Appears in Proceedings of the 2nd International Conference on Educational Economics, August 2008, Athens, Greece.

E-learning investments evaluation: a multicriteria model

Georgios N. Angelou, Anastasios A. Economides[1]

University of Macedonia
gangelou@tee.gr, economid@uom.gr

Abstract

E-learning markets have been expanding very rapidly. As a result, the involved senior managers are increasingly being confronted with the need to make significant investment decisions related to the e-learning business activities. The valuation of e-learning business activities is a challenging task since it is characterized by rapidly changing business and technology conditions. In this paper, we apply ROs (Real Options) to the e-learning investments evaluation. Given the investment's requirements, assumptions and risks, the goal is to maximize the investment's value by identifying a good way to structure it using carefully chosen ROs. However, ROs models are based on quantitative analysis and the required input parameters sometimes are difficult to be estimated for evaluating real life investment opportunities. In addition, e-learning investments experience tangible and intangible factors and the latter can be mainly treated by qualitative analysis. For this reason, we integrate ROs thinking and Analytic Hierarchy Process (AHP) to take into account financial tangible, intangible and risk factors providing a decision analysis framework. The proposed framework provides a better understanding of projects risks and various intangible factors inherent in e-learning projects enabling these projects to be deployed more optimum and valued with higher accuracy. Finally, we apply the proposed model in an e-learning case study showing how it can be formulated and solved.

[1] Georgios Angelou, Ph.D. Candidate, UNIVERSITY OF MACEDONIA, Information Systems Department, Egnatia 156, Thessaloniki 54006, GREECE, Tel: 6949720732, email: **gangelou@tee.gr**.

Prof. Anastasios A. Economides, UNIVERSITY OF MACEDONIA, Information Systems Department, Egnatia 156 Thessaloniki 54006, GREECE, Tel: +30-2310-891799, Fax: +30-2310-891750, email: **economid@uom.gr**, **http://conta.uom.gr**

1. INTRODUCTION

E-learning is the delivery and management of teaching, training and learning by electronic means. Various devices (workstations, portable computers, handheld devices, smart phones, etc.), networks (wireline, wireless, satellite, etc.) can be used to support e-learning (Wentling et al., 2000). E-learning may incorporate synchronous or asynchronous communication, multiple senders and receivers (one-to-one, one-to-many, many –to many, etc.), multiple media and format independently of space and time. Recently the e-learning markets have been expanding very rapidly and led to an unexpected revelation: the forces affecting higher education around the world are strikingly similar. This is true in at least four important areas: expanding enrollments; the growth of new competitors, virtual education and consortia; the global activity of many institutions; and the tendency for policy makers to use market forces as levers for change in higher education. Expansion of enrollments, accompanied by shifts in student demands and expectations, is a global phenomenon. The number of tertiary students worldwide doubled in size in just twenty years, growing from 40.3 million students in 1975 to 80.5 million students in 1995 (Newman and Couturier, 2002).

The valuation of e-learning business activities is a challenging task since it is characterized by rapidly changing business and technology conditions. Traditional finance theory suggests that firms should use a Discounted Cash Flow (DCF) methodology to analyze capital allocation requests. However, DCF does not properly account the flexibility inherent in most e-learning investment decisions. For example, an e-learning infrastructure project may have a negative Net Present Value (NPV) when evaluated on a stand-alone basis, but it may also provide the option to launch future value-added services if business conditions are favorable. Real Options (ROs) analysis presents an alternative method since it takes into account the managerial flexibility of responding to a change or new situation in business conditions. Given the investment's requirements, assumptions and risks, the goal is to maximize the investment's value by identifying a good way to structure it using carefully chosen ROs. The applications of ROs to risk management and investment evaluation of the Information and Communication Technologies (ICT) have mainly focused on a single and a-priori known option. However, these options are not inherent in any ICT investment. Actually, they must be carefully planned and intentionally embedded in the ICT investment in order to mitigate its risks and increase its return. Moreover, when an ICT investment involves multiple risks, by adopting different series of cascading options we may achieve risk mitigation and enhance investment performance.

The proposed framework represents a systematic approach to decision analysis in ICT projects focusing on e-learning business activities. There is empirical evidence to support the fact that managers who are aware of some options-like ideas do a better job of managing risky research and development (R&D) projects. Also, senior finance executives are becoming increasingly aware of the need to view major risky capital investments as options. ROs analysis for risk management and evaluation of ICT investments has been recently proposed in the literature.

The ROs approach applies methods of financial planning to investment valuation problems. An investment project embeds a RO when it offers to management the opportunity to take some future action (such as abandoning, deferring, or scaling up the project) in response to events occurring within the firm and its business environment (Trigeorgis, 1996). For example, by taking advantage of the option to defer the investment for some time the management can learn whether there are better alternative technologies (Li and Johnson, 2002). This management's flexibility (called active management) to adapt its future actions in response to altered future business conditions expands an investment opportunity's value by improving upside potential and limiting downside losses (Trigeorgis, 1996). Business condition either refers to market conditions or firm conditions depending on where the investment is focusing. For example, an investment of an e-learning infrastructure for providing educational services only inside the premises of a big organization mainly refers to firm conditions. On the other hand, an e-learning application, which mainly focuses on providing services in the market (by a university or other institution), refers to market conditions. Most previous research considers only ICT investment that embeds a single and a-priori known option. However, ROs are not inherent in any ICT investment (Benaroch, 2002), and in any case they are not always easily recognizable (Bräutigam and Esche, 2003). In order to optimally configure an ICT investment it may require considering a series of cascading (compound) options that will help to mitigate risk and enhance economic or strategic performance. Previous research on investment evaluation has applied ROs to ICT, pharmaceuticals and petroleum fields (Iatropoulos et al., 2004; Mun, 2002). In this paper, we apply ROs to the e-learning investments risk management and evaluation adopting the Benaroch's (2002) framework. The target is to configure the investment using ROs analysis so that the risk is minimized while the economic performance is maximized. However, ROs models are based on quantitative analysis and the required input parameters sometimes are difficult to be estimated for evaluating real life investment opportunities. In addition, ICT investments experience tangible and intangible factors and the latter can be mainly treated by qualitative analysis. For this reason, we integrate ROs thinking and Analytic Hierarchy Process (AHP) to take into account financial tangible, intangible and risk factors providing a decision analysis framework. The proposed framework provides a better understanding of projects risks and various intangible factors inherent in ICT projects enabling these projects to be deployed more optimum and valued with higher accuracy. Finally, we apply the proposed model in an e-learning case study showing how it can be formulated and solved.

The remainder of the paper is organized as follows. In Section 2, we offer background material on ROs and how they are related to the e-learning business field. In Section 3, we discuss limitations of ROs and present the Analytic Hierarchy Process. In Section 4, we present the proposed model and methodology. In Section 5, we apply the proposed methodology to justify and extract the optimum deployment strategy for a specific e-learning infrastructure investment. In Section 6, we discuss about the overall applicability of the methodology and present key issues for future research. Finally, in Section 7 we offer some concluding remarks.

2. ROS IN CONTROLLING ICT INVESTMENT RISK

ROs Review

An option gives its holder the right, but not the obligation, to buy (call option) or sell (put option) an underlying asset in the future. Financial options are options on financial assets (e.g. an option to buy 100 shares of Motorola at 80€ per share on January 2010). The ROs' approach extends the options' concept to real assets. A real option is defined as the right, but not the obligation, to take an investment action on a real asset at a predetermined cost for a predetermined period of time. The real option approach to capital investment has the advantage to capture the value of managerial flexibility, which cannot be properly addressed by the traditional discount cash flow (DCF). This value is manifest as a collection of call or put options embedded in capital investment opportunities. These options typically include: option to defer, time-to-build option, option to alter operating scale (expand or contract), option to abandon, option to switch, growth option and multiple interacting options.

Spending money to exploit a business opportunity is analogous to exercising an option on, for example, a share of stock. It gives the right to make an investment's expenditure and receive an investment's asset. RO's thinking considers that investment's asset fluctuates stochastically.

Option valuation models can be categorized in continuous time and discrete time domains. In the continuous time domain, the most widely applied model is the Black-Scholes formula, while in the discrete time domain it is the Binomial one. However, continuous time models are not readily applicable for practical valuation purposes or integration with the models in strategic management theory, for example in combining game theory and ROs (Trigeorgis, 1996). For a general overview of real option, Trigeorgis (1996) provided an in-depth review and examples of different ROs. For more practical issues the reader is referred to Mun (2002; 2003). Finally, Angelou and Economides (2005) presented an extended survey of ROs applications in real life ICT investment analysis.

Risk management with ROs in E-learning business field

Virtual learning environments are providing teachers with new tools to manage courses and curricular resources, to communicate with students and to coordinate discussions and assessment tasks. Traditional support services such as libraries are changing dramatically; digital collections are overtaking physical collections with students being able to access their services at any time and from almost anywhere. Administrative systems such as student records are being linked to virtual learning environments making for a seamless linkage across administrative and teaching functions. Wiring and internet connectivity have become business critical to the modern university.

New pedagogical approaches are being developed to capitalize on the opportunities afforded by virtual environments and this is necessitating new forms of preparation and support for students and staff. The scope of these developments are extensive, they cut across all areas of institutional functioning and pose significant challenges to senior managers. How are they to make sense of the range of influence of e-learning developments within their institution and assess the risks associated with these developments? What information will help decision-makers to make strategic choices about where to invest, what to invest and how much to invest? While some institutions have invested heavily in technologies to support learning others have followed a more cautious approach. These differences in levels of investment depend on a complex mix of internal and external factors – institution's mission, strategic plan, level of technological expertise, staff and student skills in ICT, awareness of the benefits of e-learning and beliefs about what is possible, available funding, attitudes to risk, government policy and funding council initiatives.

The valuation of e-learning business activities is a challenging task since it is characterized by rapidly changing business and technology conditions. E-learning investment risks include firm-specific risks, competition risks, market risks, and environmental and technological risks. For example, an e-learning project may experience more market risk characteristics while another one may experience more firm risk characteristics. Actually, if a project is focusing more on the open market, for example e-learning services provided by a university, the risks are mainly coming from the market and the competition field. On the other hand, when the e-learning service/product is focusing more on internal use by an organization, the risk is more firm specific.

3. ROS LIMITATIONS AND AHP FOR QUALITATIVE ANALYSIS

So far in the literature, the ROs models concern quantitative factors analysis for both benefits and costs. However, very often an ICT project owns a number of qualitative factors that should be taken into account in parallel with the quantitative ones. Managerial flexibility, which is expressed by the ROs analysis, may apply to both quantitative and qualitative factors. However, the known ROs models take into account only the tangible factors. In addition, the estimation of revenues and cost volatility, used as input parameters in the typical options values, can be a very difficult task. Also, the estimation of various risk factors contribution to the overall uncertainty level (technology, competition, demand uncertainties etc.) may not be possible. For example, the customers demand uncertainty may be quantified by estimating its contribution in the overall investment volatility, while the contribution of the technology and firms capability uncertainty to optimally exploit investment benefits may not. By adopting qualitative analysis we can model some of the uncertainties “clearness” inherent in the investment opportunity that cannot be quantitatively estimated and included in the overall projects volatility.

Benaroch (2002) provided a method for estimating the overall investment uncertainty (volatility), which can be broken down into its components (e.g. customer demand uncertainty, competition uncertainty, technology uncertainty). However, the estimation of each component of the uncertainty may be impossible. We may extent this work by considering that some of the overall uncertainty’s components may be treated as qualitative factors, while the sources of uncertainty that can be quantified and included in the estimation of the overall project volatility can be integrated in the typical ROs models.

Several conceptual and practical issues emerge when trying to use in business practice the options theory as proposed in the current literature (Renkema, 1999). An important barrier to the successful implementation is a general inability to reliably estimate cash flows that are enabled by infrastructure investment. Existing models for option valuation assume a certain distribution of the resulting cash flows, based on an efficient market or another appropriate indicator of expected returns. However, this is only rarely the case in the context of investments in the ICT business filed, which is known for its uncertain and unpredictable business conditions. It has been further recognized that finance-oriented option valuation models are too complex for managerial decision making practice. In addition, after the ICT markets liberalization the required competition modeling has increased the existing options models. Options theory in its present state does provide a conceptual decision framework to evaluate the pros and cons of an investment but in many cases it cannot be considered as a fully operation tool for management.

Hence, in many cases it is much more feasible, simpler and faster to apply what could be called “option thinking” in the context of risk control that an option can provide for a specific investment opportunity. This means that alternative options can be designed, categorized, and examined for finding the optimum combination of them that management intuition will recognize the most promising in terms of risk mitigation.

We enhance the ROs analysis by adopting qualitative analysis for estimating the risk control between the various deployment alternatives for an investment, which may contain a number of ROs. We introduce the AHP methodology and construct a specific decision analysis model. One of the key factors behind choosing AHP is the value that AHP places on a decision maker's inputs and the crucial role these inputs play in the decision-making process. Additionally, AHP is capable of integrating both qualitative and quantitative criteria into the decision-making process. Finally, through the pair-wise comparison process, the AHP decomposes large and complex decisions and allows the decision maker to focus his attention on each criterion. To our knowledge this is the first time that the ROs and AHP are integrated into a common decision analysis framework regarding e-learning investment decisions.

A brief AHP presentation and literature review

AHP is a multi-criteria decision analysis technique. It aims at choosing from a number of alternatives based on how well these alternatives rate against a chosen set of qualitative as well as quantitative criteria (Saaty and Vargas, 1994; Schniederjans, 2005). AHP is developed at the beginning of seventies to tackle complex, multi valued, political and economic decision problems. Using AHP it is possible to structure the decision problem into a hierarchy that reflects the values, goals, objectives, and desires of the decision-makers. Thus, AHP fits to the strategic investments problems and the framework of this study. The main advantage of the AHP approach is that different criteria with different measures can be easily transformed into a single utility measure. As input, AHP uses the judgments of the decision makers about the alternatives, the evaluation criteria, the relationships between the criteria (importance), and the relationships between the alternatives (preference). In the evaluation process, subjective values, personal knowledge, and objective information can be linked together. As an output, the goal hierarchy, the priorities of alternatives and their sensitivities are reached. Regarding examples of AHP application to ICT problems, Bodin et al. (2005) proposed the AHP method to determine the optimal allocation of a budget for maintaining and enhancing the security of an organization's information system. Hallikainen et al. (2002) proposed an AHP-based framework for the evaluation of strategic IT investments. They applied the principles of AHP to compare a number of Information Technology investment alternatives. Tam and Tummala (2001) formulated and applied the AHP to select a vendor for a telecommunications system. Lai et al. (1999) applied the AHP to the selection of a multimedia authoring system. Kim (1998) used the AHP to measure the relative importance of Intranet functions for a virtual organization. Santhanam and Guimares (1995) applied the AHP to evaluate various Decision Support Systems. Finally, Roper-Lowe and Sharp (1990) used the AHP for the selection of a computer operating system.

4. THE PROPOSED MODEL-METHODOLOGY

Next, we present a methodology that helps to address the question: *What is the amount of flexibility embedded in an ICT business activity? How can we control firm, market and competition risks so as to configure the business activity in a way to minimize risk and increase investment performance?*

The proposed model contains three perspectives: financial tangible factors (FTF) perspective, risk mitigation (RM) perspective, and intangible factors (IF) perspective.

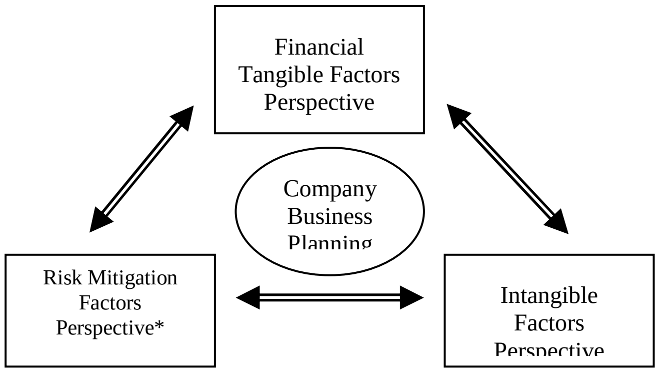

Figure 2. *The proposed model – three perspectives*

Financial Tangible Factors Perspective

The financial perspective evaluates how a company is meeting though financial measures. For the valuation of financial perspective, we may adopt traditional accounting techniques such as Net Present Value (NPV), Return on Investment (ROI), Internal Rate of Return (IIR) and typical quantitative ROs analysis. In this work we focus on the ROs itself and adopt the work of Angelou and Economides (2007a) for the quantitative analysis.

Intangible Factors (IF) perspective

Intangible factors are difficult if not impossible, to quantify in absolute monetary terms, but they are still important to the decision making process. Particularly, ROs analysis itself brings to the "surface" a number of factors that cannot be quantified, at least easily, by existing ROs models and methodologies. Fichman et al. (2005) called them potential pitfalls of option thinking for risk management and investment evaluation. We integrated some of them in our analysis, in order to achieve a balance between risk control achieved by options adoption and other issues influencing the overall investment's deployment strategy and limiting the options thinking applicability.

Among others, not all investments can be divided into stages implementing stage and expand options. Sometimes a firm should consider an investment as a whole entity, such as when external funds must be raised or when co-investment from other parties is required. Another issue is that stakeholders may prefer all at once funding to obtain maximum control of the investment and have so more time to get a troubled investment back on track before facing a next track of justification. We introduce this possibility in our analysis by considering the intangible factor "*Capability-Interest of staging the investment*" (CSI).

In the ROs literature, investment opportunities known in advance, based on initial infrastructure investments, are treated as growth options. For the estimation of their values, the compound option models are utilized. However, telecommunication growth investment opportunities in reality can be hardly defined during the decision phase (Benaroch, 2002). For this reason, we model qualitatively the existence of growth investment opportunities, which are based on investments in previous phases of a firm's business activity and cannot be defined quantitatively in advance.

Concerning growth options, the main challenge is the difficulty of estimating their values (due to ambiguity of future cash flows) and uncertainty about the appropriate value for option model parameters. We name this intangible option factor as "*no clarified growth options*" (NCO). Also, building in option to abandon or contract operation may concern intangible costs related to credibility and morale. We model this possibility by the intangible factor "*cost of scaling down operation*" (CSO). Finally, a potential pitfall of switch-use option is that it can add extra time and expense to the development of the initial information communication technology platform in order to change from shadow to real option. Creating this option (making it real) usually involves making the ICT platform more generic and modular for obtaining higher flexibility, experiencing however higher cost. We model this issue as intangible factor named "*cost of systems flexibility-modularity*" (CSF).

Another factor that can be integrated in a future work is the higher uncertainty clearness-control (UC) during waiting period. In our model, we consider the amount and type of uncertainty control achieved by each of the portfolio's projects. We do not want to substitute the UC achieved by the ROs analysis and quantified by the volatility of the stochastic parameters, such as investment revenues V and one time investment cost C (σv, σc). However, the overall uncertainty of an investment opportunity cannot be easily quantified. For example, the uncertainty of customers' demand may be quantified by estimating its contribution to the overall investment's volatility, while the contribution of technology and the firm's uncertain capability to optimally exploit investment benefits may not. By adopting qualitative analysis, we can model some of the uncertainties inherent in the investment opportunity that cannot be quantitatively estimated and included in the overall investment's volatility.

Benaroch (2002) provided a method for estimating the overall investment's uncertainty (volatility), which can be broken down into its components (e.g. customers' demand uncertainty, competition's uncertainty, and technology's uncertainty). However, the estimation of each component of the uncertainty may be impossible. We may extend this work by considering that some of the overall components of the uncertainty may be treated as qualitative factors, while the sources of uncertainty that can be quantified and included in the estimation of the overall volatility can be integrated into the typical ROs models. Angelou and Economides (2008b) provide an extensive discussion of these subjects.

Risk Mitigation Factors Perspective

Risk management strategies are oriented towards identifying different types of risks, assessing their relative importance for the project, and implementing strategies for managing risks (Kumar, 2002). Risk management actions can be viewed as being of two types. The first is oriented towards reducing the degree of risk; for example, a major source of uncertainty in IT projects is the uncertainty regarding the scope or specifications of the project. This can be partially resolved by interviewing multiple stakeholders. However, since risk cannot be completely eliminated, a second type of strategy oriented towards hedging risks is important. Risk hedging strategies are insurance-like ones oriented towards minimizing the negative impact of risk, when the associated uncertainty is resolved over time. For example, specification uncertainty in IT projects may be due to uncertain business conditions that may be resolved as the project progresses (Kumar, 2002). Telecommunication risks can be placed into three categories (Benaroch, 2002; Bräutigam and Esche, 2002):

- Firm-specific risks are due to uncertain endogenous factors (endogenous or technical uncertainty). They could be the result of uncertainty about the ability of the firm to fully fund a long-term capital-intensive investment, the adequacy of the firm's development capabilities to a target investment, the fit of the target application with various organizational units, etc. These factors affect the ability of the investing firm to successfully realize an investment opportunity.
- Competition risks are the result of uncertainty about whether a competitor will make a pre-emptive move, or simply copy the investment and improve on it. These risks give rise to the possibility that the investing firm might lose part or all of the investment opportunity.
- Market risks are due to uncertain exogenous factors that affect every firm considering the same investment (exogenous or market-related uncertainty). These risks could be the result of

uncertainty about customer demand and prices for the products or services, a target investment yields, potential regulatory changes, unproven capabilities of a target technology, the emergence of a cheaper or superior substitute technology, and so on. These factors can affect the ability of the investing firm to obtain the payoffs expected from a realized investment opportunity.

Research on technology investment's evaluation and risk management recognizes that ROs thinking emphasizes the sources of risks inherent in such investments and contributes to risk control.

Life-cycle of investment opportunity ROs

The lifecycle of an investment starts at the inception stage. During this period the investment exists as an implicit opportunity for the firm that can be facilitated by a prerequisite investment (Figure 2). The firm possesses a shadow option. During the recognition stage, call "Wait-and-See" (WaS) period, the investment is seen to be a viable opportunity. The opportunity can be treated as a RO. The building stage follows upon a decision to undertake the investment opportunity. In the operation stage, the investment produces direct and measurable payoffs. Upon retirement, the investment continues to produce indirect payoffs, in the form of spawned investment opportunities that build on the technological assets and capabilities it has yielded. When these assets and capabilities no longer can be reused, the investment reaches the obsoleteness stage. Each stage of the investment opportunity is relevant to a number of operating and growth ROs, such as option to defer, stage, lease, expand (Benaroch, 2002). The reason is that each type of RO essentially enables the deployment of specific responses to threats and/or enhancement steps. In addition, each stage of the investment is also experiencing a variety of risks.

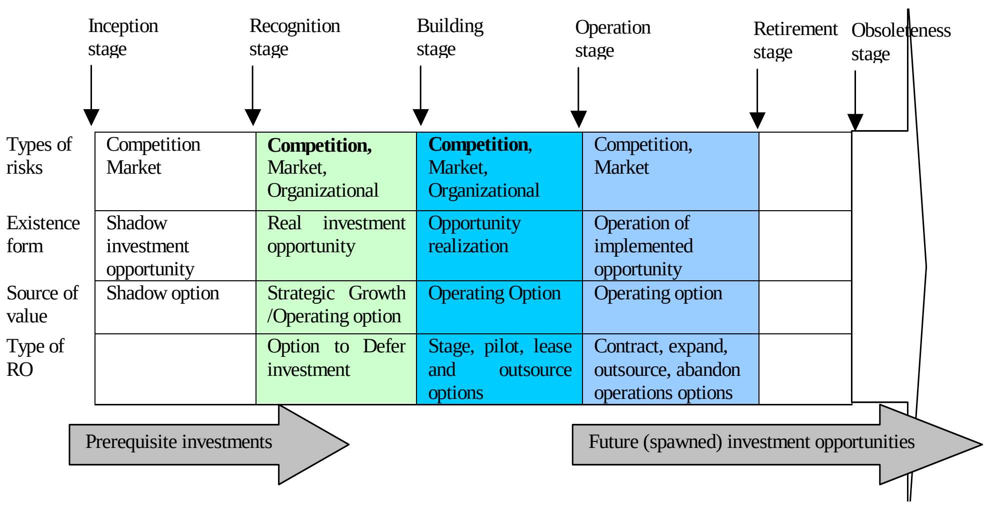

***Figure 2**. Types of risks and ROs arising at different stages in the investment lifecycle*

For controlling these risks we can adopt a number of investment modes:

Defer investment to learn about risk in the investment recognition stage. If we do not know how serious some risk is, the option to *defer* investment permits learning about the risk by acquiring information passively (observe competitor moves, review emerging ITs, monitor regulatory actions, etc.) or actively (conduct market surveys, lobby for regulatory changes, etc.). Such *learning-by-waiting* helps to resolve market risk, competition risk, and organizational risk. Apparently, the greater the risk, the more learning can take place, and the more valuable is the deferral option.

Partial investment with active risk exploration in the building stage. If we do not know how serious some risk is, investing on a smaller scale permits to actively explore it. Three options facilitate *learning-by-doing*, that is, enable gathering information about the firm's technological and organizational ability to realize the investment successfully. The option to *stage* investment supports learning via a sequential development effort, and the options to *pilot* and *prototype* support learning through the production of a scaled down operational investment. The last two options compress the investment lifecycle, thus allowing on learning early how competitors, customers, regulatory bodies and internal parties will react to the investment initiative. Put another way, these options permit market risk, development risk and organizational risk to be transferred to earlier parts of the full-scaled investment lifecycle. Similarly, the *stage* option divides the investment realization effort into parts, thus permitting to transfer risk across parts within the building stage. For example, implementing the riskiest parts of the realization effort as early as possible helps to reveal up-front whether the entire realization effort can be completed successfully (e.g., within schedule and budget).

Full investment with reduction of the expected monetary impact of risk in the building and operation stages. Here, the options help to lower the value consequences of risk and/or the probability of its occurrence. An example of the former is the option to *lease* development resources, which protects against development and market risks by allowing on killing an investment in midstream and save the residual cost of investment resources. A way to lower the probability of risk occurrence is the option to *outsource* development. This option lowers the risk of development failure by subcontracting (part or all of) the realization effort to a third party that has the necessary development capabilities and experience. In essence, both these options permit *transferring risk* (partially or fully) to a third party.

Dis-investment/Re-investment with risk avoidance in the operation stage. If we accept the fact that some risk cannot be actively controlled, two options offer contingency plans for the case it will occur. The option to *abandon* operations allows redirecting resources if the competition, market or organizational risks are realized. The option to *alter scale* allows contracting (partially disinvest) or expanding (reinvest) the operational investment in response to unfolding market and organizational uncertainties.

Based on the logic of these investment modes, the mapping of specific risks to specific options that control them can be refined to fit any class of IT investments. Benaroch (2002) and Angelou and Economides (2007a) provided cases of ROs thinking on the basis of the aforementioned investment modes. Particularly, information technology investment opportunities have been analyzed using ROs thinking based on the aforementioned investment modes. ROs analysis can control different sources of risks existing in the various stages of the investment life-cycle. We classify the telecommunication risks based on proposals by Benaroch (2002), and Bräutigam and Esche (2002). Table 1 shows the main sources of telecommunication risks as well as their mapping to the specific ROs that can control them.

Risk Opportunity	Recognition	Building				Operation			
	Defer	**Stage**	**Explore/Pilot**	**Outsource Developmen**	**Lease**	**Abandon**	**Contract**	**Expan d**	**Outsource**
F1 firm cannot afford the project (unacceptable financial exposure)	+		+	+	+				
F2 costs may not remain in line with projected benefits	+		+	+	+	+	+		+
P1 staff lacks needed technical skills	+	+	+	+	+				
P2 project is too large or too complex		+	+	+	+				
P3 inadequate infrastructure for implementation		+	+			+	+		
P4 the project is not on Time		+	+		+	+			
F1 wrong design (eg, analysis failed to assess correct requirements)		+	+	+		+			
F2 problematic requirements (stability, completeness, etc.)		+	+			+			
O1 uncooperative internal parties	+	+	+			+			
O2 parties slow to adopt the application		+	+			+	+		
C1 competition's response eliminates the firm's advantage	+	+	+		+	+	+		
C2 competition acts before the firm	+		+						
E1 low customer demand, with inability to pull out of market	+	+	+	+	+	+	+		+
E2 demand exceeds expectations (follow-up opportunities exist)	+		+					+	
E3 too high customer response may overwhelm the application	+		+		+	+	+	+	+
E4 customers may (bypass) develop their own solutions	+		+			+	+		
E5 unanticipated action of regulatory bodies	+				+	+			
E6 Price uncertainty	+					+			
E7 environment changed requirements (expected benefits vanish)	+		+			+			
E8 Other factors such as Legal issues, Natural Phenomena, Social issues, Armed conflicts, Taxation.	+					+			
T1 application may be infeasible with the technologies considered		+	+	+	+	+			+
T2 the introduction of a new superior implementation technology may render the application obsolete	+				+	+			+
T3 the implementation technologies considered may be immature	+		+	+		+			

Table 1. *Risk factors inherent in telecommunication investments and options that can control them*

Next, we propose an AHP structure in order to combine all the aforementioned factors into one utility function.

4.1 Integrating ROs with AHP model

The structure of the decision analysis framework contains four levels: i) the content of the specific investment opportunity, which can be deployed in various ways, ii) the life-cycle stages of the investment opportunity, iii) the options level that is embedded in each one of these stages and mapped to specific types of risks, iv) the multi-criteria level that contains financial tangible, risk and intangible analysis (Figure 3). The overall utility is composed of all these criteria (factors) which may be further decomposed into their applicable sub-criteria. We apply the pair-wise comparisons for each of these sub-criteria. The final result of the analysis, at the top, is the prioritization of the various deployment scenarios according to the overall firm business utility.

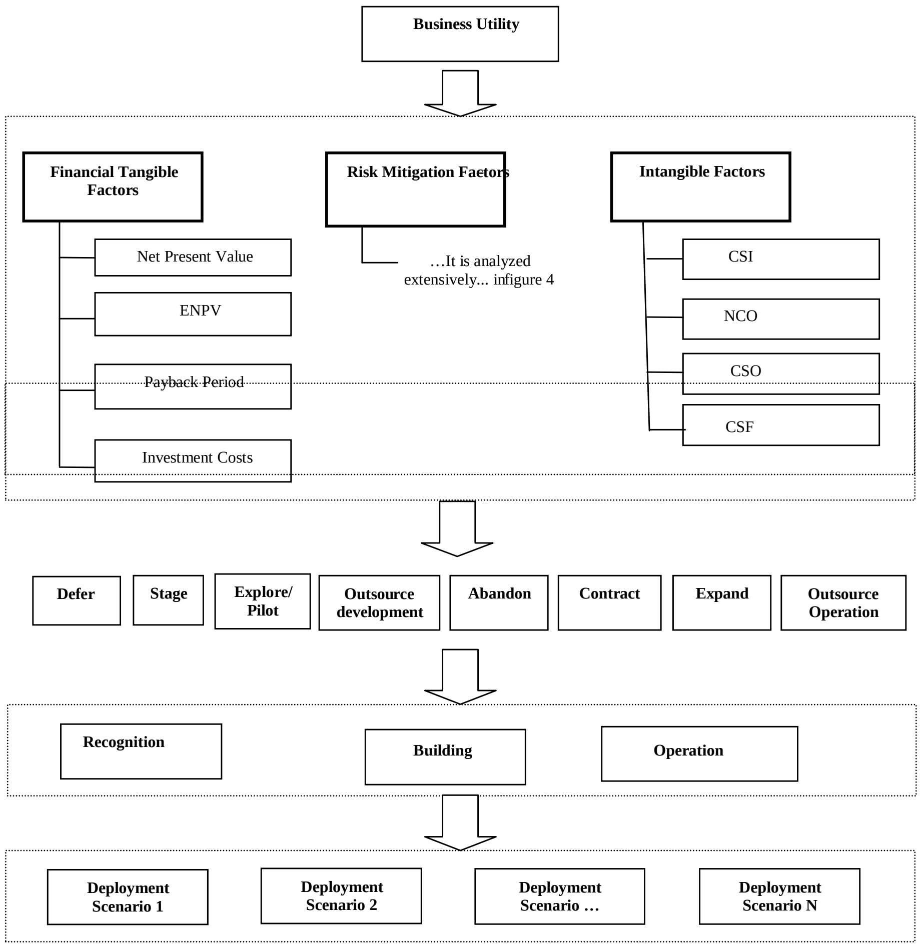

Figure 3. *Analytical view of the decision analysis framework*

The analytical view of the Risk Mitigation sub-module is extensively analyzed in Figure 4. The criteria used in our structure are coming from Table 1 and indicate the risk inherent in ICT investments. Analytically, we perform pair-wise comparisons of the deployment scenarios for each one f the risk factors focusing on the risk control that each scenario can provide. The pair-wise comparisons concern the amount of risk that is resolved and controlled, depending on the provided option(s) about each scenario. Our target is to select the deployment scenario that provides the highest value for the risk mitigation utility.

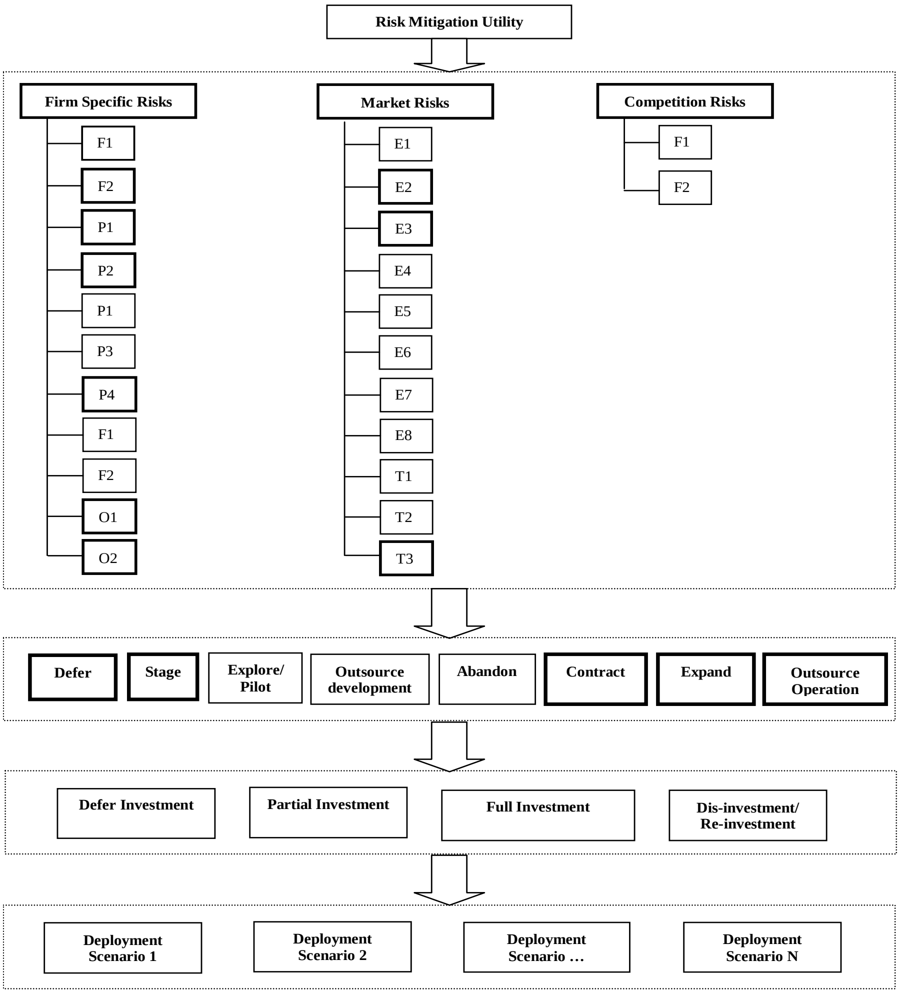

Figure 3. *The risk mitigation sub-module of the proposed framework*
(risks relevant to the ICT investment of the case illustration are indicated by bold boxes)

Summary

In order to maximize the risk mitigation utility, our methodology involves four main steps that must be repeated over time. These steps help to optimally configure the investment under the information set available initially. As time passes, they must be re-applied in case that some risks get resolved or new risks surface. In the following we present these steps.

- Define the content of the overall ICT business activity and its risk profile. State the investment goals, requirements and assumptions (technological, organizational, economic, etc.), and then identify the risks inherent in the investment.

- Recognize the options mapped to specific risks and use them to adopt investment modes to be examined.
- Evaluate investment-structuring alternatives (investment modes) and find a subset of the recognized options that maximally contributes to the investment value. For the evaluation of the structuring alternatives we use AHP analysis and perform pair-wise comparison for the alternatives concerning the most efficient control of various types of risks.
- Perform sensitivity analysis in order to understand the contribution of each risk factor control in the overall risk control utility.

5. A SPECIFIC E-LEARNING BUSINESS ACTIVITY

Description of a specific E-learning Business Activity and NPV analysis

We examine a business activity to establish an enterprise which will offer services for learning foreign languages through the World Wide Web (Mantzari and Economides, 2004). The users of our services will be students and adults having access to the Internet. The base scale investment concerns learning English. It is matter of further growth investment opportunity to provide services for other foreign languages. The courses are developed digitally on a special educational software platform that is purchased to cover the needs of our company and it is installed on the collocated server. Afterwards the users of our services submit their own personal passwords and ID's in order to get connected to the server and attend the lessons through the Internet. Competitive advantages of such business model for providing distance-learning services comparing to the conventional syllabus are: i) the absence of traditional classrooms which leads to reduced Operating Costs, ii) the absence of traditional way of teaching which reinforces autonomous learning, iii) offering services 24h a day, 7days a week that leads to maximum exploitation while at the same time it is more convenient for the users, iv) flexible pace of attending the lessons, and v) reduced fees due to the continuous functioning and the reduced operating costs.

Some investments assumptions

We examine the investment performance assuming an 11 years period of analysis and assume that all cash inflows and outflows are discounted at the risk-free rate r_f=5%. We consider a risk free rate 5% according to the rate of return on Greek's Treasury Bills. In addition, we separate the investment's costs, as seen in appendix B in two phases: a) in the initial phase of establishing an e-learning organization, the costs depend mainly on the number of courses (considering a large number of students), b) in the latter phase of operating it, the costs depend on the time duration, on the number of courses and on the number of students, these costs are divided in fixed and variable cost. We consider as entry time to the market (to implement the investment) when customers (students) demand is such that the operating revenues are equal to the operating costs (Mantzari and Economides, 2004).

Methodology application for an e-learning business activity

Our target is to justify economically the investment of launching e-learning activities in the Greek market. Among others, we have to decide:

1. What is the entry time into the market?
2. What is the scale to enter?
3. What is the optimum way to configure investment in order to minimize risk and maximize profitability?

We follow the aforementioned four steps:

Step1. To define the investment plan and its risk

Here we define the investment content, goals and requirements. We start with an initial ICT solution, stating investment assumptions (economic, technological, organizational, etc.), and revealing the investment risks in light of these assumptions. These activities should be carried out relative to each of the stages in the investment lifecycle. In our case, we consider the recognition, building, and operation stages, as well as the involved risks that fall into these stages (Table 2).

Stage	Goals	Risks and Opportunities
Recognition	To establish an enterprise which will offer services for learning foreign languages through the World Wide Web	Environmental (E1) - Low customer/student demand that might not be profitable to let investment pass from the Recognition to Building stage. Firm has to decide when to enter in the market and in what scale.
Building	The initial e-learning solution involves developing an infrastructure platform that will support distance learning languages services	Project (P1)/Organizational (O1) - Firm staff may lack experience on linking ICT technologies with content applications such as educational issues. Functionality (F1) - The firm may build the application right according to the required specifications, but still fail to realize the anticipated benefits because the requirements are wrong to begin with. This could result to poor application functionality
Operation	Support e-learning services for foreign languages	Environmental (E1) – low customer demand could make it non economical to let the investment live long. Environmental (E2) - demand exceeds expectations (follow-up opportunities exist). Environmental (E3) – too high customer demand could result in an inability of the back office of the firm to handle the extra processing load presented by customers/students. Competition (C1) – competitors could react by launching an improved application, and thus erode the extra demand generated produced by the e-learning application.

Table 2: First step of the approach applied to the e-learning investment

One risk would be an environmental risk. There is much uncertainty about the customer demand. Low customer demand can change investment profitability from positive to negative. Another risk would be a firm-specific capability risk. There is uncertainty about the firm's capability to efficiently integrate the initially planned scale of the ICT infrastructure with the required applications as well as with the content of them. Finally, the last area is competition risk since a competitor could react by launching improved applications that will erode revenues from future customers.

We initially assume that all these risks affect only the expected revenues and not the cost. Actually, cost influences directly the revenues too. Afterwards, we examine the impact of the cost's uncertainty on the investment's profitability.

Step2. Recognize shadow options based on risk characteristics

In the next step, we recognize shadow options that the investment could embed based on the aforementioned investment risks. The target is to configure the investment plan by using these options in a way that risks are mitigated while overall profitability is maximized. Actually, investments risks can be, at least partially, handled by adopting managerial flexibility, through option analysis. Table 3 shows the main sources of the risks of the e-learning investment that we examine in this paper and the shadow options that we adopt in order to control them.

Risk Area		**Risk Opportunity**	**Investment Lifecycle Stages - Shadow Options Allocations**			
			Recognition	**Building**	**Operation**	
			Option to Defer	**Option to Contract scale of Investment**	**Option to Expand**	**Option to Choose between further Expansion and Contraction**
Firm Specific Risks	Project	**P1** staff lacks needed technical skills to successfully integrate and operate ICT infrastructure-applications with content	+	+		
	Functionality	**F1** wrong design (e.g. analysis failed to assess correct requirements)		+		
Market Specific Risks	Competition	**C1** competition's response eliminates the firm's advantage	+	+		+
	Environmental	**E1** low customer demand, with inability to pull out of market	+	+		+
		E2 demand exceeds expectations (follow-up opportunities exist)	+		+	+
		E3 too high customer response may overwhelm the application	+		+	+

Table 3: E-learning investment risks mapped to operating options that could mitigate them

Step3. Choose alternative investment configurations based on options exercise strategy

In the next step we identify alternative ways to configure the e-learning investment using different subsets of the recognized shadow options. Although, it may seem that the number of possible configurations could be large, only configurations involving maximal subsets of shadow (viable) options are worth considering (Benaroch, 2002). We next illustrate plausible investment configuration that considers five of the recognized shadow options (Figure 2).

Business assumptions

We assume that market entry takes place when demand level reaches the critical number of students and the *Investment Operating Revenues are equal to Operating Costs (we assume that this is reached at year T).*

We start our analysis considering that T is up to 3 years. We also consider that the construction phase of our platform is 1 year. Finally, we consider that critical mass for customers is reached at T=3. At the beginning, recognition phase, we face the option to defer investment up to time T in order to resolve market uncertainty concerning customers' demand as well as competition threat. The smaller the T the sooner we should perform investment and the smaller the option value to defer will be, since less amount of uncertainty is resolved. During time period T, the firm is facing market uncertainty "clearness" and decides to enter the market when investment starts to become profitable.

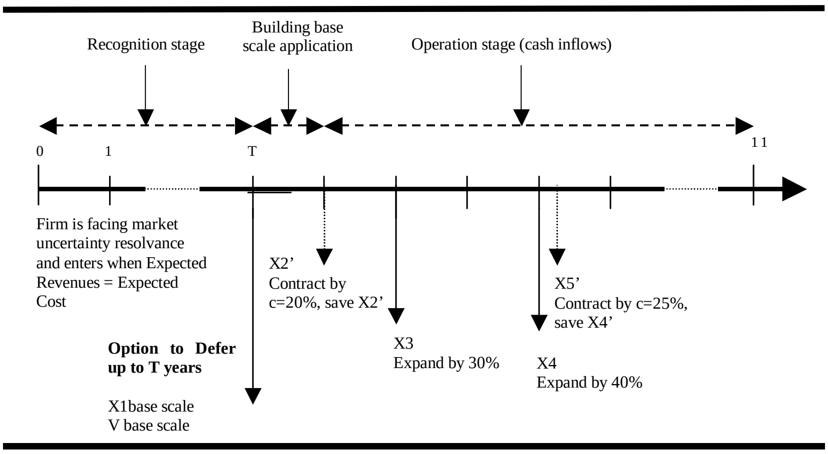

Figure 2: A configuration involving five of the shadow options that the e-learning investment can embed

1. The ***base scale*** option permits realizing the investment into one cost outlay X1 = 190.000 €, which is ***deferrable*** for up to three years, in order to resolve market uncertainty.
2. The option to ***contract*** the initially planned scope of operations by 20% saving so in cost operations X2' = 30.000 €.
3. The option to ***expand*** further operations in case of favorable customers demand by 30%, by making a third cost outlay, *X3 =55.000* € (it is one third of the initial infrastructure investment)
4. The options to choose between expand and contract operations.
   The ***expand*** option permits scaling up operations by 40%, by making a fourth cost outlay, *X4 =75.000* €, for the base scale
   The option to ***contract*** scope of operations by 25% saving so in cost operations X5' = 35.000 €.

Option exercise costs and revenues to expand – Contract operation presented above concerns base scale operations and single options analysis. In case of compound option analysis, expand and contract values as well as option revenues are changing according to predecessor option type.

Options Presentation

Our configuration considers five of the recognized shadow options (see Figure 2). In this work we consider only this deployment path. Additionally, we could consider other alternatives too, such as the deployment path that includes only the option to explore business activity. The option to explore would facilitate learning-by-doing, through a pilot effort that supports a part of the E-learning services while in case of favorable demand the full scale of the business activity takes place. In our analysis we consider a more complicated deployment path in order to control a large number of risks and show the applicability of our methodology. Finally, the high number of shadow options that are transformed to real ones does not necessarily indicate the maximum investment value since many of the options can control the same type of risks. In this case, the options are supplementary to the contribution of the overall investment value (Trigeorgis, 1996).

<u>During the recognition stage</u>

The first option is to defer the first cost outlay for up to three time periods (assuming that longer deferral would significantly increase the risk of competitive preemption). Deferral permits learning about the levels of demand experienced by other firms with comparable e-learning services, in support of resolving risks E1, E2 and E3. Deferral could also provide the time to get the cooperation of all parties so as to reduce risks F1 and P1. During the deferral period the firm faces the market uncertainty "clearing" especially concerning demand considering the trigger point to start investing when expected revenues becomes equal to investment's operating costs. Finally, competition threat, risk C1, from another firm can be at least partially resolved during deferral period.

<u>During the building stage</u>

The building firm's staff may lack experience on linking ICT technologies to content applications such as educational issues. In addition, the firm may build the application correctly according to the required specifications, but still fail to realize the anticipated benefits because the requirements are wrong to begin with. This could result to poor application functionality. In order to control these risks (F1, P1) we consider the option to contract, the initially planned, investment scale during the building stage. In addition, the competition risk (C1) (e.g. a competitor's response eliminates the firm's advantage) is reduced through the option to contract the initial planned investment scale. Moreover, customers' uncertainty E1 during the building stage can be mitigated by adopting the contract option. Finally, the aforementioned option to defer enhances the possibilities of mitigating such kind of risk during this stage, too.

During the Operating stage

The next option is the option to expand operations scale by 30% in year T+2 in case of favorable demand and risk mitigation E2 and E3. The last option is actually a combination of one call option and one put option having the same time to maturity. In time T+4 the firm possesses the option to choose between to expand or contract operation scale according to market conditions. Actually, the second option is to contract operations of the investment, by 25%, at time period T+4, in support of hedging risks E1 and E3. At the same time there is the call option to expand operations in case of high demand by making a fourth cost outlay. This option could control demand risk E2. In general a call option is optimally exercised when circumstances become favorable and a put option is exercised when circumstances become unfavorable. Finally, competition risk C2 can be hedged through the option to choose between contracting or expanding the investment scale according to the competitors actions that could either eliminate the firm’s market share or just influence the overall market demand for such kind of applications.

Step4. Options evaluation and Investments configurations alternatives profitability

In the final step, we evaluate the embedded options included in the configuration alternatives. Due to space limitation we do not present the process of evaluation, while the interest reader is referred to Angelou and Economides (2007a).

Option analysis and specific investments characteristics map

For the valuation of options we use the Log-Transformed Binomial Model (LTBM) with 50 steps time resolution. Also, the variance of payoffs is considered at $\sigma = 50\%$ as it is suggested in the literature (Oslington, 2004; Angelou and Economides, 2005).

Value of option Combinations with Interactions between each other

The value of an option in the presence of other options may differ from its value in isolation because of its strong interaction with these options. Trigeorgis (1996) provided a formal discussion of the factors affecting the “non-additivity” of the options. The valuation of complex options remains a difficult endeavor. Since e-learning investments could be exposed to multiple risks, they may need to be configured using a series of cascading (compound) options. Table 4 shows the value of the project with different combinations of the shadow options. In particular, the highest option value (in isolation) is the option to defer with value at 53,6 k€. For comparison, we give the values of the rest options (in isolation) at time where the operation stage is starting. The option to choose the strategy between contraction and expansion in year 7 presents the highest value (34,8 k€) among the rest of the options. Actually, the option to choose between expansion and contraction is the sum of the two separate options, the call option to expand and the put option to contract with the same expiration dates.

In our multi-option analysis we consider that the option to Defer is prerequisite for the rest of the options. This means that the option to defer should be included in any of the combinations of the embedded options that we analyze.

Adopting the two-embedded options analysis in the investment plan we can see that the option to Contract contributes negatively to its predecessor option to Defer since their combined value is 38,3 k€. This happens due to the fact that in case of exercising the contract option, the revenues V that correspond to the initially planned base scale investment, will be decreased. We consider that by contracting operation by 20% we have 10% decrease of the initial infrastructure cost, since the infrastructure is the basis and prerequisite for a range of future operating capabilities. On the contrary, the contribution of the option to Choose to the option to Defer is higher giving a value close to 64,2 k€.

In case of three options analysis for more efficient risk handling, the combination of options to Defer, Expand and Choose gives the highest value at about 67 k€. Finally, taking into account the total number of options the overall value is just 50 k€, since the option to contract operations contributes negatively to revenues V base scale of the option to Defer as in the two options analysis.

Hence, the most promising configuration deployment strategy is the combination of the options to DECH that presents the highest value for the investment profitability.

Option Combination	**Option Value LTBM 50 steps (values in k€)**	**ENPV (overall investment value)**	**Value at**
Defer **(D)**	53,6	50,6	t=0
Contract **(CN)**	3,1	0,1	t=T
Expand **(E)****	12,6	9,6	t=T+1
Option to Choose **(CH)***** (expand/contract)	34,8	31,8	t=T+1
DCN 1	38,3	35,3	t=0
DE 2	57	54	t=0
DCH 3	64,2	61,2	t=0
DCNE 4	42	39	t=0
DCNCH 5	48	45	t=0
DECH 6	67	64	t=0
DCNECH 7	50	47	t=0

Option Name	**Exercise Price X (for base scale)**	**PV(V) base scale**	**Year to maturity**	**Option Type**
Defer **(D)**	190	161 (187)	up to T=3	Americal Call
Contract **(CN)** (20%)	30	37	T+1	European Put
Expand **(E)** (30%)	55	56	T+2	European Call
Option to Choose **(CH)** (expand/contract) (40%/25%)	75/35	74/46	T+4	European Call/Put

In this case we consider that base scale investment results to V'=0,8V while X'=0,9X

** Option to Expand at time T+2, value at t=T

*** Option to Choose at time T+4, value at t=T+2

**** Option to Switch use between T+5 and 11, at t=T+4

ENPV = Option Value x 1.000 - 3.000

1 max (0,8V+CN-0,9X, 0)	We consider the Option to Defer and the Option to Contract
2 max (V+E-X, 0)	We consider the Option to Defer and the Option to Contract
3 max (V+CH-X, 0)	We consider the Option to Defer and the option to Choose betwee E and CN
4 max (0,8V+max ((Xc+E-0,2V,E)-0,9Xbasescale, 0)	……………………………………………………………………………..
5 max (0,8V+max((Xc+CH-0,2V,CH)-0,9Xbasescale, 0),	……………………………………………………………………………..
6 max (V+max((eV+CH-Xe,CH)-Xbasescale, 0) where e=0,3	…………………………………………………………………………….
7 max (0,8V+max((Xc+max(eV+CH-Xe, CH)-cV,max(eV+CH-Xe, CH))-0,9Xbasescale, 0)	……………………………………………

To mention here that these expressions do not give the value of three options all together since all are excercised in different time moments.

With this we want to indicate the logical model that we follow based on nested option analysis as presented by Herath and Park 2002

Finally, to mention that values for nested options are at times where their predecessor option is exercised.

In our analysis only option to Defer exercise is prerequisite for the next options

Table 4: comparative value contribution of options in the investment alternatives.

6. DISCUSSION AND FUTURE RESEARCH

The presented methodology enables the management to optimally configure technology investments under a multi-criteria perspective. It facilitates a systematic identification of investment's configurations by framing flexibility in terms of the risks that can be controlled by ROs. Otherwise, it supports a solid quantitative configuration valuation for the purpose of identifying the most valuable configuration. This does not mean that the methodology is perfect. One of the main difficulties is the way we estimate the variances of investment's revenues and cost.

The methodology has been applied to an e-learning case study. It can be quite easily extended to other ICT business fields. For example, Angelou and Economides (2008a; 2006) applied the ROs analysis to find optimum investment deployment strategy in the Broadband investments business field under competition threat that can eliminate part of the business value during deferring period.

In general, the method can be applied in business cases where investments contain wait and see components (deferring periods) as well as risk issues that can be controlled and partially resolved by ROs analysis. In case of competition, it is a matter of compensation between uncertainty control achieved by the ROs analysis and competition threats from other competitors that can enter sooner into the market, while the firm under investigation is waiting, and eliminate the available investment value. Under this analysis, the competitors can arrive randomly following a Poisson distribution (Trigeorgis, 1996). This is more valid in case of high number of competitors (players) where exogenous competition modeling is more practical. In particular, it can be considered that there is an e-learning platform that can support a number of e-learning courses, to similar scientific fields, provided by the firm (institution) of interest. However, other organizations (e.g. universities) can also provide similar courses causing degradation to the investment opportunity which is available to the organization of interest.

In case of limited number of competitors (oligopoly), endogenous competition modeling is required adopting the ROs with game theory. In this case, each of the players (competitors) will choose their optimum investment deployment strategy. The game equilibrium will be the deployment strategies or ROs implementation, which will maximize the utility of each player. It is a subject of further work to consider a real competitive environment and customize or enhance existing ROs models evaluation based on compound options analysis under endogenous competition modeling.

7. CONCLUSION

In this work, we present a ROs methodology for controlling risk and choosing the optimum ICT investment's deployment strategy. We apply it to the e-learning infrastructure business field (Mantzari and Economides, 2004). The target is to find the optimal investment's configuration, to handle more efficiently the investment's risk and so to increase its overall performance. The results of our analysis show that by adopting multi-option analysis in a compound basis can enhance investment performance. The specific e-learning investment scenario appears to be more profitable when we adopt ROs analysis instead of NPV analysis, taking into account the same business assumptions given by Mantzari and Economides (2004) case study. In addition, we apply both revenues' and cost's uncertainties modeling estimating the impact of the investment's cost uncertainty to the options' value as well as to the overall economic performance. The e-learning investment's profitability appears even higher. Actually, as the project uncertainty is increasing, the managerial flexibility achieved by adopting ROs contributes more to the final economic performance. Finally, it is the subject of further work to consider a real competitive environment and customize or enhance existing ROs models evaluation based on compound options analysis.

REFERENCES

Angelou, G.N. & Economides, A.A (2008a). A Real Options approach for prioritizing ICT business alternatives: A case study from Broadband Technology business field. Journal of the Operational Research Society. Forthcoming.

Angelou, G.N. & Economides, A.A. (2008b) "A decision analysis framework for prioritizing a portfolio of ICT infrastructure projects". IEEE Transactions on Engineering Management – Forthcoming.

Angelou, G.N. and Economides, A.A. (2007) E-learning investment risk management. Information Resource Management Journal, Vol. 20, No. 4, pp. 80-104, October – December.

Angelou, G. and Economides, A. (2006). Broadband investments as growth options under competition threat. FITCE 45th Congress 2006, Athens, Greece.

Angelou G. and Economides A., 2005. Flexible ICT investements analysis using ROs. International Journal of Technology, Policy and Management, 5(2):146–166.

Benaroch M., 2002. Managing information technology investment risk: a ROs perspective. Journal of Management Information Systems, 19(2): 43-84.

Bodin L., Gordon L. and Loeb M., 2005. Evaluating information security investments using the analytic hierarchy process. Communications of the ACM, 48(2):78 - 83

Expert Choice, 1995. Expert Choice for windows based on Analytic Hierarchy Process, Version 9, User Manual, Pittsburgh, PA.

Hallikainen P., Kivijarvi H. and Nurmimaki K., 2002. Evaluating strategic IT investments: An assesment of investment alternatives for a web content management system. Proceedings of the 35th Hawaii International Conference on Systems Sciences.

Gunasekaran A., Love E., Rahimi F. and Miele R., 2001. A model for investment justification in information technology projects. International Journal of Information Management, 21: 349-364.

Iatropoulos A., Economides A. and Angelou G., 2004. Broadband investments analysis using ROs methodology: A case study for Egnatia Odos S.A. Communications and Strategies, 55(3): 45-76.

Kim J. and Sanders L., 2002. Strategic actions in information technology investment based on real option theory. Decision Support Systems, 33: 1-11.

Kim J., 1998. Hierachical structure of intranet functions and their relative importance: Using the analytic hierarchy process for virtual organizations. Decision Support Systems, 23:59-74.

Lai S., Trueblood P. and Wong K., 1999. Software Selection: a case study of the application of the analytic hierarchy process to the selection of multimedia authoring system. Information & Management, 36: 221-232.

Mantzari, D. and Economides, A. (2004). Cost analysis for e-learning foreign languages. European Journal of Open and Distance Learning, November, issue 2, vol 1, http://www.eurodl.org.

Mun J., 2002. ROs Analysis: Tools and techniques for valuing strategic investments and decisions, Wiley Finance.

Oslington, P. (2004). The impact of Uncertainty and irreversibility on Investments in Online Learning. Distance Education, vol 25, No. 2.

Renkema, T., (1999) The IT value quest: how to capture the business value of IT-based infrastructure, Jhon Wiley & Sons, Ltd.

Roper-Lowe G, and Sharp J., 1990. Analytic hierarchy process and its application to an information technology decision. Journal of Operational Research Society, 42(1): 49-59.

Saaty T.L and Vargas L.G., 1994. Decision making in economic, political, social, and technological environments with the analytic hierarchy process. Pittsburgh: RWS Publications.

Santhanam R. and Guimares T., 1995. Assessing the quality of institutional DSS. European Journal of Information Systems, 4: 159-170.

Schniederjans M., Hamaker J. and Schniederjans A, 2005. Information technology investment – decision-making methodology. Singapore: World Scientific Publishing.

Tam M. and Tummala R., 2001. An application of the AHP in vendor selection of a telecommunications system. Omega, 29: 171-182.

Trigeorgis L., (1996), ROs: managerial flexibility and strategy in resource allocation. The MIT Press. Cambridge MA.

Zhu K. and Weyant J.P., 2003. Strategic decisions of new technology adoption under asymmetric information: A game-theoretic model. Decision Sciences, 34(4): 643-675.