2009

How Much to Spend on Flexibility? Determining the Value of Information System Flexibility

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ABSTRACT

In the current paper, we outline several approaches to determine the value of information system (IS) flexibility, defined as the extent to which an IS can be modified and upgraded following its initial implementation. Building on an earlier conceptual model by Gebauer and Schober (2006), we calculate the value of IS flexibility for a numerical example with deterministic and stochastic model parameters. We compare the results of decision tree analysis and real option analysis and present the results of a simulation experiment. Besides practical implications, our results contribute to earlier research on IS flexibility as they highlight the need to include stochastic elements in the evaluation of IS flexibility.

Keywords

Information system flexibility, risk analysis, decision tree analysis, real option analysis, simulation experiment.

INTRODUCTION

In a world of increasing uncertainty, the ability to utilize resources in a flexible way plays an important role for managerial decision making (Evans 1991; Ghemawat and Del Sol 1998). The need for flexibility applies to many corporate assets, including capital investments (Carlson 1989; Vokurka and O'Leary-Kelly 2000); employees and business partners (Bahrami and Evans 2005); organizational structures and processes (Maier 1981; Stigler 1939); and information systems (IS) (Byrd and Turner 2001; Chung, Rainer and Lewis 2003). The formulation and implementation of efficient IS flexibility strategies have become important aspects of risk management (Palanisamy and Sushil 2003; Robey and Boudreau 1999), whereby scholars have also analyzed the often contradictory effects of IS on organizational flexibility and efficiency (Allen and Boynton 1991; Robey and Boudreau 1999), and on various aspects of usability (Silver 1991).

Even though there is some agreement in the flexibility literature that flexibility comes at a price (Duimering, Safayeni, and Purdy 1993; Koste and Malhotra 1999), scholars of flexibility typically focus on various attributes and design parameters of flexible assets but are less concerned with the economics of flexibility (Saleh et al. forthcoming). In contrast, questions regarding the economic value of flexibility have been included in recent approaches of decision theory and financial analysis.

Traditional approaches to determine the value of an investment include net present value (NPV) and were based on discounted cash flow analysis (DCF) in a deterministic setting. If at all, risk was included in DCF models only indirectly via the selection of an appropriate discount rate. The risk associated with investment decisions in general, and investments in flexible assets in particular have been included in newer approaches, such as decision tree analysis (DTA), real options analysis (ROA), and risk simulation experiments.

Scholars of DTA enumerate the various choices of an investment and the various corresponding environmental states to find the optimal investment decision (Copeland and Keenan 1998). The approach requires the estimation of probabilities of occurrence for each environmental state. Scholars of ROA take a different approach to capture risk: ROA hedges against risk by constructing a set of options that ensure the same outcome for different environmental states. Consequently, ROA does not require explicit probability estimates for the various environmental states (Amram and Kulatilaka 1999; Copeland and Keenan 1998; Trigeorgis 1993). As a general concept of investment evaluation, ROA has found widespread support in the management and IS literature. It has also been suggested as an important lens to establish the value of flexibility for organizations (Copeland and Weiner 1990), business processes (Billington, Johnson and Triantis 2002), and IS (Benaroch and Kauffman 1999; Fichman 2004; Fichman, Keil and Tiwana 2005; Sambamurthy, Bharadwaj and Grover 2003; Tallon, Kauffman, Lucas, Whinston, and Zhu 2002). In summary, the discussion has come a long way to demonstrate the advantages of DTA and ROA over traditional approaches to evaluate flexibility. Still, concrete methods of how to determine the value of flexibility in specific cases are less well developed—an issue that we address in the current paper in the context of IS flexibility.

We build on research work by Gebauer and Schober (2006) who have developed a formal model to evaluate the impact of different IS flexibility strategies on the cost efficiency of business processes. Contingent on the characteristics of the business process that is supported by the IS, the model determines the cost-efficient mix of flexibility strategies. In the current paper, we go one step further and discuss specific approaches to calculate the economic value of IS flexibility. We emphasize flexibility-to-change, that is the extent to which an IS can be modified and upgraded in response to future requirements.

The paper is structured as follows: We begin with a brief description of the original model, whereby we introduce a few changes concerning the dynamics of IS development and utilization. Given that the main focus of the paper is on the value of flexibility, we first apply the model to perform DTA and ROA to determine this value in the case of uncertain business process loads (volume uncertainty). Next, we include additional stochastic parameters, and demonstrate ROA and explicit risk assessment based on simulation experiments. We close with a brief summary and re-iterate the importance of determining the value of flexibility in non-deterministic settings.

The current paper relates to our earlier works as follows: First, the notion of flexibility in general and IS flexibility in particular, including the specific characteristics of a flexible IS that is applied in the current paper, have been discussed in greater detail in Gebauer and Schober (2006). Second, the general applicability of the model and its limitations in practice were outlined in Gebauer and Lee (2008). Some of the practical shortcomings pointed out by Gebauer and Lee (2008) inspired the modifications that we propose in the current paper. These modifications relate in particular to the characteristics of the IS development process.

A MODEL TO ASSESS THE IMPACT OF IS FLEXIBILITY STRATEGIES ON BUSINESS PROCESS EFFICIENCY

Overview

In the following we distinguish between two structural elements of a business process, such as general purchasing: (1) “Process tasks” correspond with the different functionalities that the business process implies, such as the purchase of office furniture, the purchase of office material, or the purchase of company cars. (2) “Process activities” correspond with a single event that occurs as part of the business process, such as a specific request to purchase an office chair.

In our model framework, the characteristics of a business process are represented by the four parameters: Uncertainty (p), variability (v), time-criticality (r), and load (L), see Figure 1. Uncertainty refers to the degree to which process tasks are known to the IS developer at the time of system initialization. This parameter tries to assess in a subjective manner how structured and well-understood a business process is at the time of initialization of the IS in support of the process. Variability refers to the degree to which process activities are concentrated on the same process task; time-criticality measures the share of time-critical process activities; and load is a normalized factor that expresses the overall activity load of the business process.

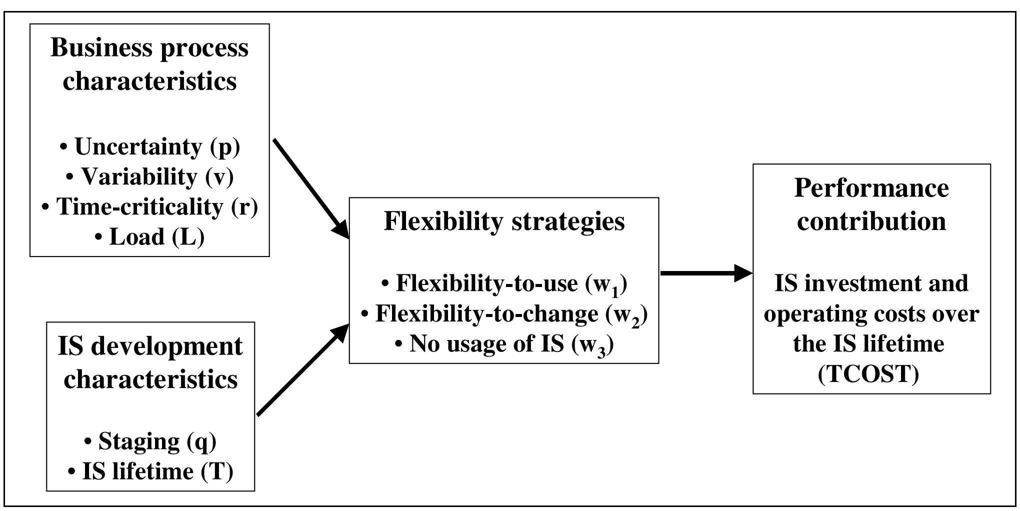

Figure 1. Model Overview

The characteristics of the IS development process are summarized by the two parameters staging (q) and IS lifetime (T): Staging takes into account that an IS is often not put into operation all at once, but in consecutive stages; and IS lifetime defines the total lifetime of the IS in years.

The variables w_1, w_2 and w_3 express the recommended mix of flexibility strategies in response to the business process and IS development characteristics. With w_1, we indicate the share of all process activities that utilize the functionality that is built a-priori into the IS upon its initialization (flexibility-to-use). Share w_2 refers to the activities that are handled by the IS after it has been modified or a new functionality has been implemented during its operational lifetime (flexibility-to-change). Lastly, w_3 denotes the share of activities that are not handled by the IS under consideration, but by different means, such as manually or by a different IS (no usage of IS). The weights w_1, w_2 and w_3 are derived decision variables that are calculated by minimizing total costs (TCOST) over the lifetime of the system.

Investment Decisions

The model includes two investment decisions that have to be made before the IS under consideration can become operational: The first decision concerns the basic investment (ICOST), and determines the extent of functionality that is included in the IS from its inception (flexibility-to-use). The second decision concerns an additional investment (FCOST) in the infrastructure that is necessary to modify or upgrade the IS during its operational lifetime (flexibility-to-change). Alternatively, ICOST can be viewed as an investment into an "off the shelf" standard IS, whereas FCOST refers to an incremental initial investment in the case where a custom-tailored and modifiable IS is selected instead. The possibility of subsequent modifications and upgrades depends on the additional initial investment FCOST.

ICOST is modeled as

(1) $$\text{ICOST} = \{ a + b\, L(x_1)\, (q + (1-q)\, DC) \}\, z,$$

where a denotes fixed development and purchase costs, and b denotes variable development and purchase costs if all process activities that are expected to occur at the time of the investment decision were supported by the IS. However, for process activities that are expected to occur with low frequency, it is often not considered economical to include the corresponding process task in the IS. Instead, the small number of occurrences can be handled outside of the IS, be it manually or by using a different IS that is outside of the scope of the model.

The percentage of known process tasks that is included in the initial IS is expressed by $L(x_1)$, where x_1 with $0 \leq x_1 \leq 1$ is a decision variable that denotes the share of all process activities in association with tasks that are known at IS initialization and that will be handled by the IS (note: x_1 relates to the number of activities and $L(x_1)$ to the number of corresponding tasks). $L(x_1)$ with $0 \leq L(x_1) \leq 1$ measures the concentration of activities on certain tasks and can be expressed by the well-known LORENZ curve (Figure 2). The value of $L(x_1)$ determines the extent of flexibility-to-use that is built into the IS from its very beginning.

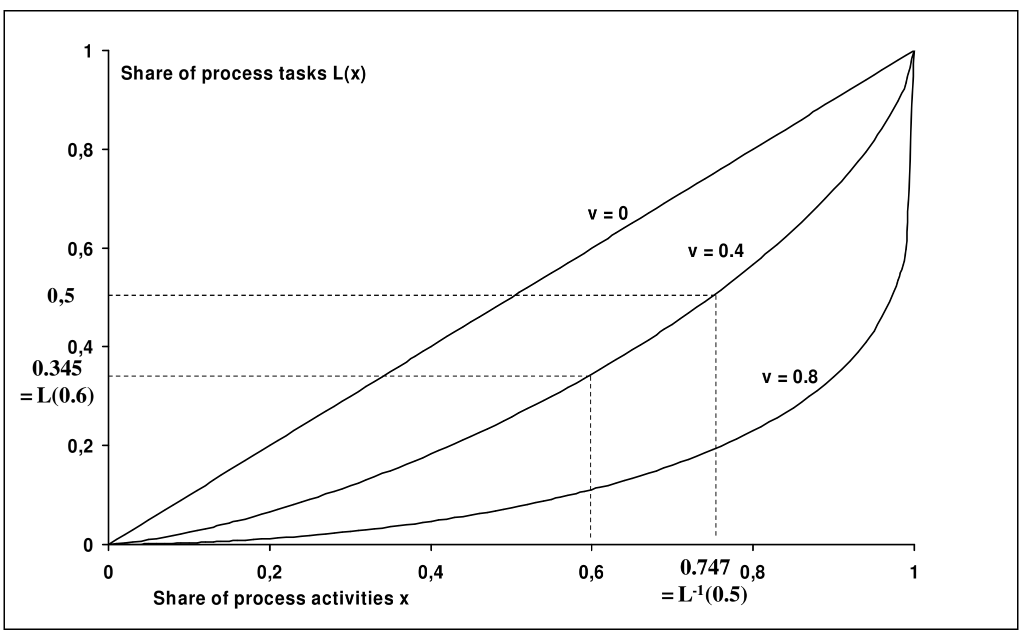

Figure 2. Lorenz Curve

Recent empirical work by Gebauer and Lee (2008) indicates that the assumption of a one-shot ("big bang") implementation of an IS is not very realistic, even if all process tasks were known in advance. In practice, IS management often prefers a "staged" implementation approach with a certain percentage q of the IS being implemented immediately and the rest (1 – q) being implemented subsequently during the system's lifetime, see Figure 1. Among the reasons for a staged approach are resource constraints and lack of user readiness. In order to account for the dynamic effects of investment staging we apply an average discount factor (DC). Assuming that the remaining investments are spread out evenly over the IS lifetime T in years (see Figure 1), we apply the annuity method and set DC as

(2) $DC = ((1+i)^T - 1) / (i\,(1+i)^T\, T)$ for $i > 0$ and $DC = 1$ for $i = 0$,

where i denotes the yearly discount rate (Copeland, Weston and Shastri 2007, p. 886).

For practical reasons, such as to produce meaningful model results even for extreme parameter constellations, we further include in equation (1) a binary variable z with z = 1, if the IS is implemented at all, and z = 0 if not. The values for the decision variables x_1 and z are yet unknown and will be computed endogenously by the model.

The additional cost premium FCOST for providing flexibility-to-change is modeled as

(3) $FCOST = c\, y$,

where y is a binary decision variable with y = 1, if flexibility-to-change is provided, and y = 0, if not. The parameter c denotes the value of the premium. Note that FCOST includes only the initial investment into flexibility-to-change while the subsequent costs for modifying and upgrading the IS are measured by a separate model term UCOST, as described in more detail just below. While c is a fixed cost parameter for the moment, it will later be endogenously calculated as the value of flexibility-to-change.

The costs UCOST to modify and upgrade the IS over its lifetime are modeled as

(4) $UCOST = e\, L(x_2)\, DC$.

In (4), the decision variable x_2 with $0 \leq x_2 \leq 1$ denotes the share of process activities that correspond to tasks that are not known at the time the IS is initialized, but that are supported by the IS after flexibility-to-change is utilized. The parameter e measures the costs if all relevant process activities tasks were included in the update (i.e., for $x_2 = 1$). As in equation (1), $L(x_2)$ refers to the Lorenz curve and here describes the amount of functionality that is built into the IS after modification or upgrade. And similar to equation (1), DC is the average yearly discount factor according to equation (2) that reflects the assumption that upgrades and modifications are spread out evenly over the IS lifetime.

A number of proposals exist for the analytical form of the Lorenz curve (Ortega, Martin, Fernandez, Ladoux and Garcia 1991). Following Gebauer and Schober (2006), we use the form

(5) $L(x) = x^v\, (1 - (1-x)^{1-v})$.

The variability parameter v measures the concentration of process activities, with $0 \leq v \leq 1$ (see Figure 1). Values of v that are close to 0 describe business processes with little concentration, thus high levels of variability. In contrast, values of v that are close to 1 describe business processes with low levels of variability, where activities for a small number of process tasks dominate (see Figure 2).

Ongoing Operations

While equations (1) through (5) of the current model refer to investment decisions, the following equations (6) through (8) refer to parameters and costs of ongoing operations. We distinguish IS operating costs OCOST that are associated with IS use, and manual costs MCOST that are associated with activities that are handled outside of the current IS (manually or by using different systems that are not considered here). To model the IS operating costs we use the parameters p as a measure for process uncertainty, and r as a measure for time-criticality (Figure 1).

However, before formulating the operating costs as such, we express the shares of the three different flexibility strategies (Figure 1) as

(6) $w_1 = p\, x_1$; $w_2 = (1-p)\, x_2$; $w_3 = 1 - w_1 - w_2$.

The variables w_1, w_2 and w_3 in (6) are decision variables that are derived based on the primary decision variables x_1 and x_2 and the estimated parameter p. Following equation (6), the operating costs OCOST of the IS can be written as

(7) $OCOST = L\, d\, \{\, (q + (1-q)\, L^{-1}(0.5)\,)\, w_1 + 0.5\, w_2 \,\}\, T\, DC$.

In equation (7), the parameter d is an estimate for the yearly operating costs if all process activities were handled by the system (i.e., $w_3 = 0$). These costs are multiplied by the shares of activities w_1 and w_2 that actually utilize the IS. Since we also assume that system additions, modifications and upgrades are staged equally over the lifetime of the IS, half of the share w_2 is handled outside of the system, as the corresponding activities occur before the system has been modified or upgraded. For share w_1, the list of activities that are supported by the IS and their variability according to the Lorenz curve are known in advance, which means that implementation priority can be given to tasks with higher frequency of occurrence. We consequently multiply w_1 with the inverse $L^{-1}(0.5)$, instead of 0.5 as in the case of w_2 (see Figure 2). The yearly operating costs are multiplied with the number of years T that depict the IS lifetime, and the average yearly discount factor DC. Lastly, the factor L will later serve to evaluate different scenarios for process load (Figure 1). For the moment, we set L = 1 as the normalized factor for a base load scenario.

In equation (8), the operating costs MCOST for activities that are handled outside of the system are modeled similarly to (7) and include all of the remaining process activities. Here, the operating costs are multiplied by a yearly cost factor f that applies in cases where all process activities are handled outside of the IS ($w_3 = 1$). In addition, we include a percentage cost premium g that applies in cases where a share r of time-critical activities is processed outside of the system, assuming that outside processing is less time-efficient, and thus more expensive. We obtain

(8) $MCOST = L\ f\,(1 + r\,g)\,\{(1-q)\,(1-L^{-1}(0.5))\,w_1 + 0.5\,w_2 + w_3\ \}\ T\ DC.$

To ensure meaningful calculation results, we further include two logical constraints in the model. First, for flexibility-to-change to be applicable ($x_2 > 0$), it has to be provided (y = 1 in equation (3)). We, thus, state the following constraint:

(9) $y \geq x_2.$

Second, for the system to be usable at all (i.e., $x_1 + x_2 > 0$), variable z in equation (1) has to be equal to 1. Our second constraint, thus, reads as follows:

(10) $z \geq 0.5\ (\ x_1 + x_2\ ).$

Equation (11) depicts the model's objective function as the minimum of the total costs over the entire lifetime of the IS. As TCOST joins the primary decision variables x_1, x_2, y and z, it provides the basis for the derived decision variables w_1, w_2 and w_3:

(11) $TCOST = \text{minimize}\ (\ ICOST + FCOST + UCOST + OCOST + MCOST\ )$

subject to $0 \leq x_1, x_2 \leq 1$ and $y, z \in \{0,1\}$.

In mathematical terms, the model constitutes a small-scale, non-linear, and mixed-integer program. Its solution is somewhat complicated, due primarily to the non-linear form of the Lorenz curve. To solve the original model as well as its variations that are discussed in the remainder of the paper, we used the optimization software LINGO (see LINDO 2003).

COMPUTING THE VALUE OF FLEXIBILITY

In the following, we compute the value of IS flexibility-to-change based on the discussed model and by using a specific numerical example. After presenting the example, we first assess the value of flexibility in a deterministic scenario. This situation corresponds to the traditional discounted cash flow (DCF) method. We then gradually add stochastic elements and apply decision tree analysis (DTA) and real options analysis (ROA), assuming a risk-neutral decision-maker in both cases. Finally, we run a risk analysis-based simulation experiment that relaxes the assumption of risk-neutrality.

Numerical Example

We first introduce the numerical example that we use throughout the remainder of the paper. The model parameters are set as follows (see also the Appendix for an overview table):

- Cost-related parameters: a = 100, b = 300, c = 50 (later c = 0), d = 150, e = 300, f = 450, g = 0.7, i = 0.05
- Parameters that characterize the business process: p = 0.8, v = 0.6, r = 0.1, L = 1
- Parameters depicting the IS development and implementation project and IS lifetime: q = 0.5, T = 5

For this set of parameters the cost-minimal solution of the model is $w_1 = 0.78$, $w_2 = 0$ and $w_3 = 0.22$ with TCOST = 1,355.1. In other words, the model suggests that 78 percent of the process activities be handled by the IS using the flexibility-to-use strategy, and 22 percent be handled outside of the IS. Flexibility-to-change is not included at all, resulting in $x_2 = 0$ and y = 0, and, as a consequence, $w_2 = 0$ for the optimal solution.

Value of Flexibility when Process Load is Deterministic

In equation (3), we assigned a fixed value for the initial investment in flexibility-to-change, namely c = 50. As the model solution shows, that value of c exceeds the level at which flexibility-to-change would enter the final solution. Therefore, we address the following question: What is the critical value of c, below which an investment in flexibility-to-change becomes interesting?

Had we insisted in an investment in flexibility-to-change at a level of c = 50, the result would have been TCOST = 1,374.7 and $w_1 = 0.78$, $w_2 = 0.09$, $w_3 = 0.13$, a result that we obtain by adding the constraint y = 1 to the model. In comparison with the optimal solution above, the cost difference is 1,374.7 – 1,355.1 = 19.6 monetary units. In other words, had we been able to reduce the investment into flexibility-to-change by that amount (c = 50 – 19.6 = 30.4), the investment would have been included in the optimal solution. The value c = 30.4 consequently defines the threshold below which an investment in flexibility-to-change becomes cost-efficient. In the following, we denote this threshold with c* and label it as the "value of flexibility".

The value of flexibility c* can be calculated without reference to an initial investment level by setting c = 0 in equation (3) and running the model twice: In the first run, flexibility-to-change is excluded by setting $x_2 = 0$. The resulting solution of the model is denoted with TCNF (<u>t</u>otal <u>c</u>osts with <u>n</u>o <u>f</u>lexibility-to-change provided). In the second run, we solve the model without the restriction $x_2 = 0$ allowing an investment in flexibility-to-change to occur at zero costs (c = 0). We call the resulting solution of the model TCF (<u>t</u>otal <u>c</u>osts with <u>f</u>lexibility-to-change provided). Given that the first optimization is derived under the additional constraint of $x_2 = 0$ (and as a consequence y = 0), we always observe TCNF $\geq$ TCF. Obviously, the value of flexibility c* is given by the difference

(12) $c^* = TCNF - TCF$.

For our numerical example above, we obtain TCNF = 1,355.1 and TCF = 1,324.7. Hence, c* = 30.4 as before. Note that TCF is lower than the optimal solution above because flexibility-to-change is assumed to come at zero cost (c = 0), and consequently the option of flexibility-to-change will be applied. If 50 monetary units are added to TCF, we again obtain the original solution TCOST = TCF + 50 = 1,374.7 for the case that flexibility-to-change is provided at c = 50.

Value of Flexibility when Process Load is Stochastic

Extending the deterministic scenario above, we now consider a situation of stochastic process load, as follows: Besides the process load that underlies the deterministic scenario, we include two additional scenarios, namely an upward scenario and a downward scenario. Compared to the deterministic scenario (base load), let us assume that the upward scenario involves a 40 percent higher process load regarding the number of process activities (load up); and the downward scenario assumes a 50 percent lower process load (load down). Let us further assume that we are able to provide probabilities for the occurrence of the base, upward, and downward scenarios, for example $P_b = 0.25$, $P_u = 0.50$ and $P_d = 0.25$. Moreover, we assume that the load variations lead to proportional changes in the operating costs so that in equations (7) and (8) the normalized factor L takes the values $L_u = 1.4$ in the upward, $L_b = 1$ in the base and $L_d = 0.5$ in the downward scenario. Note that for simplicity we do not assume an impact of load variation on the initial investment ICOST, although the model could be easily modified to handle this impact. In the following, we demonstrate the solution of the problem first based on decision tree analysis (DTA) and second based on real-option analysis (ROA).

Decision Tree Analysis

The results of the model runs that apply DTA to the various scenarios are depicted on the right-hand side of Figure 3. Assuming a risk-neutral decision-maker, we can use the expected values of TCF and TCNF as the main decision criterion. In the case of investment in flexibility-to-change, E(TCF) = 0.25 x 1,708.3 + 0.50 x 1,324.7 + 0.25 x 813.6 = 1,292.8. Accordingly, E(TCNF) = 1,325.0. The expected value of flexibility-to-change is then determined by the difference c* = E(TCNF) – E(TCF) = 32.2. This number is larger than it has been in the fully deterministic base case above, where c* = 30.4. The result is plausible because the positive cost impact of the flexibility-to-change option is large in the upward scenario, but rather small in the downward scenario; it is nonetheless not zero because flexibility-to-change is assumed to be cost-free in all scenarios (c = 0).

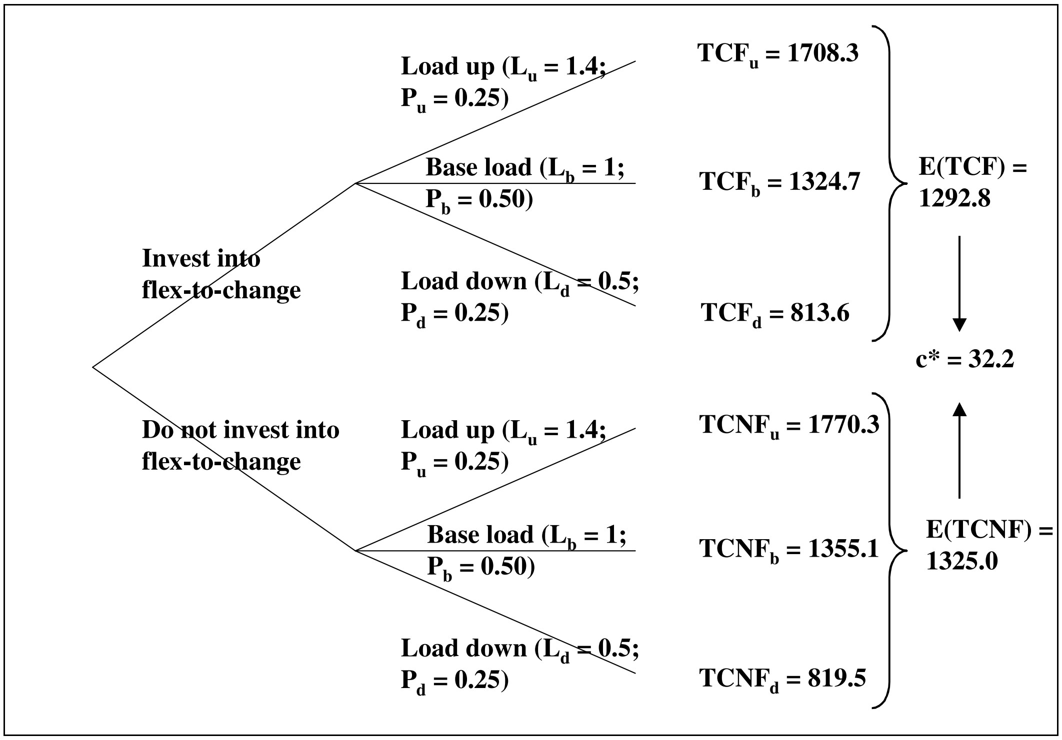

Figure 3. Decision Tree for Non-deterministic Business Process Load

Real Option Analysis

As an alternative to DTA, ROA allows us to calculate the value of flexibility c* without explicit reference to scenario probabilities (Copeland and Keenan 1999; Trigeorgis 1993). As before, if flexibility-to-change were not available, the three scenarios resulted in costs $TCNF_b$ = 1,355.1, $TCNF_u$ = 1,770.3 and $TCNF_d$ = 819.5 (Figure 3). Compared to the base scenario, the corresponding upward (U) and downward (D) changes are U = 1,770.3 / 1,355.1 = 1.306 and D = 819.5 / 1,355.1 = 0.605 (Figure 4).

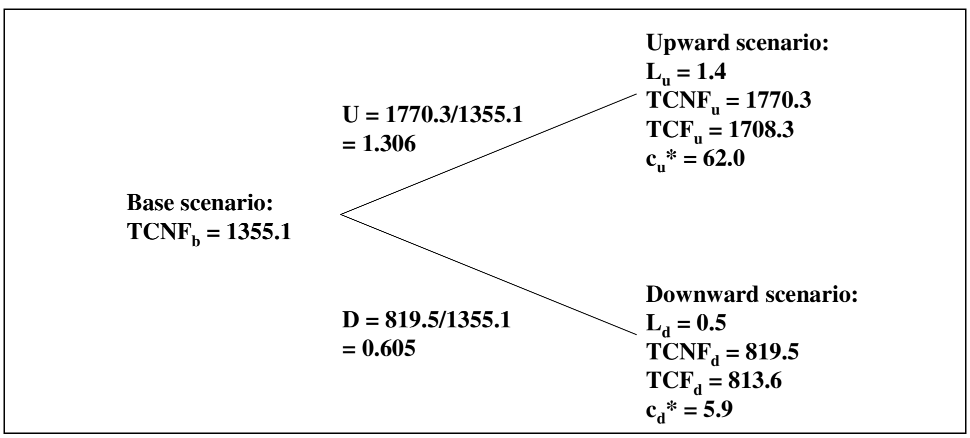

Figure 4. Interpretation as Real Option

If the option of flexibility-to-change were available, we would expect a profit c_u* = $TCNF_u$ – TCF_u = 62.0 in the upward scenario and a profit of c_d* = $TCNF_d$ – TCF_d = 5.9 in the downward scenario. Obviously, the expected value of the flexibility option c* must lie somewhere in between these levels as a weighted average of c_u* and c_d*. In the following, we use an analogy to financial options analysis to calculate appropriate weights for c_u* and c_d*.

For this purpose, let us assume that at the time of the initialization of the IS we were able to buy m "options" with a value of c* that hedge our cost development against unforeseen future process load variations. Hedging means that the final costs of the base, upward and downward scenario are identical:

(13) $TCNF_u - m\, c_u^* = TCNF_b - m\, c^*$ and $TCNF_d - m\, c_d^* = TCNF_b - m\, c^*$.

This also indicates that the decision maker behaves indifferently in each of the three situations. In other words, we assume risk-neutrality, similar to what we did for DTA.

Equation (13) can be solved for the two unknown variables m and c*, yielding

(14) $m = (TCNF_u - TCNF_d) / (c_u^* - c_d^*)$

and

(15) $c^* = P\, c_u^* + (1\text{-}P)\, c_d^*$ with $P = (1\text{-}D) / (U\text{-}D)$; $(1\text{-}P) = (U\text{-}1) / (U\text{-}D)$

and $U = TCNF_u / TCNF_b$; $D = TCNF_d / TCNF_b$.

Equations (14) and (15) are equivalents to the well-known formulas of option price theory in the binomial form (Copeland, Weston and Shastri 2007, p. 219). Applied to our numerical example, equations (14) and (15) result in m = (1,770.3 – 819.5) / (62.0 – 5.9) = 16.9 and c* = { (1-0.605) / (1.306-0.605) } x 62.0 + { (1.306-1) / (1.306-0.605) } x 5.9 = 0.563 x 62.0 + 0.437 x 5.9 = 37.5. The weights are P = 0.563 and 1 – P = 0.437.

In essence, ROA is based on a weighting scheme P and 1-P (called "hedging probabilities") that is, however, different from the weights P_u, P_b and P_d that we used in DTA. Consequently, c* takes a different value in ROA than in DTA. As an obvious advantage, ROA does not require the determination of explicit probabilities P_u, P_b and P_d. Instead, the weights are calculated endogenously by assuming a hedging strategy according to equation (13). A disadvantage of ROA in the presented form results from the fact that in comparison with DTA we do not fully utilize all of the information on hand, in particular TCF_b.

Table 1 shows flexibility values that result from ROA for various combinations of upward and downward scenarios. We note that an increasing spread between base and upward scenarios is associated with a substantially higher flexibility values.

Table 1. Value of Flexibility for Different Scenarios (ROA)

Business process load scenario		Value of flexibility-to-change (c*)
Upward	Downward	
+0%	-0%	30.4 (base scenario)
+5%	-5%	30.6
+10%	-10%	30.8
+20%	-20%	31.8
+30%	-30%	33.5
+40%	-40%	36.0
+40%	-50%	37.5
+50%	-50%	39.1
+100%	-50%	45.7
+100%	-70%	53.1
+20%	-50%	34.1
+20%	-70%	35.8

Extension of Real Options Analysis to Include Multiple Model Parameters

So far, only one of the model parameters, namely process load L, has been applied in stochastic form. We are now ready to extend the analysis, and apply non-deterministic forms to the three other business process parameters p (uncertainty), v (variability) and r (time-criticality) as well. While most other model parameters could also be treated stochastically (Schwartz and Zozaya-Gorostiza 2003), we will keep these parameters deterministic in the current paper in order to limit the complexity of the analysis.

Both, DTA and ROA could be applied to evaluate flexibility in this more complex situation. DTA, however, leads to a rather straight-forward explosion of the decision tree that requires additional assumptions regarding the various probabilities of occurrence, and, as a consequence quickly becomes very complex. In the following, we therefore demonstrate ROA only, which is easier to handle because no explicit probabilities have to be provided. Figure 5 depicts the new situation, whereby we skip the up and down indices of the respective parameters, for notational simplicity.

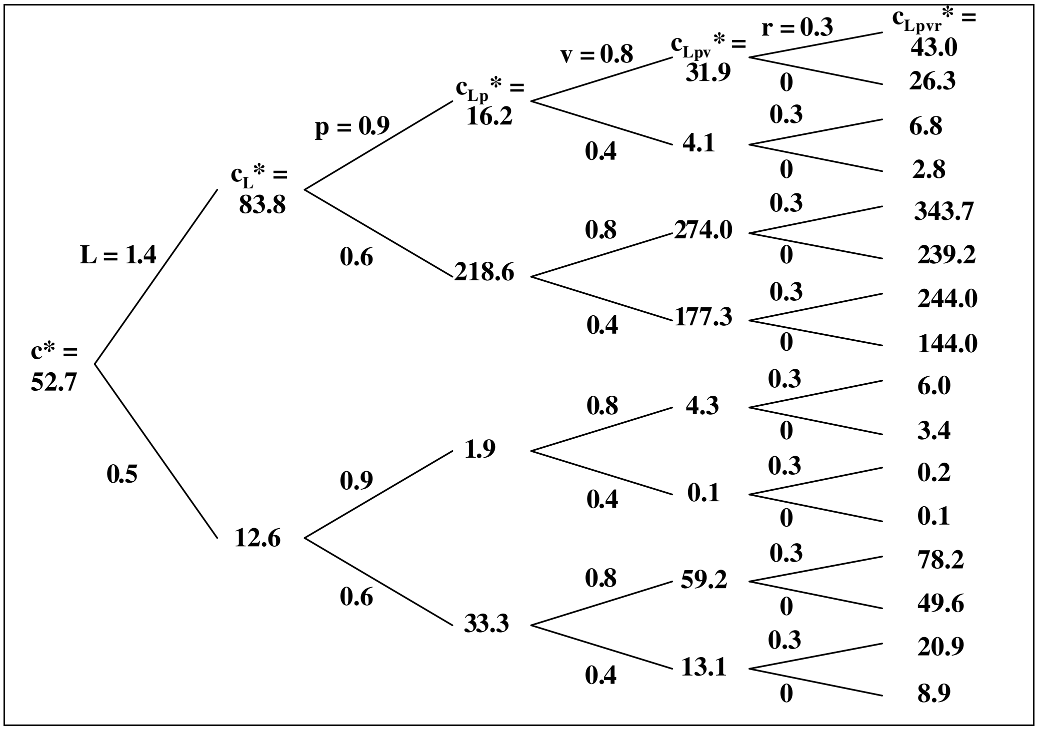

Figure 5: Real Options Analysis Extended to Multiple Parameters

To calculate the value of flexibility c*, the tree needs to be traveled recursively from right to left. For instance, for the top-most path in Figure 5, the value c_{Lpvr}* = 43.0 denotes the profit if flexibility-to-change were provided for the parameter constellation L = 1.4, p = 0.9, v = 0.8 and r = 0.3, and is computed as the difference c_{Lpvr}* = $TCNF_{Lpvr} - TCF_{Lpvr}$ with the corresponding parameter settings in both model runs. Accordingly, c_{Lpvr}* = 26.3 is the profit for the parameter constellation L = 1.4, p = 0.9, v = 0.8 and r = 0. On the next stage to the left, both profit values are consolidated using binomial ROA according to equation (15), resulting in c_{Lpv}* = 31.9. The iterative application of binomial ROA continues until we reach the node c* = 52.7 in the final stage of the analysis (Figure 5, far left). We obtain a compound value of flexibility c* = 52.7 that reflects the stochastic nature of all four process parameters.

Throughout our example, we assumed that the stochastic parameters are statistically independent. This assumption can easily be relaxed by applying different parameter levels within the various paths in Figure 5. For example, we could put p = 0.8 and p = 0.5 for the upward and downward scenarios respectively if L = 0.5 and p = 0.9, and p = 0.6 if L = 1.4. The calculation of the compound value of flexibility c* is performed in a similar way as before, but with different parameter settings along the paths.

Exploring the Full Risk Structure with Stochastic Simulation (Risk Analysis)

Both DTA and ROA are based on the assumption that decision-makers are risk-neutral and indifferent in their choice between the full risk-structure of the problem on the one hand and expected values on the other hand. In both methods of analysis, decision making is driven by the expected values only. While an analysis of the full risk structure of the decision problem allows us to relax the assumption of risk-neutrality, it does require information about the underlying probability functions.

In the following, we discuss the results of a simulation experiment that we performed using explicit distribution functions for the parameters L, p, v and r. A reasonable approach would be to use beta distributions with endpoints that correspond with the values of the upward and downward scenarios. For computational convenience, however, we chose to approximate the beta distributions by normal distributions with means that reflect the averages between the upward and downward scenarios. For example, for parameter p we used the mean $E(p) = (p_u + p_d) / 2$ so that if $p_u = 0.9$ and $p_d = 0.6$, $E(p) = 0.75$. To determine the standard deviations, we applied the 3-sigma rule and set $\sigma (p) = (p_u - p_d) / 6 = 0.05$. Similar approaches were used for the computation of E(v), E(r), E(L) and σ (v), σ (r), σ (L). The substitution of the normal distributions for beta distributions may lead to a situation where a random draw of one of the parameters falls outside of the feasible region $0 \leq p, v, r \leq 1$, and $L \geq 0$. Because of the 3-sigma rule, however, such outliers occur with a probability of less than 1 percent only. In this case we truncated the random draw to its boundary value.

For the simulation experiment, we drew 100 normally distributed samples (L, p, v and r) with mean and standard deviations as defined above, and calculated the corresponding value of flexibility c* based on equation (12). Thereby, we again assumed statistical independence between the parameters. Figure 6 shows the results of the experiment.

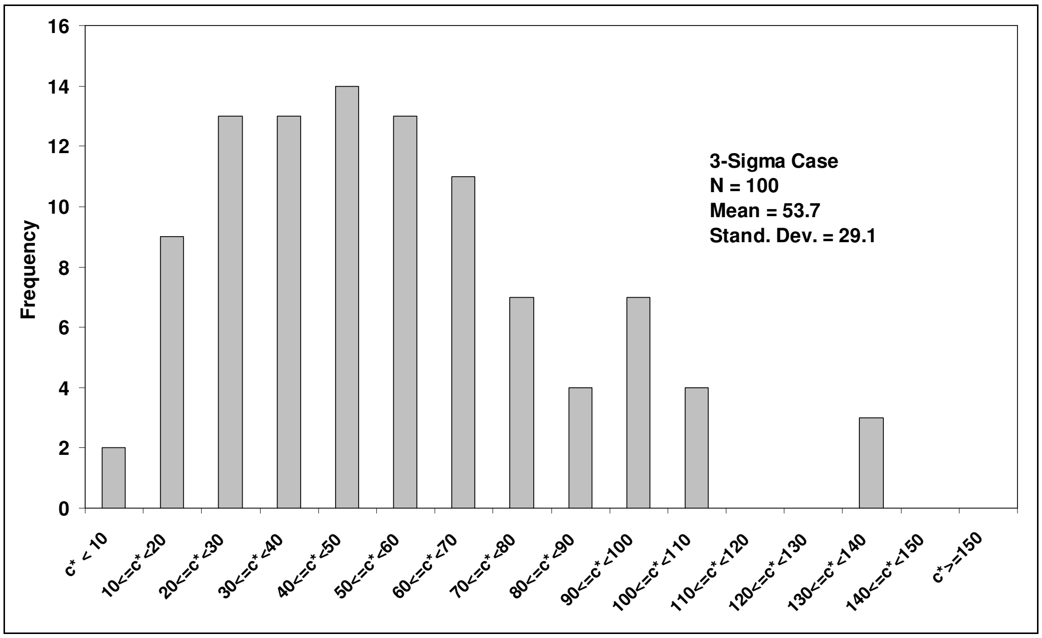

Figure 6. Distribution of the Value of Flexibility

The results exhibit a mean value of flexibility of 53.7 monetary units, a value that is remarkably similar to the result that we obtained from compound ROA earlier, where c* = 52.7 (Figure 5). With 29.1 monetary units, the standard deviation is relatively large, which indicates that the calculation of c* by DTA or ROA, i.e., based on expected values only, is quite imprecise.

As is depicted in Table 2, we can now explicitly assess the risk that is involved with an investment into flexibility-to-change. For instance, the probability that the value of flexibility c* is larger than 40 monetary units is 63 percent, and the probability that c* is larger than 50 monetary units is 49 percent. The simulation experiment reveals that the computation of the value of flexibility in the deterministic case (c* = 30.4) strongly underestimates the economic benefits of flexibility-to-change. It also indicates that standard deviations can become rather high. As a consequence of our findings, we suggest that DTA and ROA should be applied with care.

Table 2. Risk Assessment of an Investment in Flexibility

Level (=value of flexibility in monetary units)	Probability that value of flexibility exceeds level
10	0.98
20	0.89
30	0.76
40	0.63
50	0.49
60	0.36
70	0.25

80	0.18
90	0.14
100	0.07

CONCLUSIONS

In this paper, we built on and extended a model that was proposed by Gebauer and Schober (2006) to compute the value of IS flexibility. Taking into explicit consideration the stochastic nature of a flexibility-related decision situation, we included decision tree, real options and risk analysis, the latter based on a stochastic simulation experiment.

For the parameter constellation that we used throughout the paper our analyses show that in comparison to stochastic approaches, a deterministic method systematically underestimates the value of IS flexibility. This result reflects the asymmetric risk structure that we incorporated in the model and that arguably corresponds with the underlying reality: The cost benefit of IS flexibility-to-change in an upward scenario may be quite substantial while the cost benefit in a downward scenario may be comparatively small.

Moreover, the simulation experiment indicates that the assessment of the value of flexibility can become very imprecise if the full stochastic nature of the situation is neglected, which leads us to caution the use of DTA or ROA alone. Based on the results of our analysis we suggest that in order to provide truly valuable information to management, the stochastic nature of the situation needs to be explored to full extent. Computer and software technologies are readily available today to perform meaningful risk analyses. The current paper strongly supports their use.

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APPENDIX – MODELING NOTATIONS

Decision variables (direct)	
y	Binary variable with $y = 1$ if flexibility-to-change is provided, else $y = 0$
z	Binary variable with $z = 1$ if IS is implemented at all, else $z = 0$
x_1	Share of process activities for tasks that are anticipated at the time of IS initiation and use flexibility-to-use
x_2	Share of process activities for tasks that are not anticipated at the time of IS initiation and use flexibility-to-change
Decision variables (derived)	
w_1	Share of total process activities performed based on flexibility-to-use
w_2	Share of total process activities performed based on flexibility-to-change
w_3	Share of total process activities performed based on manual operations

Process and IS project characteristics	
p	Probability that a process task is anticipated at the time of system initiation (measures process uncertainty)
P	Scenario probabilities (DTA) respectively hedging probabilities (ROA)
v	Curvature of the Lorenz curve (measures process variability)
L(x)	Functional value of the Lorenz curve with either $x = x_1$ or $x = x_2$
r	Share of time-critical process tasks (measures time-criticality)
q	Percentage of the IS being implemented immediately
i	Yearly discount rate
T	IS lifetime in years
DC	Average discount factor reflecting equal cash flows (except initial investments) throughout the IS lifetime T
Cost and value parameters	
ICOST	Total investment in flexibility-to-use at the time of IS initiation
a	Base investment in flexibility-to-use at the time of IS initiation
b	Additional investment in flexibility-to-use, if all process tasks that are anticipated at the time of IS initiation were supported by the IS
FCOST	Actual investment in flexibility-to-change at the time of IS initiation
c	Investment in flexibility-to-change if provided (i.e., if y = 1)
OCOST	Actual system operating costs
d	System operating costs if all process activities were supported by the system
L	Normalized process load factor with L = 1 for a base scenario
UCOST	Actual system upgrade costs using the flexibility-to-change option provided
e	System upgrade costs if all process tasks that are not anticipated at the time of IS initiation were included in the upgrade
MCOST	Actual costs for manual operations
f	Manual operating costs if all process activities were performed manually
g	Cost markup for manually performing time-critical process activities
TCOST	Total costs over the entire lifetime of the system
TCF	Total costs with flexibility-to-change provided (y = 1)
TCNF	Total costs with flexibility-to-change not provided (y = 0)
c*	Value of flexibility
E	Expected value (for the stochastic cases)