Real Options for Risk Management in Information Technology Projects

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Abstract

Given the rapid pace of technological innovation, IT projects (especially software projects) are fraught with technology risk. Anticipating the pace of future innovation is difficult but essential. Furthermore, once a decision is made to invest in a current technology, additional risks are involved in deciding exactly how much to invest at each stage of the implementation process. Financial options are extensively used for risk management in various industries. Real or embedded options are analogs of these financial options and can be used for evaluating investment decisions made under significant uncertainty. Real options can be identified in the form of opportunity to invest in a currently available innovative project with an additional consideration of the strategic value associated with the possibility of future and follow-up investments due to emergence of another related innovation in future. In this paper, we explain how option valuation techniques can be used for assessment and management of risks in the adoption of technological innovations. We also present a new risk-driven process framework that is well-suited for risk management of software projects.

1. Introduction

Given the rapid pace of technological innovation as well as changing economic and sociological environments, information technology (IT) projects are inherently risk-sensitive. Unfavorable events such as component integration mismatch, non-compliance of standards etc. result in substantial loss for the project in the form of (a) overrunning estimated costs and time schedule and (b) affecting quality and reliability of the product. Efficient risk management methodologies must be devised and implemented in order to avoid, minimize or transfer the risks to external entities. The events that cause unfavorable impacts can be analyzed and decomposed into their root causes. The key risk factors thus identified are:

(a) Technology risk -- uncertainties in technological advancement which has twofold effects. Technological progress changes the environment and causes events like “feature creep” arising from continuous stream of changes in the requirement of features during the course of development of the project. On the other hand, arrival of innovations in the technologies applicable to the project under consideration gives rise to questions regarding adoptions of these innovations to stay ahead in competition.

(b) Resource risk -- uncertainties in the price and availability of the resources required for implementation of the project.

(c) Communication risk -- lack of communication among various groups of developers and also between the management and the developers.

(d) Business risk -- position and maturity of the firm in its business environment, according to the “Capability Maturity Model” (CMM) designed and developed by the Software Engineering Institute (SEI) at Carnegie Melon University (CMU).

(e) Sociological factors -- inefficient work atmosphere, employee dissatisfaction, non-compliance by the employees to their assigned roles and responsibilities, resistance to accept innovations etc.

Consider the case of “integration mismatch”. The primary causes can be resource risk due to non-arrival of sufficient resources uniformly to all the groups involved in the project, communication risk due to lack of proper interaction among the groups and other sociological factors such as non-fulfillment of assigned responsibilities etc. On the other hand, feature creep can be caused by a combination of technology risk as explained above and sociological factors like change in management, changes in company policies etc.

Different approaches can be adopted to deal with each of the key risk factors [5, 13]. Risk control actions are
often prescribed for each risk factor to avoid, mitigate or transfer the risks. However, most often these actions are empirical or heuristic. Technology risk is one of the most vital factors for an IT project given the rapid pace of technological innovation. Most of the IT companies realize the existence of technology-related risks, but very few are able to translate these risks into business implications [3]. Effects of sociological factors are rarely considered appropriately. In this paper, we have developed a framework that is oriented towards software project development in particular but can be generalized for any IT project development and that involves risk analysis studies as an integral part.

Risk assessment and management are common practices in the financial world. Meaningful measures of risk have been defined that summarize the probability and impacts of unfavorable events. Further, many useful techniques have been devised and implemented to eliminate, diversify or reduce the risk involved in financial markets [6, 16]. These measures and techniques have already been found useful for assessing and managing risks associated with research and development, capital investments, operation of industrial plants etc. We have developed a methodology for managing technology risk using financial techniques. We have organized this paper as follows: section 2 discusses the evolution of real options methodologies and their applicability in project management, section 3 presents a survey of the relevant work by engineers and economists in the literature, section 4 presents the proposed spiral-circle framework for risk-based software development and section 5 explains the precise formulation of the real options problem and the evaluation techniques. Concluding remarks are presented in section 6.

2. Real Options Methodologies

The real options methodologies were preceded by the traditional Decision Tree Analysis (DTA) that helps management structure a decision problem by mapping out all feasible alternative actions over time contingent on chance events in a hierarchical or “tree-like” manner [15]. Probabilities for the chance events need to be assigned based on historical data, modeling or judgements by experts. To solve the tree, one starts at the terminal date, recursively computes expected payoffs and chooses the best decisions. Probabilistically weighted average of payoffs corresponding to chance events at a chance node associated with every decision at a decision node provide expected payoff resulting from such decisions. The decision providing maximum the expected payoff is chosen. Present values of payoff corresponding to the chance events at the chronologically previous stage are computed by time discounting expected payoff associated with the downstream decision. The net present value, incorporating benefits of flexibility, can thus be found at the root of the tree.

The main shortcoming of DTA is the problem of determining the appropriate discount rate to be used in working back through the decision tree. A single (or constant) risk-adjusted discount rate cannot be used since asymmetric claims on an asset with limited downside risk and unlimited upside risk do not have the same expected rate of return as the underlying asset itself [15].

The options techniques are rectified versions of DTA that are able to value the managerial flexibility that limits downside risk. Computations are made independent of individual risk preferences by transforming into a “risk-neutral” domain, although the effects of risk adjustments are incorporated. Recent work in financial economics has led to the concept of “real options” [11]. A real option can be viewed as an opportunity to acquire/dispose real assets at a negotiated price on a pre-specified strike date where the holder of the option has the right but not the obligation to purchase/sell an asset. An investor desiring to purchase an asset buys a “call” option whereas the owner of an asset buys a “put” option. A real option can be American if it can be exercised on or before the strike date or European if it can only be exercised on the strike date. On a settlement date, against a premium the trader buys an opportunity to postpone his decision to purchase/sell an asset until more information become available. The strike date, depending on profitability as determined with the current market prices, the trader decides to exercise the option or otherwise. The downside loss is limited to the premium paid (option is not exercised) instead of the entire investment whereas the upside gain is unlimited (option exercised). A hedger buys/sells options to be able to eliminate/reduce/diversify the risk associated with his asset or business whereas a speculator does so purely for monetary gain.

![Figure 1. Value of a call option](image-url)

In any real world investment of resources, it is possible to identify real options [11]. A student has the option to borrow and invest money for higher educational
purposes immediately or postpone his studies until he can gather enough money by taking up a job. Likewise, in project management, a manager has to carefully analyze the returns, both short-term and long-term, before allocating resources into a particular project [10]. Depending on the physical constraints on the ability to exercise the option, the above options can be identified with either American call options or European call options in the financial market. Appropriate valuation methods can also be adopted from financial world to evaluate the options.

The options approach also computes the “strategic” option value of a project taking into account its interdependence with future and follow-up investments [12, 14, 16]. In many cases, the investment in a particular project is divided into a number of phases where at the end of every phase, the project performance is reviewed to decide on the continuation of the project. The investments in the earlier phases can be viewed as premiums for a larger investment, which is the total cost of the project. If further investment is found to be unsuitable, the downside loss will be the investments made so far, excluding the benefits out of building of knowledge, gaining of experience or use of the intermediate product developed in the earlier phases. Otherwise, the follow-up investment can be postponed until a time when the immediate investment would be more profitable than delaying it any further. This resembles an American call option in the financial world. It can also be path-dependent if we consider the benefits of an exploratory research resulting in ruling out the necessity of one or more early phase.

3. Prior Relevant Work

Avinash K. Dixit and Robert S. Pindyck, in their book “Investment under Uncertainty” [11] have presented the drawbacks of the historical “net present value” (NPV) approach to capital investment decisions. They have shown the inadequate consideration of irreversibility, uncertainty and the opportunity to delay, associated with an investment in the NPV approach. The cost associated with losing the opportunity to wait for additional information before taking a major investment decision was shown to have significant effect on the value of a potential investment. The authors have shown how techniques using “dynamic programming” (DP) and “contingent claims analysis” (CCA) can incorporate the above factors. Uncertainties were represented as stochastic processes. Financial options were shown to represent the irreversible and flexible investment opportunities for a firm, and techniques of DP and CCA were shown to be useful for valuation of such options. These techniques were also found to be useful by the authors for decisions regarding suspension/abandonment of a production plant, temporary/permanent labor employment and many other economic and non-economic applications.

Graham R. Mitchell and William F. Hamilton [12, 14] expressed concerns that the U.S. industry is primarily driven by short-range financial perspectives viz. either knowledge building/exploratory research or return on investments (ROI) attuned to easily quantifiable results. The potential major advances and innovations that can arise out of long-term projects are not considered in many industrial firms. They indicated that a number of R&D situations involving applied research, exploratory development etc. typically do not fit the two prevailing viewpoints: (a) necessary cost of business associated with exploratory research and (b) readily implementable business investment.

This form of R&D was described as concerned with reducing technical uncertainties and building a strong technical position. They presented an approach for “managing R&D as a strategic option” (strategic positioning) by treating a current R&D project as financially directed towards creation of an option on a potentially profitable follow-up investment for a future project. Value of the option was shown to be dependent on identification of strategic objectives and positioning targets and impact of strategic options.

Michel Benaroch and Robert J. Kauffman in their paper [1] chose the specific area of using option pricing models (OPM) to a real world business investment situation involving information technology (IT). Flexible investment opportunities in the face of business uncertainties were viewed as resource options and their valuation was suggested using option valuation. For investment opportunities that can be delayed, the significant value of the ability to wait for further information and thereby avoid potential losses were found to be absent in the NPV approach. This method of valuation was found to be generalizable for application to other IT investment settings. Similar applications of
options techniques to problems related to capital investments, operational strategies and resource allocation by other engineers and financial economists are also found in the literature [7,8,9].

Recent work by Steven R. Grenadier and Allen M. Weiss [4] uses the option pricing approach for determination of optimal investment strategy by a firm facing a sequence of technological innovations. Four potential migration strategies were identified:
(i) a “Compulsive” strategy of purchasing every innovation;
(ii) a “Leapfrog” strategy of skipping an early innovation, but adopting the next generation of innovation;
(iii) a “Buy-and-Hold” strategy of only purchasing an early innovation;
(iv) a “Laggard” strategy of waiting until a new generation of innovation arrives before purchasing the previous innovation.

The authors have attempted to elicit the forces that drive the differences in the probabilities of pursuance of each of the migration strategies and expected time of adoption of an innovation by a firm. These forces are shown to be dependent on the market (industry) as well as firm specific factors e.g. its policies, history of adoption of innovations etc. Important characteristics of real-world technology markets e.g. consideration of ability to respond to future innovations while confronting adoption of a current innovation, uncertainty in the timing and significance of future innovations, realistic cost-concerns etc. were incorporated.

It is evident from a survey of prior relevant work that since the nature of technology risk management problems in IT projects is very similar to those involving flexible capital investment and project management decisions, real options methodologies can be used. Mitchell and Hamilton first applied options techniques for strategic positioning in R&D project management. The flexibility associated with investment decisions in the business investment phase is not included in their work. Benaroch and Kauffman identified real options in IT business investment situations, but they only concentrated on the initial investment decision. That is, they did not consider the migration strategies and firm/industry characteristics that are relevant in the current context of rapid technological innovations. Grenadier and Weiss presented the migration framework for a firm facing a sequence of technological innovations, but they did not delve into a detailed analysis involving individual project management. We develop a methodology for technology risk management that is refined and extended from the migration framework suggested by Grenadier and Weiss, incorporated as an integral part of a software process model derived and modified from the ideas of Barry Boehm. Additional risk factors in such applications are numerous and include social factors such as acceptance by end users that are nontrivial to model.

4. A risk-driven model for Software Process

Our approach begins with the realization that management of technology risk in software projects can be best performed as an integral part of the software development process itself. Consequently, we have developed a risk-driven spiral-circle model for the software process as shown in fig.3, which was derived on the ideas presented by Barry Boehm [2]. Simply put, the circles are prototypes and each cycle of spiral is the process between the consecutive prototypes.

❖ The first step for the initial stage involves planning for the entire project. This includes preparation of initial specifications document through elicitation of requirements and division of the project into a number of meaningful stages. A prototype is expected at the end of each stage, building on the prototype of the previous stage according to the development plan selected for the stage. In all the subsequent stages, the first step involves planning for the remaining stages through evaluation of the current specifications document in the light of changes in the environment and requirements and the prototype of the previous stage. The document is suitably modified to incorporate the changes as found necessary.
❖ The next step in each stage involves selection of objective for the current stage and identification of
the alternative methods of implementation along with the existing constraints.

- The next step involves risk analysis studies performed to evaluate (a) the profitability of continuing with the project and (b) the alternative development plans against the objectives and the constraints identified in the previous step. Along with analyzing and managing some of the other risks involved in the development process, innovative technologies available are evaluated against the existing technologies to decide on whether to adopt the former. A real options approach can cater to the technology risk evaluation needs, as described in section 6. If continuation of the project is found feasible and profitable, development plans are formalized. The portion of the spiral up to the next prototype will be determined based on the chosen development plan.

- Actual development and integration of components and testing are performed at the next step. A working prototype is obtained at the end of this step.

5. Real Options for Management of Technological Innovations

Managerial decisions regarding adoption of technological innovations are crucial due to the following reasons: (a) to meet the changing requirements in an evolving environment caused by technology risk and (b) to make the product one of the most attractive ones by incorporating state-of-the-art features to stay ahead in the competitive IT industry.

Analysis will begin with identification of innovative technologies, if any, with proven performance in areas related to the project at hand. This will be followed by evaluation of the current position of the firm to determine its ability to venture into adoption of any of these new technologies. Careful consideration of the expertise of the employees in the firm, the costs associated with resource acquisition and training, the firm’s policies and history of adoption of innovations by the firm will be required. A shortlist of technologies for further consideration will be obtained as a result of this analysis.

Option valuation techniques can be used for evaluating and comparing conventional and innovative technologies which will be useful as a decision aid for the project manager. Real options can be identified in the form of opportunity to invest in a currently available innovative project. In addition, the value associated with the strategic option in terms of the possibility of emergence of another innovation in future wherever applicable should also be included to determine the net worth of an investment in the adoption of an innovation at hand. The method incorporates some of the ideas presented by Grenadier and Weiss. The following assumptions are made:

- A sequence of evolutionary innovations is expected to arrive during the course of the project. A future innovation will provide enhancement on the earlier innovations in technological sense.
- Adoption of innovations can occur only at discrete times when risk analysis is performed for each stage.
- The objective of the risk analysis is to aid the manager in deciding for the current development plan, whether (a) to continue using technologies already in possession of the firm (which may include an innovation adopted earlier) or (b) to adopt an innovation that became available earlier or (c) to adopt a new innovation that just became available. It is generally impractical and uneconomic to consider adoption of an innovation that is not suitable for the current stage, but may be useful for a later stage.
- The “state of technological progress” (STP) follows a stochastic time-dependent process. Most often, a geometric Brownian motion is chosen.
- Suitable tools are available with the firm for estimating the costs to be incurred and revenues that are expected to be generated by the final product in its various forms depending on the technologies used to develop the product. This assumption is quite realistic since without such a tool, a firm will never be able to correctly estimate its position in the future and enter into negotiations with a customer.
- The value added from adoption of an innovation is reflected through (a) direct revenues expected to be generated from the current stage as well as any later stage and (b) a strategic value in terms of reduction of implementation cost of only the immediate next innovation (compliant with the evolutionary nature of the innovations). In terms of real options, the option to invest on a current innovation has the embedded option to invest on a future innovation at a reduced cost. This kind of option on another option is referred as “compound options” in the financial world. The value of this option can be compared against pre-decided threshold to decide whether to adopt the current innovation.
- The cost of adoption of an innovative technology depends on STP which in turn is a function of time. For example, in an advanced technological environment, the costs of resources may be significantly reduced. Moreover, the cost will be maximum if it is adopted as soon as it becomes available and performance found reliable. If it is adopted only when a future innovation becomes available (“laggard strategy” [4]) then the cost will be significantly reduced. If adopted at an intermediate time, the cost will be lower than the first case, but higher than the second case.
- Development plans once adopted cannot be made obsolete during the course of the project such that a
previous stage needs to be redeveloped using a new technology. However, upgrades are not ruled out, which can be incorporated in the development plan of a subsequent stage.

The first step is to model STP as precisely as possible since the complete analysis will depend on this model. Quite often, geometric Brownian motion is assumed for the process and parameters are determined based on historical information.

The next step will be to determine the value of the compound option. The return on investment on a particular innovation has two components: (a) the direct return from the current innovation and (b) value of the option to invest in the future innovation. The direct return is computed using the return evaluation tool mentioned earlier. It requires the model for STP for estimation of future revenues. The return will depend on the current strategic position of the project not including the value added through innovations already applied, the history of success/failure by the firm while adopting innovative technologies, any later stages that are expected to use the same innovation and other sociological factors. Many of these factors will have to be estimated based on available current information. The second part of the return, i.e. the value of the option to invest in the immediate future innovation is the expected discounted payoff from the future innovation and has an inherent assumption that the current innovation is already adopted. Hence, the problem is recursive by nature and it has to be solved by starting at the last innovation that is expected to arrive.

**Figure 4(a). Evaluation of the option to adopt an innovation that is part of a sequence of related Innovations**

**Figure 4(b). Evaluation of an option to adopt a “current” innovation that is followed by a sequence of related Innovations**
The option valuation algorithm is depicted in fig.4. The model for STP will provide an estimate for the time of arrival of all the future innovations that are expected within the schedule of the project. The last innovation will only have a direct return which, along with the cost of implementation can be easily estimated recognizing the fact that the very existence of the option for adoption of the particular innovation implies that all the previous innovations were adopted. The expected value addition will be computed by the return evaluator and the discounted (at the risk free rate since risk neutral environment is adopted for evaluation) expected payoff will be the value of the option embedded in the immediately preceding, i.e. the penultimate innovation. This option value will be combined with the direct return computed using the return evaluator to determine the net return on investment in the penultimate innovation. This process will continue until we arrive at the current innovation. If the value of the compound option for the current innovation is below the pre-selected threshold, the alternative is discarded. Otherwise, the value is noted. This process is repeated for all the existing and innovative technologies and the one associated with the highest value of the compound option is selected to be adopted in the development plan for the current stage. If none of the alternatives provides an option value more than the threshold, it would be advisable to abandon the project.

6. Conclusion

Our spiral-circle framework for project development provides opportunity to integrate risk analysis studies at every stage of the project which will serve to provide periodic evaluation of the overall performance. The real options approach for managing technology risk provides the best technique available so far that endogenously considers managerial flexibility and strategic value of the project. Realistic assumptions are made while deriving the technique. If the required inputs can be collected appropriately, the real options methodology can be implemented to provide very useful results.

References