	
Stage two (twelve departments)	8,07	
Three stage implementation		2,298,951
Stage one (six departments)	4,44	
Stage two (six departments)	4,03	
Stage three (six departments)	3,67	

**Table 4-3:** Volatility values for the different implementation stages (in %) and option values for the different implementation strategies (in €1000)

#### *Sensitivity Analysis*

We conducted a sensitivity analysis for a wide range of volatility values to measure its impact on the selection of the most suitable strategy. We let  $\sigma$  range from  $\sigma = 0.10$  to  $\sigma = 0.90$  and used a constant volatility for each implementation

stage. The option values for the different implementations at different volatility values are summarised in Table 4-4. The value of  $\sigma$  does not influence the final decision on the most favourable implementation strategy.

Option values of the different implementation strategies					
Volatility	One stage	Two stage nine- nine	Two stage six- twelve	Three stage	Preferred strategy
$\sigma : 0,1$	3,043	2,704	2,591	2,386	One stage
$\sigma : 0,2$	4,833	4,412	4,272	4,018	One stage
$\sigma : 0,3$	8,676	8,081	7,882	7,522	One stage
$\sigma : 0,4$	14,653	13,786	13,498	12,792	One stage
$\sigma : 0,5$	22,925	21,683	21,268	20,515	One stage
$\sigma : 0,6$	33,736	32,002	31,424	30,373	One stage
$\sigma : 0,7$	46,897	44,828	43,963	42,709	One stage
$\sigma : 0,8$	62,664	60,499	59,188	57,876	One stage
$\sigma : 0,9$	81,949	79,712	77,840	76,485	One stage

**Table 4-4:** Option values at varying volatility values for the different implementation strategies (in €1000)

In other words, the one-stage implementation is preferable. Relaxing the assumption that the volatility  $\sigma$  remains constant, we then lowered the volatility value at each new project implementation stage by 50%. As expected, this only strengthened the preference for a one-stage implementation. In this case, at all different volatility values ( $\sigma = 0.10$  to  $\sigma = 0.90$ ), a one-stage implementation is the preferred implementation strategy.

We also conducted a sensitivity analysis after augmenting the value of the organisational benefits while keeping the volatility constant across all stages. Raising the organisational benefits does not affect the choice of the most favourable form of project staging. Lowering the organisational benefits for all departments by 25% results in a negative NPV and a positive option value for all

scenarios only if  $\sigma$  is higher than 0.50. In these conditions, the three-stage implementation is preferable to the two-stage nine-nine, the two-stage six-twelve and the one-stage implementation in this order. Thus from an options perspective, if it is likely that the organisational benefits will turn out to be lower, and if there is a high degree of uncertainty as to whether these benefits can be realised, a different implementation scenario then becomes more favourable.

### **4.5.3 Combining the Use of Real Options Analysis and Dempster-Shafer Theory**

We have already discussed the optimum implementation strategy from a financial viewpoint using the NPV method and, when including risk and the value of embedded managerial flexibility, using option analysis. The most favourable implementation strategy from a financial viewpoint is the one-stage implementation strategy using the NPV method. The same strategy was also found to be best when we included risk and the value of embedded managerial flexibility using option analysis.

Using the framework presented above, we combine options analysis and the rule-based evidential reasoning approach. The attributes for assessing the various implementation scenarios have already been presented in section 4.3. There are four thematic topics, consisting of both qualitative and quantitative attributes.

This stage involves the users assessing the strength of evidence for each attribute. This indicates the level of support for each attribute. In the evidential reasoning process, the decision-makers have to assign weights  $\omega_i$  to the various attributes. In our case, we assessed attributes and assigned weights to the attributes using information on the project obtained both from documentation and from interviews. We verified the assessment of attributes and weights with the HRMS project manager, in terms of their plausibility with regard to the proposed implementation strategies, leading to the final attribute assessment and weights set out in Table 4-5.

Attribute	Weight	One stage	Two stage nine-nine	Two stage six-twelve	Three stage
(e1) Costs and benefits	0,15	{{(I, 1.0)}	{{(G, 1.0)}	{{(A, 0.7), (B, 0.3)}	{{(W, 1.0)}
(e2) Risk	0,35				
(e2a) Project size	0,4				
(e2a1) Implementation time	0,4	{{(G, 0.5), (E, 0.5)}	{{(A, 0.5), (G, 0.5)}	{{(A, 0.5), (G, 0.5)}	{{(I, 0.7), (A, 0.3)}
(e2a2) Number of departments	0,6	{{(B, 1.0)}	{{(I, 0.4), (A, 0.6)}	{{(I, 0.6), (A, 0.4)}	{{(G, 0.5), (E, 0.5)}
(e2b) Experience with technology	0,3				
(e2b1) New hardware	0,2	{{(I, 0.5), (A, 0.5)}	{{(A,1.0)}	{{(A, 1.0)}	{{(A, 0.5), (G, 0.5)}
(e2b2) New software	0,2	{{(B, 1.0)}	{{(A, 0.6), (G, 0.4)}	{{(A, 0.4), (G, 0.6)}	{{(G, 0.4), (E, 0.6)}
(e2b3) User IT knowledge	0,2	{{(A, 0.5), (G, 0.5)}	{{(A, 0.5), (G, 0.5)}	{{(A, 0.5), (G, 0.5)}	{{(A, 0.5), (G, 0.5)}
(e2b4) Project team knowledge	0,4	{{(B, 1.0)}	{{(A, 0.6), (G, 0.4)}	{{(A, 0.4), (G, 0.6)}	{{(G, 0.4), (E, 0.6)}
(e2c) Project structure	0,3				
(e2c1) Replaced functions	0,1	{{(A, 0.5), (G, 0.5)}	{{(A, 0.5), (G, 0.5)}	{{(A, 0.5), (G, 0.5)}	{{(A, 0.5), (G, 0.5)}
(e2c2) Procedural changes	0,2	{{(A, 0.5), (G, 0.5)}	{{(A, 0.5), (G, 0.5)}	{{(A, 0.5), (G, 0.5)}	{{(A, 0.5), (G, 0.5)}
(e2c3) Structural changes	0,2	{{(A, 0.5), (G, 0.5)}	{{(A, 0.5), (G, 0.5)}	{{(A, 0.5), (G, 0.5)}	{{(A, 0.5), (G, 0.5)}
(e2c4) User attitude	0,25	{{(B, 0.8), (G, 0.2)}	{{(B, 0.6), (G, 0.4)}	{{(B, 0.4), (G, 0.6)}	{{(B, 0.3), (G, 0.7)}
(e2c5) Management commitment	0,25	{{(B, 0.8), (G, 0.2)}	{{(B, 0.6), (A, 0.2), (G, 0.2)}	{{(B, 0.4), (A, 0.4), (G, 0.2)}	{{(B, 0.4), (A, 0.2), (G, 0.4)}
(e3) Business change	0,35				
(e3a) Improvement in consumer service	0,2	{{(A, 0.6), (G, 0.4)}	{{(A, 0.8), (G, 0.2)}	{{(A, 0.8), (G, 0.2)}	{{(A, 1.0)}
(e3b) IT aligned with business strategy	0,1	{{(G, 0.8), (E, 0.2)}	{{(G, 0.6), (A, 0.4)}	{{(A, 0.6), (G, 0.4)}	{{(A, 1.0)}
(e3c) Improvement of organisational image	0,2	{{(E, 1.0)}	{{(G, 0.5), (E, 0.5)}	{{(G, 0.4), (E, 0.6)}	{{(G, 0.5), (A, 0.5)}
(e3d) Improvement of strategic positioning	0,2	{{(E, 1.0)}	{{(G, 0.6), (A, 0.4)}	{{(A, 0.6), (G, 0.4)}	{{(A, 1.0)}
(e3e) Improved efficiency and control of internal processes	0,3	{{(E, 1.0)}	{{(G, 0.6), (A, 0.4)}	{{(A, 0.6), (G, 0.4)}	{{(A, 1.0)}
(e4) Learning effects	0,15				
(e4a) Functional flexibility	0,25	{{(B, 1.0)}	{{(B, 0.6), (A, 0.4)}	{{(A, 1.0)}	{{(E, 0.2), (G, 0.8)}
(e4b) Technical scalability	0,25	{{(B, 1.0)}	{{(B, 0.6), (A, 0.4)}	{{(A, 1.0)}	{{(E, 0.2), (G, 0.8)}
(e4c) Technical compatibility	0,25	{{(B, 1.0)}	{{(B, 0.6), (A, 0.4)}	{{(A, 1.0)}	{{(E, 0.2), (G, 0.8)}

Attribute	Weight	One stage	Two stage nine-nine	Two stage six-twelve	Three stage
(e4d) Improved implementation processes	0,25	{{(B, 1.0)}	{{(B, 0.6), (A, 0.4)}	{{(A, 1.0)}	{{(E, 0.2), (G,0.8)}

**Table 4-5:** The assessment of attributes for the different implementation strategies

To this end, we used a window-based software tool called *Intelligent Decision System* (IDS) (Yang 2001) to apply the evidential reasoning approach based on the Dempster-Shafer theory of belief functions.

We defined a set  $H$  of evaluation grades for assessing all the attributes of each alternative implementation strategy:

$$H = \{h_j, j = 1, \dots, 5\} =$$

$$\{\text{Excellent (E), Good (G), Average (A), Indifferent (I), Bad (B)}\} \quad (6)$$

All attributes, apart from quantitative ones, can be assessed using these evaluation grades. We only considered complete assessments. If certain qualitative assessment values do not refer to this set, we can use the rule-based information transformation technique to assess all attributes with reference to this set. Because of the limited amount of space available to us, we will not demonstrate this technique here and refer the reader instead to a detailed description of this technique in (Yang 2001).

We then incorporated the option values into a multi-attribute decision analysis framework. To estimate the utilities of the cost attribute we assume a linear marginal utility function. For the option valuation, we normalised the option value for each alternative (see Table 3) by assigning the highest option value (one-stage implementation)  $u(3,411,470) = 1$  and the lowest option value (three-stage implementation)  $u(2,298,951) = 0$ . As we assume a linear utility function,  $u(3,133,340) = 0.75$ ,  $u(2,855,211) = 0.5$  and  $u(2,577,081) = 0.25$ . Let

$$h_{1,1} = 3,411,470, h_{2,1} = 3,133,340, h_{3,1} = 2,855,211, h_{4,1} = 2,577,081, h_{5,1} = 2,298,951.$$

The option value of the two stage six-twelve alternative can be represented using equation (4). The option value of the two stage six-twelve alternative,  $h_1 =$

2,487,099. Since  $h_{5,1} < h_1 < h_{4,1}$ , we can represent the option value as  $S_3(2,487,099) = \{(h_{4,1}, \beta_{4,1}), (h_{5,1}, \beta_{5,1})\}$ , where

$$\begin{aligned}\beta_{4,1} &= (h_{5,1} - h_1) / (h_{5,1} - h_{4,1}) \\ &= (2,298,951 - 2,487,099) / (2,298,951 - 2,577,081) \\ &= 0,7 \quad \text{and}\end{aligned}$$

$$\beta_{5,1} = 1 - \beta_{4,1} = 0,3$$

So,  $S_3(2,487,099) = \{(h_{4,1}, 0.7), (h_{5,1}, 0.3)\} = \{(L, 0.3), (B, 0.7)\}$ . In a similar way we calculate the two stage nine-nine alternative  $S_2(2,566,928) = \{(h_{4,1}, 1.0)\} = \{(L, 1.0)\}$ . Using a similar calculation, we calculated the utilities assuming a linear utility function. We normalised the NPVs for each alternative by assigning the highest NPV (one-stage implementation)  $u(1,183,678) = 1$  and the lowest NPV (three-stage implementation)  $u(690,395) = 0$ . The NPVs may be represented as:

$$\begin{aligned}S_1(1,183,678) &= \{(E, 1.0)\}, \\ S_2(929,329) &= \{(E, 0.2), (G, 0.8)\}, \\ S_3(844,546) &= \{(G, 0.1), (A, 0.9)\}, \text{ and} \\ S_4(690,395) &= \{(B, 1.0)\}.\end{aligned}$$

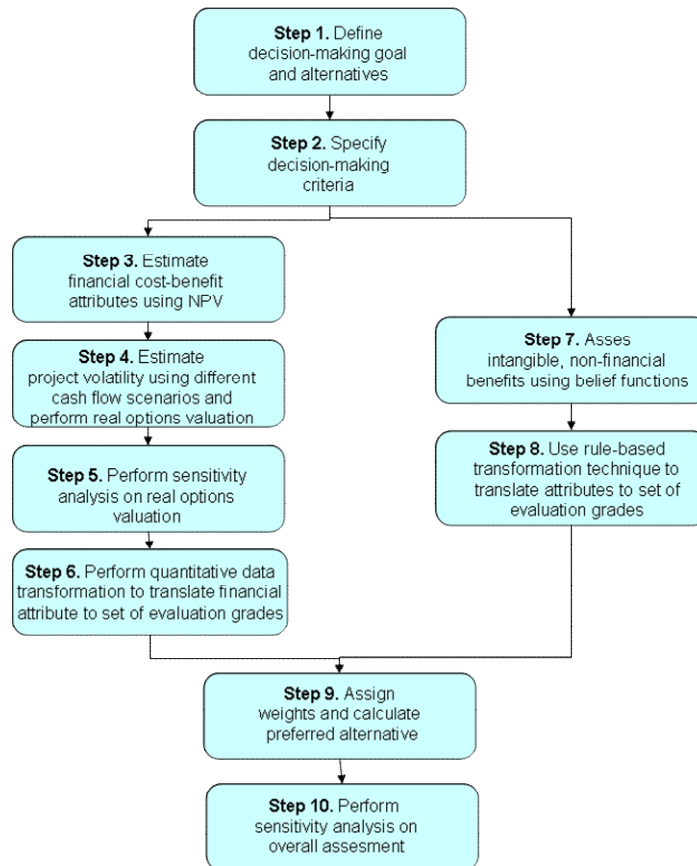
Using the IDS software tool mentioned above, which is based on the evidential reasoning algorithm referred to in Yang (2001), we were able to calculate the overall degrees of belief. We aggregated all the attributes, leading to a final assessment of the proposed implementation strategies.



Implementation strategy	Assessment	Ranking
One stage implementation	0.514	2
Two stage nine-nine implementation	0.491	4
Two stage six-twelve implementation	0.521	1
Three stage implementation	0.511	3

**Table 4-6:** Quantified assessment of implementation strategies

Combining real options analysis with the Dempster-Shafer theory of belief functions results in a preference for the two-stage six-twelve implementation (see Table 4-6). This is what one would intuitively expect, since more attributes are used that support phase-wide implementation. The one-stage implementation is ranked second, followed by the three-stage implementation and the two-stage nine-nine implementation. Figure 4-3 represents a stepwise summary of our overall approach.



**Figure 4-3:** Summary of the combined approach of real options analysis and Dempster-Shafer theory

#### *Sensitivity analysis*

As the final stage of the assessment process, we performed a sensitivity analysis to see how the preferred alternative changes if weights are assigned differently. If the weight for cost and benefits changes from 0.15 to 0.24, the two stage nine-nine implementation becomes the preferred implementation strategy. If the weight for the 'costs and benefits' attribute is changed to 0.53, the preferred strategy changes to one-stage implementation. These outcomes support what one would intuitively

expect, since the cost-benefit attribute supports earlier implementation of the system in a large number of departments because of the earlier payback of benefits. If we use the NPV calculation in the multi-attribute decision analysis model, we get the same outcome, but the aggregated value for each alternative varies.

## **4.6 Discussion and Conclusion**

In this chapter, we have defined a theoretical model for selecting the most favourable strategy for implementing an IT infrastructure in conditions of uncertainty. The aim of this chapter is to help decision-makers to opt for the best implementation strategy by combining the Dempster-Shafer theory with real options analysis. We draw on Dempster-Shafer belief functions to evaluate decision-making attributes that cannot be easily quantified. This combined model takes full account of the multi-dimensional nature of the decision that needs to be taken. We applied the model in a case study, in which we used data from a large European-based service-provider to define a favourable strategy for implementing a human resource management system.

Decisions on IT investments are complex decisions based on multiple goals and values. It may well be because of this complexity that organisations often fail in practice to follow a well-structured, accountable and reproducible decision-making process for assessing the profitability of IT investments. We have shown that our model for analysing investments in IT infrastructures, which takes account of the multi-dimensional nature of such investments, generates vital information for selecting the most appropriate strategy. Whilst previous research studies have valued multi-stage investments using real options analysis, they have ignored the multi-dimensional nature of IT infrastructure investment decisions. Although options analysis generates valuable insights into the trade-off between risk and benefits from a financial perspective, as we have shown in this chapter, adding non-financial attributes that support phase-wide implementation can lead

to very different outcomes in terms of the most suitable implementation strategy. Combining the Dempster-Shafer theory with real options analysis supports both qualitative and quantitative decision attributes, as well as different types of risk for both quantitative and qualitative attributes. This is shown in Table 4-7.

Comparison of Methods				
	NPV	Real options analysis	Evidential Reasoning based on Dempster Shafer and NPV	Evidential Reasoning based on Dempster Shafer and real options
<b>Evaluation criteria</b>				
Financial	Yes	Yes	Yes	Yes
Non-financial	No	No	Yes	Yes
Risks	Risk-free rate of return	Variability of the projects' financial value and risk-free rate of return	Uncertainty in subjective judgments and risk-free rate of return	Uncertainty in subjective judgments and variability of the projects' financial value & risk-free rate of return
<b>Process support</b>				
Participatory planning	No	No	Yes	Yes
<b>Impact of method</b>				
Learning	No	Yes	Yes	Yes
Flexibility	Does not take flexibility into account	Takes managerial flexibility from a financial perspective into account	Takes multiple definitions of flexibility into account	Takes managerial flexibility from a financial perspective into account & multiple definitions of flexibility

**Table 4-7:** Comparison of the different methods

The case study shows that a combined analysis can generate valuable information that can help decision-makers to select the most suitable strategy from a range of competing strategies. This is because, as both the multi-attribute decision analysis and the real options calculation make it easy to perform a sensitivity analysis of the stated preferences, the various scenarios can be evaluated for different parameter ranges. The advantage of using the options model lies in identifying the trade-offs between risk and benefits from a financial viewpoint. Since the

combined analysis also facilitates transparent group decision-making, it can help to overcome one of the main objections to the use of real options analysis, namely its lack of transparency for decision-makers. However, the difficulty of obtaining an accurate estimate of the volatility of the investment benefits remains to be a source of criticism when using options valuation (Yang 2001).

Our approach covers a wide range of competing strategies for IT infrastructure projects where there is a project risk. These include, for example, the implementation of group-wide computer platforms, application platforms (e.g. ERP) and data warehouses. The analysis provides flexible decision support that can be adapted to the specific domain in question.

As we have seen, a multiple attribute approach results in a different decision than when a NPV or real options analysis is used. There may be two reasons for this: first, the decision-maker's objectives may diverge from those of capital market players. Alternatively, the NPV or real options valuation may not have been correctly calculated. To elaborate on the first reason, the normative decision models assume that a firm pursues the sole objective of stockholder wealth maximisation. However, IT infrastructure projects undertaken by large organisations are complex and involve interactions among a wide variety of stakeholders. The latter may have their own interpretations of wealth maximisation, subject to individual concerns about risk, liquidity, responsibility and so forth. For example, as is shown in the sensitivity analysis in the real options calculation, raising the degree of uncertainty leads to a higher real options value and therefore to a higher preference for the one-stage implementation strategy. However, the decision-maker in question may well have a preference for a lower project risk, resulting in a different implementation strategy. As regards the risks in relation to non-financial aspects such as learning, these are difficult to quantify in practice. This is easy to model by combining the Dempster-Shafer theory with real options analysis. Consequently, certain criteria that are not

quantified in an NPV or real options analysis may be made explicit in a multiple attribute approach, thus resulting in a different decision.

The second possible reason for a different decision is if the NPV or real options valuation is not correct. This may be the case if cash flows cannot be accurately projected at the time when the decision is taken. For example, in our case, the results of the application of the *improvement of strategic positioning* attribute cannot be incorporated into the cash flow calculation for the project since it is not yet possible to place a monetary value on the attribute.

As for the limitations of our combined model, first real options and decision analysis rest on assumptions that lead to a lack of theoretical elegance when used in combination. Converting NPV to utilities requires clear assumptions about the decision-maker's preferences as described earlier. Also, the decision-maker's probabilities and utility function for describing its preference for cash flow over time may well be different from assumptions underlying real options theory. Violation of the theoretical assumptions underlying real options theory has been extensively discussed in literature, see for example Benaroch and Kauffman (1999), and these arguments on the validity of using real options analysis for IT infrastructure investment decisions can be extended to the combined model as presented in this chapter.

Second, in the case we presented we assumed no project inter-dependencies between the 18 different HRMS implementations. Project inter-dependencies between two projects exist when a capability developed for one project is required by one or more other project(s) or when a capability developed for one project supports capabilities required by other projects (Bardhan et al. 2004). Recently, a real options approach has been developed to prioritize a portfolio of IT projects that have interdependencies (Bardhan et al. 2004). There are also examples of modelling project interdependencies using programming techniques in a multi-attribute decision analysis as in Lee and Kim (2001). The specific goal of our approach was to define an implementation strategy for an isolated application in

autonomous departments which can be modelled as a stage option. Of course, also in this case project interdependencies may exist. For example, benefit interdependencies can occur due to a synergy effect when the HRMS is implemented in all departments.

A vital issue for further research is how to combine real options analysis with multi-attribute decision analysis to model these project interdependencies. In the presented combined model, project interdependencies from a financial perspective can be made transparent by using the real options approach that deals with project inter-dependencies mentioned above (Bardhan et al. 2004). Non-financial project inter-dependencies can be made transparent by introducing attributes to the model that represent the inter-dependencies. For example, a specific attribute for resource interdependencies may be added to account for the extent to which software resources can be shared among the various implementation projects.

When dealing with project interdependencies to prioritize a portfolio of IT projects, uncertainty about the benefits or a lack of information on other characteristics of future projects may exist. This makes the combined use of real options and the Dempster-Shafer theory of belief functions a strong candidate for the support of these investment decisions.

The model can be further refined with the aid of validation techniques such as user assessments to further extend the attribute hierarchy. It can also be extended to deal with project-interdependencies as discussed above. Furthermore, for the purpose of our option analysis, we assumed that uncertainties surrounding different projects in different departments are not related. This may of course not be the case in real life. A future study should take into account the correlation of risk between projects. Also, we used the model to identify a multi-stage implementation strategy for an IT application the aim of which is to cut costs. It would also be interesting to analyse an IT infrastructure investment in which growth options form part of the investment proposal, given that there will be a greater disparity between the different implementation scenarios.





## Chapter 5

### IT Project Risks and the Managerial Valuation of Real Options

From a real options and risk management perspective, the specific risk one seeks to control dictates the choice of which specific real options to embed in a project. A project embeds real options when managers have the ability, but not the obligation, to alter the operating strategy, or the course of a single project, by acting in response to the occurrence of risk over time. Recently, researchers have shown that managers recognize and value the presence of real options in IT projects and they have suggested ways in which specific real options can be used to manage risk in IT projects. There has, however, yet to be an empirical validation of whether and how managers assess the value of the different types of options in the presence of specific risks. This insight is particularly important since real options may encompass a large part of a project's value, and mapping flexibilities to risks is one of the core steps that must be taken in deciding how to manage projects so that the option value may be effectively realized in practice.

By using data from 5520 risk assessment observations in a field experiment, the primary contribution of this study is to provide empirical evidence that managers differentially assess the relative value of different types of options when controlling IT project risks. Supplemental to prior research conducted by Tiwana et al. (2006), who show that IT professionals place a relative value on various real options in an experiment setting, we demonstrate that this value is also driven by the risk factors associated with an IT project. We also demonstrate that this assessment generally follows real options-based risk management reasoning. The study contributes to managerial practice by identifying necessary conditions for management to improve their real options reasoning in high-risk IT projects.

## 5.1 Introduction

IT project performance is influenced by the fit between the project's risks and how these project risks are managed (Barki et al. 2001). The bulk of prior work on IT project risk management deals with identifying and categorizing critical risk factors in IT projects, developing checklists, proposing frameworks, risk dimensions and risk countermeasures (Leavit 1964, Boehm 1989, 1991, Davis 1982, McFarlan 1982, Schmidt et al. 2001, Wallace et al. 2004). Although several IT risk management approaches have been developed to serve as a means to identify and manage project risks, the approaches are very diverse and provide relatively weak theoretical analyses of the nature of risk management (Lyytinen et al. 1998). Also, the proposed frameworks offer no guidance on how risk countermeasures influence IT project cost and value (Benaroch et al. 2006).

Recently researchers have emphasized the need to use concepts from real options theory for IT risk management purposes (Boehm 1998, Benaroch 2002, Kumar 2002). A project embeds real options when managers have the opportunity, but not the obligation, to adjust the future direction of a project in response to external or internal risks. These adjustments can take the form of deferring the project, switching the project to serve a different purpose, changing the scale of the project, implementing it in stages, abandoning the project, or using the project as a platform for future growth opportunities. The value of real options originates from the managerial flexibility to decide whether to exercise the option depending on future conditions. This flexibility implies that option holders can participate in the upside of the project, but limit their losses to the cost of acquiring the option (Fichman et al. 2005).

Since real options are not inherent in any IT project, they usually must be planned and intentionally embedded in a project in order to control specific risk factors (Benaroch 2002). Several researchers have proposed combinations of risk and real options to be embedded in IT projects in order to optimally control risk

and maximize IT project value (Kim and Saunders 2002, Kumar 2002, Benaroch 2002, Bräutigam 2003). Benaroch et al. (2006) have proposed a fine-grained option-based risk management model suggesting the most effective risk-option mappings. Since real options can encompass a substantial portion of a project's value (Taudes et al. 2000) and proactively embedding the right option as a risk countermeasure can add value to an IT project (Benaroch 2002), it is important that managers should have a sound understanding of how options create value and know how to manage projects so that the option value that exists in theory is actually achieved in practice (Fichman 2005).

In a recent study, Tiwana et al. (2006) show that managers recognize and differentially assess the presence of different types of real options in IT projects. While prior research shows diverse effects of risk on the subjective quantitative valuation of real options (Busby and Pitts 1997, Sirmans and Yavas 2001), recent research by Benaroch et al. (2006) indicates that the intuition of managers coincides with the logic of option-based risk management. However, so far no solid empirical evidence has been presented on how managers intuitively assess the relative importance of the different types of options in relation to specific risks. This insight is particularly important since real options may encompass an important part of a project's value, and mapping flexibilities to risks is one of the core steps that must be taken in deciding whether or not a real option valuation is relevant for a specific project.

The aim of this study is to empirically investigate whether the link between risk and real options based on option-based risk management reasoning aligns with the intuition of managers. In so doing, the central research issues we investigate are twofold. Firstly, we investigate whether managers differentially assess the relative value of the different types of options when controlling different types of risks. Secondly, we investigate whether this assessment follows the proposed option-based risk management reasoning. We use a field experiment to examine how different risk factors and real options mappings affect managers'

perceptions of project value. We study IT project scenarios where there is high risk caused by different types of uncertainty and, as in Tiwana et al. (2006), where managers should be indifferent toward the project value from a traditional Net Present Value (NPV) perspective. In this way, we isolate the effects of the presence of specific real options in relation to particular risk factors.

The article's key contributions to managerial decision-making theory are twofold. Firstly, our results show that managers differentially assess the relative value of different types of options when controlling IT project risks. Extending prior findings by Tiwana et al. (2006) who show that IT professionals place a relative value on various real options in an experiment setting, we demonstrate that this value is also driven by the risk factors associated with an IT project. This suggests that managers understand that the value of managerial flexibility offered by different types of options in IT projects can serve as an effective risk countermeasure. Secondly, our results show that real option-based risk management reasoning generally corresponds with the reasoning of managers. This suggests that managers understand how options can create value as a response to specific risks and understand how to manage projects so that the option value may be effectively achieved in practice.

The article is structured as follows. In the following sections, we will look at existing research on IT risk management and the use of real options theory for risk management purposes, and present the use of real option-based risk management reasoning to develop our hypotheses. We will then go on to describe the methodology and data collection method and present our analyses and results. Finally, we will summarize our findings and their limitations, discuss their theoretical and practical implications, and identify directions for future research.

## 5.2 Real Options Based Risk Management in IT Projects

Researchers have contended that a disciplined approach to IT project risk management focuses on what typical risk factors managers face, which of these factors managers consider more deserving of their attention, and which countermeasures are the most effective in mitigating risk, given a particular set of risk factors (Schmidt et al. 2001). The bulk of prior work on IT project risk management deals with the identification of critical IT project risk factors, the development of checklists and risk countermeasures (Leavit 1964, Davis 1982, Keil et al. 1998, Barki et al. 2001, Wallace et al. 2004). Table 1 distinguishes four risk areas derived from Keil et al. (1998). We will summarize the definitions for the different types of risks included in our study and representative references for each of these risk areas. In our study, we selected a common set of risk factors including the ones that experienced IT project managers in various countries judge as being among the more important items (Keil et al. 1998). In a critique of IT risk management literature, Lyytinen et al. (1998) contend that IT risk management approaches are very diverse and provide relatively weak theoretical analysis of the nature of risk management. Although advocates of IT risk management claim that, by identifying risk, action can be taken to reduce the chance to exceed IT project costs or of IT project failure, thus far the proposed frameworks offer no guidance on how risk countermeasures influence IT project costs and value (Benaroch et al. 2006).

Risk area	Risk factor	Definition	Representative references
Scope and requirements	Scope creep	The degree of uncertainty about the scope of the project and hence about the ability of the resulting application to provide the functionality needed by all the target users.	[1], [3], [4], [5], [6], [7], [9], [10]
	Inadequate requirements	The degree of uncertainty about the application meeting the requirements needed by the intended users.	[2], [3], [4], [6], [7], [9], [10]

Project execution	Expertise	The degree of uncertainty about the existing level of IT skills and experience being adequate for the project.	[1], [2], [3], [4], [6], [7], [9], [10]
	Project size	The degree of uncertainty due to the size complexity of the application task as well as due to dependence on individuals.	[2], [3], [7], [8], [10]
	Technology newness	The degree of uncertainty about the maturity of the implementation technology.	[2], [3], [6], [7], [8], [9], [10]
Customer mandate	User involvement	The degree of uncertainty about user involvement and participation during the project and hence about the ability of the resulting application to provide the required functionality.	[1], [2], [5], [6], [7], [9], [10]
	Management support	The degree of uncertainty about the organizational support offered at the level of management.	[1], [3], [6], [7], [9], [10]
Environment	Organizational change	The degree of uncertainty about the ability of the affected organization to handle change.	[1], [2], [3], [6], [7], [9], [10]
	Customer demand	The degree of uncertainty about customer demand being unstable and unpredictable to the point where it could impact the expected project benefits.	[1], [3]

- 
- [1] Alter et al. 1978                      [4] Boehm 1988, 1991                      [7] Leavit 1964                      [10] Wallace et al. 2004  
[2] Barki et al. 2001                      [5] Davis 1982                              [8] McFarlan 1982  
[3] Benaroch et al. 2006                      [6] Keil et al. 1998                      [9] Schmidt et al. 2001

**Table 5-1** IT Risk Factors

Recently researchers have emphasized the need to use concepts from real option theory for IT risk management purposes (Boehm 1998, Benaroch 2002, Kumar 2002, Kim and Saunders 2002, Benaroch et al. 2006). A project embeds real options when managers have the ability, but not the obligation, to alter the operating strategy, or the course of a single project, by acting in response to the occurrence of risk. Real options theory suggests that a project with an embedded option is more valuable than a project without, since the managerial flexibility that is offered by real options acts in ways that avoid potential losses while preserving potential gains. The extent of this extra value depends on the degree of uncertainty and corresponding variability in potential future gains or losses, and the options' time to maturity. Prior research has identified six types of real options

that can be embedded in IT projects (Trigeorgis 1993, Fichman et al. 2005): (i) deferring the project, (ii) switching the project to serve a different purpose, (iii) changing the scale of the project, (iv) implementing it in stages, (v) abandoning the project, or (vi) using the project as a platform for future growth opportunities. Table 2 shows a summary of the real options types as used in our study. For the option to change scale, we make a distinction between the option to scale-up and the option to scale-down. Since the underlying asset of the option to growth is that of a future project and is not applicable as a risk countermeasure for an ongoing project (Benaroch 2002), it is excluded from this study.

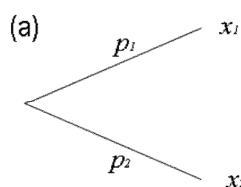
Option type	Description
Defer	The initiation of a project can be delayed without risking foregoing a valuable opportunity (Benaroch & Kauffman, 1999; Hubbard, 1994).
Stage	The option to stage investments exists when a project is structured as a series of incremental expenditures that allows the project to be terminated if business conditions become unfavorable.
Change Scale	The option-to-change scale allows the scope or the scale of a project to be <i>reduced</i> or <i>expanded</i> in order to change the scope or the scale of the project result (Pindyck, 1988, Kumar 2002).
Abandon	An abandonment option is associated with a project if managers can discontinue the project prior to completion and redeploy remaining project resources (Hubbard, 1994).
Switch use	The option to switch use refers to the option to put an asset to a different purpose from that for which it was originally intended (Trigeorgis, 1993).

**Table 5-2** Real Option Types

There are several arguments why it is fruitful to view IT risk management through a real options lens. First of all, from a risk management perspective flexibility is a crucial success factor in IT projects as it enables deployment of risk countermeasures as a response to risk (Avison et al. 1995) and risk countermeasures described in literature often coincide with the flexibility offered by the different types of options. Secondly, real options theory offers an economic perspective on the link between IT risks and risk countermeasures offered by

managerial flexibility in IT projects, and proactively embedding the right options as a risk countermeasure can add value to an IT project (Benaroch 2002). Thirdly, in line with the decision theoretic view, option theory defines risk as a trait of an IT project or its environment that can negatively or positively affect the degree of variation in expected outcome (Benaroch et al. 2006). The general IT risk management focus on the negative aspects of risk (Lyytinen et al. 1998) neglects the opening up to future growth opportunities as a response to positive risk, which is regarded as specifically valuable (McGrath 1997, Benaroch 2002). Lastly, real options theory considers risk management to be a proactive process aimed at favourably lowering variance in expected outcomes (Amran and Kulatilaka 1999). This is in line with behavioural research, which shows that managers believe that risk is manageable and controllable (MacCrimmon and Wehrung 1986, Shapira 1986).

To show a clear distinction between the effects of risk management actions using a real options perspective as opposed to risk mitigation actions on the payoffs of a high-risk project decision, we will address the key principle of real options reasoning for risk management purposes which can be motivated from the high-risk choice problems commonly found in behavioural decision theory (Kahneman and Tversky 1979), as in Figure 1. We used a simple two-branch decision tree to portray the possible outcomes of a high-risk IT project decision problem, and the effects that different type of options have on reducing the consequences of risk.

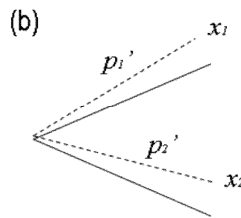


We start from a software development project that is exposed to risk. The risk can either be negative, i.e., it may reduce the project's payoffs in case of an unfavourable outcome, or it can be positive, i.e., it may favourably enhance the project's payoffs in case of a favourable outcome. We use a simple two-branch decision tree to portray the possible outcomes of the decision problem as shown in (a). Due to the risk, the project offers a payoff  $x_1$  with probability  $p_1$  ( $0 < p_1 < 1$ ) and payoff  $x_2$  with probability  $p_2$ , where  $p_1 + p_2 = 1$ . The project has an expected value of  $p_1 x_1 + p_2 x_2$ .

Now, if a project manager wants to intervene, the risk management decision and the accompanying action can be viewed as being of two types (Kumar



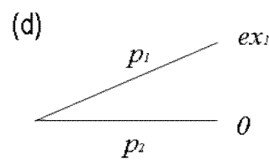
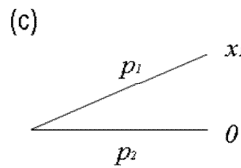
2002).



The first is oriented towards risk mitigation by reducing or enhancing the *probability* of the risk affecting the payoff of the project. In case of negative risk (or positive risk respectively), the project manager can try to reduce the risk (or enhance it respectively). If successful, the degree of risk of the project outcome will change from  $p_1$  to  $p_1'$  and  $p_2$  to  $p_2'$  as shown in (b), where  $p_1' + p_2' = 1$ , thereby changing the expected value of the project to  $p_1'x_1 + p_2'x_2$ .

The second strategy is oriented towards favourably reducing the negative *distribution* of the project's payoff in case of negative risk, and favourably enhancing the *distribution* project's payoffs in case of positive risk.

In case of negative risk due to scope creep, the project manager may want to wait to invest in the project, allowing the project manager to wait for the lack of stable requirements being solved satisfactorily over time. Allowing for a waiting period prior to committing to a high-risk outcome is the key in looking at risk management actions through a real options lens. If  $x_1$  is a gain and  $x_2$  is a loss, holding this option on the project favourably truncates the distribution of the project's payoff to  $\max(p_1 x_1, 0)$ , as is shown in (c). The option to defer, the option to stage, the option to scale down, the option to abandon and the option to switch use can serve to reduce the impact of negative risk on the IT project's payoffs. These options act like a financial put option on a share of stock (Benaroch 2002), where a *put option* confers the right, but not the obligation, to sell an asset at a specified exercise price at a given time. If the project goes badly, the operational option is exercised and the losses are moderated. If the project goes well, the option is not exercised and the upside potential payoffs are unchanged.



In case of positive risk due to customer demand exceeding expectations, using the simple two-branch decision tree, the project manager waits for the outcome and then decides to expand the scale of the project in case of a favourable outcome. If  $x_1$  is a gain and  $x_2$  is a loss and  $e\%$  is the value that represents the project expansion, holding this call option on the project favourably truncates the distribution of the project's payoff to  $\max(e\% p_1 x_1, 0)$ . The option to scale-up can serve to enhance the impact of positive risk on the IT project's payoffs. This option acts like a financial *call* option on a share of stock (Benaroch 2002). A *call option* offers its holder the possibility (but not the obligation) to purchase a particular asset at a given price at a given time.

**Figure 5-1** Risk Management Actions (a) Project Payoffs; (b) Risk Mitigation; (c) Real Options Based Risk Management in case of Negative Risk; (d) Real Options Based Risk Management in case of Positive Risk.

Since risk is the key value driver of options (Bräutigem et al. 2003) and the flexibility offered by real options is not inherent in any IT project, they usually

must be planned and intentionally embedded in an IT project in order to control specific risk factors (Benaroch 2002). Although real options can represent project value, if there is no purpose (i.e., risk) to exercise an option, there is no value in having or creating it. Managerial flexibility can also have negative effects on project decision-making, insofar as the commitment of the organization to a proposed plan can be undermined, and looking for strike signals for exercising real options is costly and resources are limited (Busby and Pitts 1997, Barnett 2005). Therefore, mapping the most relevant types of real options to reduce specific IT risk factors is one of the core concepts in practice for deciding whether or not to embed and value real options in project execution. Micalizzi and Trigeorgis (1999), Kumar (2002), Benaroch (2002) and Benaroch et al. (2006) have proposed how different types of risk can be related to specific real options to capture the inherent value of active management of a specific risk factor. Benaroch (2002) has developed a framework that explores the most effective combination of options to embed in an IT project in order to optimize the control of risk and maximize the project's payoffs. The option-based risk management strategies are derived from the clear correspondence between generic risk management strategies and the managerial flexibility as offered by the different types of real options (derived from Benaroch et al. 2006), which are presented in Table 5-3.

Risk management strategy and characteristics	Corresponding real option	Appropriate risk area	Type of risk
<b>Risk reduction</b> is considered to include both loss prevention and loss control efforts. It assumes taking steps to reduce, mitigate, or otherwise manage risk and can take the form of providing information to assess more accurately the impact, likelihood, or timing of a risk. It helps to learn about the severity of various risks, for example through learning-by-waiting.	Option to defer	Scope and requirements Project execution Customer mandate Environment	Negative

<b>Risk transfer</b> means moving risk from one part of a project to another or by moving risk from one party to another. If knowledge, skills, or other attributes can reduce the risk, it is reasonable and economically efficient to transfer the risks.	Option to stage	Scope and requirements Project execution Customer mandate Environment	Negative
<b>Risk avoidance</b> is the elimination or avoidance of some risk, or class of risks, by reconfiguring the project such that the risk in question disappears or is reduced to an acceptable value. Risk avoidance should be used in those instances in which the exposure is potentially frequent or severe and cannot be reduced or transferred.	Option to scale up	Customer mandate Environment	Positive
	Option to scale down	Scope and requirements Project execution Customer mandate Environment	Negative
	Option to switch use	Customer mandate Environmental	Negative
<b>Risk retention</b> is the "residual" or "default" risk management technique. All risks that cannot be reduced, transferred or avoided must, by definition, be retained.	Option to abandon	Customer mandate Environmental	Negative

**Table 5-3** Options Related Risk Management Strategies

Using a field experiment, Tiwana et al. (2006) recently provided solid empirical evidence that managers differentially assess the presence of different types of real options in IT projects. While prior research shows diverse effects of risk on the subjective quantitative valuation of real options (Busby and Pitts 1997, Sirmans and Yavas 2001), recent research by Benaroch et al. (2006) indicates that the intuition of managers coincides with real options-based risk management reasoning. However, so far no solid empirical evidence has been presented on how managers intuitively value the different type of options in relation to specific risks. This insight is particularly important since mapping the right flexibilities to risks can encompass an important part of a project's value and is one of the main capabilities that managers must possess to adopt real options thinking in IT project management. Even though it may be difficult to precisely calculate the value of

real options, it is plausible that managers motivated by the prospect of producing a positive economic project return would follow real options-based risk management reasoning and that they would attribute a higher value to the most relevant types of real options to reduce risk.

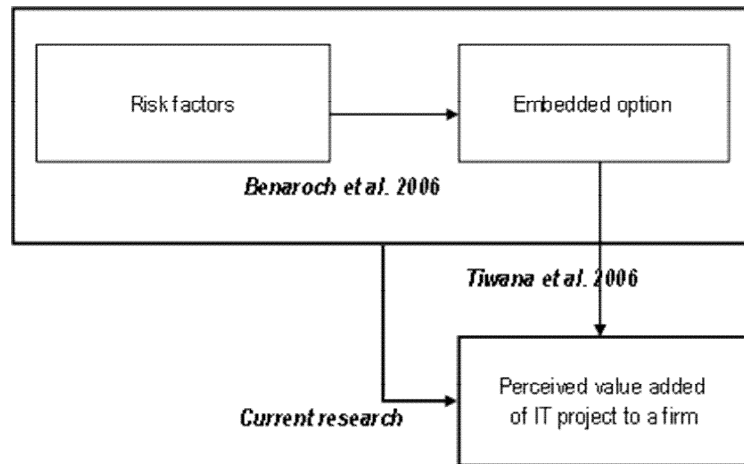
### 5.3 Research Model and Hypotheses

In our research, we combine the proposed relations between risk and real options, and the findings on the relationship between embedded real options and perceived value added of a project. We assume that, if an IT project is subject to a particular risk, then a suitable option may provide the opportunity for managers to intervene across the project's trajectory if the risk materializes (Benaroch et al. 2006). Real options theory allows for a more accurate valuation of the opportunity to take such risk countermeasures than traditional net present value (NPV) analysis. The goal of a real options analysis is to determine the active NPV of a project. The active NPV is equal to the traditional, or passive, NPV (without managerial flexibility) plus the value of the embedded real options (managerial flexibility), i.e.,

$NPV_{Active} =$

$$NPV_{Passive} + f(\text{value of risk-related real option embedded in the project}) \quad (1)$$

We hypothesize that, in case of a given type of risk, the perceived value added associated with a project will be a function of the  $NPV_{Passive}$  of the project plus the value of the real option that acts as a risk countermeasure. As Tiwana et al. (2007) show, real options are generally associated with project value only when a project's easily quantifiable benefits are low. Therefore, as in Tiwana et al. (2006), if the  $NPV_{Passive} = 0$ , the value added of a given type of risk is equal to the value of the real option that acts as a countermeasure.



**Figure 5-2** Representative studies and gap at the intersection of risk, real options and perceived IT project value

The specific rationales linking each risk and option mapping to perceived value added are presented in the following subsections.

### 5.3.1 Risk of Scope Creep

Risk of scope creep can be caused by uncertainty about the scope of the project and hence about the size of the development effort (Schmidt et al. 2001). There are three preferable risk management strategies to deal with risk of scope creep. Firstly, risk of scope creep can be reduced by embedding the option to defer. Since it is often not possible to pin down the exact requirements at the outset of a project (Keil et al. 1998), waiting can clarify the scope of the system, since users can develop more realistic expectations of what the system will do. Meanwhile, risk mitigation actions can be undertaken such as deriving functionality from existing systems (Davis 1982). Secondly, risk of scope creep can be transferred by embedding the option to stage (Leavit 1964, Alter et al. 1978, Boehm 1991). Staging the project allows one to learn about the system's scope by carefully planning and

managing milestones, for example by delivering small system releases at the end of each project stage (Boehm 1991). When a project stage is not successfully completed, a project can be killed midstream to reduce aimless project expenditures. Thirdly, risk can be avoided by scaling down the initially planned application capabilities. The option to scale down can be used to focus the scope of the system, e.g., by reducing some of the system's functions (Leavitt 1964, Benaroch et al. 2006). This option can be created by pursuing risk countermeasures such as drawing a line between desirable ('nice to have') and necessary functionality (Keil et al. 1998), allowing management to lower initial project development costs.

Since managers consider scope creep as controllable (Schmidt et al. 2001), associating the option to abandon or the option to switch use with project value in case of this type of risk would indicate that managers are willing to drastically change the project's initial goals. This would suggest that they perceive this type of risk as largely outside their control, instead of being a risk that should be managed by emphasizing the management of change (Keil et al. 1998). Since the option to scale up is like a call option on the underlying asset in case of positive risk, managers will not associate the option to scale up with project value in case of risk of scope creep. Therefore, our hypothesis is that managers are more likely to associate an embedded option to defer, stage or scale down with project value in case of risk of scope creep than an embedded option to scale up, abandon or switch use.

*Hypothesis 1a (1b, 1c respectively): Under conditions of risk of scope creep the option to defer an IT project (or the option to stage an IT project or the option to scale down an IT project respectively) will be more highly valued than the option to scale up, abandon or switch the use of an IT project.*

### **5.3.2 Inadequate Requirements Risk**

Inadequate requirements risk refers to the degree of uncertainty about the application meeting the performance requirements of the intended users, which may increase the problems associated with a software development project (Wallace 2004, Benaroch et al. 2006). There are two preferable risk management strategies to deal with risk of inadequate requirements. Firstly, the consequences of inadequate requirements risk can be transferred by embedding the option to stage the project (Benaroch et al. 2006). Technical performance problems with the application can be detected in an early stage of the project and if updated information on performance shortfalls has a severe negative impact on the project costs and benefits, the manager can avoid investing in stages that no longer have a worthwhile payoff. A second adequate risk management strategy is to avoid the consequences of inadequate requirements by scaling down the project (Boehm 1988), an option which can be useful in case of technical barriers (Fichman et al. 2005). By scaling down the project the system's number of users can be limited, or some of the system's functions can be disabled so as to reduce the performance problems (Benaroch et al. 2006).

Since risk of inadequate performance requirements calls for proactively taking steps to interface with users or technical staff, managers will be more likely to associate the option to stage or scale down with project value than the option to defer. Avoiding or retaining inadequate requirements risk by associating the option to abandon or the option to switch use with project value would suggest that managers perceive this type of risk as largely outside their control. However, although inadequate requirements risk is considered as one of the most important risk factors, it is regarded as controllable (Keil et al. 1998). Since the option to scale up is like a call option on the underlying asset in case of positive risk, managers will not associate the option to scale up with project value in case of inadequate requirements risk. Therefore, our hypothesis is that managers are more likely to

associate an embedded option to defer, stage or scale down with project value in case of risk of inadequate requirements than an embedded option to scale up, abandon or switch use.

*Hypothesis 2a (2b respectively): Under conditions of inadequate requirements risk the option to stage an IT project (or the option to scale down an IT project respectively) will be more highly valued than the option to defer, scale up, abandon or switch the use of an IT project.*

### **5.3.3 Expertise Risk**

Expertise risk is caused by uncertainty about the required skills and experience being adequate for the project (Keil et al. 1998). There are three preferable risk management strategies to deal with expertise risk. Firstly, a staffing problem can be solved by deferring a project, for example by successfully countering this risk by taking time to hire or develop the right expertise, and developing contingency plans to cope with staffing shortfalls (Keil et al. 1998). As long as project benefits are not eroded, for example when first-mover advantages exist, the option to wait can prevent reconversion costs that may have to be incurred if risk is resolved unsatisfactorily. Secondly, as know-how and technical knowledge associated with technologies is tacit and relatively immobile (Attewell 1992), it can be created by project staff via the process of learning-by-doing. By exercising the option to stage (Alter and Ginzberg 1978, Benaroch et al. 2006), managers can proactively anticipate, and respond to, a lack of expertise by planning high-risk parts of the project at the end of the project so as to gain time to invest in overcoming a lack of knowledge. Thirdly, keeping a system simple by focusing the its scope can be an effective risk countermeasure in case of expertise risk (Alter and Ginzberg 1978). By renouncing the cash flows of the capacity, the option to scale down mitigates loss by saving part of the investment expenditures, and some project resources can



be reassigned. When an initial lack of knowledge is overcome over time a system's scope may eventually be expanded.

Firms boasting a knowledgeable and technologically advanced staff base can innovate more economically and with greater probability of success (Fichman 2004). Therefore, and since experienced project managers believe to have reasonable control over expertise risk (Keil 1998), it will not be likely that that managers are willing to change the project's goals by abandoning the project or switching the use of the project in case of expertise risk. Also, the option to scale up will not be associated with project value to reduce the negative impact of inadequate requirements risk. Therefore, our hypothesis is that managers are more likely to associate an embedded option to defer, stage or scale down with project value in case of expertise risk than an embedded option to scale up, abandon or switch use.

*Hypothesis 3a (3b, 3c respectively): Under conditions of expertise risk the option to defer an IT project (or the option to stage an IT project or the option to scale down an IT project respectively) will be more highly valued than the option to scale up, abandon or switch the use of an IT project.*

#### **5.3.4 Project Size Risk**

If a project runs the risk of being too large, there are two preferable risk management strategies to deal with this risk. A first obvious risk management tactic includes using a disciplined development process by breaking the project down into manageable chunks as offered by the option to stage (Benaroch et al. 2006). By staging the project, a project manager can hold reviews after each project stage to learn about the complexity of the project. Also, deferring parts of the project to later stages can offer time to clearly define project roles and responsibilities, and learn about the possibility of reducing system requirements. Secondly, the option to scale down is an effective risk countermeasure in case of

project size risk (Leavit 1964) by enabling the system's capacity to be scaled down or by focusing its scope. In case of a large project, a project manager can typically invest in activities or products that may increase the ease of changing the project's scale, for example by reducing the user requirements or investing in the modularity of a system (Boehm 1989).

Project size risk calls for risk management tactics that proactively respond to events that can threaten the development process (Keil et al. 1998). Under these conditions managers will not be more likely to associate the option to defer with project value. Since project size risk has to be managed using disciplined processes and methodologies to break down the project into manageable stages, radically changing the goals of the project either by abandoning it or switching its use will not be highly appreciated by managers. Obviously, from an economic perspective, the option to scale up will not add value to a project as it may increase the negative consequences of the risk. Therefore, our hypothesis is that managers are more likely to associate an embedded option to stage or scale down with project value in case of project size risk than an embedded option to defer, scale up, abandon or switch use.

*Hypothesis 4a (4b respectively): Under conditions of large project risk the option to stage an IT project (or the option to scale down an IT project respectively) will be more highly valued than the option to defer, scale up, abandon or switch the use of an IT project.*

### **5.3.5 Technology Newness Risk**

Technology newness risk is caused by using new or immature technology that has not been used successfully at other companies (Schmidt et al. 2001). There are five preferable risk mitigation strategies to deal with technology newness risk. Firstly, consequences of technology newness risk can be successfully reduced by using the option to defer, since it allows managers to counter the risk by either waiting for

the technology to mature or proactively conducting activities such as technical analysis or reference checking, and developing contingency plans to cope with the new technology (Boehm 1988, Keil et al. 1998). Secondly, the option to stage allows managers to detect possible technology problems in an early project stage. As the full advantages of new and innovative technologies are won by patiently and carefully tailoring the technology to fit a firm's organizational context (Tyre and Orlikowski 1993), this option will transfer risk while leaving future possible benefits accessible. Execution of a follow-up stage is made contingent on a reassessment of the costs and benefits of completing earlier stages, so that managers will avoid investing in stages that do not have a worthwhile payoff. Thirdly, the option to scale down by changing a project's scope or reducing the project's implementation scale can be an adequate strategy to avoid the consequences of technology newness risk (Leavitt 1964), while at the same time allowing firms not to lose their innovative capabilities or their ability to appreciate new technologies (Schilling 1998). Fourthly, as the adoption of a new technology is essentially an investment in a new organizational capability (Fichman 2004) and the introduction of new technology is a trial-and-error process, managers are likely to associate the option to abandon a project facing new technology risk with project value. It allows them to redeploy remaining resources when risk is resolved unsatisfactorily. Lastly, from the same perspective, having the ability to change the goals of the project by embedding a switch-use option will allow managers to probe into the possible technology configurations. Adoption of complex organizational technologies should be viewed as a special category of innovation and has to be recreated by the organization via the processes of learning-by-doing and learning-by-using (Attewell 1992), requiring that organizations are willing to experiment. Although the necessary investments that make an alternative use possible have to be taken into consideration (McGrath et al. 2004), project benefits can be salvaged cutting risks by changing the goals defined for the project.

Since the option to scale up is associated with increasing the potential upside gain of an IT project in case of positive risk, managers will not associate this option with project value in case of technology newness risk. Therefore, our hypothesis is that managers are more likely to associate an embedded option to defer, stage, scale down, abandon or switch use with project value in case of technology newness risk than an embedded option to scale up.

*Hypothesis 5a (5b, 5c, 5d and 5e respectively): Under conditions of technology newness risk the option to defer an IT project (or the option to stage an IT project, the option to scale down an IT project, the option to abandon an IT project or the option to switch the use of an IT project respectively) will be more highly valued than the option to scale up an IT project.*

### **5.3.6 User Involvement and Commitment Risk**

The lack of user involvement during system development is one of the most often cited risk factors in the literature (Wallace et al. 2004) and is among the top three risks encountered in IT projects (Keil et al. 1998). There are four risk management strategies to deal with user involvement and commitment risk. Firstly, by embedding the option to defer, managers are given the opportunity to forge relationships with users and build trust (Keil et al. 1998, Alter and Ginzberg 1978) which may lead to reducing the user involvement risk. Since obtaining user involvement and commitment cannot be effectively controlled by managers (Keil et al. 1998), waiting prevents investments that may fail initial goals or that may become obsolete when the user involvement problem cannot be solved. Secondly, since managers must periodically probe the level of commitment from the user community to avoid being caught in a situation where support for the project suddenly evaporates (Keil et al. 1998), staging can be an efficient risk management strategy. By using incremental development managers can rely on diffusion and exposure, and try to persuade users to voluntary use the system (Alter and

Ginzberg 1978). Thirdly, in order to avoid change in case of user involvement and commitment risk (Alter and Ginzberg 1978) the option to scale down can be used relatively easily by limiting the number of involved departments or users deploying the system. Also, by scoping down the project, for example by reducing the system's functions, system complexity can be hidden and the system can be tailored to the users' capabilities (Alter and Ginzberg 1978). Using the scale-down option can mitigate loss by saving part of the investment outlays through reassignment of some of the project resources. Fourthly, since the failure to gain user commitment is viewed as critical in managing IT projects and the effective control of managers to gain user commitment is perceived as low (Schmidt et al. 2001), managers can decide to retain the risk by abandoning the project. Although terminating an ongoing project may be difficult because of personal and organizational constraints, in situations where risk is resolved unsatisfactorily, redeploying any remaining resources can be economically sensible as opposed to continuing a failed project.

User involvement and commitment in an IT project helps to ensure that users are actively involved in the requirements determination process, creating a sense of ownership, thereby minimizing the risk that the system will be rejected (Keil et al. 1998). Avoiding this risk by switching the use of a project may largely leave the project's risk profile unchanged or even change it for the worse, since it may be more difficult for a manager to regain the necessary commitment from new users for a project that has not been rejected in the organization earlier. Since the option to scale up will not add value to a project as it may enlarge the negative consequences of the risk, managers will not associate the option to scale up with project value in case of user involvement and commitment risk. Therefore, our hypothesis is that managers are more likely to associate an embedded option to defer, stage and scale down with project value in case of technology newness risk than an embedded option to scale up, abandon or switch use.

*Hypothesis 6a (6b, 6c, 6d respectively): Under conditions of user involvement and commitment risk the option to defer an IT project (or the option to stage an IT project, the option to scale down an IT project or the option to abandon an IT project respectively) will be more highly valued than the option to scale up or switch the use of an IT project.*

### **5.3.7 Management Support Risk**

Risk of insufficient senior management support is regarded as the most important risk factor identified by managers (Schmidt et al. 2001), and sometimes even regarded as 'a risk that overshadows all others' (Keil et al. 1998). There are three preferable risk management strategies to deal with risk of insufficient top management support. Firstly, lack of management support to the project can be mitigated by embedding the option to defer. By waiting to invest, business conditions can change giving management a reason to support the project, while project managers are given the opportunity to seek commitment from top management (Keil et al. 1998, Alter and Ginzberg 1978). Waiting prevents starting high-risk investments that may fall short of their goals. Secondly, staging can be an efficient risk management strategy in case of a lack of senior management support. Since good relationships with management cannot be built overnight (Keil et al. 1998), by using incremental development managers can rely on diffusion and exposure by emphasizing positive payoffs associated with early project stages and by creating opportunities for senior managers to publicly display their support for the project. Thirdly, managers can decide to retain the risk by abandoning the project (Benaroch et al. 2006), since the failure to gain management commitment is viewed as critical and it is possible to influence rather than control management commitment to a project (Schmidt et al. 2001). If risk is resolved unsatisfactorily, redeploying remaining resources can be economically sensible as opposed to continuing a high-risk project.

If a project's reputation is damaged by a lack of management support, avoiding risk by scaling down a project or switching the use of a project may largely leave the project's risk profile unchanged, since it will be difficult for a project manager to regain the necessary top management's oversight, the commitment visibility, and the commitment of required resources (Schmidt et al. 2001). Since the option to scale up is associated with increasing the potential upside gain of an IT project in case of positive risk, managers will not be likely to associate the option to scale up with project value in case of management support risk. Therefore, our hypothesis is that managers are more likely to associate an embedded option to defer, stage and abandon with project value in case of management support risk than an embedded option to scale up, scale down or switch use.

*Hypothesis 7a (7b, 7c respectively): Under conditions of management support risk the option to defer an IT project (or the option to stage an IT project or the option to abandon an IT project respectively) will be more highly valued than the option to change the scale or switch the use of an IT project.*

### **5.3.8 Organisational Change Risk**

Organizational change risk refers to the degree of uncertainty about the ability of the affected organization to handle change (Benaroch et al. 2006). The ability of the organization to handle change is strongly related to the extent to which it possesses learning-related endowments such as knowledge, skills, routines and other resources to adopt innovations (Fichman 2004). It can negatively be affected, for example, by conflicts between user departments or changes in organizational structures. There are three risk management strategies to deal with organizational change risk. Firstly, because of high knowledge barriers in the adoption of IT, the option to stage can be used to judge whether successful implementation is well within the organization's capabilities, or exceeds those capabilities (Fichman 2004). By using the option to stage, the chance of major implementation fiascos can be reduced and embedding this option in the project may positively affect the

expected project payoffs. Secondly, having the managerial flexibility to scale down a project can be valuable since during the course of a project, management will eventually know to what extent the organization is capable of implementing the system. Organizational change risk makes it difficult to anticipate the project payoffs in advance, and having the ability to limit the number of involved departments implementing the system, or by scoping down the project, to reduce the system's complexity can positively affect project value. Thirdly, since organizational change risk can be significant and dangerous, it is a risk over which the project manager has little or no control (Keil et al. 1998). If the organization's technology innovation is too costly to acquire, managers can decide to retain the risk by abandoning the project and thereby avoid large operational losses.

Since the ability of the organization to handle change is strongly determined by the extent to which it has the knowledge, skills, routines and other resources to adopt innovations, this risk emphasizes the proactive management of change which will not be reduced by deferring a project. It may not only prevent an organization from reaping the intended benefits of the effort itself, but also from a more indirect benefit stemming from increases in the absorptive capacity of the firm (Cohen and Levinthal 1990). If organizational change risk is resolved unsatisfactorily, and thus the organization does not have the change capability to adopt the project, changing the goals of the project by embedding a switch-use option will largely leave the project's risk profile unchanged, since the use of a new technology will continue to call for a high degree of knowledge and skill involving the technology. Since the option to scale up is associated with increasing the potential upside gain of an IT project in case of positive risk, managers will not associate the option to scale up with project value in case of organizational change risk. Therefore, our hypothesis is that managers are more likely to associate an embedded option to stage, scale down and abandon with project value in case of management support risk than an embedded option to defer, scale up or switch use.



*Hypothesis 8a (8b, 8c respectively): Under conditions of organizational change risk the option to stage an IT project (or the option to scale down an IT project or the option to abandon an IT project respectively) will be more highly valued than the option to defer, scale up or switch the use of an IT project.*

### **5.3.9 Customer Demand Risk**

Customer demand risk refers to uncertainty about the demand or usage of the system to exceed expectations. Five risk management strategies can be effective to deal with customer demand risk. Firstly, embedding the option to defer will offer management the flexibility to wait until uncertainty regarding the demand (Benaroch et al. 2006), either inside or outside the organization, is resolved and the impact on the project's payoffs is known. Secondly, by embedding the option to stage, management can use an evolutionary approach to proactively transfer risk while being flexible enough to participate in the upside of the project. Motivated by the prospect of producing a positive economic project return caused by demand exceeding expectations, managers may believe that they can realistically break down a project into stages that can achieve identifiable positive benefits at the completion of early stages (Tiwana et al. 2007). Thirdly, high customer demand can present project expansion opportunities (Benaroch et al. 2006) and can positively affect project payoffs. Therefore, by expanding the project's initially planned scope or scale, the project's expected benefits can be expanded and unforeseen future opportunities can be exploited (Taudes 1998). Fourthly, an unsatisfactory resolution of the risk can be avoided by embedding the option to scale down the initially planned application capabilities, either by limiting the number of products or services supported by the system, or by focusing on specific target groups. This allows management to lower initial project development costs. When changing the scale of a project, either up or down, management may deliberately favour a more expensive technology for its built-in

flexibility to change the scale of production if and when it becomes desirable (Trigeorgis 1993). The option to switch use can be embedded to deal with both a favourable and an unfavourable outcome of the customer demand risk. An organization can decide to sell a system to competitors in case of high demand, for example when it becomes an industry standard (Clemons 1991). Also, when the system has little impact and customer demand turns out to be low, the system can be sold to another party and the organization can accept its share of the limited additional profit that the system earns (Clemons 1991).

Embedding the option to abandon may add value to a project, but since it may prevent the organization from exploiting the future upside opportunities that are present, managers are less likely to associate the option to abandon with having value for the organization. Therefore, our hypothesis is that managers are more likely to associate an embedded option to defer, stage, scale down, scale up and switch use with project value in case of customer demand risk than an embedded option to abandon.

*Hypothesis 9a (9b, 9c, 9d and 9e respectively): Under conditions of customer demand risk the option to defer an IT project (or the option to stage an IT project, the option to scale down an IT project, the option to scale up an IT project, or the option to switch the use of an IT project) will be more highly valued than the option to abandon an IT project.*

## **5.4 Research Method**

### **5.4.1 Research Design**

A field experiment was used to test the hypothesized model. Since our research aims to test real options theory, a field experiment was considered appropriate for this purpose because it allows experimenter control to examine the question of how risk influences the valuation of different types of options. In the experiment, each respondent assessed eight IT project scenarios with different risk factors.

Similar to Tiwana et al. (2006), we assumed that the  $NPV_{Passive}$  of an IT project scenario is zero. If the  $NPV_{Passive}$  of the IT project is zero, according to equation (1), the eventual perceived value added of the IT project to the organization will be determined by the value of the option. In each scenario, respondents were presented with a short IT project description, a specific IT risk factor, and with six different types of options. For every risk-option relation they were then asked to assess the value of the IT project for their organization. Respondents received the instructions as given in the Appendix. Similar to Tiwana (2006), we used a seven-point Likert scale to evaluate the different option types. The project description remained constant for each project scenario. The presented order of the risk factors was randomly assigned. Also, the different types of options in the experiment were randomly sorted and remained constant during an individual session.

To develop and test the content and structure of the experiment, we took three steps. Firstly, we operationalized each risk and option attribute based on existing descriptions of IT risk (see Table 1) and real options (Trigeorgis 1993, Benaroch 2006 et al., Fichman et al. 2005, Tiwana et al. 2007). Secondly, we presented the instrument to five experts knowledgeable about IT project assessment to ensure that the instrument and its items were relevant and meaningful for practitioners. Thirdly, we conducted a pre-test experiment providing a total of 3,888 non-independent risk observations. Based on the results of the pre-experiment, we critically reviewed and adjusted some operationalizations in the experiment.

Five control variables were included to account for rival explanations for the influence of risk on the perceived value added of a project to an organization: (i) the number of IT projects that the respondent had assessed previously, (ii) the respondent's prior IT experience (measured in years), (iii) the respondent position in the organization, (iv) the number of employees in the respondent's organisation, and (v) risk propensity. We added risk propensity as a control variable, since it has been commonly observed that people differ in their risk appetite (Fishburn 1977; MacCrimmon and Wehrung 1990; Farmer 1993; Fu 1993).

Since, in our experiment, we started from a high-risk IT project context, we may assume that an individual's risk propensity influences their decision-making behaviour. This variable was measured using a five-item scale adapted from Keil et al. (2000).

#### **5.4.2 Survey Sample and Data Collection**

For the experiment, we contacted delegates at a Dutch national conference for senior IT executives and alumni of an Executive Master's in Information Management from TiasNimbas Business School in the Netherlands, giving us a sample of 570 senior IT executives from over 350 organizations in the public and private sectors. We contacted the respondents using a personalized email, providing a URL for a web-based version of the questionnaire. Respondents were offered the chance to win an Apple iPod to increase the overall response rate. We received 128 completed sets of responses (22.4% response rate), providing a total of 5,520 relevant non-independent risk observations. After completing the pre-questionnaire, respondents were asked to assess the project scenarios. Similar to Tiwana et al. (2006), respondents were informed that, despite the risk facing the project, the expected project returns equal the project expenditures.

#### **5.4.3 Respondent Demographics and Sample Characteristics**

Our respondents had an average IT experience of 18.99 years ( $SD = 7.16$  years) and had previously been involved in assessing 82.27 ( $SD = 127.17$ ) IT investment proposals. This suggests that our respondents are highly experienced with and knowledgeable about IT projects and had previously had a decision-making role in project assessment. On average, the organizations represented in our sample had 8,729 ( $SD = 23,321$ ) employees. The organisational functions of the respondents consisted of CIOs (14,8%), CEOs (15,6%), general managers (7%), IT managers (23,4%), projectmanagers (9,4%), Information Managers (17,2%),

business consultants (10,2%) and IT consultants (2,3%). This also suggests that our respondents are senior employees.

## 5.5 Analysis and Results

### 5.5.1 Hypotheses-Testing and Results

Table 4 shows the mean and variance for each option type per risk factor. Grey cells represent the hypothesized mappings between risk factors and real options.

Risk factor	Defer	Stage	Scale up	Scale down	Abandon	Switch use
Scope creep	3.98/2.11	5.05/2.12	1.66/1.01	4.53/2.01	3.31/2.12	2.20/1.58
Inadequate requirements	3.34/2.21	4.21/2.20	1.66/1.24	3.53/2.09	4.34/2.27	2.43/1.83
Expertise	3.60/1.94	4.93/1.84	1.76/1.26	3.85/1.95	3.33/2.10	2.23/1.58
Project size	2.96/1.80	5.87/1.63	1.43/0.96	6.04/1.28	2.73/1.78	2.54/1.70
Technology newness	3.13/2.00	5.75/1.51	1.55/0.79	5.00/1.77	2.42/1.61	2.44/1.49
User involvement	4.23/2.02	5.28/1.67	2.10/1.56	4.49/1.89	3.38/2.02	2.61/1.68
Management support	4.77/2.01	4.48/2.19	1.90/1.37	3.58/1.84	4.63/2.12	2.61/1.76
Organizational change	4.04/2.09	5.33/1.92	1.91/1.29	5.27/1.60	3.64/2.12	2.66/1.73
Customer demand	1.71/1.07	4.33/2.24	3.83/2.19	3.37/2.18	1.55/1.19	2.28/1.72
<b>Overall</b>	3.52/2.11	5.03/2.02	1.98/1.51	4.41/2.05	3.44/2.20	3.26/2.14

**Table 5-4.** Mean and variance of perceived project value for six option types and ten risk factors

We used an analysis of variance (ANOVA) model to examine the significance of the relationship between options and perceived project value for each risk factor. We find for each risk factor the perceived value added of a project is significantly ( $p < 0.001$ ) influenced by the real option type, confirming prior

research by Tiwana et al. (2006) who show that managers assign a relative importance to different types of real options.

Multiple regression analysis was performed to provide comparative analysis to the results obtained through prior research and for analysis of any potential interaction between risks and options. We applied multiple regression modelling using the equation,  $Perceived\ value\ added\ of\ IT\ Project = \alpha + \beta * Option_i + \gamma * Option_i * Risk_j + \delta * Risk_j + \varepsilon$  based on one dependent variable (*Perceived value added of IT Project*), and the independent variables (*Option<sub>i</sub>* and *Risk<sub>j</sub>*) and their interaction term (*Option<sub>i</sub> \* Risk<sub>j</sub>*). The options significantly ( $p < 0.000$ ) explained 25.5% of the variance in perceived IT project value. The interaction effect between risk and options significantly ( $p < 0.000$ ) explains 11.8% of the variance in perceived IT project value. Risk alone significantly ( $p < 0.000$ ) explains 2.3% of the variance in perceived IT project value. These results extend prior research by Tiwana et al. (2006) by providing evidence that not only real option types increase perceived IT project value, but the interaction effect between risk and options also increases perceived IT project value.

To test the hypotheses, we examine the significance of the relationship between options and perceived project value for each risk factor by making multiple comparisons between the different option types per risk factor. The results are summarized in Table 5. For each risk factor, we have hypothesized that a subset of the options, say subset A, will be more highly valued than each of the remaining options, say subset B. Therefore, for each hypothesis, we have to make a paired comparison between the relationship between options and perceived project value for every element in subset A and the relationship between the option with the highest perceived project value in subset B. To take the first group of hypotheses, we tests the relationship between the options to defer, the option to stage and the option to scale up and perceived project value and compare it to the relationship between the option to abandon and perceived project value. As is shown in Table 5, the option to defer is not significantly higher valued than the option to abandon,

which rejects Hypothesis 1a. The option to stage and the option to scale down are significantly higher valued than the option to abandon, which supports Hypotheses 1b and 1c. Under conditions of inadequate requirements risk, both the option to stage and the option to scale down are not significantly higher valued than the option to abandon, which rejects Hypothesis 2a and 2b. Under conditions of expertise risk, the option to defer is not significantly higher valued than the option to abandon, which rejects Hypothesis 3a. Both the option to stage and the option to scale up are significantly higher valued than the option to abandon, which supports Hypotheses 3b and 3c. Under conditions of project size risk, the option to stage and the option to scale up are significantly higher valued than the option to defer, which supports Hypotheses 4a and 4b. Under conditions of technology newness risk, the option to defer, the option to stage, the option to scale down, the option to abandon and the option to switch use are significantly higher valued than the option to scale up, which supports Hypotheses 5a, 5b, 5c, 5d and 5e. Under conditions of user involvement risk, the option to switch use is significantly lower valued than the option to defer, the option to stage, the option to scale down and the option to abandon, which supports Hypotheses 6a, 6b, 6c, and 6d. Under conditions of management support risk, the option to defer, the option to stage and the option to abandon are significantly higher valued than the option to scale down, which supports Hypotheses 7a, 7b and 7c. Under conditions of organizational change risk, the option to stage and the option to scale down are significantly higher valued than the option to defer, which supports Hypotheses 8a and 8b. The option to abandon is not significantly higher valued than the option to defer, which rejects Hypotheses 8c. Under conditions of customer demand risk, the option to stage, the option to scale down and the option to scale up are significantly higher valued than the option to abandon, which supports Hypotheses 9b, 9c and 9d. The option to defer and the option to switch use are not significantly higher valued than the option to abandon, which rejects Hypotheses

9a and 9e. A total of 23 of 30 hypothesized relations (77%) are significantly supported.

Risk factor	Multiple comparisons	MD	Risk factor	Multiple comparisons	MD
Scope creep	Defer- Abandon	0.67	User involvement	Defer- Switch use	<b>1.62***</b>
	Stage – Abandon	<b>1.74***</b>		Stage - Switch use	<b>2.68***</b>
	Scale down – Abandon	<b>1.22***</b>		Scale down – Switch use	<b>1.88***</b>
Inadequate requirements	Stage – Abandon	- 0.13	Management support	Abandon – Switch use	<b>1.28***</b>
	Scale down – Abandon	<b>- 0.81*</b>		Defer – Scale down	<b>1.19***</b>
Expertise	Defer – Abandon	0.27	Organisational change	Stage – Scale down	<b>0.90*</b>
	Stage – Abandon	<b>2.70***</b>		Abandon – Scale down	<b>1.05**</b>
	Scale down – Abandon	<b>1.62***</b>		Stage – Defer	<b>1.29***</b>
Project size	Stage – Defer	<b>2.90***</b>		Scale down – Defer	<b>1.23***</b>
	Scale down – Defer	<b>3.08***</b>		Abandon – Defer	- 0.39
Technology newness	Defer – Scale up	<b>1.58***</b>	Customer demand	Defer – Abandon	0.16
	Stage – Scale up	<b>4.20***</b>		Stage – Abandon	<b>2.78***</b>
	Scale down – Scale up	<b>3.45***</b>		Scale down – Abandon	<b>1.82***</b>
	Abandon – Scale up	<b>0.87**</b>		Scale up – Abandon	<b>2.27***</b>
	Switch use – Scale up	<b>0.89**</b>		Switch use – Abandon	0.73

\* $p < 5\%$ , \*\* $p < 1\%$ , \*\*\* $p < .1\%$ ; significant pairs in bold.

**Table 5-5.** Mean differences for paired comparisons between real options and perceived project value



Overall, for all risk factors, the option to stage is significantly higher valued than the option to scale down ( $MD = 0.62, p < 0.000$ ). The option to scale down is significantly higher valued than the option to defer ( $MD = 0.89, p < 0.000$ ). The option to defer is significantly higher valued than the option to abandon ( $MD = 0.26, p < 0.05$ ). The option abandon is significantly higher valued than the option to switch use ( $MD = 0.81, p < 0.000$ ). Lastly, the option to switch use is higher valued than the option to scale up ( $MD = 0.47, p < 0.000$ ).

### **5.5.3 Control Variables: An Assessment of Rival Explanations**

We controlled for rival explanations based on respondent characteristics and on risk characteristics. Where respondent characteristics were concerned, we controlled for the number of previously assessed IT projects, prior IT experience measured in years, position in the organization, number of the organization's employees, and risk propensity respectively, using the five scale measure proposed by Keil et al (2000). Of these, the number of prior IT experience measured in years, number of the organization's employees and risk propensity have no statistically significant effect on on perceived IT project value. The number of previously assessed IT projects and the position in the organization had a significant but very small effect on perceived IT project value (respectively  $\beta = -0.001, p < 0.05, \beta = -0.040, p < 0.01$ ). Therefore, they are not included in the analysis as covariates.

## **5.6 Discussion**

This study was motivated by the central idea that managers would differentially associate real options with project value in the presence of different types of risk and that their reasoning is in line with the real options-based risk management reasoning. The overall pattern of results from our field experiment largely supports this idea. Our results show that managers differentially assess the

relative value of different types of options when controlling IT project risks. Our results show that their assessment of real option value is driven by not only a real option's intrinsic value, confirming prior results by Tiwana et al. (2006), but also by a project's specific risk exposure. We also show that real option-based risk management reasoning generally corresponds with the reasoning of managers. However, we also found some interesting exceptions.

Our results show that in case of risk, managers associate the highest project value with the option to stage, the option to scale down and the option to defer respectively. An explanation for this is that IT projects are characterized by a high level of fixed costs, which makes them rigid and difficult to modify (Damodaran 2001). In this case, adapting the project's operating strategy in response to changing conditions can be very difficult. From this perspective, it is intuitively clear that staging or deferring a project will lead to a delay in project expenditures while maintaining exposure to the project benefits. Although scaling down the project may be more difficult during an ongoing project since it may call for initial investments that allow for the creation of the scale down option, at the outset of a project it can still be relatively easy to change the scale or scope of a project without a high loss of initial project costs. It shows that managers are taking a prudent approach to funding the project. The high appreciation of the option to stage is not consistent with results found by Tiwana et al. (2006), which may be explained by the difference in the operationalization of the real options in this study. The option to stage is also highly valued in case of positive risk and the corresponding perspective for high project payoffs. This is consistent with prior literature, which suggests that in this case managers think they can easily decompose the project into incremental stages in a way that allows them to achieve positive benefits at the completion of the different stages, while, at the same time, seeking to control the risk by learning-by-doing (Tiwana et al. 2007).

The option to defer is mostly appreciated in case of risk of insufficient management support, insufficient user involvement and commitment, and the

organization's incapacity to handle change. Interestingly, these risks are described in prior literature as being the risks that project managers perceive as difficult to control and influence (Keil et al. 1998), suggesting that managers prefer delaying expenditures when they perceive that their actions cannot prevent the risk from occurring, even if this means they might delay exposure to the project benefits.

In case of both positive and negative risk, managers ascribe a relatively low value to the option to abandon and the option to switch use. The low appreciation of the option to abandon is consistent with prior literature (Busby & Pitts, 1997, Tiwana et al. 2006). The low assessment of the option to abandon may arise from personal or organizational biases which make it difficult to exercise the option in practice. A personal bias may arise from an aversion to loss (Shin and Ariely 2004), which refers to a general reluctance to give up. As ownership can increase attachment (Kahneman et al. 1990, 1991, Carmon and Ariely 2000) and hence valuations, and in our experiment managers were framed to have justified the project earlier, this may increase their disutility to associate the option to abandon with project value. An organizational bias may arise from interpreting project termination as a sign of failure. However, in case of a risk of inadequate requirements and insufficient management support the abandonment option is a highly appreciated option. These risks are described in prior literature as among the top three important risks as perceived by IT project managers (Keil et al. 1998). The high perceived relative importance of these types of risk may be a reason for managers to associate the abandonment option under these conditions with project value, despite negative personal and organizational biases that make it difficult for a project to be terminated. The low appreciation of the option to switch use is not consistent with earlier findings by Tiwana et al. (2006). This may suggest that in our research managers correctly viewed the option to switch use as a tool to contain downside losses, rather than as affecting payoffs similarly to a growth option as in Tiwana et al. (2006). The low appreciation of the option to switch use may be explained by the difficulty of changing the purpose of an IT project in practice. Although

software may be highly malleable (Fichman et al. 2005) and generic applications can be useful in reducing the total cost of ownership of IT systems, the added value of most IT systems lies in improving delivery of highly specific products and services through unique business processes for particular user groups by using proprietary technologies. The choices that are made in this development process make a system 'illiquid' and make switching the use of the system particularly difficult. Switching the use of a system may lead to high switching costs, as the relevant licensed technologies may restrict switching use, selected proprietary technologies may not be easily switched to different platforms, and new users have to adapt their working methods to the repurposed system. In addition, the option to switch use particularly may lead to new risks, which may make it even more difficult to exercise than the option to abandon. However, where there is risk of technology newness, the option to abandon is valued slightly lower than the option to switch use, suggesting that managers appreciate the possibility that the option to switch use allows probing into the possible technology configurations. This also may explain why the option to switch use is more highly valued than the option to abandon in case of customer demand risk that may positively affect the project benefits. Consistent with the hypothesized relationships, managers associate the option to scale up with project value in case of positive risk and not in the case of negative risk. This indicates that they intuitively understand the real options rationale which proposes that the option to scale up increases benefits in case of positive risk.

### **Limitations**

Before discussing the results, we will evaluate the limitations of the study. Firstly, managers face very complex situations in IT projects in which multiple types of risk may exist and different types of options are not, by definition, easy to identify or to embed. Therefore, the results we have found may not be as easily expanded

to real-life situations. Secondly, caution should be used when generalizing our findings beyond our respondents' assessments, who were [framed?] in their decision-making by the indication that they were responsible for approving the project initiation, and other project stakeholders, who may weigh options differently. Thirdly, experiments and surveys show that the economic valuation of real options and uncertainty is not well estimated in practice (Busby and Pitts 1997, Howell and Jägle 1997). This suggests that caution has to be taken in interpreting the outcome of the value assessment of the relationship between risk and different types of real options. Assessment of real options cannot rely on intuition alone, since this may lead to non-optimal decisions (Benaroch et al. 2006). Lastly, we made no distinction in the presentation of the different types of risk in relation to the project lifecycle phase, i.e., whether the risk is related to the initiation phase, the development phase or the implementation phase of the project. We stated that the project had just recently been approved, leaving it up to the respondents to relate the risks to the different project phases, based on their own experience. Perceived option valuation may be useful in making a distinction between project phases.

## **5.7 Implications and Directions for Further Research**

The primary contribution of this study is to provide solid empirical evidence that the value that managers ascribe to different types of real options is influenced by both a real option's intrinsic value and a project's specific risk exposure and that their assessment of real option value under conditions of risk generally follows real options-based risk management logic. The key implication of the study is that risk management strategies in IT projects can be explained as being largely rational from a real options-based risk management perspective. These results have important implications for research and practice.

### 5.7.1 Theoretical Implications

The article's key contributions to the managerial decision-making literature are twofold. Firstly, where prior literature found that managers differentially associate project value with different types of options, we have shown that this value is also driven by the presence of specific types of risk. Secondly, we have established that many of the most effective IT risk and real option mappings as proposed in prior research correspond with managerial reasoning.

Real options theory can offer a theoretical perspective on risk management literature by giving an economic explanation for managing risk. Prior risk management literature outside the realm of real options literature offers no theoretical underpinning of the relationship between risk, risk countermeasures and project value, and the real options perspective can serve as a useful complementary theory to study risk management. Since real options theory supposes risk management to be a proactive process aimed at lowering variance in expected outcomes, and our research shows that managerial behaviour is in line with real options theory, it can serve as a rational economic impetus for further study of risk management behaviour in practice.

Prior research of real options theory in IT projects either focused on real options analysis, which is based on the valuation of real options using formal option pricing models, or on real options thinking or reasoning, which is based on the idea that the theory of real options serves as a basis for a management philosophy that can provide heuristics to deal with projects in uncertain environments. Although our study is more grounded in real options thinking literature, its theoretical contributions are important for both research focuses. In relation to real options analysis, our research shows that managers generally understand which real options should be analyzed and valued to enhance project value as a response to specific risks. In relation to the literature of real options thinking or reasoning, it suggests that managers understand how to manage

projects by embedding managerial flexibility as a response to specific risks so that the option value may be actually achieved in practice.

Future research can extend our understanding of risk management and real options reasoning in IT projects. Future research may examine further behavioural biases that managers possess when dealing with risk associated with IT projects. As is suggested in our research, the perceived relative importance of risk factors and the perceived level of control of risk factors may be influential predictors of managerial behaviour when facing risk in IT projects. Also, as is shown in our research, real options reasoning is in line with managerial reasoning, and it may be fruitful to dive further into obstacles that negatively influence managerial valuation of real options and managerial commitment to exercise real options in IT projects in practice. For example, since IT project decisions are group-decisions in general, it may be interesting to find out how group pressure influences the actual exercise of real options.

### **5.7.2 Practical Implications**

Our research shows that managers generally understand how options can create value as a response to specific risks, which suggests that they understand how to manage projects so that the option value may be actually achieved in practice. This research has two main implications for practice.

Firstly, the intuitive managerial valuation of real options in the face of risk in an experimental setup will have little profitability if managers are not made explicitly aware that taking into account the managerial flexibility as offered by real options can add substantial value to a project. In practice, management must actively and expressly identify and select operational options to manage risk at the onset of IT projects. This can be achieved by identifying the most important risks that affect a project's success. By using a simple checklist, the most viable options to manage the risk can be selected and, if possible, valued. Based on the selected real options, management has to explicitly define and communicate decision rules

and triggers to be able to manage and control the embedded flexibility during the course of a project, including conditions under which a project can be abandoned. The real option-based risk management framework can offer substantial support for framing project assessments, before proceeding with a quantitative real options analysis.

Secondly, there is a need to separate the two aspects of recognizing and managing the value of managerial flexibility by decision-makers and technically valuing the flexibility by mathematicians. This is so relevant, since a manager is informed about the risk that may present itself during the IT project's lifecycle. Also, a manager is informed about the potential operational flexibilities that she possesses to change the operating strategy of the project. The manager has to make the preliminary decision of properly determining the potential real options inherent in a project in the face of risk. Naturally, flexibility cannot or need not be valued in all projects, with the most obvious candidates for the valuation of managerial flexibility being projects that are managed in fast-moving environments, projects that are large and complex, or projects that are experimental and innovative. In projects where valuation of flexibility is not viable, for example for reasons of insufficient skills or resources, rules of thumb or experience may be used to 'value' flexibility.

Thirdly, management must be committed to actually exercising options when appropriate. This implies that project management practices to continuously track the evolving value of options should be employed. Obviously, the degree to which these project investment and planning capabilities can be successfully developed and implemented depends on the maturity and culture of the organization, the maturity of the IT department and the skills of its staff, but most importantly, on the adequacy of the organization's and project's governance structure. This includes the mandate to actively embed and manage flexibility to fully extract its value, but also the mandate to abandon or switch the use of projects if they do not deliver their expected value. In practice, this may boil down to the need for



managers to be brash enough to overcome personal and organizational biases, but also for managers to take steps to change the elements of organizational culture and procedures, for example by defining and implementing 'exit strategies' when making the IT project investment.

## **5.8 Conclusion**

In our study, we presented and tested an IT project decision-making model that investigates whether and how the value that IT professionals assign to different types of real options in IT projects is influenced by various IT risk factors. Supplemental to prior research conducted by Tiwana et al. (2006), who show that IT professionals place a relative value on various real options in an experiment setting, we have demonstrated that this value is also driven by the risk factors associated with an IT project. We have shown that many of the most effective IT risk and real option mappings as proposed in prior research correspond with managerial intuition. Extending the preliminary evidence found by Tiwana et al. (2006) and Benaroch et al. (2006), the main theoretical contribution of the study is that it offers solid empirical evidence of the link between risk, embedded real options and managerial assessment of IT project value.



## Chapter 6

### Conclusions and recommendations

This chapter gives a synthesis of the main findings and subsequently gives a brief summary of the findings of each empirical chapter. Next, we discuss the generalizability and limitations of the results and the theoretical and managerial relevance of these findings. Finally, we look at some directions for future research.

#### 6.1 Summary of Main Findings

Our summary of the findings starts with the overall research question of how managerial flexibility with real options as a response to risk impacts IT project valuation. We tried to answer this overall research question along three separate studies. In this section we first synthesize the findings of these studies, before presenting them separately.

##### 6.1.1 Synthesis of the Findings

The synthesis of the three studies is provided in the overall research question of this dissertation, which is:

**Overall Research Question:**

*How do real options, as a response to risks, impact IT project valuation?*

As real options reasoning proposes, managers should take into consideration the value of real options in assessing the value of an IT project, and the specific risk one seeks to reduce influences the type of option to embed. Our results support the central idea that managers differentially associate real options with project value in the presence of different types of risk. The perceived added IT project value is primarily driven by the value contribution of different types of options, as

also found by Tiwana et al. (2006), and subsequently by the interaction effect between of risk and real options.

From a real options risk management perspective certain risk mitigations strategies that coincide with different types of real options are considered more effective than others (Benaroch et al. 2006). The real option based risk management reasoning as proposed in earlier literature (Benaroch et al. 2006) generally corresponds with the reasoning of managers. Consistent with the hypothesized relationships by Benaroch et al. (2006), managers associate the option to scale up with project value in case of positive risk and not in the case of negative risk. In case of negative risk, managers associate the highest project value with respectively the option to stage, the option to scale down and the option to defer. In case of negative risks, managers ascribe a relatively low value to the option to abandon and the option to switch use.

Extending the preliminary evidence found by Benaroch et al. (2006) and Tiwana et al. (2006), the main theoretical contribution of the research is thereby giving solid empirical evidence of the link between risk, embedded real options and managerial assessment of IT project value. Our findings suggest that managers understand how options can create value as a response to specific risks and that they understand how to manage projects so that the option value may be actually realized in practice.

Our results support the idea that when changing the operating strategy of a project, the number of choices an organisation possesses, the likelihood of the change as well as the ease of change depends on both financial and non-financial criteria which can not be provided for by real options analysis alone. Although real options analysis may generate valuable insights into the trade-off between risk and benefits from a financial perspective, ignoring the multi-dimensional nature of IT infrastructure investment decisions in options analysis that support phase-wide implementation can lead to very different outcomes in terms of the most suitable implementation strategy.

Prior research of real options theory in IT projects has either focused on real options analysis or on real options reasoning. Although the present research is more grounded in the real options reasoning literature, its theoretical contributions are important for both research streams. In relation to real options analysis, the research suggests that managers generally understand which real options should be analysed and valued to enhance project value as a response to specific risks. Although options analysis may generate valuable insights into the trade-off between risk and benefits from a financial perspective, our research shows that insights into the trade-off between risk and benefits from a non-financial perspective can play an important role in selecting preferable managerial flexibility with real options in practice. In relation to the literature of real options reasoning, our research suggests that managers understand how to manage projects by embedding managerial flexibility as a response to specific risks so that the option value may be actually realized in practice.

### **6.1.2 Findings from the Exploratory Case Studies**

Chapter three, our first empirical chapter, tries to answer the first detailed research questions.

#### **Detailed Research Question 3-1 and 3-2:**

*How do firms develop IT infrastructure capabilities and what is the role of the needed strategic flexibility? How do firms recognize and value different types of managerial flexibility?*

We concluded chapter three by proposing that different types of strategic flexibility ask for different types of IT infrastructure capabilities. This would suggest that if managers can identify the type of strategic flexibility their firm needs, they can identify the IT infrastructure capabilities their firm has to develop further. Our results indicate that managers recognize and implicitly associate different types of real options with IT investment value when facing risks.

Specifically, our results indicate that managers in the cases implicitly value the strategic real options which are present in IT infrastructure projects. Also, our results indicate that both financial and non-financial criteria may be necessary to value managerial flexibility in IT investments. In chapter four and five we therefore further investigated these issues.

### **6.1.3 Findings from the Theoretical Decision Model and Case Study Application**

Chapter four, our second empirical chapter, treats the following detailed research question.

#### **Detailed Research Question 4-1:**

*How can managerial flexibility in an IT project be evaluated so that different types of risk, and financial and non-financial criteria can be taken into account?*

In chapter four, our results support the idea that when changing the operating strategy of a project, the number of choices an organisation possesses, the likelihood of the change as well as the ease of change depends on both financial and non-financial criteria which can not be provided for by real options analysis alone. When decision-makers ignore these non-financial benefits in the valuation of managerial flexibility in IT projects, they will ignore vital information in the selection of the most viable type of flexibility to embed in an IT project. Although real options analysis may generate valuable insights into the trade-off between risk and benefits from a financial perspective, ignoring the multi-dimensional nature of IT infrastructure investment decisions in options analysis that support phase-wide implementation can lead to very different outcomes in terms of the most suitable implementation strategy. There may be several reasons for this. Firstly, the decision-maker's objectives may diverge from those of capital market players, resulting in a different decision outcome. Secondly, certain criteria that

are not quantified in an NPV or real options analysis, such as learning, can be made explicit in a multiple attribute approach, thus resulting in a different decision. Thirdly, the NPV or real options valuation may not have been correctly calculated, which may be the case if it is not (yet) possible to place a monetary value on an attribute. We define a theoretical model to evaluate managerial flexibility - as offered by the option to stage - when selecting the most favourable strategy for the development and implementation of an IT project under conditions of uncertainty. The aim of the theoretical model is to help decision-makers to opt for the best implementation strategy by combining Dempster-Shafer theory with real options analysis. This combined model takes full account of the multi-dimensional nature of IT project decisions. We apply the model in a case study, in which we used data from a large service-provider to define a favourable strategy for implementing a human resource management system. Based on a literature investigation, we propose decision criteria that should be taken into account to optimally configure an IT project from both a financial as from a non-financial perspective when dealing with risk about the variability of the project's financial value as well as risk in non-financial judgments. These criteria include criteria concerning project implementation risk, the possibility of the IT project implementation to provide for opportunities for business transformation, and the possibility of the IT project implementation to provide for learning effects. We also showed that performing a sensitivity analysis of the stated preferences in both the multi-attribute decision analysis and the real options calculation generates valuable information for finding an optimal trade-off between risk and benefits when valuing managerial flexibility in competing IT project configurations.

#### **6.1.4 Findings from the Field Experiment**

In chapter five, our third empirical chapter, we presented and tested an IT project decision-making model using a field experiment to investigate our last detailed research question.

### **Detailed Research Question 5-1:**

*How do different types of risk influence the relative value that managers intuitively ascribe to different types of real options in IT projects?*

As real options reasoning proposes, managers should take into consideration the value of real options in assessing the value of an IT project; the specific risk one seeks to reduce influences the type of option to embed. From a real options based risk management perspective certain risk mitigations strategies that coincide with different types of real options are considered more effective than others, as proposed by Benaroch et al. (2006). The overall pattern of results from our field experiment supports the central idea that managers differentially associate real options with project value in the presence of different types of risk. The perceived added IT project value is primarily driven by the value contribution of different types of options, as also found by Tiwana et al. (2006), and subsequently by the interaction effect between of risk and real options.

Consistent with the hypothesized relationships by Benaroch et al. (2006), managers associate the option to scale up with project value in case of positive risk and not in the case of negative risk. In case of negative risk, managers associate the highest project value with respectively the option to stage, the option to scale down and the option to defer. In case of operational risks, adapting the project's operating strategy in response to changing conditions can be very difficult. From this perspective, it is intuitively clear that delaying, staging or scaling down a project will lead to a (partial) delay of project expenditures while maintaining full exposure to the benefits. In case of negative risks, managers ascribe a relatively low value to the option to abandon and the option to switch use. The low appreciation of the option to abandon is consistent with prior literature (Busby and Pitts 1997, Tiwana et al. 2006). The low assessment of the option to abandon may arise from personal or organisational biases which make it difficult to exercise the option in practice (Tiwana et al. 2007). The low appreciation of the



option to switch use may be explained by the difficulty of changing the purpose of an IT asset in practice. Although generic applications can be useful in reducing the total cost of ownership of IT systems, the added value of most IT systems comes from finding ways to improve the delivery of highly specific products and services through unique business processes among particular user groups using proprietary technologies. The choices that are made in this development process make a system difficult to change and make switching the use of the system particularly difficult. The option to switch use may particularly lead to new risks, which may make it even more difficult to exercise than the option to abandon. In cases where there is a risk of inadequate requirements, insufficient management support, insufficient user involvement and commitment, and the disability of the organisation to handle change, the abandonment option is the highest appreciated option after the option to defer and the option to stage. The high perceived relative importance of these types of risk in relation to the low perceived level of control to influence these risks may be a reason for project managers to associate the abandonment option under these conditions with project value.

Our experiment sample consisted of managers from more than 400 organisations. The central idea behind our study is that managers differentially associate real options with project value in the presence of different types of risk.

## **6.2 Limitations of the research**

This research is aimed at increasing our understanding of the impact of risk and managerial flexibility on IT project value. We achieve this goal by following a multimethod, multilevel approach, in which we combined case study research and field experiments to study decision-making at various levels. Such sequential triangulation allows the findings of one study to inform the following, thus refining the research. The combination of case studies and field experiments combines the main strengths of both methods: high external validity for the case study and high internal validity for the experiments. This should ensure that our

study has greater validity than when investigated with a single method. A multilevel approach aims at explaining macro level outcomes using micro level inputs, or vice versa. The combination of investigating decision-making at a strategic firm level, at a tactical project level and at a managerial individual level allowed us to explain the relationships between different levels of decision-making, suggesting the influence of individual managerial decision-making on strategic firm level and tactical project level, and vice versa. However, despite the multimethod multilevel research approach, there are some limitations to the research. We summarize the limitations of the different studies and refer to a detailed overview of the limitations to the separate studies.

### **6.2.1 Limitations of the Exploratory Case Studies**

In chapter three, we conducted exploratory case study research. As for the limitations in this research, we investigated only two cases using an exploratory research model. Also, we researched firms in different industries, so a comparison in investment behavior between these firms cannot be made. This means that the findings can be regarded as only preliminary and indicative.

### **6.2.2 Limitations of the Theoretical Decision Model and Case Study Application**

In our second empirical study in chapter four, we developed a theoretical decision-making model and applied it to select a favourable project implementation strategy. As for the limitations of our combined model, firstly, real options and decision analysis rest on assumptions that lead to a lack of theoretical elegance when used in combination as described in chapter four. Secondly, in the case we presented we assumed no project inter-dependencies between the 18 different HRMS implementations which may exist in the case

study project. If these inter-dependencies would have been modelled, this may have led to a different favourable implementation strategy in the case study.

### **6.2.3 Limitations of the Field Experiment**

In chapter five we conducted a field experiment (including a pretest). The study has several limitations. Firstly, managers face very complex situations in which different types of options in IT projects are not per definition easy to identify or to embed. Therefore, the support we find between risk factors and the different types of options may not be as easily expanded to 'real life' situations. Secondly, caution should be observed in generalizing our findings beyond our respondents' assessments, who were framed in their decision-making by the indication that they were responsible for approving the project initiation, and other project stakeholders, who may value options differently. Thirdly, experiments and surveys show that the economic valuation of real options and uncertainty is not well estimated in practice (Busby and Pitts 1997, Benaroch et al. 2007). This suggests that caution has to be taken in interpreting the outcome of the value assessment of the relationship between risk and different types of real options. Fourth, we made no distinction in the presentation of the different types of risk in relation to the project lifecycle phase, i.e. whether the risk is related to the initiation phase, the development phase or the implementation phase of the project. Perceived option valuation may be sensible to making a distinction between project phases. Last, interaction effects among the presented various options are possible. However, assessing interactions between options is outside the scope of our study.

### **6.3 Theoretical Contributions**

The first and main contribution of this research is to offer new insight into real options and risk management literature. While earlier research has shown that managers understand that the flexibility offered by real options has value (Tiwana et al. 2006), our empirical results show that this valuation is also driven by the presence of different types of risk. Our results show that the proposed option based risk management reasoning as proposed in earlier research generally corresponds with the reasoning of managers. The results suggest that managers understand that managerial flexibility offered by different types of options in IT projects can serve as an effective risk countermeasure. To our knowledge, the field study presented in chapter five is the first study to systematically and empirically demonstrate the relative value that managers assign to different options in the presence of different types of risk. The study thereby extends the theoretical literature in which mappings are suggested between different types of risk and the managerial flexibility as offered by different types of options (Micalizzi and Trigeorgis 1999, Kim and Saunders 2002, Bräutigem et al. 2003, Benaroch et al. 2006). This insight is particularly important since real options theory allows us to study a risk management approach from an economic perspective by linking between risk, flexibility and economic value. Therefore, real options theory can be used as a complementary theory to study risk management behaviour.

The second contribution of this research is to show that by changing the operating strategy of a project, the number of choices an organisation possesses, the likelihood of the change as well as the ease of change depend on both financial and non-financial criteria which can not be provided for by real options analysis alone. Many IT project benefits are seldom associated to goods or services sold on an outside market. When decision-makers ignore these benefits in the valuation of managerial flexibility in IT projects, they will ignore vital information in the selection of the most viable type of flexibility to embed in an IT project. This may negatively impact the valuation of the IT project. Whilst previous research studies

have valued multi-stage investments using real options analysis, they have ignored the multi-dimensional nature of IT project decisions. We provide for a decision model to value managerial flexibility in a way that takes account of the multi-dimensional nature of IT projects by combining real options analysis and decision analysis. We offer a contribution to real options theory and decision theory, by giving an insight in the main theoretical hurdles that have to be taken into account when combining real options theory and decision theory.

The third contribution of this research is to provide for a model that relates risk, managerial flexibility and IT project value at different decision-making levels. The model links risk, managerial flexibility and IT project value at a strategic, tactical and managerial decision-making level. However, additional research is necessary to give insight in how managers perceive IT project value and which biases they demonstrate in valuing IT projects. This insight is particularly important, since it may give insight in their decision-making rationale when making IT project selection and management decisions at a tactical and strategic level.

#### **6.4 Managerial Relevance**

Our research has several implications for practice. One practical implication of our research is that practitioners may invest in different types of IT infrastructure capabilities when aiming for different types of strategic flexibility needed at the business side. The major practical implication of our study is based on our finding that the managerial valuation of the different types of real options largely follows real options based risk management reasoning. This suggests that managers may select the preferable options as a countermeasure to manage specific risks. However, to optimally configure managerial flexibility in practice, several issues have to be resolved.

Firstly, as our exploratory cases indicate, the valuation of different types of real options is only implicitly taken into account. The intuitive managerial valuation of

real options in the face of risk will be of little practical consequence unless managers become explicitly aware of the value of managerial flexibility. There is no free lunch in managing flexibility; managing and valuing flexibility can be costly when resources are limited, and flexibility may have a negative effect on project commitment (Barnett 2005). Therefore, mechanisms have to be put in place to select the proper options in case of risk and maximize real options reasoning in practice.

Secondly, contingency factors may influence decision-making when managing real options in IT projects. These are for example the needed quality of the decision, the amount and quality of the available information as possessed by the manager and the project staff, or the importance of decision acceptance when followers are likely to disagree with one another (Vroom and Yetton 1973). The degree to which an organisation's project investment and planning capabilities are mature enough to maximize real options value in practice depends on the maturity and culture of the organisation, the maturity of the IT department and the skills of its staff, but most importantly, on the adequacy of the organisation's and project's governance structure.

Mechanisms have to be put in place to overcome the issues as mentioned above. These mechanisms include several elements:

1. Managers should become aware of the value of flexibility. In practice, many million euro technology projects are started without embedding flexibility in the project configuration or project funding. If organisations become more aware of the value of flexibility in IT projects, and grant consequences to the resolution of risk in projects, this may lead to more focussed and successful investments.
2. Managers should explicitly identify and value future growth opportunities when investing in IT (infrastructure) projects. Since the strategic growth options are mainly business driven, both IT and business can be involved when searching for growth options. These growth options must be

managed, by staying aware of strike signals that may lead to the exercise of the options. They can develop a set of explicit statements about conditions under which a growth opportunity should be pursued, such as the external uncertainties that need to be resolved.

3. Managers should identify the most important risks that can affect the IT project payoffs at the onset of IT projects. By developing a set of explicit statements about how favourable and unfavourable shifts in the risk factors may affect the project, they can actively and explicitly identify and select operational options to manage risk. By using a simple checklist, the most viable options to manage the risk can be selected. Managers can structure the implementation so that incremental funding, prototypes and pilot projects are used to manage risk. They can structure the project in a way that each stage creates value even if no further stages are funded (Fichman et al. 2005). Also, parts of the development process with high uncertainty can be deferred to later stages, or - the opposite - may be planned at the beginning of a project.
4. Managers can value the flexibility (either quantitatively or qualitatively). Of course, flexibility does not need to be valued in all projects. This may be viable in projects with competing scenarios or in projects in which the uncertainty is high or the time-frame is long. The most obvious candidates for the valuation of managerial flexibility are projects that are managed in fast moving environments, projects that are large and complex, or projects that are experimental and innovative. The flexibility can be valued using for example real options analysis, Dempster-Shafer theory and decision tree analysis. As is implied by our research, financial analysis tools have to be complemented by non-financial decision analysis tools to take into account the full benefits of the embedded flexibility. In projects where valuation of flexibility is not viable, for example due to reasons of

insufficient skills or resources, rules of thumb or experience may be used to 'value' flexibility.

5. Managers should invest in the use of practices and technology that create future expand, scale down or strategic growth options by promoting future flexibility of delivered applications. This includes making systems more generic, modular, multi-purpose, interoperable and scalable.
6. When defining a project investment configuration, management should to explicitly define decision rules and triggers at the various project planning decision nodes (option expiration dates) to be able to manage and control the embedded flexibility during the course of a project, including conditions under which a project can be abandoned. At each decision node the current status of uncertain factors and the project more generally should be re-evaluated and matched against expectations (Fichman et al. 2005) when conditions change. Managers can adjust the project planning and control (project budgeting) to the decision rules and triggers (budgeting) and re-evaluate the decision triggers when conditions change.
7. Managers can communicate and create support for the decision triggers with the responsible decision makers and project staff. This enhances awareness for the value of flexibility and can create support for future decisions, including abandonment and switch use decisions.
8. Management should be committed to actually exercising options when appropriate. This may be achieved by assigning one responsible executive for exercising the decision and communicate effectively about the decisions. This includes the mandate to actively embed and manage flexibility to fully extract its value, but also the mandate to terminate or abandon projects if they do not deliver their expected value. Project management practices to track the evolving value of options should be employed.



9. To overcome personal and organisational biases, managers should take steps to change the elements of organisational culture and procedures. These steps should strengthen a positive attitude towards investing in high risk projects, and weaken a negative attitude towards project failure, for example by defining and implementing 'exit strategies' when making the IT project investment at the outset.

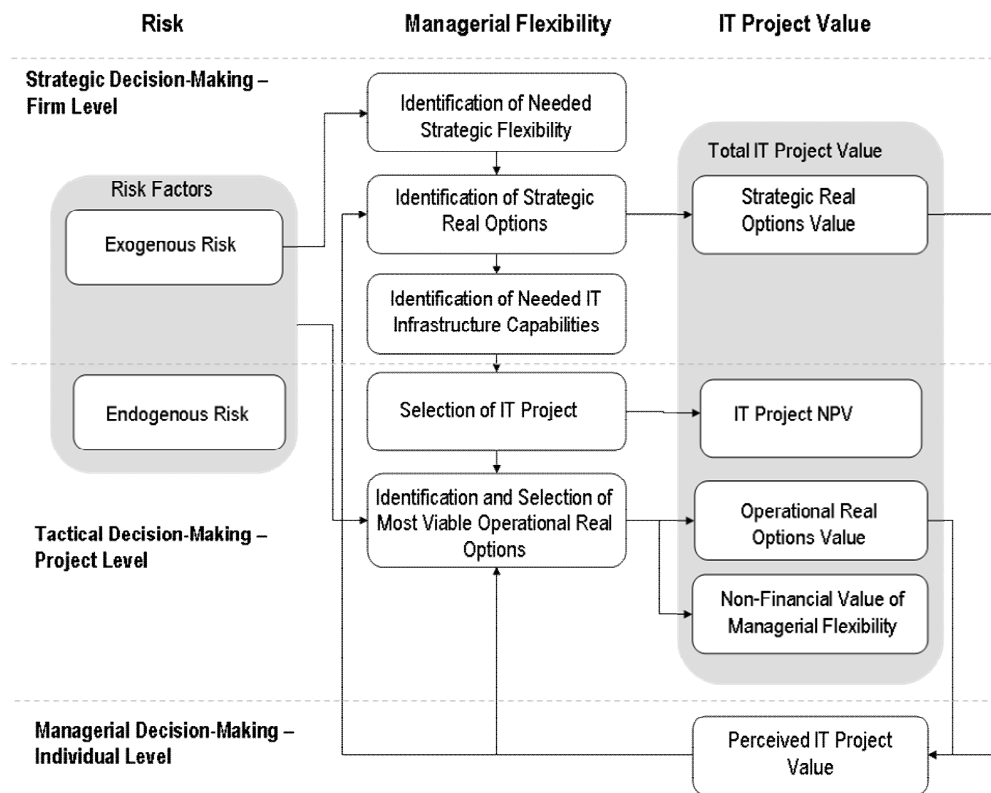
We synthesize our findings using Figure 6-1, which provides a summary of the different constructs that are investigated in the empirical chapters and the relationships between them on the different decision-making levels. In this model, we make a distinction between constructs regarding Risk, Managerial Flexibility, and IT Project Value. Also, we make a distinction between constructs regarding strategic decision-making at firm level, tactical decision-making at a project level, and managerial decision-making at an individual level.

## **6.5 Directions for Future Research**

We will conclude this dissertation with suggestions for future research. For a detailed discussion of further research directions we refer to the separate studies.

Firstly, as our research shows, real options logic represents a promising paradigm for explaining managerial decision-making in risky IT projects. Therefore, real options theory can be used as a complementary theory to behavioural theory and decision theory to study IT project investment and IT risk management behaviour. Future research may explain whether managerial behaviour is in line with real options rationality to keep options open when facing risk, to wait when risk is beyond one's ability to influence it, and to move fast when opportunities for risk reduction exist (McGrath et al. 2004). Research may give us insights into whether and which biases (Simon 1979, Hammond et al. 1998) exist in the valuation of risky IT projects, and how these biases may be overcome to lead to the improvement of IT project decision-making when facing risk.

Secondly, although real options logic may be compelling in explaining IT project decision-making, there are practical issues to overcome to make real options reasoning and valuation salient in practice. Very few organisations have adopted real options analysis. Future research should therefore concentrate on the development of practical models to make real options reasoning and valuation easier and more appealing for use in practice. Future research should investigate the organisational conditions under which real options reasoning will fall on fertile ground in practice.



**Strategic decision-making level**  
 At a firm level, different types of exogenous uncertainty or risks can influence the identification of needed strategic flexibility. At this level, managers may try to identify strategic growth options which represent the

<p>opportunity to grow the investment through follow-up investments beyond what was initially anticipated. These growth options possess a real options value, which is part of the total IT project value. Management may implicitly recognize the value of strategic real options in case of exogenous risk. However, when making strategic IT infrastructure investments, management may implicitly justify the value of these investments by the strategic growth options they embed. Through the identification of strategic growth options, different types of needed strategic flexibility can be identified and differentially influence the identification of needed IT infrastructure capabilities. The identification of needed IT capabilities can lead to the selection of IT projects.</p>
<p><b>Tactical decision-making level</b></p> <p>A selected project possesses a financial IT project value. Also, operational options may possess real options value as part of the total IT project value. As we have described earlier in this dissertation, different types of exogenous and endogenous risk influence the identification and selection of the most viable operational options to embed in IT project. Because of the multi-dimensional nature of IT projects, non-financial IT project benefits also must be taken into account to select the most viable type of managerial flexibility.</p>
<p><b>Individual managerial decision-making level</b></p> <p>The managerial valuation of IT projects is largely consistent with the proposed real options based risk management. This suggests that at a project level, managers identify and select the most viable operational options in response to risk. However, in these circumstances, it would be unfortunate if practitioners were to fall back on unguided managerial intuition rather than seek to apply the logic of real options in a systematic but qualitative fashion. It is worthwhile that managers place a value on flexibility in some (either quantitative or qualitative) way. At the onset of a project, managers would need to explicitly identify the risks that the project faces, and select the appropriate types of operational flexibility to address these risks.</p>

**Figure 6-1:** Model of Risk, Managerial Flexibility and its impact on IT Project Value at different decision-making levels



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## Appendix A: IT infrastructure capability clusters

1. Channel management capability	<p>To what extent does your firm provide electronic channels to customers or partners to support multiple applications?</p> <ol style="list-style-type: none"> <li>1. Websites</li> <li>2. Call centres</li> <li>3. Electronic funds transfer/point of sale</li> <li>4. Interactive voice response</li> <li>5. Mobile computing (dial up, wireless networking)</li> <li>6. Mobile phones</li> </ol>
2. Data management capability	<p>To what extent does your firm have the availability of:</p> <ol style="list-style-type: none"> <li>1. Management of key data independent of applications (e.g. centralized product data)</li> <li>2. Centralized data warehouse</li> <li>3. Data management advice and consultancy</li> <li>4. Electronic provision of management information</li> <li>5. Storage farms or storage area networks (e.g. major storage separate from LANs and workstations)</li> <li>6. Knowledge management (e.g. contact database, KM architecture, knowledge databases, communities of practice)</li> </ol>
3. Application infrastructure capability	<p>To what extent does your firm:</p> <ol style="list-style-type: none"> <li>1. Set and communicate internet policies (e.g. employee access, URL logging)</li> <li>2. Provide Internet capability and enforce policies</li> <li>3. Set and communicate e-mail policies (e.g. inappropriate and personal mail, harassment policies, filtering policies)</li> <li>4. Provide e-mail capability and enforce policies</li> <li>5. Centralized management of applications (e.g. centralized management of applications owned by, or on behalf of, the business unit)</li> <li>6. Integrated mobile computing applications (e.g. laptop dialup, ISP access, handheld infrastructures for internal users, etc.)</li> <li>7. Enterprise Resource Planning (ERP) services (e.g. operating ERPs, implementing new modules, upgrading versions, etc.)</li> <li>8. Middleware linking systems on different platforms (i.e., integrating web "shopfronts" to ERP systems)</li> <li>9. Wireless applications (e.g. applications used by business units, centrally provided and charged by usage with an ASP model)</li> <li>10. Application service provision (ASP) (e.g. applications used by business units, centrally provided and charged by usage with an ASP model)</li> <li>11. Workflow applications (e.g. applications to manage and monitor work flow, moving tasks between workstations)</li> <li>12. Payment transaction processing (e.g. electronics funds transfer (EFT))</li> <li>13. Centralized management of infrastructure capacity (e.g. monitoring and optimising server traffic and adding new capability)</li> </ol>
4. IT Architecture and standards capability	<p>To what extent does your firm:</p> <ol style="list-style-type: none"> <li>1. Specify and enforce data architectures (set high level guidelines and blueprint for the way data will be used and integrated and enforce compliance with high level architecture)</li> <li>2. Specify and enforce technology architectures</li> <li>3. Specify and enforce communications technology architectures</li> <li>4. Specify and enforce applications architectures</li> </ol>

	<p>5. Specify and enforce work architectures</p> <p>6. Set and enforce standards for IT data architectures (set standard operating environment (SOE) to implement data architectures and enforce compliance with high level architecture)</p> <p>7. Set and enforce standards for IT technology architectures</p> <p>8. Set and enforce standards for IT communications technology architectures</p> <p>9. Set and enforce standards for IT applications architectures</p> <p>10. Set and enforce standards for IT work architectures</p>
5. IT infrastructure facilities management	<p>To what extent does your firm have:</p> <p>1. Large scale data processing facilities (e.g., mainframe)</p> <p>2. Server farms (e.g., mail server, web servers, and printer servers)</p> <p>3. Installation and maintenance of workstations and LANs</p> <p>4. Common systems development environment (e.g., create firm-wide competencies to develop or acquire applications, accreditation, etc.)</p> <p>5. Pilot new initiatives (e.g., pilot web e-business initiatives or product configuration tools for customers)</p>
6. Security and Risk	<p>To what extent does your firm have:</p> <p>1. Security policies for use of information systems (e.g., data protection, access privileges, and hacker protection)</p> <p>2. Enforce security policies for information systems</p> <p>3. Disaster planning for business applications</p> <p>4. Firewall on secure gateway services</p>
7. Communications	<p>To what extent does your firm have:</p> <p>1. Communications network services (e.g., full Service TCP/IP networks linking all points within a business)</p> <p>2. Broadband communication services (e.g., higher bandwidth activities such as video)</p> <p>3. Intranet capabilities (e.g., an intranet to support a variety of applications including publishing, company policies, directories, message boards etc)</p> <p>4. Extranet capabilities (e.g., providing information and applications via TC/ICP protocols to a select group of customers and suppliers)</p> <p>5. Workstation networks (e.g., workstation networks, LANs and POS networks)</p> <p>6. EDI linkages to customers and suppliers</p> <p>7. Electronic support to groups (e.g., groupware)</p>
8. IT management services	<p>To what extent does your firm have:</p> <p>1. IS project management</p> <p>2. Negotiate with suppliers and outsourcers (e.g., centralized and negotiated pricing for software)</p> <p>3. Service level agreements (e.g., agreements between Corporate IT, outsourcers, and BU's)</p> <p>4. IS planning, investment, and monitoring (e.g., forward plans and strategy, IT investment process, aligning IT to strategy, value management)</p>
9. IT Research and Development	<p>To what extent does your firm:</p> <p>1. Identify and test new technologies for business purposes</p> <p>2. Evaluate proposals for new information systems initiatives</p>
10. IT Education	<p>To what extent does your firm have:</p> <p>1. Training and use of IT</p> <p>2. Management education for generating value from IT use</p>

## Appendix B: The evidential reasoning algorithm

The evidential reasoning algorithm uses the concepts in set theory and probability theory for aggregating multiple attributes [Error! Reference source not found.]. Suppose there is a simple two level evaluation hierarchy with a general attribute  $A_i$  at the upper level and a set of  $L$  basic attributes at the lower level. The assessments represented in (2) for an alternative  $O_i$  can be aggregated using the following evidential reasoning algorithm.

Suppose  $\omega_i$  is the relative weight of the attribute  $A_i$  and  $\omega_i$  and is normalised, so that  $0 \leq \omega_i \leq 1$  and  $\sum \omega_i = 1$  for  $n = 1, \dots, L$ . Without loss of generality, we present the evidential reasoning algorithm for combining two attribute assessments given by the assessment  $S(A_1(O_1))$  as presented in equation (1) and the assessment  $S(A_2(O_1))$ , which is given by

$$S(A_2(O_1)) = \{(H_1, \beta_{1,2}), (H_2, \beta_{2,2}), \dots, (H_N, \beta_{N,2})\},$$

$$\text{where } 0 \leq \sum \beta_{n,1} \leq 1 \text{ for } n = 1, \dots, N$$

We need to aggregate the two assessments  $S(A_1(O_1))$  and  $S(A_2(O_1))$  to generate a combined assessment. Suppose  $S(A_1(O_1))$  and  $S(A_2(O_1))$  are both complete. Let

$$m_{n,1} = \omega_1 \beta_{n,1} \quad \text{and} \quad m_{H,1} = 1 - \omega_1 \sum \beta_{n,1} = 1 - \omega_1$$

$$\text{for } n = 1, \dots, N$$

$$m_{n,2} = \omega_2 \beta_{n,2} \quad \text{and} \quad m_{H,2} = 1 - \omega_2 \sum \beta_{n,2} = 1 - \omega_2$$

$$\text{for } n = 1, \dots, N$$

where  $m_{n,1}$  and  $m_{n,2}$  are referred to as basic probability mass and each  $m_{H,i}$  (for  $j = 1, 2$ ) is the remaining belief for attribute  $j$  unassigned to any of the  $H_n$  (where  $n = 1, \dots, N$ ). The evidential reasoning algorithm is used to aggregate the basic probability masses to generate combined probability masses, denoted by  $m_n$  (where  $n = 1, \dots, N$ ) and  $m_H$  using the following equations:

$$\{H_n\} : m_n = k(m_{n,1} m_{n,2} + m_{H,1} m_{n,2} + m_{n,1} m_{H,2}) \text{ for } n = 1, \dots, N$$

$$\{H\} : m_H = k(m_{H,1} m_{H,2})$$

$$\text{where } k = [1 - \sum \sum m_{n,1} m_{p,2}]^{-1}$$

$$\text{for } n = 1, \dots, N \quad \text{and } p = 1, \dots, N \quad \text{and } n \neq p$$

Now the combined probability masses can be aggregated with another assessment in the same way until all assessments are aggregated.

If there are only two assessments, the combined degrees of belief  $\beta_{n,1}$  for  $n = 1, \dots, N$  are generated by:

$$\beta_n = m_n / 1 - m_H \quad \text{for } n = 1, \dots, N$$

The combined assessment for the alternative  $O_1$  can then be represented as follows:

$$S(O_1) = \{(H_1, \beta_1), (H_2, \beta_2), \dots, (H_N, \beta_N)\} \text{ where } 0 \leq \sum \beta_n \leq 1 \text{ for } n = 1, \dots, N$$

Since the Dempster's rule of combination proved to be commutative and associative (Yang 2001), evidence can be combined in any order. In case of multiple belief structures, the combination of evidence can be carried out in a pairwise way (Yang 2001).

## Appendix C: Pretest Experiment

### 1 Risk Management and Valuation of Real Options in IT Projects: Results of the Pretest

This appendix<sup>11</sup> describes a pretest experiment that was conducted before doing a final experiment to determine whether IT professionals explicitly recognize that the value of managerial flexibility, as offered by different types of options, is driven by the presence of specific risks (as described in chapter five). The pretest was conducted among 150 management consultants. The results indicate partial support for the risk-options relations as proposed by Benaroch et al. (2006). They also give a first indication of possible biases in how options are valued as a response to particular risks. The results offer insight in possible improvements for conducting the final experiment.

### 2 Research Model and Propositions

In order to empirically test the relations between risk factors, embedded options, and perceived added value, we selected ten risk factors (Table 5-1) ranging from different categories of firm-specific risks (risk factors 1-8) to market risks (risk factors 9 and 10)<sup>12</sup>. Also, we selected five option types, being the options to defer, prototype<sup>13</sup>, stage, abandon and scale up. Based on the research

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<sup>11</sup> The results of the pretest experiment were presented at the European Conference on Information Systems 2008. C.A.R. Hilhorst, P.M.A. Ribbers, E. van Heck, M.T. Smits, 'How IT risks affect real options valuation in IT projects: an experimental approach', *European Conference on Information Systems*, Galway, Ireland, 2008. The presented pretest results here are an abstract from this paper.

<sup>12</sup> In the final experiment we excluded the benefits risk factor, and replaced the risk factor 'Introduction of new superior technology' by the 'Technology newness' risk factor, and 'Inadequate infrastructure' risk is replaced by 'User commitment' risk.

<sup>13</sup> In the final experiment we replaced the option to prototype by the option to switch use. The option to prototype exists when management creates flexibility to partially invest in a prototype effort. Building parts of an application using prototyping can be used to conduct performance tests, technical feasibility studies, or study technology issues. The reason for the replacement are twofold. First, the option to prototype is very similar to a

model, we tested the propositions as shown in Table 5-1 and described in section 5.3.1 (effects of firm-specific risks and embedded options on project value) and section 5.3.2 (effects of market-specific risks and real options on project value).

Risk category	Risk factors	Defer	Proto type	Stage	Abandon	Scale up
Monetary	1. Unclear project benefits	√	√			
Project	2. Team lacks needed skills	√	√	√		
	3. Project is too large		√	√		
Functionality	4. Inadequate infrastructure	√	√	√		
	5. Inadequate design (e.g. performance)		√	√		
Organisational	6. Problematic requirements	√	√	√		
	7. Insufficient management support	√	√	√	√	
	8. Ability of units to handle change		√	√	√	
Environmental	9. Demand exceeds expectations	√				√
Technological	10. Introduction of new superior technology	√			√	

**Table 5-1.** IT project risk factors mapped to operating options that could mitigate them (extracted from Benaroch et al. (2006))

### 3.1 Effects of Firm-Specific Risks on Project Value

In this part we present our propositions. The foundations for the propositions that are also treated in the final test are not given here. For these foundations we refer to the description of the final test in the chapter five.

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stage-abandonment option (Fichman et al. 2005). Second, we remain in line with earlier research by Trigeorgis (1993) and Tiwana et al. (2006).



### *Monetary Risk*

Monetary risk can be caused by uncertainty over the expected project costs and benefits. One aspect of monetary risk is benefits risk. Benefits risk can be caused by uncertainty over whether the expected project benefits are clear or validated, for example due to poor benefit estimation. When facing benefits risk, management can decide to acquire information to adjust the course of the IT project. In an economically rational approach, buying information can be obtained by the flexibility afforded by the option to defer or the option to prototype (Benaroch et al. 2006). The option to defer and prototype can give the flexibility to wait for new information to arrive over time (Boehm 1989), for example by waiting for regulatory changes or new technology standards, or it could be obtained proactively through, for example, conducting a better benefits analyses to find out whether an early version can give insight in the expected project payoffs.

**Proposition 1:** *In case of risk of unclear project benefits, the option to defer (resp. prototype) an IT project will be more highly valued than the option to stage, abandon or scale up.*

### *Project Risk*

Project risk can be caused by (1) uncertainty over whether the project staff (technical) skills are adequate (Barki et al. 2001, Benaroch et al. 2006), (2) the project is too large or too complex (Applegate et al. 2005, Barki et al. 2001, Benaroch et al. 2006, McFarlan 1981, Wallace et al. 2004) or whether (3) the firm's IT infrastructure is adequate (Benaroch et al. 2006).

**Proposition 2a (resp. 2b, resp. 2c):** *In case of risk of inadequate project staff skills, the option to defer (resp. the option to prototype, resp. the option to*

*stage) an IT project will be more highly valued than the option to abandon or scale up.*

**Proposition 3a (resp. 3b):** *In case of risk of a large project, the option to prototype (resp. the option to stage) an IT project will be more highly valued than the option to defer, abandon or scale up.*

Inadequate infrastructure risk refers to uncertainty of the organisation's infrastructure to support the project's system (Benaroch et al. 2006). It can affect the entire system implementation, without leaving the possibility for implementing parts of the system or enabling a system expansion. For example, when implementing a large organisation-wide application, an organisation's network architecture may be inadequate to support the extensive use of the system, which may lead to performance problems. Therefore, transferring risk is perceived a less adequate mitigation strategy when facing infrastructure risk. By acquiring information through running simulations or performance tests, initiate technology feasibility or compatibility, management can learn about infrastructure risk facing an IT project.

**Proposition 4a (resp. 4b, resp. 4c):** *In case of inadequate infrastructure risk, the option to defer (resp. the option to prototype, resp. the option to stage) an IT project will be more highly valued than the option to abandon or scale up.*

#### *Functionality Risk*

Functionality risk may be caused by (1) an inadequate system design (e.g., inadequate interfaces, performance or availability shortfall) (Boehm 1989, Wallace et al. 2004) or (2) by problematic, unstable or unclear requirements, also referred to as requirements volatility (Applegate et al. 2005, Boehm 1989, Wallace et al. 2004).

**Proposition 5a (resp. 5b):** *In case of inadequate system design risk, the option to prototype (resp. the option to stage) an IT project will be more highly valued than the option to defer, abandon or scale up.*

**Proposition 6a (resp. 6b, resp. 6c):** *In case of unclear requirements risk, the option to defer (resp. the option to prototype, resp. the option to stage) an IT project will be more highly valued than the option to abandon or scale up.*

#### *Organisational Risk*

Organisational risk can be caused by uncertainty over (1) the ability of the organisation to handle change (Barki et al. 2001, Wallace et al. 2004) or (2) through insufficient management support (Applegate et al. 2005, Barki et al. 2001, Wallace et al. 2004).

**Proposition 7a (resp. 7b, resp. 7c, resp. 7d):** *In case of risk of insufficient management support, the option to defer (resp. the option to prototype, resp. the option to stage, resp. the option to abandon) an IT project will be more highly valued than the option to scale up.*

**Proposition 8a (resp. 8b):** *In case of risk of inability of business units to handle change, the option to stage (resp. the option to prototype, resp. the option to abandon) an IT project will be more highly valued than the option to defer or scale up.*

### **3.2 Effects of Market-Specific Risks on Perceived Project Value**

#### *Environmental Customer Demand Risk*

Environmental risk may be caused by customer demand that exceeds expectations. We specifically test customer demand exceeding expectations since this will allow us to test a risk that can have positive consequences.

**Proposition 9a (resp. 9b):** *In case of risk of customer demand exceeding expectations, the option to defer (resp. the option to scale up) an IT project will be more highly valued than the option to prototype, stage or abandon.*

#### *Technological Risk*

A specific case of environmental technological risk is the introduction of a new superior technology, which may render the initial system obsolete. For example, when investing in an older version of an operation system technology when a new improved operating system version can appear, project returns may be lower than when management decides to wait for the newer version. To mitigate this type of risk, management can decide to wait to invest or abandon the entire project.

**Proposition 10a (resp. 10b):** *In case of risk of the introduction of a superior technology, the option to defer (resp. the option to abandon) an IT project will be more highly valued than the option to prototype, stage or scale up.*

## **4 Research Method**

A field experiment is used to test the proposed model. For the details on the experimental design and instrument, see chapter five.

The operationalisation of each risk and option attribute is based on existing descriptions of IT risk and real options in IT projects (Benaroch et al. 2006, Tiwana et al. 2007, Trigeorgis 1993). We pre-tested materials with five IT professionals to ensure the instrument was unambiguous and possessed face validity and that the project scenarios were realistic. After filling in a pre-questionnaire (industry, years of experience,...), subjects were asked to assess the project scenarios (see Appendix D). We conducted the experiment in September 2007 and contacted 151 management consultants in a large global consultancy firm. The management

consultants all work in the IT Effectiveness competence group, operating in various public and private industries. We sent out 151 invitations by email. Six emails were returned as undeliverable. We received 88 completed sets of responses (60% response rate) for the eight different project scenarios, providing a total of 704 non-independent risk observations.

## 5 Results

On average, the respondents had 8.9 years (standard deviation 7.02) years of IT experience and had previously been involved in making project assessments for 12.50 projects (standard deviation 28.34). Table 5-2 shows descriptive statistics of our findings. Means and standard deviations for each risk factor are given for each option type. Grey cells represent the proposed risk-options relations. We find that for each risk factor, our respondents assign different values to an IT project for different real options. This is true for each type of project risk ( $p < 0.001$ , one-way repeated measures ANOVA). This shows that the valuation of real options in IT projects is differentially influenced by different types of risk factors. To test the propositions, we first performed a sign test to make a comparison between the valuations of the different option types per risk factor. Since this test offers us no significant results, we exploratory tested our propositions using a one-tailed t-test. The one-tailed t-test is used to make a paired comparison between the different option types. For each risk factor we make a paired comparison between the option types.

Risk factor ( <i>N</i> )	Defer	Prototype	Stage	Abandon	Scale up
1. Unclear project benefits (71)	4.24/2.067	4.23/1.958	4.17/1.935	3.73/2.210	2.32/1.697
2. Team lacks needed skills (63)	3.40/1.922	3.65/1.944	4.46/1.533	3.17/1.783	4.84/1.771
3. Project is too large (76)	2.71/1.757	4.28/1.852	5.83/1.331	3.03/1.869	2.41/1.525
4. Inadequate infrastructure (67)	3.25/1.980	4.72/1.968	3.85/2.009	2.90/1.970	3.60/1.939
5. Inadequate design (e.g. performance) (71)	3.14/2.058	4.85/1.925	3.77/1.936	3.13/2.083	3.77/1.936
6. Problematic requirements (76)	3.76/2.006	5.07/1.754	4.74/1.836	3.29/2.226	2.96/1.969

7. Insufficient management support (74)	4.54/2.134	4.03/2.067	3.84/1.843	4.26/2.041	2.00/1.345
8. Ability of units to handle change (66)	3.27/1.861	4.14/1.805	4.86/1.718	3.06/1.864	3.67/1.908
9. Demand exceeds expectations (76)	1.83/1.215	4.05/2.065	4.46/1.907	1.92/1.354	4.43/1.864
10. Introduction of superior technology (70)	4.20/2.237	3.07/1.868	3.70/2.010	3.73/2.078	2.20/1.557

**Table 2.** Main results of perceived project value for five options and ten risk factors

The first pair of propositions (1a and 1b) for risk factor ‘Unclear project benefits’ indicated that the option to defer, respectively the option to prototype, would more highly valued than the options to stage, abandon and scale up. However, we found no significant support for propositions 1a and 1b. The second group of propositions (2a, 2b and 2c) for the risk factor ‘Team lacks skills’ indicated that participants would value the option to defer, respectively the option to prototype or stage, more highly than the options to abandon and scale up. Since the option to scale up is higher valued than all other options for this type of risk factor, there is no support for propositions 2a, 2b and 2c. The third pair of propositions (3a and 3b) for the risk factor ‘Team lacks skills’ indicated that the option to prototype or the option to stage, would more highly valued than the options to defer, abandon and scale up. Propositions 3a and 3b are significantly ( $p < 0.001$ ) supported. The fourth group of propositions (4a, 4b and 4c) for the risk factor ‘Inadequate infrastructure risk’ indicated that participants would value the option to prototype, respectively the option to stage or the option to defer, more highly than the options to abandon and scale up. Only proposition 4a (option to prototype) is significantly supported. The fifth pair of propositions (5a and 5b) for the risk factor ‘Inadequate design’ indicated that the option to prototype, respectively the option to stage, would more highly valued than the options to defer, abandon and scale up. Proposition 5a for the risk factor ‘Inadequate design’ is significantly ( $p < 0.001$ ) supported for the option to prototype. The sixth group of propositions (6a, 6b and 6c) for the risk factor ‘Problematic requirements’ indicated that the option to defer, respectively the option to prototype or stage,

would more highly valued than the options to abandon and scale up. Propositions 6a, 6b and 6c on 'Problematic requirements' are significantly supported for the option to prototype and the option to stage ( $p < 0.005$ ), and the option to defer ( $p < 0.05$ ). The seventh group of propositions (7a, 7b, 7c and 7d) for the risk factor 'Insufficient management support' indicated that participants would value the option to defer, respectively the option to prototype, stage, or abandon, more highly than the option to scale up. All propositions are significantly supported ( $p < 0.001$ ). The eighth group of propositions (8a, 8b and 8c) for the risk factor 'Ability of units to handle change' indicated that participants would value the option to prototype, respectively the option to stage or abandon, more highly than the option to defer or scale up. Proposition 8a (option to stage) is significantly ( $p < 0.01$ ) supported. The ninth pair of propositions (9a and 9b) for the risk factor 'Demand exceeds expectation' indicated that the option to defer, respectively the option to scale up would be more highly valued than the option to prototype, stage or abandon. Both propositions are not significantly supported. The tenth pair of propositions (10a and 10b) for the risk factor 'Introduction of superior technology' indicated that the option to defer, respectively the option to abandon would be more highly valued than the option to prototype, stage or scale up. These propositions are not significantly supported. In total 12 out of 26 propositions (46%) are significantly supported. We also performed a t-test analyzing results for more experienced IT professionals ( $N=51$ ), selecting a group having more than 4 years IT experience and having assessed at least five IT project. This did not influence the support of propositions as reported here. Overall, for all risk factors, the option to stage and the option to prototype are significantly higher valued than the option to defer, which is significantly higher valued than the option to abandon and scale up. Both for market risk (risk factors 9 and 10) as for firm risk (risk factors 1 to 8) the option to stage and the option to prototype are more highly valued than the other option types.

## 6 Discussion and Conclusion

In our pretest we presented and tested an IT project decision-making model that investigates whether and how the value that IT professionals assign to different risk countermeasures as provided by different types of real options (flexibility) in IT projects is influenced by various IT risk factors. In relation to earlier research conducted by Tiwana et al. (2006), who show that IT professionals place a relative value on various real options in escalation decisions, our pretest indicates that this value is actually driven by the risk factors an IT project faces. The pretest gives an empirical indication that the intuition of IT professionals is partly consistent with the risk management logic as proposed from a real options perspective. The pretest evidence indicates that, for the risk factors presented in this research, professionals have an overall preference for the option to stage and the option to prototype, taking a proactive stance to risk. The option to abandon is the least preferred option. A particular finding is that for three out of ten risk factors presented in our research, professionals prefer the option to scale up higher than or equally high as the proposed options. This is the case for the risk factors 'Team lacks skills', 'Inadequate infrastructure' and 'Inadequate design'. In these situations we may assume that professionals will try to add team skills or add infrastructure to solve the risk. This would suggest that they expect to mitigate the risk by lowering the variance of the risk (by augmenting the quality of the resources, infrastructure or system). One possible explanation for this finding is we did not use a suitable operationalisation for the option to scale up. For the scale up option we used the operationalisation based on the 'expansion of resources initially allocated to the project to enlarge the scope or quality of the project'. In our research, the operationalisation of the scale up option may also lead to an interpretation of opening up the possibility to mitigate the risk in case of negative risk by adding resources. So the option to scale up may not be well operationalised for the particular application domain in this research.



The preference for the option to scale up in case of external risk indicates that professionals comprehend the positive nature of this type of risk. In relation to this particular risk, the evidence suggests that the option to scale up is interpreted as opening up the possibility to expand the scope of the project.

The pretest has several limitations. First, the operationalisation of the option to scale up may be improved for the particular application domain. Second, given the experimental setting limitations to generalization apply. Findings found in an experiment do not always hold true for real-life situations. In practice, managers face very complex situations in which different types of options in IT projects are not per definition easily identifiable. Therefore in practice, the support we find between risk factors and the different types of options may not be as easily expanded to 'real life' situations. Third, experiments and surveys show that the economic valuation of real options and risk is not well estimated in practice (Busby and Pitts 1997, Howell and Jäggle 1997). This suggests that assessment of real options cannot rely on intuition alone, since this may lead to non optimal decisions.



## Appendix D: Pretest IT Project Scenario

### INSTRUCTIONS

Imagine that you are asked to assess 8 IT-projects in your organisation. Eight short IT-project scenarios are presented. They are all risky software development projects. Every presented project is important for your organisation and fits in the available budget. Despite the risk the expected financial returns of the project equal the expected expenditures on the project.

The type of risk facing each project differs. In every scenario the type of risk the project faces is presented, and five investment options for the project to reduce the risk are given. Please assess, based on the type of risk, the five presented investment options for your organisation. You can assess the investment options on a scale of 'Does not add value to my firm' to 'Adds value to my firm'.

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#### IT Project Scenario 1

The project concerns the development of a software system.

Assess the options mentioned below for the execution of the project in relation to the given type of risk. Also use your own knowledge and experience.

---

**There is a high risk that the project is too large.**

	Adds value to my firm	Adds no value to my firm
You defer the project, until further information about the risk is available.		
The project is divided in phases and you invest in the first phase of the application development. After each phase you can decide to invest in a subsequent project phase.		
You invest in research using a prototype. Based on the outcome you can decide to make a full investment.		
You expand the initially needed project resources to enlarge the scope or the quality of the project.		
You abandon the project.		



## Appendix E: Field Experiment IT Project Scenario

### GENERAL DIRECTIONS

Say that you have been asked to assess and score eight recently launched IT projects within your organization. Say also that you were responsible for approving all of those eight projects. We will present you with eight short, high-risk, IT project scenarios. Despite the uncertainties associated with them, the outlay for each project will balance their expected financial earnings.

The type of risk is different for every project. Each scenario tells you which risk is incurred, and six project investment options are proposed to mitigate the relevant risk. Please score, **based on the relevant risk and the different investment options** presented in every scenario, the value of the project to your organization on a scale from 'Of no value to my organization' to 'Of value to my organisation'.

### IT Project Scenario 1

The scenario describes a high-risk IT project. Project resources are budget, staff, hardware and software. Please score, **based on the relevant risk** and the six proposed investment options, the value of the project to your organization using your own knowledge and experience.

#### RISK 1: There is a major risk of the system's functional scope being insufficiently clear

	Of no value to my organization						Of value to my organization
I <b>implement</b> the project <b>in stages</b> so that further expenditures are undertaken only if a previous stage has been completed successfully.							
I <b>abandon</b> the project so that project resources can be utilised elsewhere.							
I <b>defer</b> project outlay as long as this does not cause any loss of valuable income.							
I <b>expand</b> the scope or scale of the project.							
I <b>limit</b> the scope or scale of the project.							
I switch the project to serve <b>a different purpose</b> .							



## Samenvatting

Door de risico's waarmee informatietechnologie (IT) projecten gepaard gaan, zijn IT projecten berucht moeilijk te managen en veel IT projecten eindigen in een fiasco. Een verklaring voor de hoge fiascoratio bij IT projecten is dat managers niet voldoende maatregelen nemen om IT project risico's op waarde te schatten en te sturen op risico's.

Omdat managers aanzienlijke flexibiliteit hebben bij het vormgeven van een aanpak en het structureren van IT projecten, bepleiten wetenschappers de laatste jaren voor gebruikmaking van flexibiliteit om IT risico's te managen, en zo de waarde van IT projecten te vergroten. Recent is daarom veel aandacht besteed aan de toepassing van reële optietheorie in de IS management literatuur. Een project bevat reële opties wanneer managers de mogelijkheid - maar niet de verplichting - hebben om de toekomstige richting van een project aan te passen als reactie op de ontwikkeling van exogene of endogene risico's. Voorbeelden van reële opties zijn het uitstellen van een project, het inzetten van het project voor een andere toepassing, het veranderen van de schaal van een project, het invoeren van een project in fasen, het stopzetten van een project, of het gebruiken van een project als een platform voor toekomstige groeimogelijkheden. Reële-optietheorie stelt dat flexibiliteit waarde heeft omdat het managers de mogelijkheid geeft om actief te interveniëren en de positieve effecten op de waarde van het project te maximaliseren of de mogelijke negatieve effecten op de projectopbrengst te minimaliseren wanneer de onzekerheid is opgelost. Met behulp van reële optieanalyse kan de optimale inzet van flexibiliteit kwantitatief bepaald worden als een optimum tussen projectrisico's en projectkosten- en opbrengsten.

Om de waarde van reële opties in projecten zo effectief mogelijk te laten zijn, moeten managers reële opties herkennen, waarderen en managen. Dit onderzoek heeft als doel ons begrip te vergroten van de invloed van risico's en reële opties op de waardering van IT projecten. Dit onderzoek stelt de algemene

onderzoeksvraag: hoe beïnvloeden reële opties, als reactie op risico's, de IT projectwaardering? Wij onderzoeken deze algemene onderzoeksvraag in drie separate studies.

Het eerste deel van het onderzoek, gepresenteerd in hoofdstuk 3, heeft voornamelijk een exploratief karakter, met als belangrijk doel de onderzoeksvraag voor het vervolgonderzoek te verfijnen. In dit onderzoeksdeel onderzoeken we hoe de gewenste strategische flexibiliteit (wendbaarheid) van een organisatie invloed heeft op de IT infrastructurele vermogens die organisaties ontwikkelen, en hoe organisaties flexibiliteit opnemen in hun IT investeringsbeslissingen. Onze resultaten indiceren dat verschillende vormen van strategische flexibiliteit verschillende vormen van IT infrastructurele vermogens behoeven. Onze resultaten geven weer dat managers verschillende typen reële opties in de praktijk herkennen en dat zij deze met waarde associëren in een risicovolle omgeving. Specifiek duiden onze resultaten erop dat managers in IT infrastructurele projecten impliciet strategische groeiopties waarderen. Ook duiden onze resultaten erop dat niet alleen financiële, maar ook niet-financiële criteria een belangrijke rol spelen bij het waarderen van flexibiliteit in IT projecten.

In het tweede deel van het onderzoek, gepresenteerd in hoofdstuk 4, beantwoorden we de tweede onderzoeksvraag. Dit hoofdstuk richt zich op de vraag hoe flexibiliteit in het managen van projecten geëvalueerd kan worden zodat verschillende typen risico's, en financiële en niet-financiële criteria betrokken kunnen worden. Onze resultaten tonen aan dat wanneer de operationele strategie van een project gewijzigd wordt, het aantal keuzes dat een organisatie heeft, de waarschijnlijkheid van de verandering en het gemak van verandering afhangt van zowel financiële als niet-financiële criteria. Hoewel reële optietheorie waardevolle inzichten genereert in de wisselwerking tussen risico's en opbrengsten vanuit een financieel perspectief, leidt het negeren van het multidimensionale karakter van IT investeringen in de optieanalyse tot heel andere uitkomsten in termen van de meest geschikte invoeringsstrategie. Als



beslissers deze niet-financiële opbrengsten in de waardering van flexibiliteit in IT projecten negeren, dan negeren zij vitale informatie bij de selectie van de best uitvoerbare vorm van flexibiliteit die ingebed moet worden in een IT project. Er zijn verschillende redenen hiervoor. Ten eerste kunnen de objectieven van een beslisser afwijken van die van spelers op de kapitaalmarkt, wat kan resulteren in een andere uitkomst. Ten tweede, bepaalde beslissingscriteria die niet gekwantificeerd wordt in een netto contante waarde of optie analyse, zoals het lerend vermogen van de organisatie, kunnen expliciet gemaakt worden in een multicriteria aanpak, zoals met behulp van de voorgestelde Dempster-Shafer theorie met *belief functions*, daarmee resulterend in een andere beslissing. Ten derde, de netto contante waarde of optie analyse kan niet goed berekend zijn omdat het (nog) niet mogelijk is een monetaire waarde te plaatsen op een attribuut.

Het belangrijkste deel van ons onderzoek wordt gepresenteerd in hoofdstuk 5. Dit deel beantwoordt de onderzoeksvraag hoe verschillende typen risico's de relatieve waarde beïnvloeden die managers aan verschillende typen opties toekennen in IT projecten. Recent hebben onderzoekers aangetoond dat managers de aanwezigheid van verschillende typen reële opties in IT projecten herkennen en waarderen. Vanuit het perspectief van reële opties en risicomanagement is het specifieke risico dat men beoogt te beheersen bepalend voor de keuze van het type optie dat in een project moet worden ingebed. Onze resultaten ondersteunen het centrale idee dat managers reële opties verschillend associëren met projectwaarde in de aanwezigheid van verschillende risico's. De door managers ervaren toegevoegde waarde van een IT project wordt voornamelijk gedreven door de waardebijdrage van verschillende typen opties, zoals eerder onderzocht door Tiwana et al. (2006), en in de tweede plaats door het interactie effect tussen risico's en reële opties. Ook tonen we aan dat de op reële opties gebaseerde risicomanagement strategieën zoals ontwikkeld door Benaroch et al. (2006) over het algemeen overeenkomen met de wijze van redeneren van managers.

Consistent met deze voorgestelde strategieën associëren managers de optie om een project op te schalen met projectwaarde in het geval van positieve risico's en niet in het geval van negatieve risico's. In het geval van negatieve risico's associëren managers de hoogste projectwaarde met respectievelijk de optie om te faseren, de optie om een project naar beneden bij te stellen en de optie om een project uit te stellen. Managers kennen een relatief lage waarde toe aan de optie om een project stop te zetten en een project een andere toepassing te geven. Door de eerdere bevindingen van Benaroch et al. (2006) en Tiwana et al. (2006) uit te breiden, is de belangrijkste theoretische bijdrage van dit onderzoek een solide empirisch bewijs te geven van de relatie tussen risico's, reële optiewaarde en de IT projectwaardering door managers. Onze resultaten suggereren dat managers begrijpen hoe flexibiliteit in IT projecten waarde kan creëren als een reactie op risico's.

## Curriculum Vitae

Cokky Hilhorst was born in Soest, the Netherlands, on September 7, 1971. She attended Griffland College in Soest, from which she graduated in 1989. After spending a year at the Institute d'Etudes Françaises pour pour Etudiants Etrangers in Aix-en-Provence, France, she studied Artificial Intelligence at Utrecht University, where she specialised in mathematical logic and theoretical computer science. In September 1995, she received her Master's degree with a thesis on category theory. In September 1995 she went to Cambridge University, King's College for six months as a research student.

She works in management consultancy at PricewaterhouseCoopers (PwC) since 1997, where she is a principal manager in Information Management. In 2000, she interrupted her career at PwC to work for a dot-com firm and to become department head at the Hogeschool Zeeland in Business Informatics and Computer Science. In 2004, she started working for PwC again. The most part of her work she advises senior management on large IT projects, IT portfolio management, IT strategy and IT governance issues.

In 2000, a few years after starting her professional career, she completed her Master's degree in Information Management from TiasNimbas Business School in Tilburg, the Netherlands. In 2003, she started her doctorate at Tilburg University, at the Department of Information Management. Her work has recently been published in Decision Support Systems and she has presented her research at the European Conference on Information Systems (ECIS) in 2004, 2005, 2006 and 2008. In 2006 she attended the ECIS Doctoral Consortium. In March 2008 she spent a trimester at the Institut d'Administration des Entreprises in Aix-en-Provence, France, as a visiting researcher. She has served as a reviewer for several international IS conferences. Her research interests focus on strategic management of IS, IS projects, behavioural economics of IS, and IT project risks.