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A Real Option based Six Sigma project evaluation and selection model

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Abstract

Identification and selection of Six Sigma projects are one of the most frequently discussed issues in the Six Sigma literatures today. In this paper a two-stage methodology has been proposed based on (i) Real Option Analysis for evaluating the value of the project to improve the managerial flexibility (ii) a zero–one integer linear programming model for selecting and scheduling an optimal project portfolio, based on the organization's objectives and constraints. The methodology is illustrated through a case study from petrochemical industry carried out during 2007. The study contributes to managerial practices by identifying a new way of valuing the Six Sigma projects through Real Option Analysis by considering various kinds of risks. Resource-constrained environment has been chosen to test the proposed approach of selection of project portfolio and the model is validated with a detailed discussion.

Keywords: Six Sigma; Project evaluation and selection; Real option; Project portfolio

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1. Introduction

Businesses today are challenged by continually changing business environment. To remain competitive in the global business, organizations need to continuously upgrade their technologies and processes, comply with the changing statutory provisions besides keeping their expenses under control. Under such competitive and constrained situations, organizations have no choice, but to undertake transformational initiatives which can facilitate implementation of new business strategies. Six Sigma has emerged as the most effective business transformational initiative in recent times. Most of the researches on successful implementation of Six Sigma point to "selection of right projects" as one of the key success factors. Kwak and Anbari (2006) suggested that among several key factors, the project selection plays a very vital role in effective introduction and implementation of Six Sigma. Pande et al. (2000) opined that good project selection is itself a process and if properly carried out, the potential benefits of Six Sigma can improve substantially. As companies become more mature in their Six Sigma programs, they start expecting more benefits using fewer resources. Hence it appears that the success of six sigma program lies in, the ability of management to select the right mix of Six Sigma projects that maximize business impact with fewer resources allocated to them. That apart, the process of identification of a subset from a set of projects i.e. portfolio of projects, which can successfully achieve the multiple objectives under constrained resource conditions is also yet another critical decision for any organization to make.

At macro level the investments in Six Sigma projects can be viewed as capital investment projects. Capital investments share three common important characteristics; i.e. (1) they can be partially or completely irreversible, (2) there is uncertainty over the future rewards from the investment, and (3) the managers have some leeway about timing of the investment (Dixit and Pindyck, 1993). Traditional financial theory suggests that firms should use Discounted Cash Flow (DCF) approach to analyze capital allocation requests for projects. Estimated cash flows from an investment are discounted to their present value at a discount rate commensurate with the project risk. However, the assumptions made in calculating the value of investments are known to have some drawbacks. According to Miller and Park (2002), these methods require the assumption of certainty of project cash flows, but fail, when used to evaluate strategic

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investments where payoff is uncertain or at risk. That apart, DCF technique ignores the need for flexibility to modify decisions during the course of the project, as and when new information arrives. These passive methods may be appropriate in deterministic situation, but might not be so under conditions of uncertainty. Another limitation in Six Sigma project is that the existing literature is silent about the risks associated with project. The expected payoffs of the projects may fluctuate owing to the risks related both to the project and market. Since, typical Six Sigma project investments could be exposed to more than one source of risks, it is necessary to find ways to model and evaluate such investment vis-à-vis the related risks. It is also very imperative to impart flexibility in managerial decisions, by identifying the various options embedded in the project.

A review of literature strongly points towards the Real Option Analysis as a competent approach to overcome the above demerits. Copeland and Antikarov (2001) have formally defined real option as: “A real option is the right, but not the obligation, to take an action at a predetermined cost called the exercise price, for a predetermined period of time”. Real Option Analysis presents an attractive alternative to the existing valuation methods as it explicitly accounts for the value of future flexibility in decision-making (Trigeorgis, 1996). Hence the option values of the projects not only act as a real value of the project, but also augment the flexibility in decision making. Keeping in view the above challenges, the study aims at testing yet another approach for improved and flexible decision making by the managers under constrained resource conditions and associated risks. This paper tries to explore the following questions:

- How to evaluate Six Sigma project investments, especially when it is exposed to multiple sources of risks
- What are the options embedded in Six Sigma projects and how it can enhance the managerial flexibility in decision-making and add value to the Six Sigma projects
- How to select and schedule a portfolio of projects based on organization’s objectives and resource constraints to provide maximum value to the Organization

This paper deals with the application of real option approach to evaluate and prioritize a portfolio of Six Sigma projects. The main contribution of this paper is a model developed through the application of methods from operation research and financial engineering. Implementing this project selection method will put the Six Sigma program on a sound financial basis, to ensure that it continues to be the approach for Organizations, far into the future. The proposed model provides a better understanding of the Six Sigma project valuation in light of various risks and offers provisions of flexibility in managerial decision making and in terms of its investment and payoff potential.

In the next section we discuss related works, which include work on real options, first on project and then on various approaches on project selection. In the section that follows we present our methodology, which includes real option approach and portfolio optimization steps. Our approach has then been tested through a case study, carried out in a petrochemical industry. The last section comprises of the summary of results, limitations of the study and conclusion besides throwing light on the scope for future studies.

2. Review of literature

In this section the works of various authors have been reviewed under two major heads viz. application of real options on projects and project portfolio optimization.

2.1. Application of real options on projects

First coined by Meyers in 1977, the real option framework facilitates decision makers with the options to invest, grow or abandon a project contingent upon the arrival of new information. The literature available on real options is quite exhaustive. A review of literature reveals that a lot of research work has still date been carried out on applications of real options on Research & Development (R&D) and Information Technology (IT) projects. The most recent ones being the application of real options to R&D projects by Schneider et al., 2008; and Eckhause et al., 2009; while Schwartz and Zozaya-Gorostiza, 2003; Kumar, 2002 in IT projects. Costa and Paixao (2010) has applied real option techniques such as contingent claim analysis and dynamic programming for project evaluation when the project develops stochastically over time and the decision to invest into this project can be postponed. Similarly Helga et al. (2001) have proposed a simple capital budgeting model for finding the portfolio of options that has maximum value and fulfills the capital expenditure constraints. However these approaches have some shortcomings regarding its applicability in traditional budgeting situations. Though there are many applications of real options to various types of projects, studies pertaining to application of real options on Six Sigma projects are conspicuously limited. Mawby (2007) suggested that real option application on Six Sigma projects will give more dynamicity to the selection of portfolio of Six Sigma projects. Recently Tkac and Lyocsa (2009) proposed a new model based on real options approach for evaluating Six Sigma projects, which involves the stochastic nature of project outcomes, cost and uncertainty regarding future payoffs and managerial options. However the usefulness of this model in practice may be perceived as limited due to its computational complexity and difficulty to use in real life situation.

2.2. Project portfolio optimization

Project selection is the process of evaluating individual projects or groups of projects, followed by making a choice to implement a sub set of them, so that the objectives of the organization will be achieved. However from a project selection aspect, the large majority of published literature relates to the R&D project selection area (Hu et al., 2008). Six Sigma projects apparently differ from typical R&D project in various aspects. Six Sigma projects focus more on application and orientation towards results, shorter time of project execution, more deterministic nature of

Table 1
Various methods for project selection (Banuelas et al., 2006).

Author	Proposed methods or tools to prioritize Six Sigma projects
Larson (2003)	Pareto analysis
De Feo and Barnard (2004)	Reviewing data on potential projects against specific criteria for project selection six sigma
Adams et al. (2003)	Project ranking matrix
Kelly (2002)	Project selection matrix
Breyfogle et al. (2001)	Project assessment matrix
Pyzdek (2000, 2003)	Project priority index, analytic hierarchy process (AHP) Quality function deployment (QFD), Theory Of constraints (TOC)

project outcome and necessitates participation of entire stakeholder. However, very few powerful tools are available for prioritization and selection of six sigma projects (Su and Chou, 2008). The selection and prioritization of projects in many organizations are still based on pure subjective judgments. The reports on approaches used by leading organizations in the selection of Six Sigma projects in International Journal are rather scanty. Surveys carried out in the UK have pointed out several tools and approaches used by various organizations for selection of Six Sigma projects (Banuelas et al., 2006). These selection approaches are Cost-Benefit Analysis, Cause and Effect Matrix, Pereto Priority Index, Theory of Constraint and various non-numeric models. However in reported literature Nokia uses Project Filter based on Balanced Score Card Framework for the selection of Six Sigma projects (Breckline, 2003). The types of tool and methods for selecting Six Sigma projects are shown in Table 1.

The concept of building business portfolios emerged in the late 1950s and evolved through the 1970s to become an established planning tool (Rousel and Erickson, 1991). In the 1980s and 1990s, companies extended the use of portfolio management into new product selection and R&D resource allocation. A survey conducted among major aerospace companies by Aviation Week magazine reveals that 60% of the companies selected opportunities for improvement on an ad-hoc basis while only 31% relied on portfolio approach (Zimmerman and Weiss, 2005). It was observed that companies that used a portfolio approach gained better results. Very few authors have dealt with the portfolio aspect of the Six Sigma project selection. Kumar et al. (2007) have proposed a non-linear programming based Six Sigma portfolios but the focus was on defect reduction and yield enhancement. Similarly in another work Kumar et al. (2007) also proposed data envelopment analysis to identify the portfolio of projects, which results in maximum benefits.

Project portfolio selection is usually a multiple criteria problem, where tradeoff must be made among potentially conflicting criteria. Few 0–1 ILP models have been suggested in the literature for project portfolio selection. The models proposed by Evans and Fairbairn (1989) and Kira et al. (1990) address many real issues than the other related models. In spite of their advantages, these models have some shortcomings in that, they do not take project starting point into consideration. Ghasemzada et al. (1999) proposed a 0–1 integer programming for selecting projects but it is based on NPV as input parameter. Against this backdrop the proposed approach has been tailored for selecting and scheduling a portfolio of Six Sigma projects taking real option value of the project as input. Some decision rules specific to Six Sigma projects have also been applied for optimization of the selection project portfolios.

3. Proposed methodology

The proposed methodology involves a two stage process. In the first stage the Six Sigma project investments have been evaluated in the light of multiple risks and imperative for flexibility in managerial decision making as available option. The second stage involves a portfolio optimization model in which several Six Sigma projects are simultaneously considered for funding. At this stage the proposed multiperiod 0–1 integer linear-portfolio-optimization model that contains binary variables has been tested for the selection of projects over a finite planning horizon in the face of resource constraints besides

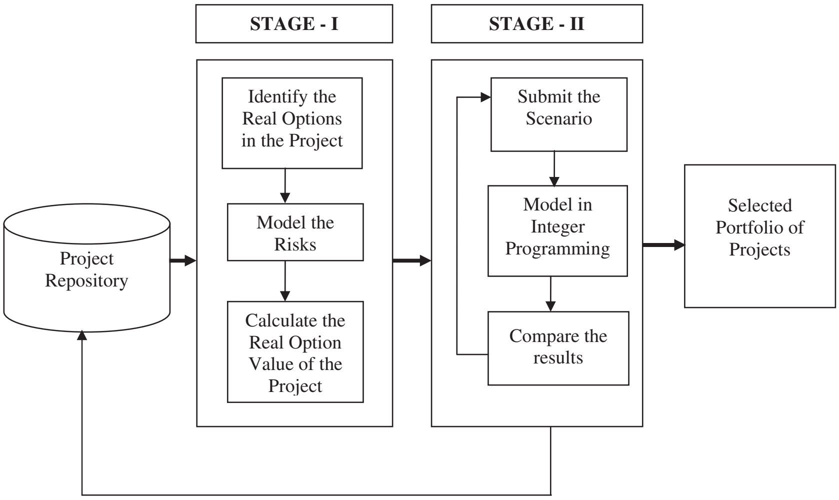

Fig. 1. Proposed methodology of project portfolio selection.

Table 2
Four types of Real Options and Six Sigma projects.

Sl.No	Option	Implication for Six Sigma projects
1	Growth	The option that provides the management an opportunity for future follow on investments, many of which may not be foreseen at the time of initiating the Six Sigma project
2	Stage	The option that provides the management an opportunity for sequential investment at different phases of an going Six Sigma project depending on the success of previous one
3	Scale	Also called Change of Scale and Expansion and Contraction option. The option that provides the management the opportunity to expand or reduce the scale of investment in Six Sigma projects in terms of resources in accordance with the availability of information.
4	Defer	It is also called Delay option. The option that provides the management to wait or delay the investment in the project with a hope that the future information will decrease the decision risk.

other business rules. The two stages proposed methodology has been depicted in Fig. 1.

The detailed steps of determining the option value of the project has been given in steps.

3.1. Categorization the projects

The repository of projects, which are selected over the period of time, may be categorized based on the ability of the project to satisfy the goal of the organization. Based on above consideration a scheme for the classification of the projects is proposed. The Six Sigma projects can be classified into as:

- Customer satisfaction
- Productivity Improvement/waste minimization
- Cost Reduction
- Quality Improvement
- Process Improvement
- Reliability Improvement
- Health, Safety and Environment (HSE)
- Others: like projects pertaining to employee satisfaction

Depending upon the strategic alignment and statutory nature of the project, the management may define some project as mandatory.

3.2. Application of real options to Six Sigma projects

There are six types of options described in the literature. Prior research has identified six real options, based on types of flexibility that has been associated with each options viz: (i) Growth (ii) Stage (iii) Scale (iv) Switch Use (v) Defer and (vi) Abandonment (Trigeorgis, 1996). However, in the present study four primary management options regarding Six Sigma projects have been discussed. The summary of various options and its implication for Six Sigma projects are summarized in Table 2.

3.3. Collection of the project related information

The information pertaining to each project (both financial and non-financial) need to be collected. Non-financial information includes duration of the project, human resource requirements which include black belts and green belt requirement. Similarly financial information includes discount rate, working capital requirement or quarterly investment plan, savings potentials of the project or potential project payoffs. However, the expected payoffs of the projects may fluctuate due to the influence of the uncertainties, which include project and market related risks. Market related risk is public risk, which comprises of uncertainties that affect the market demand for the firm's products or services, such as customer acceptance, competitor(s) reactions and other external factors. Risks specific to the project known as private risks are common in Six Sigma projects. Private risks are constituted by specific internal factors such as team experience, project complexity, planning and controlling, including unforeseen technical problems. The various steps for computing the real option value of the project have been enumerated below.

3.4. Determination of the option value of the each of the project

Determination of the option value of any project undergoes three distinct phases, as is illustrated in Fig. 2.

We first address the most important step in a project valuation, that is to build a Project Model representing managerial decisions depicting the projects at hand in the context of real world. After having determined the project structure it is necessary to model the inputs correctly (Modeling the Uncertainties) and to represent them in a way that allows for a later valuation. This aspect is explained in the section on Tree Generation.

3.4.1. Identification of real options in the project

At the project level, real options often exist in bundles where in a project can create multiple distinct real options. The option to wait or defer, is virtually embedded in almost all projects, which has been studied for all the Six Sigma projects in this piece of work.

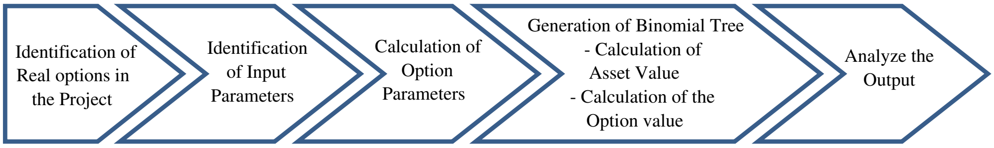

Fig. 2. Procedure for determining the ROV of projects.

3.4.2. Modeling the uncertainties through binomial method

3.4.2.1. Identifying the input parameter. The major challenge a practitioner faces in calculating the option values is, estimating the input parameters. The input parameters, their relevance and the procedure of calculating these parameters for Six Sigma projects have been explained below:

3.4.2.1.1. Current value of the underlying asset (So). The value of the underlying security at the time zero represents the underlying asset value and is easily known for financial options. With real options, the project value is estimated from the cash flows the project is expected to generate over the project life cycle. The present value of the expected free cash flows based on the DCF technique is considered to be the same as the value of the underlying asset. For example, assuming an annual discount rate of 25%, the present value of the project would be around 3.1 million INR (Indian Rupees) which generates a cash flow of 1, 1.5, 1, and 0.5 million INR in 9th, 12th, 15th and 18th month of the project period respectively.

3.4.2.1.2. Strike price/option's exercise price (X). The strike price or option's exercise price of Six Sigma or any other project in general is the present cost of all the investments made for the project over the project life cycle. For example, if the investment for the project in first quarter and 2nd quarter are 1 million and 1.5 million INR, respectively, the present value of the investment would be 2.3 million INR taking into account an annual discount rate of 25%. Hence the strike price of the project is 2.2 million.

3.4.2.1.3. Option life of the project (T). Generally Six Sigma projects are intended to be 3 to 6 months. However we have considered the duration of certain projects more than that. The 15 months has been taken for **option life** of the group of projects. The reason being as follows.

The time to maturity is clearly known (written in the contract) for a financial option, but, in most cases, that is not true for real options. Often it is not known how long the opportunity will exist to exercise the option. The option life has to be long enough for the uncertainty to clear, but not so long that the option value becomes meaningless because of other external factors. The time duration is taken keeping view of the selection of certain projects and in some cases **defer** option of the projects.

3.4.2.1.4. Chosen interval size (δt). The Black–Sholes model offers a closed form of analytical solution that does not require the life of the option to be split into time increments, as the binomial or any lattice based method does. With the increment of time the binomial solution will closely approach Black–Sholes results with the increments of time in the equation. However five or six time increments will be sufficient and will not be significantly different from the Black–Scholes solution (Kodukula and Papudesu, 2006). Hence time increment of 3 months has been taken in proposed binomial lattice for calculation of the option value of the project.

3.4.2.1.5. Volatility of the asset value (σ). Volatility is a measure of the variability of the total value of the underlying asset over its lifetime. It signifies the uncertainty associated with the cash flows that comprises of the underlying asset value. It is an important input variable that can have significant impact on the option value and is probably the most difficult variable to estimate, for real option problem (Kodukula and Papudesu, 2006). There are many approaches described in literature for estimating the volatility of the asset value. These methods include logarithmic cash flow return, Project Proxy Approach, Market Proxy Approach and Management Assumption Approach (Kodukula and Papudesu, 2006). All the above approaches except the Management Assumption Approach necessitates use past data and complex computatation, which we think, is not appropriate for Six Sigma projects. In the present study for calculating volatility of Six Sigma projects, Management Assumption Approach has been adopted owing to its simplicity and consensus based approach to decision making. In this approach, management estimates optimistic (S_{opt}), pessimistic (S_{pes}) expected payoffs for a given project lifetime (t). Assuming the payoff follows lognormal distribution, it is computed with the following formula:

$$\sigma = ln\left(S_{opt} / S_{pes}\right) / 4\sqrt{t}).$$

3.4.2.1.6. Risk free interest rate/rate of return on a risk less asset during the life of the option (r). The risk-free annual interest rate used in real options model is usually determined on the basis of the U.S. Treasury spot rate return, with its maturity equivalent to the option's time to maturity. In India, risk free rate can be inferred from 3 to 6 month Treasury bill rate which is currently at 5%.

3.4.2.2. Calculation of the option parameter. The up and down factors, u and d, which are the function of the underlying asset, are described below:

$$\text{Up factor} = u = exp\left(\sigma\sqrt{\delta t}\right)$$

$$\text{Down factor} = \mathrm{d} = 1/\mathrm{u}$$

$$\text{Risk neutral probability}\, p = (exp(r\delta t) - d) / (u - d)$$

where 'r' is the risk free interest rate.

3.4.3. Generation of the binomial tree

3.4.3.1. Calculation of the asset values at each node of the tree. The binomial options approach uses a lattice to demonstrate alternative possibilities over time (Dixit & Pindyck, 1993). The starting point is the present value of the future cash flows. Over the time, two conditions can result: one up and one down (hence the term binomial). Fig. 3 shows a binomial lattice with 3 steps. The binomial tree is built based on the number of time increments selected. Starting from an initial expected value ***So*** moves either up to ***uSo*** with probability ***p*** or down to ***dSo*** with probability ***1-p***, in a fixed interval **Δt**. The same will continue for other nodes.

3.4.3.2. Calculation of the option values at each node of the tree by backward induction. Once the lattice of the underlying asset has been developed, it is the time for calculating the option value

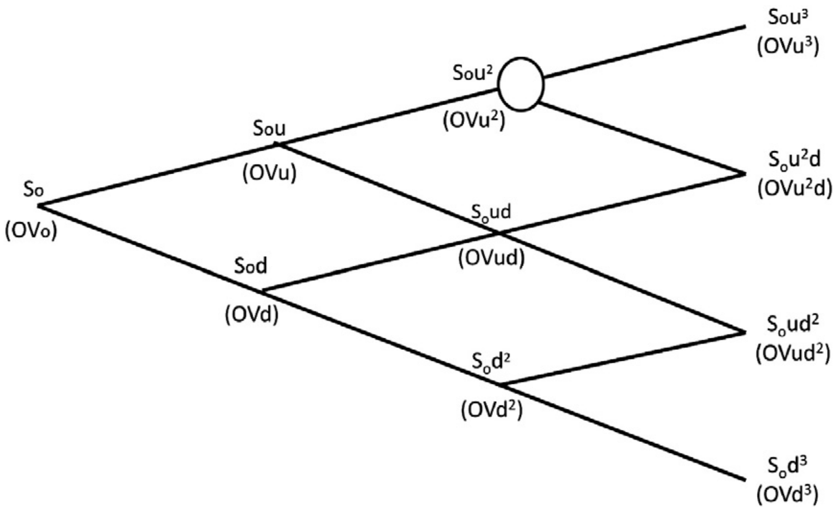

Fig. 3. Binomial tree approach.

through a process called backward induction. Starting at the far right side of the binomial tree, the decision rule is applied at each node and the optimum decision selected. For example for calculating the option value at node, the following steps need to be carried out (Fig. 3):

Compute the option value OVu^2 for waiting

Step −1: $OVu^2=[p(OVu^3)+(1-p)(OVu^2d)].e^{-r\Delta t}$
And for exercising
Step −2: $OVu^2=\max(S_0u^2-X,0)$ **For call option**
$OVu^2=\max(X-S_0u^2,0)$ **For a put option**

Select the highest value at step 1 and step 2 and find out the option value. The same process is repeated until the beginning to the get the option price of the project (OV0). Once the final option values of the project are computed, it will serve as input parameter for the proposed optimization model.

3.5. Portfolio selection

The optimization process is the central component of the proposed portfolio selection model. The major input of the project is its option price where the flexibility is already embedded. Other input parameters for the projects are:

- Expected project duration or the time horizon for which the project has been considered
- Available budget over the period of time
- Requirement of blackbelt and greenbelt mandays
- Interdependencies in the projects (projects which need to be started prior to certain projects)

The proposed model suggests a set of projects that should be incorporated in the portfolio. It will also determine the period in which each of the selected project should start. The decision variables, objective function and constraints of the proposed model are as follows.

3.5.1. Decision variables

$$x_{ij} = \begin{cases} 1 & \text{if project } i \text{ is selected} \\ 0 & \text{otherwise} \end{cases}$$

$i=1,2,\dots,P$, where P is the total number of projects being considered.
$j=1,2,\dots,T$, where the planning horizon is divided into T periods.

3.5.2. Objective function

The objective function is given below:

$$Max\ Z = \sum_{i=1}^{P}\sum_{j=1}^{T} o_i x_{ij},\ where\ o_i = \text{OptionValue}$$

where, Z is the value function to be maximized and o_i is the real option value of the i^{th} project.

3.5.3. Other constraints

Each project if selected will only start once during the planning horizon and is ensured by the constraint (1)

$$\sum_{j=1}^{T} x_{ij} \le 1, \forall\ i \in P. \tag{1}$$

The constraint (2) endures that the selected projects should be finished within the planning horizon

$$\sum_{j=1}^{T} jx_{ij} + t_i \le T + 1\ , \forall i \tag{2}$$

where, t_i = duration of completion of the project i.

The required budget should be less than equal to the available budget is given by constraint (3).

$$\sum_{i=1}^{P}\sum_{j=1}^{k} C_{i,k+1-j}x_{ij} \le B_k, k = 1,2,\dots T \tag{3}$$

where, B_k is the total budget available from the first time period up to time period k and $C_{i,k+1-j}$ is the budget required by project i in period k. Constraint (4) guarantees the selection of the projects which are mandatory (Health, Safety and Compliance related) in nature i.e.

$$\sum_{j=1}^{T} x_{ij} = 1, \forall i \in S_m. \tag{4}$$

Interdependence among projects is another important issue. For example, if project B is dependent on project A, then project A must be selected if project B is included in the portfolio. The constraints (5) and (6) guarantee the selection of its precursor projects once a project is selected

$$\sum_{j=1}^{T} x_{ij} \geq \sum_{j=1}^{T} x_{lj} \tag{5}$$

$$\sum_{j=1}^{T} jx_{lj} + (T+1).\left(1 - \sum_{j=1}^{T} x_{lj}\right) - \sum_{j=1}^{T} jx_{ij} \geq t_i \sum_{j=1}^{T} x_{ij}, \ \forall i \in P_l \tag{6}$$

where, P_l is the set of precursor projects for a particular project l ($l=1,2,\ldots,L$).

Other constraints can be used in the process depending upon the situation. Keeping in view the above constraint and formulation, a case study is presented herewith. The model has been test evaluated on a petrochemical company of repute in India which has been enumerated below.

4. Case study

This case describes a systematic way of evaluating and selecting projects using information from a leading petrochemical company of repute in India. However, the company name has not been disclosed in order to protect the company's identity. The management since few years has started implementing Six Sigma. In this case, the management wanted to select a portfolio of Six Sigma projects from a set of 16 projects over a period of 15 months. The projects have been nominated from multiple disciplines and departmental areas which are affecting the overall company performance. The challenge is to select the portfolio of projects, delivering the greatest value and lowest risk within the limitations of available resources. The detailed description of the Six Sigma projects along with its financial information has been provided in Table 3. We used the Lingo® 8.0 for computing the 0–1 optimization problem and spreadsheet for calculating the Real Option Values of the projects. The scope of the study starts with the estimation of financial implications pertaining to the projects, which includes estimated quarterly budget requirement and potential savings after implementation. The same does not include the detailed calculation with regard to the above parameters.

4.1. Estimation of real option value of the projects

To estimate the real option value of the Six Sigma projects, a project titled "*Reduction in overall cost of spinning consumables*" has been chosen as an illustration. This comes under categorization of cost reduction project. The duration of the project has been estimated as 15 months or 5 quarters. The detailed information pertaining to the project has been illustrated in Table 4 and has been explained below. The quarterly budget requirement as estimated by the management team is 0.4, 0.5, 0.7, 0.8 and 0.6 million INR.

- Quarterly discount of 8% has been taken in order to calculate the present value of the proposed quarterly investment plan.
- The Quarterly Discount Factor has been calculated based on the formulae as presented below; the present value of expected initial payoff was $1/(1+8\%)^n$. Where n is the number of quarters.
- Hence the present value of the future budget requirement comes around 2.33 million.

The management believes that by implementation of above project, the company may save substantial amount of revenue. The present value of the future cash flow or the present value of the saving potential of the project after its completion is estimated at around 1.98 million INR (as provided by the management). However, there existed many uncertain factors that may prevent the project from delivering the above monetary benefits. Some of them may arise from the changing market environment, and the others due to the company's internal factors, and inherent complexity of the projects.

4.1.1. Identification of the input parameter

So is the current value of the underlying asset (equivalent to the present value of the future cash flows based on DCF techniques), which is 1.98 million INR.

X is the Strike Price/Option's exercise price. This is same as the present value of the investment cost for the Project to be incurred in 5 quarters, which is 2.33 million INR.

T is the Option life of the project, which is around 15 months (5 Quarters).

For calculating Volatility (**σ**) of the project, Management Assumption Approach has been adopted owing to its simplicity and consensus based approach to decision making. Based on the formulae described above the volatility is calculated taking the following information:

- $S_{opt}=3.5$ million INR, signifying that there is 98% probability that the payoff will not exceed 3.5 million INR
- $S_{pes}=1$ million INR, means that there is only a 2% probability that the payoff will be less than 1 million INR
- t=5 quarters

The volatility of the project (**σ**) came out to be 14/quarter.

Regarding the risk free interest rate, at present it is 5/annum or 1.3%/quarter.

$\delta t = 1$ quarter.

4.1.2. Calculation of the option parameter

$$\text{Up factor} = u = exp(\sigma\sqrt{\delta t}) = 1.15$$

Table 3
Six Sigma projects and financial information.

Pr. no.	Project title	Project goal type (*)	Project duration (in months)	Budget requirement plan (in million INR)					Present value of future cash flows
				3 months (1st quarter)	6 months (2nd quarter)	9 months (3rd quarter)	12 months (4th quarter)	15 months (5th quarter)	
1	Cycle time reduction in results reporting in chemlab systems	PI	6	0.1	0.15				0.31
2	Introduction and stabilization of cosmo TiO2	CR	9	0.12	0.2	0.1			0.43
3	Reduction in specific consumption of spin finish	CR	15	0.1	0.15	0.2	0.15	0.1	0.495
4	To improve bobbin traceability in CP-10	PI	9	0.12	0.15	0.15	0	0	0.395
5	Reduction in traverse guide consumption and cost	CR	15	0.2	0.25	0.3	0.4	0.15	1.04
6	To increase average bobbin weight in CP-9 from 19.20 to 19.40 Kg	PDI	15	0.2	0.25	0.4	0.55	0.3	1.42
7	Production cost reduction in Spinning	CR	12	0.25	0.3	0.35	0.1	0	1.41
8	CP-10 UFPP and FN scrubber cooler efficiency improvement	CR	15	0.1	0.25	0.35	0.2	0.25	0.928
9	Reduction in DM water makeup in Hot water tank of CP 10/11	CR	15	0.25	0.3	0.35	0.2	0.25	0.99
10	Improving quality of packing in case of FDY	CS	12	0.15	0.25	0.35	0.2	0	0.928
11	Improve machine availability at POY spinning CP10 from 99.10 to 99.30%.	RI	12	0.1	0.2	0.35	0.1	0	1
12	Waste Heat recovery from CP 10 to generate Refrigeration Load	CR	15	0.3	0.65	0.7	1	0.6	1.98
13	Increase in Loading in CP-10 ABHS	PDI	12	0.2	0.35	0.5	0.4	0	1.54
14	Reduction in FOF IN CP-10	QI	11	0.3	0.65	0.7	1	0	2.01
15	Improving the safety of the bobbin loading process	HSE	15	0.4	0.65	0.7	0.8	0.6	1.98
16	Reduction in overall cost of spinning consumables	CR	15	0.4	0.5	0.7	0.8	0.6	1.98
Quarterly budget requirement				3.29	5.25	6.2	5.9	2.85	
Quarterly budget available				3	5	6.2	5.9	2.9	

(*) Project category.
Customer Satisfaction (CS), Productivity Improvement (PDI), Cost Reduction (CR), Quality Improvement (QI), Process Improvement (PI), Reliability Improvement (RI), HSE Improvement (HSE), Others (Oth).

$$\text{Down factor} = d = 1/u = 0.869$$

$$\text{Risk neutral probability}\, p = (exp(r\delta t) - d)/(u - d) = 0.51$$

4.1.3. Generation of the binomial tree

4.1.3.1. Calculation of the asset values at each node of the tree. The binomial tree has been built as shown in Fig. 4, using a quarter time interval, for 5 quarters. The upper value in Fig. 4 at each node represents the asset value at that node. Beginning with this initial value, the expected payoff was assumed to follow a binomially distributed multiplicative diffusion process. Start with S*o* at the very first node on the left and multiply it by the up factor and down factor to obtain u*S*o* (1.15*1.98=2.27) and d*So (0.869*1.98=1.72), respectively, for the first time step. The values are depicted in a tabular form in Table 5.

Table 4
Esimated financial information of a sampled project.

	Project duration (in quarters)	1	2	3	4	5
a	Quarterly discount rate in percentage	8%				
b	Quarterly discount factor	0.92	0.85	0.79	0.73	0.67
c	Quarterly Investment plan (in million INR)	0.4	0.5	0.7	0.8	0.6
d	Present value of the investment (sum (a*b)) (in million INR)	2.33				
e	Present Value of the potential savings from the project (in million INR)	1.98				

4.1.3.2. Calculation of the option value at each node of the tree. The option values at each node of the binomial tree have been calculated using a process known as backward induction. The bottom numbers at each node of Fig. 4 represent the option value. The calculation of the option values has been carried out as follows:

a. Start with the terminal nodes representing the last time step first. At node **S_0u^5**, the expected asset value is 3.99 million INR if 2.33 million INR for the project will be invested. So the net asset value is 3.99 million −2.33 million=1.66 million INR. Hence the option value at this node will be 1.66 million INR.

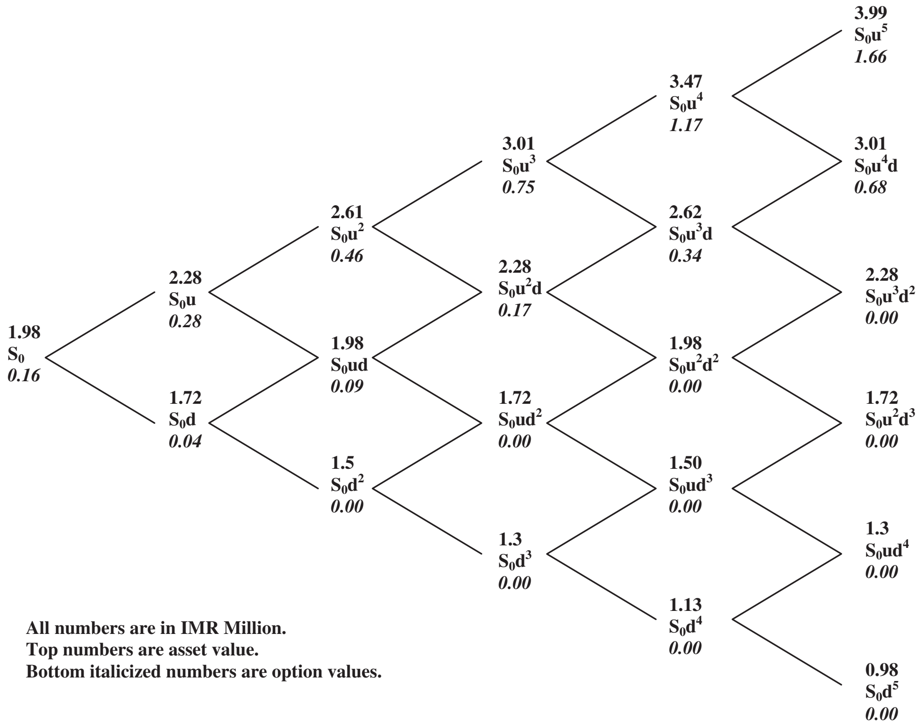

Fig. 4. Option valuation binomial tree for project 2.

b. At node $S_0u^2d^3$, the expected asset value is 1.72 million INR, if an investment of 2.33 million INR is made, resulting in a net loss of 0.61 million INR. Therefore, the decision at this node will be not to invest in project, which means the option value at this node will be 0.
c. Next, moving on to the intermediate nodes, one step away from the last time step. Starting at the top, at node $\mathbf{S_0u^4}$,the expected asset value for keeping the option open has been calculated. This is simply the discounted (at the risk free rate) weighted average of potential future option values using the risk neutral probability. The value at node $\mathbf{S_0u^4}$ is:

$$\left[p\left(S_0u^5\right)+(1-p)\left(S_0u^4d\right)\right]*\exp(-r\delta t) \\ =[0.51(3.99)+(1-.51)(3.01)]*\exp(-0.013)(1)=3.5.$$

If the option is exercised at this node by investing 2.33 million INR, the payoff would be 3.46 (the asset value at $\mathbf{S_0u^4}$), resulting in a net asset value of 1.13 million INR. Since keeping the option open shows a higher asset value (3.5 million INR), it would not exercise the option but instead continue to wait. Hence the option value at this node becomes 3.5 million INR. In similar way the option value can be calculated at each node. The option value at each node has been depicted in a tabular form in Table 6.

Table 5
Asset valuation lattice of project.

Time period (in quarters)	0	1	2	3	4	5
Valuation of underlying asset	1.98	2.27	2.61	3.01	3.46	3.98
(all numbers are in million INR)		1.72	1.98	2.27	2.61	3.01
			1.49	1.72	1.98	2.27
				1.30	1.49	1.72
					1.13	1.30
						0.98

4.1.4. Analysis of the result

In DCF method, using a risk adjusted discount rate, a payoff of the project was arrived at 1.9 million INR for the project, which is expected to cost 2.3 million INR of investments. This means that the Net Present Value (NPV) of the project is minus 0.35 million INR, which does not favor the investment. However, the project has an ROV of approximately 0.16 million INR created by the option characteristic of the project which is due to project flexibility. The additional value created by the option is the difference between the ROV of 0.16 million INR and the DCF based negative NPV of 0.35 million INR, which equals to 0.5 million INR. With such additional value created, this project may simply wait until the market uncertainty clears, at which time the project payoff would be reestimated again. If the payoff is unfavorable, it may still continue to wait or abandon the project idea altogether. On the other hand, under favorable conditions of high expected payoff, it may be prudent enough to invest in the project.

In a similar way the valuation of other Six Sigma projects can be computed. The addition to the value of the Six Sigma projects has been depicted in Fig. 5, due to addition of managerial flexibility. It is evident from the figure that due to managerial flexibility the option value of the Six Sigma projects increased only with a deferral option. The option value becomes the input to the optimization model for modeling the project portfolio and scheduling the project.

4.2. Project portfolio selection

The option value thus obtained acted as an input for modeling the portfolio selection. Lingo® has been used to run the program to arrive at conclusion for selecting the right portfolios for investment and their scheduling. The portfolio of those projects have been selected which are expected to give maximum return to the organization with available resources. There are some projects like "Improving the safety of the Bobbin Loading Process" which is under the category of projects related to Safety, Health and Environment, hence mandatory in nature.

Similarly there exist interdependencies between the projects i.e. projects which start after starting of the some selected projects. Here project 2 will be started after starting of the project 1 (Fig. 6).

5. Implication and contribution of the study

This study makes four important contributions to the literature and industrial application on Six Sigma project selection. The first contribution lies in designing real options into the Six Sigma projects which can significantly add value and flexibility in managerial decision making. Management predilection towards use of thumb rules in estimating the crucial parameters of project evaluation and negligence or unscrupulous approach to risk, has been reported in literature. Benefits are envisaged to accrue from the application of structured approach in the evaluation and selection of projects. Presently, in majority of the projects characterized by shorter duration, continual improvement in nature due importance is not being given on financial management aspects like viz. profitability, return on investment, IRR, ect which imparts negative influence on their usual business performance. The management flexibility, which the real option methodology envisages, towards the exercise of options embedded in the projects may be used unhindered, there by presenting an opportunity to utilize the benefits of the methodology to its fullest potential, in industrial sector.

The second contribution is improved approach to valuation of Six Sigma project by rigorous application of the proposed methodology, based on realistic estimates of cash flows and risks. Very little precedence is found in literature on this aspect.

The third contribution of this study is to demonstrate the advantage of the proposed project portfolio approach over the existent project selection method. The major issues that are addressed by the proposed optimization model is, it not only selects the portfolio of Six Sigma projects but also schedules the projects based on available resources in each time period. It also takes care of the time-dependent availability and constraints of resources, which is frequently encountered in the real world situations.

In the fourth contribution this study lies in redefining the traditional role of the black belt. Traditionally black belts are not usually familiar with the principles of financial evaluation, like the time value of money, managerial options, market payoffs, market uncertainty, etc. The present study envisages a redefined role of Black Belts in project financing. Hence the additional role of black belt will include:

- Regular collection, analysis and updation of data pertaining to project finance
- Regular appraisal to Master Black Belt and Steering Committee about the status of Six Sigma projects
- Work in de-mitigating the risks involved in the project execution
- Taking part in process of decision making on switching between various options of the project as new information arrived along with top management

Table 6
Option valuation lattice of project.

Time period (in quarters)	0	1	2	3	4	5
Valuation of option (all numbers are in million INR)	0.16	0.28	0.46	0.75	1.17	1.66
		0.04	0.09	0.17	0.34	0.68
			0.00	0.00	0.00	0.00
				0.00	0.00	0.00
					0.00	0.00
						0.00

6. Limitation of the study

The methodology described in this paper has a number of pitfalls and limitations. Firstly, the proposed Real Option Analysis assumes one-time risks, as they relate to an investment. Moreover, the risks pertaining to all the Six Sigma projects have been assumed to be same, which may not be the case in reality. The project risks might vary over time and from project to project.

Another limitation is that the estimated project benefits used in this real options model are based on the accuracy of scenario-planning and costing exercises carried out. The fixed real option values of the projects have been calculated ignoring their interdependencies. Besides, the determination of volatility is one of the weakest areas of Real Option Analysis. The determination of volatility by Management Assumption Approach may have number of pitfalls compared to project proxy approach.

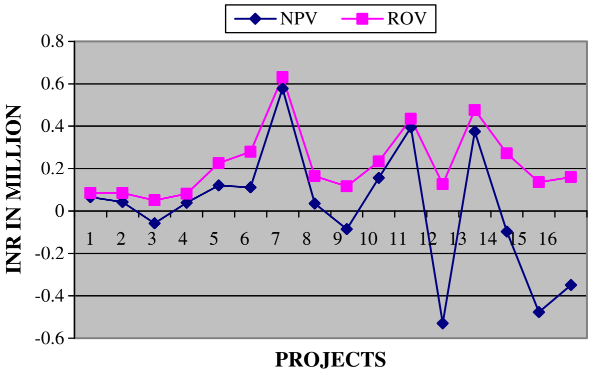

Fig. 5. Enhancement of values of the Project (NPV vs. ROV).

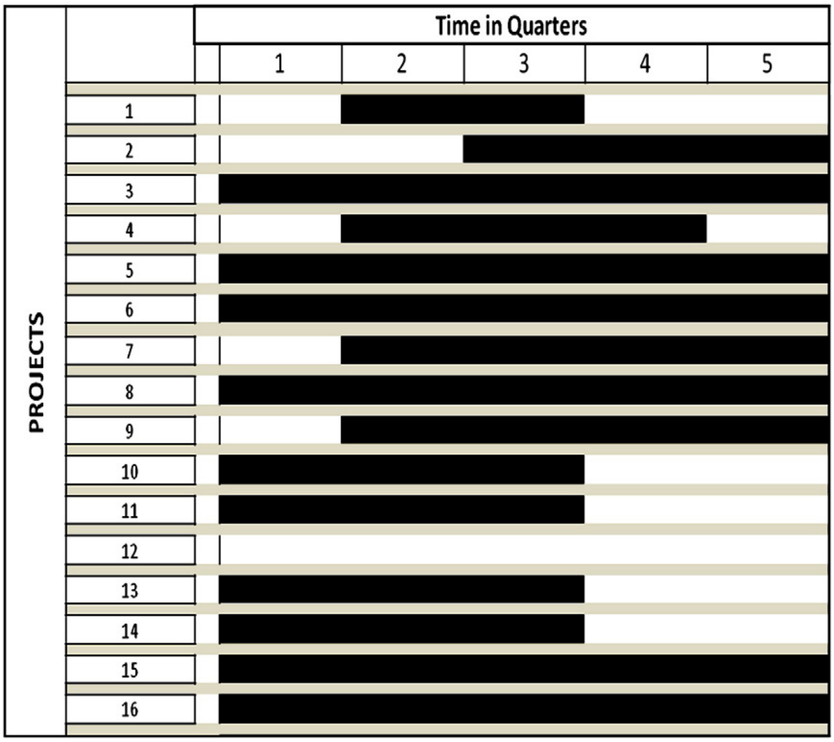

Fig. 6. Scheduling of portfolio of projects.

Moreover, while evaluating the Six Sigma projects in the proposed model, only the deferral option has been considered. The valuation of Six Sigma projects is supposed to improve substantially by considering other options. In optimization model, algorithms should not be used to prescribe solutions without allowing for the judgment. Therefore continuous interaction between the system and decision makers throughout project portfolio selection is highly essentially for selection of the project portfolio.

7. Conclusion and scope of further study

Selection of Six Sigma projects has been repleted with complex organizational factors and risks. Hence allowing implementation of portfolio of Six Sigma projects regulated by NPV leads to a situation where management is unable to respond to the uncertainties, thus creating huge loss of opportunities cost. Various studies of project management indicate that implementing projects in various phases continually addresses the uncertainties encountered in each phase. The results suggest that implementing Six Sigma projects based on real options can provide flexibility of decision making in a constantly changing environment, so as to enable the managers to reorient plans in accordance with the changing circumstances and thus demonstrate the benefits of proactive management.

This work can be further developed by extending the domain of risk. Further research can be carried out in the area for quantifying the impact of the project and organizational specific risks on project payoffs, which is very much prevalent in the Six Sigma projects. Another area for exploration includes inter-project interactions, where implementation of one project may actually result in a reduction or enhancement of real option value of another project. The reliability estimate of project cash flows and investment calculations is yet another area of concern which necessitates future research. Challenges like this call for additional and sustained research efforts.

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References

Adams, C., Gupta, P., Wilson, C., 2003. Six Sigma Deployment. Butterworth-Heinemann, Oxford.

Banuelas, R., Tennant, C., Tuersley, I., Tang, S., 2006. Selection of Six Sigma projects in UK. The TQM Magazine 18 (5), 514–527.

Breckline, J., 2003. Balanced scorecards & project filters: alignment for success. ASQ's Annual Quality Congress Proceedings, p. 219.

Breyfogle, F., Cupello, J., Meadws, B., 2001. Managing Six Sigma. Wiley Interscience, New York, NY.

Copeland, T., Antikarov, V., 2001. Real Options: A Practioners's Guide. Texer.

Costa, A., Paixao, J.M.P., 2010. An approximate solution approach for a scenario-based capital budgeting model. Computational Management Science 7, 337–353.

De Feo, J., Barnard, W., 2004. "Juran institute's six sigma breakthrough and beyond", Quality Performance Methods. McGraw-Hill, New York, NY.

Dixit, A.K., Pindyck, R.S., 1993. Investment under Uncertainty. Princeton University Press, Princeton, NJ.

Eckhause, J.M., Hughes, D.R., Gabriel, S.A., 2009. Evaluating real options for mitigating technical risk in public sector R&D acquisitions. International Journal of Project Management 27 (4), 365–377.

Evans, G.W., Fairbairn, R., 1989. Selection and scheduling of advanced missions for NASA using 0–1 integer linear programming. The Journal of the Operational Research Society 40 (1), 971–981.

Ghasemzada, F., Archer, N., Iyogen, P., 1999. A zero one model for project portfolio selection and scheduling. Journal of the Operational Research Society 50, 745–755.

Helga, M., Nicos, C., Gerry, S., 2001. Capital budgeting under uncertainty−an integrated approach using contingent claims analysis and integer programming. Operations Research 49 (2), 196–206.

Hu, G., Wang, L., Fetch, S., Bidanda, B., 2008. A multi-objective model for project portfolio selection to implement lean and Six Sigma concepts. International Journal of Production Research 46 (23), 6611–6625.

Kelly, M., 2002. Three steps to project selection. ASQ Six Sigma Forum Magazine 2 (1), 29–33.

Kira, D.S., Kusy, M.I., Murray, D.H., Goranson, B.J., 1990. A specific decision support system (SDSS) to develop an optimal project portfolio mix under uncertainty. IEEE Transactions on Engineering Management 37 (3), 213–221.

Kodukula, P., Papudesu, C., 2006. Project Valuation Using Real Options. J. Ross Publishing.

Kumar, R.L., 2002. Managing Risks in IT projects: an option perspective. Information & Management 40 (1), 63–74.

Kumar, U.D., Saranga, H., Marquez, J.E.R., Nowicki, D., 2007. Six sigma project selection using data envelopment analysis. The TQM Magazine 19 (5), 419–441.

Kwak, Y.H., Anbari, F.T., 2006. Benefits, obstacles, and future of Six Sigma approach. Technovation 26 (5–6), 708–715.

Larson, A., 2003. Demystifying Six Sigma. American Management Association, New York, NY.

Mawby, W.D., 2007. Project Portfolio Selection for Six Sigma. ASQ.

Miller, L.T., Park, C.S., 2002. Decision making under uncertainty−real option to the rescue. The Engineering Economist 47 (2), 105–150.

Pande, P., Neuman, R., Cavanaugh, R., 2000. The Six Sigma Way: How GE, Motorola and Other Top Companies are Honing their Performance. McGraw-Hill, New York, NY.

Pyzdek, T., 2000. "Selecting Six Sigma projects", Quality Digest, available at: www.qualitydigest.com/sept00/html/sixsigma.html (accessed 16 March 2005).

Pyzdek, T., 2003. The Six Sigma Project Planner. McGraw-Hill, New York, NY.

Rousel, P.K.S., Erickson, T., 1991. Third Generation R&D: Managing the Link to Corporate Strategy. Harvard Bus. School Press, Boston, MA.

Schneider, M., Tejeda, M., Dondi, G., Herzog, F., Keel, S., Geering, H.P., 2008. Making real options work for practitioners: a generic model for valuing R&D projects. R&D Management 38 (1), 85–106.

Schwartz, E.S., Zozaya-Gorostiza, C., 2003. Investment under uncertainty in information technology acquisition and development projects. Management Science 49 (1), 57–70.

Su, C.-T., Chou, C.-J., 2008. A systematic methodology for the creation of Six Sigma projects: a case study of semiconductor foundry. Expert Systems with Applications 34 (2), 2693–2703.

Tkac, M., Lyocsa, S., 2009. On the evaluation of Six Sigma Projects. Quality and Reliability Engineering International. On line publication.

Trigeorgis, L., 1996. Real Options. MIT Press, Cambridge, MA.

Zimmerman, J.P., Weiss, J., 2005. Six Sigma's seven deadly sins. Quality 44 (1), 62–66.