Ann Oper Res (2009) 168: 181–203
DOI 10.1007/s10479-008-0365-7

An approach to the valuation and decision of ERP investment projects based on real options

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Published online: 12 June 2008

Abstract The risks and uncertainties inherent in most enterprise resources planning (ERP) investment projects are vast. Decision making in multistage ERP projects investment is also complex, due mainly to the uncertainties involved and the various managerial and/or physical constraints to be enforced. This paper tackles the problem using a real-option analysis framework, and applies multistage stochastic integer programming in formulating an analytical model whose solution will yield optimum or near-optimum investment decisions for ERP projects. Traditionally, such decision problems were tackled using lattice simulation or finite difference methods to compute the value of simple real options. However, these approaches are incapable of dealing with the more complex compound real options, and their use is thus limited to simple real-option analysis. Multistage stochastic integer programming is particularly suitable for sequential decision making under uncertainty, and is used in this paper and to find near-optimal strategies for complex decision problems. Compared with the traditional approaches, multistage stochastic integer programming is a much more powerful tool in evaluating such compound real options. This paper describes the proposed real-option analysis model and uses an example case study to demonstrate the effectiveness of the proposed approach.

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Keywords Enterprise resources planning (ERP) · Real option · Uncertainty · Mixed-integer programming · Decision-making

1 Introduction

ERP investment projects involve a variety of risks and uncertainties, and the investment return is difficult to assess. Therefore, it is by no means easy to decide on the appropriate investment strategies (Alesii 2005; Benaroch 2001; MacLean et al. 2003) for technology investment projects of such nature. Traditionally, project evaluation approaches such as internal rate of return (IRR) and net present value (NPV) are used to determine the viability of an investment project (Sarkar and Kassapoglou 2001; Sarkar 2003). However, these traditional project evaluation approaches generally use expectations of future cash flows in calculating IRR or NPV, and take the viewpoint of passive decision makers who do not dynamically respond to the changing investment environment. Without recognising the possibility that a proactive decision maker could exercise the managerial flexibilities and takes corrective actions in response to the developing investment environment, such approaches are apparently inappropriate for valuating technology projects under uncertainty. On the other hand, the real-option approach overcomes the drawbacks of the traditional investment decision approaches, and can provide a new approach for enterprises to carry through ERP project investment with managerial flexibility (Black and Scholes 1973; Duku-Kaakyire and Nanang 2004; Brandão and Dyer 2005).

The applications of the real-option approach in making IT project investment decisions have been extensively reported. Taudes (1998) and Taudes et al. (2000) performed a case study on a company which decided on whether it should upgrade its existing SAP R/2 or to the more advanced SAP R/3. They considered the traditional quantitative approaches inappropriate for making investment decisions on such IT projects due to their typically long planning horizon during which major "implementation opportunities" could arise. To capture and valuate such implementation opportunities, the option pricing model of that of Black and Scholes (1973) has been applied; and the practical advantages of the real-option approach over the traditional valuation approaches were assured. Kumar (2002) put forward that IT investment projects generally include parallel investment decisions followed by sequential decision investment behaviour. A decision made in an earlier phase would influence subsequent investment decisions in that it has created certain pre-conditions or has constraints imposed for making these decisions. Also, certain options realised in a former stage (e.g. to take a partial implementation) will generate an option to learn in the subsequent decision stages (Kumar 1995, 1996). Treating IT project investment as a series of investment decisions has been widely adopted in the implementation of many IT projects (Birge 1985, 1997; Dempster and Thompson 1999). Such a decision process needs to consider the options holistically, or as compound real options, as they have path dependency and strong interactions among them. Trigeorgis (1993) is among the first to investigate the interdependence of multiple real options. So far, effective approaches for the evaluation of compound real options are found to be lacking (Dempster and Ye 1996; Kumar 2002; Martzoukos 2000).

There are various reasons for the failures of investment decision making for ERP projects. One of the most critical ones can be attributed to the uncertain input costs and benefits of an ERP project (Grenadier and Wang 2005; Yeo and Qiu 2003). Therefore, finding an effective approach for the evaluation of the various costs and benefits of IT project is crucial to making the right investment decisions in ERP projects. Hochstrasser (1990) proposed a model to identify the true costs and tangible benefits of IT investments. Premkumar et al. (1994) studied on the demand uncertainty of a product and develop a model to describe the tangible benefits of an EDI project based on the theory of Brownian motion. Kalafut and Low (2001) proposed a value creation index (VCI) to measure the intangible value of an IT project. Like many other IT projects, ERP investment projects involve multistage or sequential investment decision making under uncertainty, with the investment opportunities or options have a strong influence on one another. Therefore, the real options embedded in an ERP investment project are characterised as compound options (Alvarez and Stenbacka 2001; Benaroch and Kauffman 1999, 2000; Martzoukos 2000; Duku-Kaakyire and Nanang 2004). For example, the decision maker may have the managerial flexibility to delay the investment until conditions are more favourable, or to abolish the investment altogether when the condition becomes adverse, or to further change the scale of the investment (Grenadier and Weiss 1997; Schwartz and Zozaya-Gorostiza 2003). The types of real option embedded in an ERP investment project typically include the option to wait, the option to abandon, the option to change the project investment scale and the option to learn.

Finding a suitable approach for the valuation of real options is central to making the right investment decisions in ERP projects. Compared with the commonly used lattice simulation and finite difference method, stochastic programming is much more suitable for the evaluation of compound real options and thus a better approach to solving multistage decision making problems under uncertainty (Benaroch 2002; Birge 1985, 1997; Escudero et al. 2007). Therefore, under a real-option analysis framework, a multistage stochastic integer programming approach is employed in this study to establish an investment decision analysis model of ERP project. In Sect. 2, the risks involved in ERP projects are described and an introduction to real options for resolving these risks will be given. The development of the real-option framework will begin with a discussion of alternative investment strategies with the real option embodiment (Sect. 3). This is followed by a discussion on the approaches for the evaluation of benefits that could be derived from an ERP project (Sect. 4) and the input costs incurred (Sect. 5). In Sect. 6, a stochastic integer programming model is formulated for the evaluation of the compound real options embodied in an investment strategy. This model is evaluated based on a real case, as will be described in Sects. 7 and 8. Concluding remarks are then provided in Sect. 9.

2 Analysis of ERP project risk and real option of investment

2.1 Risk analysis of ERP project

According to the published reports on ERP implementations (see Palomino and Whitley 2007; Olson and Zhao 2007; Ifinedo and Nahar 2007), it is found that firms are in general exposed to investment risks manifested by a high failure rate of ERP projects. These risks could be categorised into external and internal risks. The former denotes marketing risks, potential regulation risks, unpredictable risks and agent risks which could mainly be derived from the uncertainties of demand of products in the future, government deregulation, and the emergence of inexpensive or more advanced technologies in the market. The latter type consists of technology risks, management risks, resource risks and implementation risks. These risks are due to uncertainties arising from long-term investment capability of the firm (e.g. running out of funds to complete the project), the internal competence in managing the new technology and the suitability of an ERP system to the business processes of a firm.

Traditional approaches to risk management aim at controlling or mitigating both the external or internal risks. Unfortunately, most risks are beyond one's control and hence many of these approaches have been to have limited effectiveness. However, the concept of real option offers useful insights in devising approaches to deal with the numerous risks and uncertainties that exist in the process of ERP investment. By maximising the value of real options embedded in an ERP investment project, it is possible for decision makers to actively respond to unfavourable investment environment and take right actions to mitigate investment risks.

2.2 Real options of ERP investment

During the course of an ERP investment project, or even before the project is approved and commissioned, a technology manager will have a number of options open to him/her. Before committing any resource to the ERP project, he/she may decide on whether it is appropriate to commence the project or adopt a wait-and-see approach. When the project has been rolled out, he/she still has to monitor the project continuously and decide on whether the project should still be confined to the pilot level, or to change the scale of investment (to expand or to withhold) or to abort it altogether (if the project is bound to be a failure). Within the framework of real options, the decision to make a particular option depends on a number of factors which exhibit major uncertainty. Therefore, the framework provides a form of roadmap for the technology manager to make the appropriate investment decisions amidst uncertainties. The following options are some of the most commonly used options and are considered suitable for valuating ERP investment projects.

Option to wait A technology manager could delay an action to some future time when the investment condition looks uncertain or to withdraw the investment if he/she is pessimistic about the investment condition. This option is valuable in that it provides the decision maker an opportunity to defer investing in cases that the right timing for making the investment is particularly crucial for achieving higher returns.

Option to abort If the expected market environment is unfavourable, the manager could abort the investment of an ERP project to cut further losses. Since an option represents a right owned by its holder and its value cannot be negative. Therefore, the value of an investment project with options to abort is higher than that those without such an option, especially when the market is volatile.

Option to change the scale of investment (*expand or withhold*) At each stage of an investment project, if the market environment looks positive, or if the progress of ERP implementation is better than what has been expected, the manager could expand the scale of project or vice versa if things turn out otherwise.

Option to learn It is useful to confine the scope of implementation at the departmental level, say, instead of the firm level at the early stage. This staged implementation strategy provides an opportunity for a company to learn the new technology. The experiences accumulated in the department level implementation will significantly benefit future, full-scale adoption of the technology at the company level.

3 Investment approaches to ERP projects

3.1 Investment strategy of ERP project

An enterprise might choose to achieve a complete as opposed to a partial implementation at the beginning of an ERP implementation project. Two possible investment strategies have been identified and given as follows:

Strategy S-1 Purchase the complete, integrated ERP system from a leading ERP solution provider. A comprehensive suite of major modules are available to support business functions (finance, production, human resource, market and sales). This is followed by the project roll-out whose tasks include process analysis and design, implementation tasks including system configuration, installation of software components, customisation, development of interfaces, training, etc.

Strategy S-2A Select the minimal system configuration to provide a software solution for major function departments in an enterprise.

Strategy S-2B Enhance the system capabilities by including other application components for use by other departments; design and develop interface software (which is used to connect application programs) and perform overall system integration (see Fig. 1).

Suppose that the investment decisions for an ERP project will be made over a multiple-period time horizon from period 1 to T, the decision maker is assumed to possess the managerial flexibilities or options with respect to investment timing and scale at each decision making period or investment evaluation stage $t \in \{1, \dots, T\}$. In the selection of an appropriate investment strategy, two assumptions are made:

- Assumption 1: at each decision evaluation period $t \in \{1, \dots, T\}$, the decision maker is free to adopt either strategy S-1 or S-2, or can choose to wait and invest until more information is available or uncertainties are resolved.
- Assumption 2: once the decision maker selects investment strategy S-2A, investment strategy S-2B must be selected before the investment valuation terminated at period T.

3.2 Investment process analysis of an ERP project

An enterprise has the opportunity to inject certain expense (I) for the implementation of an ERP system in an ERP project investment. The cost of investment is determinate but the future change of I is uncertain on every time point $t \in \{1, \dots, T\}$ in decision period T.

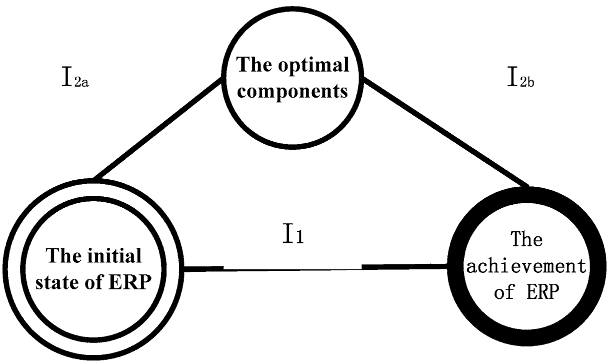

Fig. 1 Investment strategies of an ERP project

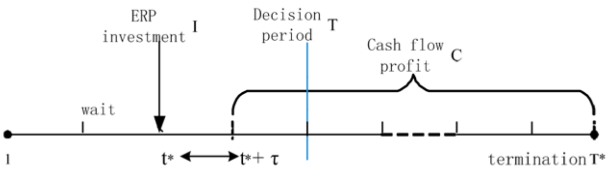

Fig. 2 Time-dimensional analysis of investment strategy S-1

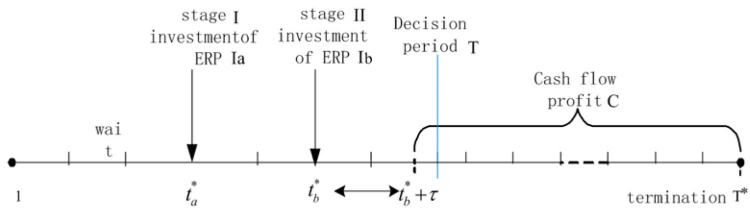

Fig. 3 Time-dimensional analysis of investment strategy S-2

τ is the period starting from the inception of the project when the investment is made up to the point in which the project has formally resulted in income for the enterprise. Let the capital investment for the ERP project be $I(t)$ at time t. For the reason that a number of unpredictable events might lead to changes of initial requirements of an ERP project, $I(t)$ is uncertain for $t > 1$. τ periods after the initial investment the enterprise will begin to receive income C in various forms until the end of the system lifecycle T^*. However, the enterprise can also delay its investment by electing to buy time because of the uncertainties that could arise from the ERP investment cost and on the possible incomes that could be attained. So, there exists an option to wait in the investment project. The time-dimensional analyses of two major investment strategies are shown as Figs. 2 and 3 respectively.

Assume that both the cost and income are uncertain, the decision to wait for a certain period before making the investment would seem to be a better approach. If the time value of an acquired ERP system decreases due to, for example, the emergence of more powerful technologies, this will justify the decision to wait until the right timing. However, the lifecycles of ERP systems are becoming shorter and shorter with the advent and development of new technologies, waiting means the enterprise is gradually losing out on new technology initiatives, thus reducing its capability to enhance its revenue and some other less tangible benefits. Therefore, these two factors must be jointly considered in order to make the optimal decision.

4 Analysis of uncertainty on investment benefits

The costs incurred and benefits derived from an ERP project are the fundamental considerations in the investment decision process. Compared with other types of capital investment projects, it is difficult to assess the costs and benefits of an ERP investment project due to the tremendous uncertainty that might occur during the project lifecycle. Since the valuation of such a project within the real-option framework involves a trade-off between these uncertain quantities, some appropriate approaches for their evaluation are required. This section will be devoted to the discussion on those pertained to benefits whereas the cost aspects will be left to Sect. 5.

The benefits that could be derived from an ERP project can be categorised either as tangible or intangible. The former denotes the reduction of production cost and inventory expenses, and increased productivity. On the other hand, the intangible benefits consist of improving product quality, reducing lead time, increasing the flexibility of firms, and promoting corporation image, among others. Unfortunately, such intangible benefits are difficult to assess and as a result, they have been effectively addressed in most valuation approaches. Also, the significant uncertainties associated with such intangible benefits in technology projects makes their assessment even more difficult. However, for valuating an ERP project, this aspect is clearly a very important factor to consider. If the intangible benefits are ignored, any similar initiative for productivity improvement will probably be under-valued. On the other hand, the tangible benefits that can be derived from an ERP project also contain significant uncertainties. It is apparently that, in today's competitive environment, no certain future demand and hence income can be guaranteed. These difficulties must be addressed (and so are the aspects of cost) in order for the decision maker to develop an optimal investment policy. The stochastic integer program described in Sect. 6 is devised to serve this purpose.

4.1 Assessment of tangible benefits under uncertainty

Given G^t to be the total demand of an enterprise's product in the market in year t, it is commonly observed that G^t is a diffusion process (Premkumar et al. 1994; Schwartz and Zozaya-Gorostiza 2003). Geometric Brownian motion (GBM) is therefore appropriate for describing such a process because the tangible profit for an enterprise will become uncertain after the implementation of ERP. With this assumption, the differential coefficient of G^t is given as

$$dG^t = \alpha G^t dt + \sigma G^t dW \tag{1}$$

$\ln(G^t)$ follows a simple Brownian motion with drift because the demand is non-negative. Thus,

$$dg^t = \left(\alpha - \frac{1}{2}\sigma^2\right)dt + \sigma dW, \quad t \in \{1, \dots, T\},\ g^t = \ln G^t \tag{2}$$

where α is the growth rate of income accrued during the project lifecycle and can be either positive or negative. $\sigma C dW$ represents the stochastic deviation of C.

With the assumption of risk neutrality, the change of cash flow C can be described as,

$$dC = (\alpha - \eta_c)C dt + \sigma C dW^* = \alpha^* C dt + \sigma C dW^* \tag{3}$$

where η_c is the risk premium of uncertainty of cash flow, and dW^* the increment of Gauss-Wiener process that is linked with the entire economic activity with the assumption of risk neutrality.

So, the income with uncertainty can be deduced from (3),

$$V(C^t, t) = E_Q\left[\int_{t+\tau}^{T^*} C(\tau)e^{-r_f \tau} d\tau\right] = -\frac{C^t}{r_f - \alpha^*}[e^{-(r_f-\alpha^*)\tau} - e^{-(r_f-\alpha^*)(T^*-t)}] \tag{4}$$

Equation (4) represents the tangible benefits that the ERP project would bring to the enterprise when the investment decision for the ERP software system is made at the decision point t, where

C^t: $G^t p$.
E_Q: measure of risk neutrality.

α^*: $\alpha - 1/2\sigma^2$.
r_f: risk-free interest rates.
p: net profit of unit product.

4.2 Assessment of intangible benefits under uncertainty

The intangible benefits that can be derived from the implementation of the ERP system are, by their nature, difficult to assess. Especially, such benefits vary widely and are very hard to assess quantitatively. This study will adopt the model of Kalafut and Low (2001) as the basis for assessing the intangible benefits due to this implementation. Based on this model, a fuzzy assessment method has been developed in this study to evaluate the intangible benefits derived from an ERP system implementation. Section 4.2.1 provides an analysis of the characteristics of such intangible benefits and this is followed by the computation of these intangible benefits (Sect. 4.2.2).

4.2.1 The value creation index (VCI) model

The ERP value creation index (VCI) comprises 9 value drivers. These value drivers can be individually assessed and quantified and, depending on their relative impact, the weighting of each driver can also be determined. Then, the weighted sum of these driver values is derived for obtaining the overall, non-financial performance (i.e. VCI) of an enterprise. See Fig. 4.

The VCI model depicts the overall effect of an enterprise's value creation capabilities described by these value drivers. A high VCI denotes a high value creation capability of the enterprise. Since ERP is an embodiment of advanced production management theories; the intangible benefits brought by an ERP system will enhance the enterprise value creation capabilities. This can be reflected in the improved value of the enterprise's VCI. Moreover, in this study, a value driver is formed by a hierarchy of sub-value driver; and the numerical value of the parent driver is determined from the values of its sub-drivers and the weights that are assigned to them. The value drivers identified for the purpose of performance assessment of the implemented ERP are shown in Table 1.

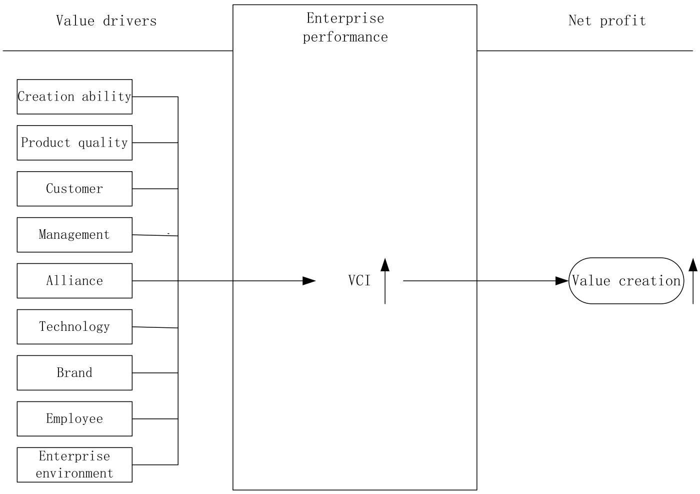

Fig. 4 ERP value creation index model

Table 1 Value drivers and their subcategories in the ERP VCI model

Main value driver	Sub-categories of value drivers
Enterprise innovation ability X_1	• Standard management (degree) to realise enterprise's R&D, X_{11} • Improve management level of R&D, X_{12} • Enhance technical creation ability, X_{13}
Product quality X_2	• Improve product quality, X_{21} • Shorten manufacturing cycle time, X_{22}
Customer relations X_3	• Reduced delivery lead time, X_{31} • Improved consumer satisfaction for product and service, X_{32}
Management capabilities X_4	• Improve group decision efficiency by more people in the organisation, X_{41} • Improve on personal (such as an executive) decision efficiency, X_{42} • Enhance cooperation, negotiation and decision efficiency of employees and external stakeholders, X_{43}
Alliances X_5 (i.e. ERP as the strategic vehicle to establish alliances with partners)	• Number and relationships of strategic alliance, X_{51} • Number and relationships of suppliers, X_{52} • Number and relationships of market sales alliance (agents), X_{53}
Technology management X_6	• Improve learning ability to new technology, X_{61} • Obtain market competitive advantages, X_{62} • Realise IT strategy planning, X_{63}
Brand X_7 (i.e. the effect on corporate image)	• Improve adaptive ability of an enterprise to environment (flexibility), X_{71} • Improve corporation identity, X_{72} • Cultivate enterprise culture, X_{73}
Employee relations X_8	• Reduce management staff, X_{81} • Improve work efficiency of employee, X_{82} • Strengthen employee's competence, X_{83}
Environment and community issues X_9	• Improve adaptive ability of an enterprise to environment (flexibility), reduce management staff, X_{91} • Improve corporation identity, X_{92} • Cultivate enterprise culture, X_{93}

The above value drivers are employed for developing a single performance measure (i.e. VCI) of the intangible benefits that could be accrued from an ERP investment project. To incorporate the VCI (or the change of it, δ) into the real-option valuation approach for assessing the effectiveness of an ERP project, the following steps are required:

(i) To determine the values of the main value drivers as well as their sub-drivers.
(ii) To determine the relative impacts of the main value drivers (for obtaining the VCI value) and those of sub-drivers (for obtaining the values of individual main value drivers).
(iii) Then, a fuzzy assessment method will be employed for the evaluation of δ.

Approach for determining driver values The intangible benefits can be associated with reduced cost or improving financial return through appropriate subjective methods. For example, the question for eliciting the intangible benefit derived from "reducing the delivery lead-time to customer" can be put as "If an ERP system could implemented successfully, do you think the delivery lead-time be shortened?" If the answer is "yes", the next question is "If the delivery lead-time could be reduced by installing the ERP system, to what extent could such an improvement be made when compared with the case of not having the system installed?" The answer to such questions can be based on the fuzzy scale comprising the ratings of "excellent, good, fair and poor".

Determination of relative impacts or weights of value drivers The motives of introducing ERP system for different kinds of enterprise are diverse because the strategic aims of different organisations will be different. The determination of these weights, therefore, should be aligned with the vision of the enterprise during the evaluation process of adopting fuzzy assessment method. For example, if the main purpose of introducing ERP system for a R&D manufacturing enterprise is to improve its innovative capabilities; the driver "innovation" should be given a higher weighting compared with the other 8 main drivers. However, if the main purpose of the enterprise is to strengthen its alliance relationship with its partners, the driver "alliance" should then be given a higher weighting.

4.2.2 *Calculation of intangible benefit*

The net profit D^t in time t earned by an enterprise due to the ERP project are related to market demand of product G^t. Therefore, it is also uncertain and,

$$D^t = G^t \cdot p \tag{5}$$

where p is net profit of a unit product. Similar to the way the tangible benefit $V(C^t, t)$ is computed, the enterprise's total net profit value $V(D^t, t)$ within years of applying ERP system can be obtained by applying

$$V(D^t, t) = -\frac{D}{r_f - \alpha^*}[e^{-(r_f-\alpha^*)\tau} - e^{-(r_f-\alpha^*)(T^*-t)}] \tag{6}$$

$$\begin{aligned} &\text{Total intangible profit cash flow of ERP} \\ &\quad = \delta \times \text{the total net profit of enterprise in the lifecycle of ERP system} \\ &\quad = \delta \times V(D^t, t) \end{aligned} \tag{7}$$

5 Analysis of uncertainty on ERP project costs

5.1 Purchasing cost of ERP software package

The price P of the ERP software is determined according to the market price. The total cost mainly includes the software purchasing cost and software license fee. The overall utility of an ERP software system can be ranked according to its attributes including the software quality, system stability, expansibility, and maintenance and training services. X is defined as the utility of an ERP software system as seen by an enterprise in relation to its installation and implementation costs.

Suppose X is a continuous variable, $0 \leq X \leq 5$, 5 represents the highest utility of ERP software system in the market. Choose a random number from 0–5, which can appropriately represent the corresponding level of ERP software system. Suppose $P(X)$ is the price function of ERP software whose level coefficient is X, which is linear function, so,

$$P(X) = \eta X + \theta \tag{8}$$

(NB η and θ will be used to denote price parameters in this paper.)

5.2 Consultancy and training expenses of ERP project

Denote by K the ERP project consultancy and training expenses, the logarithm of which follows the conditions of a heteroskedastic Gaussian process.

$$E(\tilde{K}^{t+1} | \tilde{K}^t = K^t) = \mu_k + \rho_k (K^t - \mu_k) \tag{9}$$

$$\mathrm{Var}(\tilde{K}^{t+1} | \tilde{K}^t = K^t) = \sigma_k^2 (1 - \rho_k^2) \tag{10}$$

where

$\tilde{k}^t$: the stochastic variable denoting ERP project consultancy expense at the period t.
k^t: the factual value of stochastic variable at the period t.
$\tilde{K}^t$: the logarithm of $\tilde{k}^t$.
K^t: the factual value of $\tilde{K}^t$ at the period t.
μ_k: the unconditional average value of $\tilde{K}^t$.
σ_k^2: the unconditional deviation of $\tilde{K}^t$.
ρ_k: correlation coefficient.
$\tilde{\varepsilon}_k^t$: the stochastic variable that follows the normal distribution $N(0, 1)$.
$\tilde{K}^t = \ln \tilde{k}^t$.

Suppose that $\tilde{K}^t$ follows a normal distribution, then

$$E(\tilde{K}^{t+1} | \tilde{K}^t = K^t) = \begin{cases} \mu_k + \rho_k (R^t - \mu_r) + \tilde{\varepsilon}_k^{t+1} \sqrt{\sigma_k^2 (1 - \rho_k^2)}, & \forall t \in \{2, \ldots, T\} \\ \ln k^1, & t = 1 \end{cases} \tag{11}$$

5.3 Project cost and operational expenses

Project cost refers to the expenses due to all the development and implementation works in the ERP project. These include salary, hardware costs, implementation expenses, expenses for enabling co-operations with suppliers and other partners, system support expenses and other items. Operational expenses refer to those paid for the resources for operating the system, and the required maintenance during the period between system go-live and the end of lifecycle. These include the maintenance expenses of various types of equipment, operational expense of computer systems, support expense of programs design, auxiliary activities expense and power.

6 A stochastic mixed-integer programming (MIP) model

6.1 Variables and parameters in the MIP model

For the evaluation of the compound options embedded in a technology investment decision, a stochastic MIP model is proposed. The decision variables and other parameters used in the proposed model are given as follows

Decision variables for $t \in \{1, \dots, T\}$:

U^t: 0–1 variable. If investment strategy S-1 is selected at the period t, $U^t = 1$, otherwise $U^t = 0$.
V^t: 0–1 variable. If investment strategy S-2A is selected at period t, $V^t = 1$, otherwise $V^t = 0$.
W^t: 0–1 variable. If investment strategy S-2B is selected at period t, $W^t = 1$, otherwise $W^t = 0$.
X^t: (Continuous variable) Coefficient of ERP software class selected at t if S-1 is selected.
Y^t: (Continuous variable) Coefficient of ERP software class selected at t if S-2A is selected.
Z^t: (Continuous variable) Coefficient of ERP software class selected at t point if S-2B, i.e. further purchase or develop middleware by itself, is selected.

State variable:

F^t: Cash flow at period t.

Project cost:

I^t_*: project cost of investment strategy *, namely $I^t_* = A_* e^{-\lambda_* t} + B_*$ ($* = 1, 2a, 2b$).

Software price function:

- The price of ERP aggregate software package due to S-1: $P_1(X) = \eta_1 X + \theta_1$.
- The price of ERP modules due to S-2: $P_{2a}(Y) = \eta_{2a} Y + \theta_{2a}$.
- The price of ERP middleware: $P_{2b}(Z) = \eta_{2b} Z + \theta_{2b}$.

The total prospective future net profit of ERP system = tangible profits + intangible profits – operational expenses.

If the investment strategy $S - *$ ($* = 1, 2$) is adopted, the future net profit that ERP software package bring for the enterprise = $\nu_* \times$ the total prospective future net profit of ERP software package, where ν_* is the income reward coefficient, which is relevant to the quality of and advanced featured incorporated in the selected software. For example, if the ERP software is supplied by a reputed vendor, the value of ν_* will be larger.

Other parameters as listed as follows

I: Total maximum expense budget of ERP system investment.
I': Total maximum expense budget of investment strategy S-2A.
L: Learning value from investment strategy S-2A.
δ: Change of VCI (defined above).
E: Total operation expense from the use to the lifecycle of ERP system.
$V(C^t, t)$: Total tangible benefit after ERP system go-live under the condition of making decision for investment ERP system at t point.

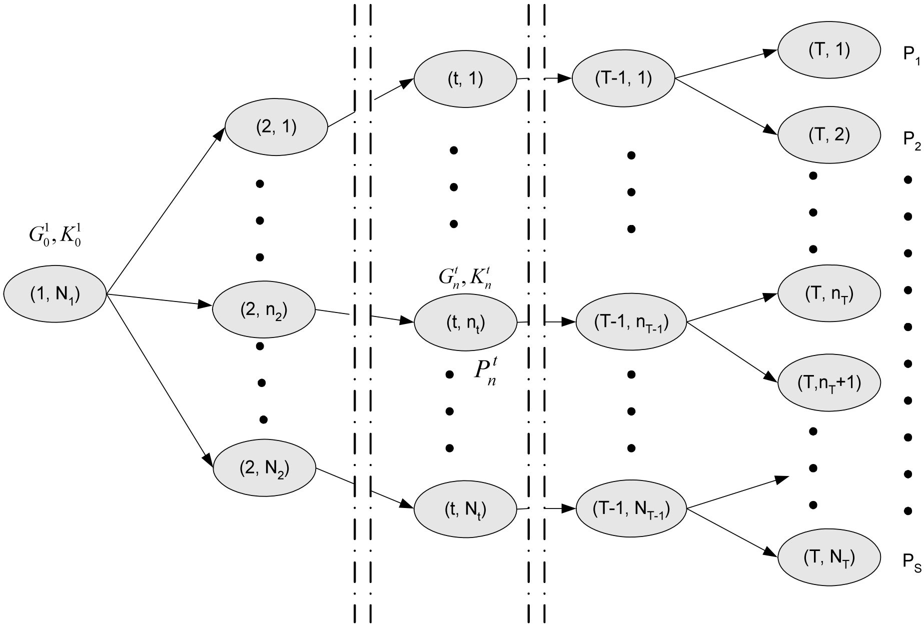

Fig. 5 The investment scenario tree of ERP project

$V(D^t, t)$: Total intangible benefit after ERP system go-live under the condition of making decision for investment ERP system at t point, here, $D^t = G^t p$.

b: Cost saved per unit product after implementing the ERP system.

p: Net profit per unit product.

γ: Risk-free interest rate.

G_n^t: Demand of product at t point in nth iteration.

K_n^t: Training expense of ERP software package at t point in nth iteration.

6.2 Model construction

The objective function of the stochastic MIP model is to maximise the NPV of ERP investment project which includes compound real options. The model is used for obtaining the maximum NPV subjected to the given set of constraints and for identifying which ERP software that enables the largest NPV to be achieved. The scenario tree of original problem is shown in Fig. 5.

$$\max \sum_{t=1}^{T} \left(\sum_{m=1}^{N_t} P_n^t \frac{F_m^t}{(1+\gamma)^t} \right) \tag{12}$$

$$\begin{aligned} F_n^t &= V_n^t L - [U_n^t I_1^t + V_n^t I_{2a}^t + W_n^t I_{2b}^t] - [U_n^t P_1 + V_n^t P_{2a} + W_n^t P_{2b} + U_n^t K_n^t + W_n^t K_n^t] \\ &\quad + \nu_1 U_n^t [V(C_n^t, t) + \delta V(D_n^t, t) - E] + \upsilon_2 W_n^t [V(C_n^t, t) + \delta V(D_n^t, t) - E] \\ &\quad \forall t \in \{2, \dots, T\}, \forall n \in \{1, \dots, N_t\} \end{aligned} \tag{13}$$

The interval between the implementation of investment strategy $2a$ and $2b$ is t^* years. Equation (13) can be transformed into

$$F_n^t = W_n^t(1+\gamma)^{t^*}L - [U_n^t I_1^t + W_n^t(1+\gamma)^{t^*} I_{2a}^t + W_n^t I_{2b}^t]$$
$$- [U_n^t P_1 + W_n^t(1+\gamma)^{t^*} P_{2a} + W_n^t P_{2b} + U_n^t K_n^t + W_n^t K_n^t]$$
$$+ \nu_1 U_n^t[V(C_n^t, t) + \delta V(D_n^t, t) - E] + \upsilon_2 W_n^t[V(C_n^t, t) + \delta V(D_n^t, t) - E]$$
$$\forall t \in \{2, \ldots, T\}, \forall n \in \{1, \ldots, N_t\}$$

$$F_m^t = \max\{F_n^t, 0\} \tag{14}$$

$$I_*^t = A_* e^{-\lambda_* t} + B_* \tag{15}$$

s.t.

$$\sum_{t=1}^{T} U_n^t \le 1 \tag{16}$$

$$\sum_{t=1}^{T} V_n^t \le 1 \tag{17}$$

$$\sum_{t=1}^{T} W_n^t \le 1 \tag{18}$$

$$\sum_{t=1}^{T} (V_n^t - W_n^t) = 0 \tag{19}$$

$$\sum_{t=1}^{T} (U_n^t + V_n^t) \le 1 \tag{20}$$

$$\sum_{t=1}^{T} (V_n^t - W_n^t)t \le 0 \tag{21}$$

$$V_n^t + W_n^t \le 1 \tag{22}$$

$$F_1^1 = -(U^1 I_{2a}^1 + V^1 I_1^1) \tag{23}$$

$$U_n^t, V_n^t, W_n^t = 0 \text{ or } 1 \tag{24}$$

$$U_n^t(I_1^t + K_n^t + P_1) \le I \tag{25}$$

$$V_n^t(K_n^t + P_{2a} + I_{2a}^t) + W_n^t(P_{2b} + I_{2b}^t) \le I \tag{26}$$

In the above constraints, $\forall t \in \{1, \ldots, T\}, \forall n \in \{1, \ldots, N_t\}$ node $(t, n) \in (T, n)$.

The various constraints of the stochastic integer program are explained as follows:

- Constraints (16)–(18): the three investment strategies can be selected at any one time in the implementation of ERP project.
- Constraint (19): once the investment strategy S-2A is selected, S-2B must be selected before the investment decision period T, or both strategies are not selected at all in the implementation of ERP project.
- Constraint (20): S-1 and S-2 can be selected only once in the implementation of ERP project. If S-1 is selected, S-2 cannot be selected, or both are not selected.
- Constraint (21): S-2A must be implemented before S-2B.

- Constraint (22): since S2-A is the prerequisite for S-2B, the implementation of S-2A gives rise to a growth option and the two strategies cannot be selected at the same time.
- Constraints (25)–(26): these are constraints on the expenses, i.e. the total investment cost cannot exceed the total expense budget.

However, the decision maker may choose to invest immediately or in future and decide to choose the investment strategy S-1 or S-2 on every investment decision. This is a typical multistage decision problem with constraints. The total real-option value (ROV) is used to evaluate compound of ERP project investment, which is,

$$\mathrm{ROV} = \max(\mathrm{NPV}_{option} - \mathrm{NPV}_{static}, 0) \tag{27}$$

where NPV_{static} is the NPV of the entire project without considering the flexibility of ERP project investment at the decision point $t = 1$. If immediate investment is made at the point $t = 1$, both the investment cost and future income both are certain. So, NPV_{static} is a constant. NPV_{option} is the NPV that takes into account the value of the options with the investment opportunities and investment scale.

6.3 Algorithm for solving the stochastic integer program

The solution procedure for the proposed stochastic integer program is shown in Fig. 6. This consists, firstly, the original problem is transformed to a deterministic problem by using the Latin hypercube stratified sampling technique (LHSST); and secondly, the model is decomposed into main problems and sub-problems, and is solved iteratively.

In transforming the initial stochastic integer program using LHSST, a set of scenarios S is obtained. The cumulative distribution of each stochastic variable is divided into N intervals

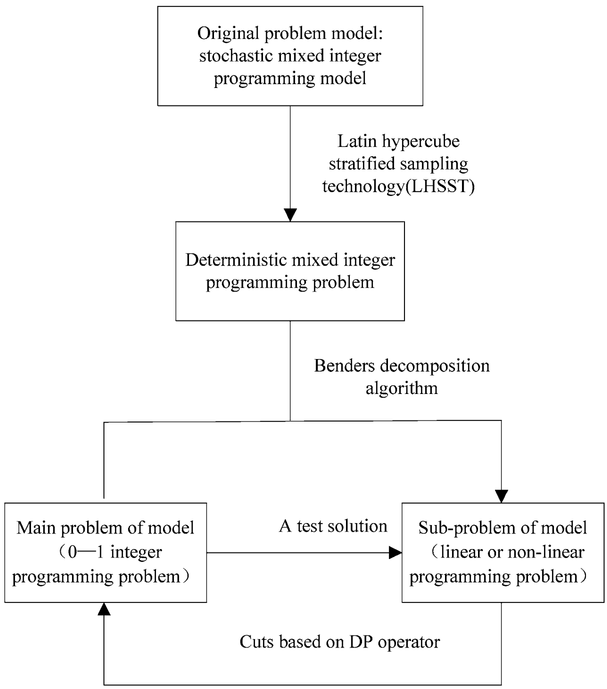

Fig. 6 The solving process of a stochastic integer program

which has equal probability due to LHSST (Minasny and McBratney 2006). The stochastic variable can take any value in each interval, thus all values in the interval are possible. It is found that the number of the sampling to perform is less than that of the Monte Carlo simulation approach. The algorithm consists of the following steps:

(1) The stochastic variables $\tilde{\varepsilon}_k^t$ and r^t are divided into N intervals which have equal probability, where stochastic variables $\tilde{\varepsilon}_k^t$ and r^t are random number that follow $N(0, 1)$.
(2) Randomly select a value U_n from every interval, $U_n = \frac{U}{N} + (n-1)/N$, U is a random number selected from (0, 1).
(3) Solve $\tilde{\varepsilon}_k^t = F_x^{-1}(U_n)$, $r^t = F_x^{-1}(U_n)$, $F_x^{-1}(.)$ is the inverse of $F_x(.)$, is the inverse function of standard normal distribution function.
(4) Use random number to solve G_n^t, and using $\tilde{\varepsilon}_k^t$ to solve K_n^t respectively.
(5) Use Constraints (16)–(22) to filter the combination of stochastic decision variables.
(6) Include in the objective function the combination of stochastic decision variables that satisfy the constraints; order the values of objective function, the largest of which is the optimum solution and the corresponding combination is the optimal investment strategy.

Next, the equivalent deterministic problem is decomposed and solved by using the Benders' decomposition process (Alvarez and Stenbacka 2001; Birge 1985; Pflug 2001). The main problem is a 0–1 integer program which is a slack version of the original problem; and the optimal value of the objective is a lower bound of original problem. By solving the objective integer program, a test solution $\{U_r^t, V_r^t, W_r^t\}$ is obtained (which is the solution of the main problem in the rth iteration) and this solution will be transformed into a number of sub-problems. During each step of the iteration, the solution for the sub-problem produces one or multiple constraints (i.e. named "cuts") which will be added to main problem to conduct the next iteration. This process is continued until the optimal solution is found. The detailed computational procedure of Benders' algorithm is shown in Appendix.

7 Case study

Datang Telecom (CDMA) was founded in April 1993 to engage in the high-tech businesses. The company mainly involves in product R&D, production, sales and service in the field of telecom and information. In order to solve the production management problems, enhance the capabilities of the management, and achieve the goals set out in the strategic development plans, the company has decided to adopt SAP's advanced ERP management information system. The project period was from 1999 to 2002. This case study represents a retrospective analysis of the project valuation process using the proposed framework based on real options.

7.1 Solution procedure of the decision model

The stochastic MIP developed in Sect. 6 was transformed to an equivalent deterministic MIP by using the LHSST. The scenario tree generated has $\{1 \times 2 \times 2 \times 2\}$ number of nodes and hence the number of scenarios generated is $N = 2^3$ (Fig. 7). The number of sample is 8. The sample value and corresponding probability is $\{G_n^t, K_n^t, p_n^t\}$, $\forall t \in \{1, \dots, T\}$, $\forall n \in \{1, \dots, N_t\}$ and $N_T = 2^3$.

Cost information provided by Datang Telecom is given as follows. The sunk costs due to the project are given in Table 2. Also, according to the market forecast, the volatility rate σ is taken to be 0.3 and $b = 30$ Yuan/Line (unit product saved cost) and $p = 100$ Yuan/Line (unit product net profit) from data provided by the company.

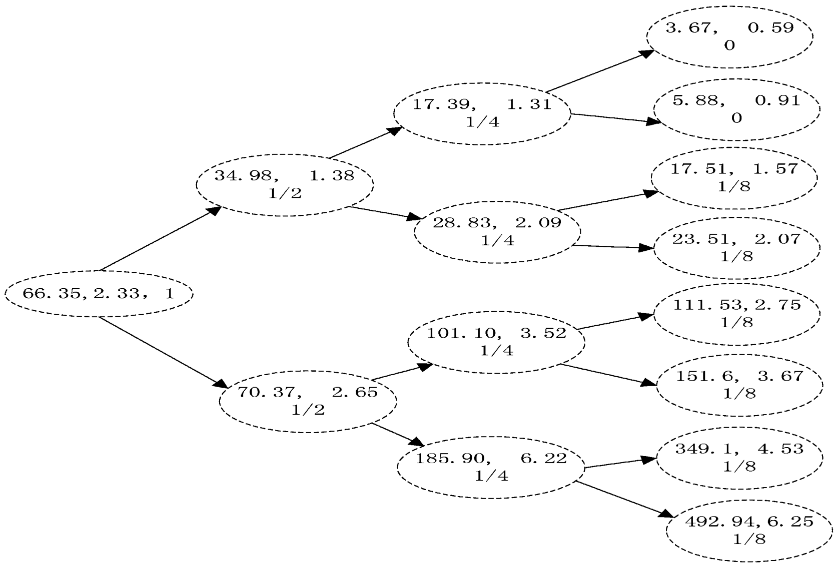

Fig. 7 G, K sample values

Table 2 Values of ERP sunk cost

Decision point	1	2	3	4
I_1	586	556	540	530
I_{2a}	397	385	375	368
I_{2b}	159	142	136	129

In terms of prediction for VCI by ERP implementation experts, δ in this case is 10%. The value of consultancy, training and other expenses are:

$$K_0^1 = 2.33 \text{ Million (Yuan)}, \qquad G_0^1 = 663.5 \text{ K lines}$$

$$\mu_k = \ln 2.62, \qquad \rho_k = 0.0012, \qquad \sigma_k = \ln 0.5$$

$$\gamma = 5\%, \qquad E = 200 \text{ K (Yuan)/year}; \qquad \nu_1 = 1.2, \qquad \nu_2 = 1.6$$

$$L = 902 \text{ K (Yuan)}, \qquad \alpha^* = 0.52, \qquad r_f = 0.82$$

$$P_1 = 823 \text{ K (Yuan)}, \qquad P_{2a} = 432 \text{ K (Yuan)}, \qquad P_{2b} = 341 \text{ K (Yuan)}$$

The constraint of expense budget:

$$I = 12000 \text{ K (Yuan)}, \qquad I^t = 8000 \text{ K (Yuan)}$$

Compute the corresponding $\{G_n^t, K_n^t, P_n^t\}$ and perform Latin super-cube sampling. The initial parameters selected are shown in Fig. 7. The combination solution of $\{U^t, V^t, W^t\}$ shown in Table 3 can be observed in terms of the particular of stochastic MIP constraints.

Set the initial feasible portfolio 1 of decision variables to be $\{1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0\}$, the sub-problems and the corresponding deterministic programs can be solved (NB: the model is developed in Visual C++ using the solver ILOG). Since the results obtained

Table 3 The portfolio of decision variables (X-Decision Variable; Y-Portfolio Set)

Y \ X	U^1	V^1	W^1	U^2	V^2	W^2	U^3	V^3	W^3	U^4	V^4	W^4
1	1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	1	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	1	0	0
5	0	1	0	0	0	1	0	0	0	0	0	0
6	0	1	0	0	0	0	0	0	1	0	0	0
7	0	1	0	0	0	0	0	0	0	0	0	1
8	0	0	0	0	1	0	0	0	1	0	0	0
9	0	0	0	0	1	0	0	0	0	0	0	1
10	0	0	0	0	0	0	0	1	0	0	0	1
11	0	0	0	0	0	0	0	1	0	0	0	0

from solving these deterministic programs are unbounded, constraints will be added to the main problem. Then, by using the ILOGHybrid20 package, the main problem of the 0–1 integer program can be solved. After 5 iterations, portfolio 8, $\{0,0,0,0,1,0,0,0,1,0,0,0\}$, is substituted into the sub-problem. The result obtained for this portfolio is $S_{\max} = 2425.6$ K (Yuan). According to this portfolio, the decision maker did not invest in the first year but adopted S-2A in the second year due to the uncertainty of income and consultancy expense. S-2B was then implemented in the third year. The maximum of the NPV of the ERP investment project with real options was 2425.6 K (Yuan).

7.2 Computation of NPV$_{static}$

The static NPV is obtained based on the following information

- NPV$_{static}$: The NPV that is to adopt investment strategy S-1 and invest immediately without considering the flexibility of ERP project investment at period $t = 1$.
- V: The net cash flow of total profit that the implementation of ERP that would bring to the enterprise. It is estimated by the expert team of the ERP project and with a reference to the IDC telecom market demand. $V = 9{,}895$ K (Yuan).
- M: NPV of the operation and maintenance total expense from ERP system go-live to the end of the ERP project $= 9 \times 200$ K (Yuan).
- I_a: Total cost required by employing S-2A = Consultant cost + software cost + project cost.
- I_l: $= 7{,}860$ K (Yuan).
- γ: Risk-free rate $= 0.05$.
- τ: The time required for the implementation of the ERP system if S-1 is adopted = 1 (year)

$$\text{NPV}_{static} = \frac{V}{(1+r)} - \frac{I_1}{(1+r)} - \frac{M}{(1+r)^2}$$
$$= 942.4 - 748.5 - 163.2 = 307 \text{ K (Yuan)}$$

The total ROV of ERP project investment was:

$$\mathrm{ROV} = \max(\mathrm{NPV}_{option} - \mathrm{NPV}_{static}, 0) = 2118\ \mathrm{K\ (Yuan)}$$

It is obvious that the NPV of investing portfolio 8 is larger than that of adopting S-1 at period $t = 1$. The reason is that the value of managerial flexibilities are explicitly considered in portfolio 8, including the value of real options such as the option of waiting, option to learn, option to abandon and option to change the project investment scale are used in project investment.

8 Discussion and findings

8.1 A comparative study of the real-option approach and the traditional NPV method

In order to compare the outcomes between the real-option approach and the NPV method, the investment strategy S-2 must be evaluated using the same decision parameters such as portfolio 8.

In the above case of Datang Telecom (CDMA), if portfolio 8 of investment is assessed by using the traditional NPV approach, the cash flow of ERP project is shown in Fig. 8.

- V: Total amount of cash flow benefit after ERP system go-live under investment portfolio 8. It is estimated by the expert team of the ERP project and with a reference to the IDC telecom market demand. $V = 9{,}392$ K (Yuan).
- M: Denotes total operation and maintenance cost from ERP system go-live to the end of ERP project $= 7 \times 200$ K (Yuan).
- I_a: Total cost required by employing investment strategy S-2A = Consultant cost + software cost + project cost = 4,860 K (Yuan).
- I_b: Total cost required by employing S-2B = software purchasing cost + project cost = 2,870 K (Yuan).
- γ: Risk-free rate = 0.05.
- τ_1: The period of optimal component pilot required by employing S-2A = 1 (year).
- τ: The period of finished the ERP system required by employing S-2 = 2 (year).

$$\mathrm{NPV} = \frac{V}{(1+r)^3} - \frac{I_a}{(1+r)^1} - \frac{I_b}{(1+r)^{(\tau_1+1)}} - \frac{M}{(1+r)^{(\tau+1)}} = -567.8\ \mathrm{K\ (Yuan)}$$

The evaluation result of having NPV < 0 indicates that the project should be rejected due to its loss in the whole project lifecycle. In this case study, under portfolio investment 8, the NPV of the project is evaluated to be negative (−567.8 K) and hence it should be rejected.

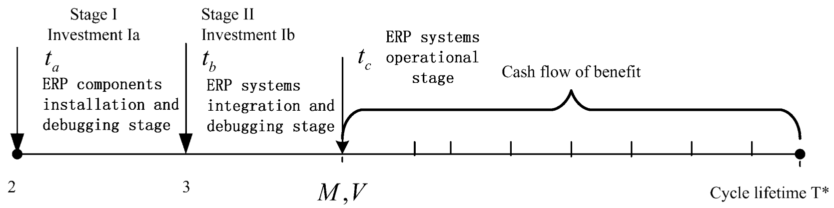

Fig. 8 NPV of cash flow ERP project investment

However, under the real-option valuation framework, the value of real option of the project is positive (2118 K), which indicates that the project could be accepted. As a result, if the result obtained from the traditional NPV approach was to be adopted, Datang Telecom Co. would miss the opportunity to employ ERP to reinforce its competitive edge.

Under the real option framework, the compound real options are considered. These include the option to learn and the option derived from the flexibility of decision-making management and the uncertainty of benefit and cost in ERP project investment. Also, the model employs investment portfolio 8, which will enable the firm to achieve the maximum NPV including the real options of the project. Therefore, the optimal investment strategy, portfolio 8, should be selected. In contrast, the traditional financial evaluation method takes no account of the uncertainty and value of real options in the project investment, and the value of NPV is negative. Consequently, the firm will miss the optimal opportunity of investment.

8.2 Findings and significant of the research

To evaluate and analyse the various ERP investment strategies, this study has employed the real-option approach that considers both the tangible and the intangible benefits obtained after the ERP project goes live. It also addresses the uncertainty of consultant expenses in the overall investment cost, thus making the decision-making model more akin to the real life investment environment.

(1) In previous studies on the valuation of ERP investment projects, few authors have considered the intangible benefits that could be derived from the ERP system. However, the motivation for such investments is due more to the potential value that could be created as a result of the introduction of the advanced management approaches and information systems. Unfortunately, such intangible benefits are known to be difficult to assess. In traditional financial valuation methods, due to a lack of an effective quantitative approach for the assessment of intangible benefits—the benefits of ERP usually have not been given a more rigorous evaluation and will lead to overrating or undervaluing of the benefits of ERP for the firm. With the option values added to the static NPV, the real-option framework will provide a basis for better approaches for valuating technology investment projects.
(2) The stochastic programming model captures the flexibility in decision-making in ERP investments and finds the optimal strategy, the optimal opportunity and optimal scale of ERP investment, thus providing investors of ERP projects with a scientific and useful decision-making method. By making use of this method, the decision maker could seize the investment opportunities more effectively, select right ERP software package, and achieve higher returns.
(3) In the model developed in this study, by making use of real options in the ERP project, a firm could effectively manage the risk encountered in the process of ERP implementation.

9 Conclusion

This paper has presented an approach to valuate a typical technology investment project (in this case an ERP system). The methodology employed in this study considers such a decision problem as one that involves multistage investment decisions made under uncertainty. The formulation of the decision problem in such a manner aims at capturing an investment

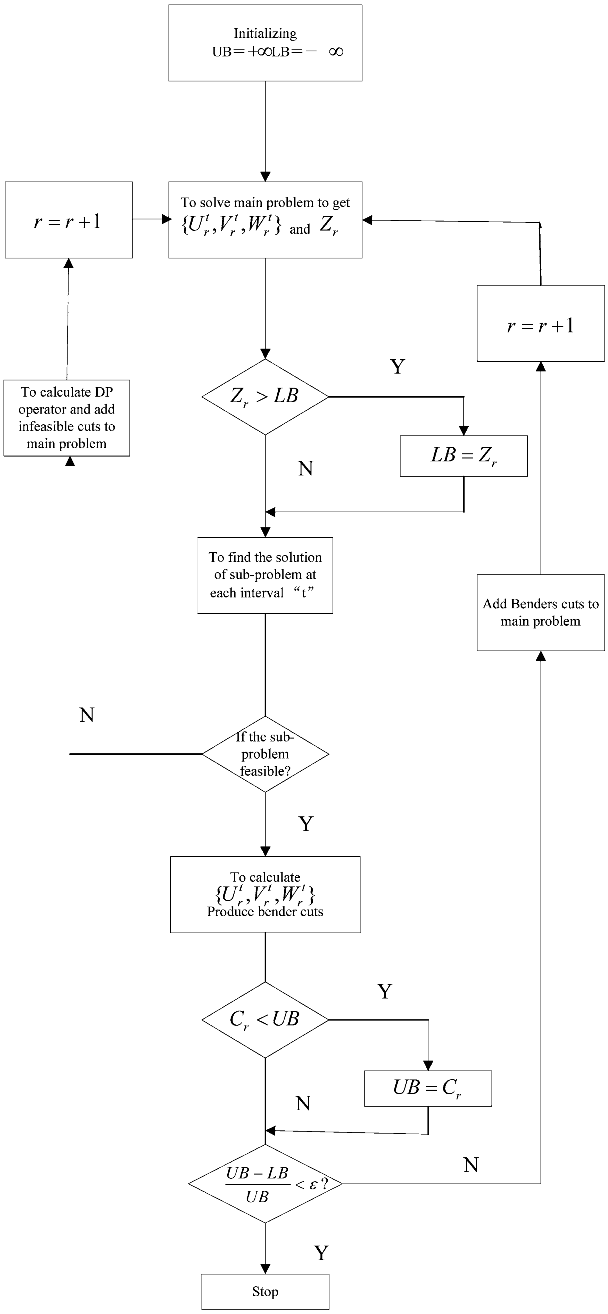

Fig. A.1 Benders' decomposition approach process

manager's behaviour in trying to explore the various opportunities and/or managerial flexibilities in the forms of real options. By including such real options in the analysis, the values of such real options can be truly reflected as compared with the traditional approaches (e.g.

IRR and NPV), which tend to under-valuate and hence fail to realise the potential inherent in many investment projects.

By taking into account the investment characteristics of an ERP system, a stochastic programming model is constructed to allow the valuation of investment projects within the real-option framework. Underpinning this model is the approaches for the analyses and assessments of the future costs incurred and benefits, both tangible and intangible, accrued from the project. The solution procedure is based on the LHSST and Benders' decomposition method. The ERP investment project of Datang Telecom (CDMA) is employed to demonstrate the above approach. According to this case study, it is found that the proposed model, by systematically addressing the real option embedded in the ERP project, allows a better appraisal of the investment opportunities that exist in the project

Acknowledgements The authors gratefully acknowledge fundings received from the Nation Natural Science Foundation of China ((NSFC) 70572038, 70433033, 70701005), the Key Lab of Information Management & Information Economics of Education Ministry, China, F0607-39, and State Key Laboratory of Mechanical Manufacturing System Engineering (China) under the research grant of 2006-06.

Appendix: Benders' decomposition algorithm

The Benders' decomposition approach is for use to decompose the equivalent deterministic MIP model into main problems and sub-problems. The Benders' decomposition process is shown in Fig. A.1.

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