

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

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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 theoretical model by GEBAUER and SCHOBBER (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, decision tree analysis, real option analysis, simulation experiment

Introduction

In a world of increasing uncertainties, the ability to utilize company assets in a flexible way plays an ever more important role. The need for flexibility applies to many assets, including capital investments; employees and business partners; organizational structures; and information systems (IS). The formulation and implementation of efficient IS flexibility strategies have become important aspects of risk management. GEBAUER and SCHOBBER (2006) 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 build on GEBAUER and SCHOBBER's (2006) research work, as we discuss a number of approaches to determine the value of IS flexibility. We specifically 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. In applying the model, we discuss two different approaches to determine the value of IS flexibility for uncertain future business process loads (volume uncertainty), namely decision tree analysis and real option pricing. Next, we include additional stochastic parameters into the analysis, and demonstrate explicit risk assessment based on simulation experiments. We close with a brief summary and reiterate the importance of determining the value of flexibility in non-deterministic settings.

A Model to Assess the Impact of IS Flexibility Strategies on Business Process Efficiency

The model presented by GEBAUER and SCHOBBER (2006) is based on the conceptual framework that is exhibited in Figure 1. In the framework, a business process, such as purchasing, is defined as a collection of distinct process tasks, such as the purchase of office

furniture, office materials or computers, and corresponding process activities, such as the processing of a single purchasing request, that are to be supported or automated by an IS.

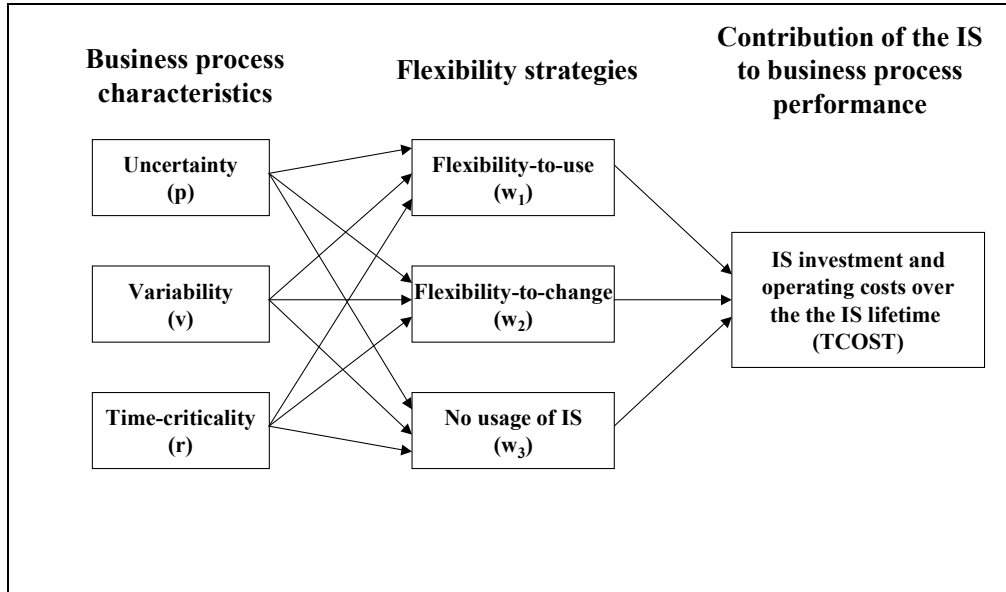


Figure 1: Conceptual Framework (see GEBAUER and SCHOBBER 2006, 124)

As indicated in Figure 1, the characteristics of a business process are represented by the three parameters uncertainty (p), variability (v) and time-criticality (r): Uncertainty refers to the degree to which a process task is known to the IS developer at the time of system initialization (qualitative uncertainty); variability refers to the degree to which process activities concentrate on certain process tasks; and time-criticality measures the share of time-critical process activities.

The variables w_1 , w_2 and w_3 express the mix of different flexibility strategies in response to the business process characteristics. With w_1 , we indicate the share of all process activities that utilize the flexibility that is built into the IS upon its initialization (flexibility-to-use). Share w_2 refers to the activities that are handled by the IS after modification or implementation of an upgrade (flexibility-to-change). Lastly, w_3 denotes the share of activities

that are performed outside of the IS, either manually or with a different IS that is not part of the model. 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.

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

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

where a denotes fixed development or purchase costs, and b denotes variable development or purchase costs if all process tasks that are expected to occur at the time of the investment decision were supported by the IS. However, for process tasks that are expected to occur with low frequency, it is typically not economical to include the respective functionality in the IS. Instead, the small number of task 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.

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. 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 rate (DC). Assuming that the remaining investments are spread out evenly over the IS lifetime, DC is given as

$$(2) \quad DC = ((1+i)^T - 1) / (i (1+i)^T T) \text{ for } i > 0 \text{ and } DC = 1 \text{ for } i = 0.$$

where i denotes the yearly interest rate and T denotes the IS lifetime in years.

For practical reasons, such as to produce meaningful model results even for some 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

$$(3) \quad \text{FCOST} = c y,$$

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-use while the subsequent costs for modifying and upgrading the IS are measured by a separate model term UCOST, as described in more detail below. While c is a fixed cost parameter for the moment, it will later be calculated as the value of flexibility-to-change.

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

$$(4) \quad \text{UCOST} = e L(x_2) \text{DC}.$$

In (4), x_2 is a decision variable with $0 \leq x_2 \leq 1$. It 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. 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 rate 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. Again following GEBAUER and SCHOBBER (2006), we use the form

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

The variability parameter v measures the concentration of business process tasks, with $0 \leq v \leq 1$ (see Figure 1). Values of v that are close to 0 describe business processes with little task 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 a small number of tasks dominates (Figure 2).

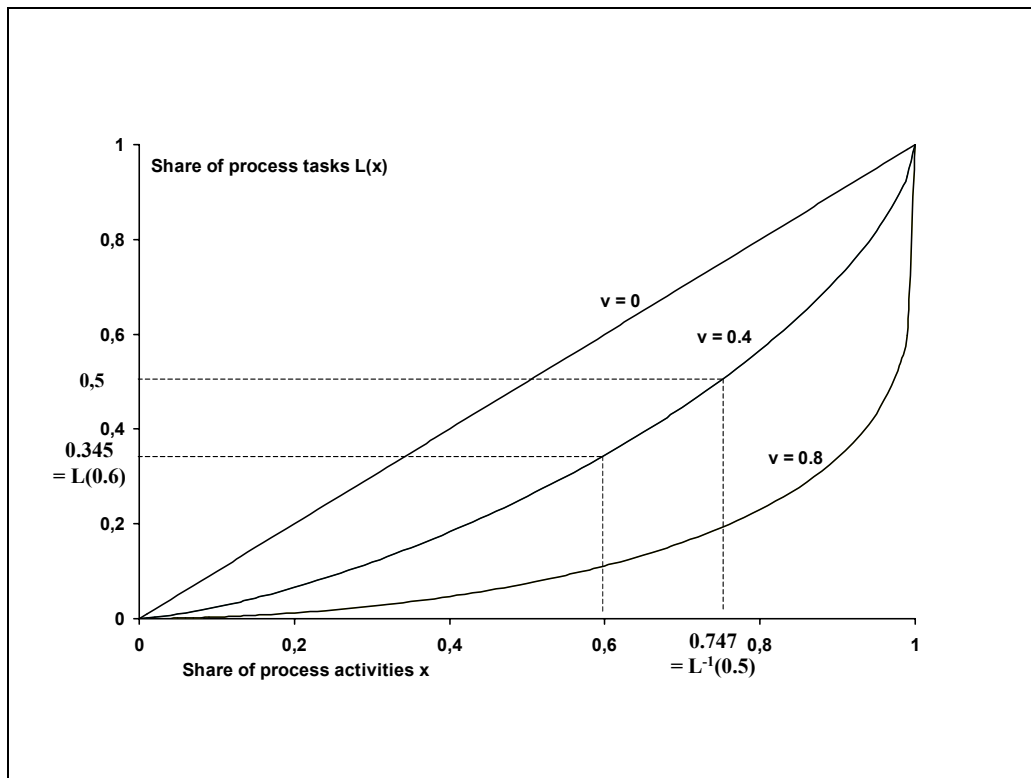


Figure 2: Lorenz Curve

Equations (1) through (5) refer to investment decisions that are made at the beginning of the IS lifetime. In contrast, model equations (6) through (10) that will be discussed next refer to parameters and costs of ongoing operations. We distinguish IS operating costs OCOST that are associated with the use of the IS, and manual costs MCOST that are associated with

activities that are handled outside of the current IS (manually or with 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

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

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

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

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. As 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 tasks 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 occurrence frequency. We consequently multiply w_1 with the inverse $L^{-1}(0.5)$, instead of 0.5 as in the case of w_2 (Figure 2). Finally, the yearly operating costs are multiplied with the number of years T that depict the IS lifetime, and the average yearly discount factor DC .

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 full load 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 time-critical activities are processed outside of the system, assuming that outside processing is less time-efficient, and thus more expensive. We obtain

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

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 (2)). We, thus, state the following condition:

$$(9) \quad y \geq x_2.$$

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 conditions, thus, reads as follows:

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

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 :

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

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 selected 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

Numerical Example

We first introduce a numerical example that we will use throughout the rest of the paper. The model parameters are set as follows:

- Cost-related parameters: $a = 100, b = 300, c = 50, d = 150, e = 300, f = 450, g = 0.7, i = 0.05$
- Parameters that characterize the business process: $p = 0.8, v = 0.6, r = 0.1$
- Parameters depicting the IS development process and 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 $\text{TCOST} = 1,355.1$. In other words, 78 percent of the process activities are handled by the IS using the flexibility-to-use strategy, and 22 percent are handled outside of the IS. Flexibility-to-change is not included at all, resulting in $y = 0$ and $x_2 = 0$ for the optimal solution.

Value of Flexibility in the Deterministic Case

In equation 3, we assigned a fixed value (c) for the initial investment into flexibility-to-change. As the model solution shows, the value of $c=50$ is too high for flexibility-to-change to enter the final solution. Knowing that for our example the correct answer needs to be less than 50 monetary units, we now address the following question: What is the critical value of c , below which an investment in flexibility-to-change becomes interesting?

If we would have insisted in an investment in flexibility-to-change, our solution 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 including the constraint $y = 1$ in 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 part of the optimal solution. The value $c = 30.4$ consequently defines the threshold below which 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 a starting investment by setting $c = 0$ in (3) and running the model twice: First, flexibility-to-change is excluded by setting $x_2 = 0$. The resulting solution of the model is denoted with TCNF (total costs with no flexibility-to-change provided). Second, we run the model once again without the restriction $x_2 = 0$ and now allow an investment in flexibility-to-change to occur at zero costs ($c = 0$). We call the resulting solution of the model TCF (total costs with flexibility-to-change provided). Given that the first optimization is derived under the additional constraint of $x_2 = 0$, we obtain $TCNF \geq TCF$, and denote

$$(12) \quad c^* = TCNF - TCF$$

as the value of flexibility.

For our numerical example above, we obtain $TCNF = 1,355.1$ and $TCF = 1,324.7$. Hence, $c^* = 30.4$ as above. Note that TCF is lower than the optimal solution above because flexibility-to-change is assumed to come for free ($c = 0$), 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 $TCOST = TCF + 50 = 1,373.7$ for the case that flexibility-to-change is provided at $c = 50$.

Value of Flexibility if Process Load is Stochastic

Extending the deterministic case above, we now consider a situation of stochastic process load, as follows: Besides the “base scenario” of normal process load that also underlies the deterministic case, we consider two additional scenarios, namely an upward scenario and a downward scenario. Compared to the deterministic case (base load), the upward scenario assumes a 40 percent higher process load (load up); and the downward scenario assumes a 50 percent lower process load (load down). We further assume that we are able to provide probabilities P_b , P_u and P_d for the base, upward, and downward scenarios. The situation can be presented as a decision tree (Figure 3).

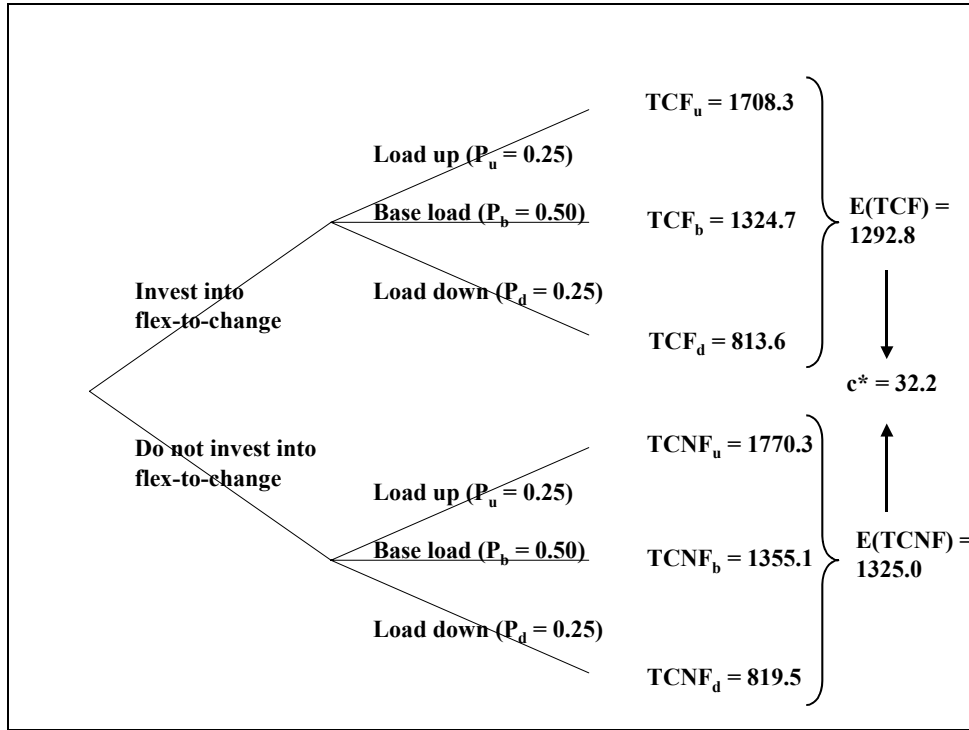


Figure 3: Decision Tree for Non-deterministic Business Process Load

We further assume that the load variation leads to proportional changes in the operating cost coefficients d in equation (7) and f in equation (8), such that $d = 150 \times 1.4 = 210$ and $f = 450 \times 1.4 = 630$ in the upward scenario and $d = 150 \times 0.5 = 75$ and $f = 450 \times 0.5 = 225$ in the downward scenario. In Figure 3, the results of the modified model are depicted on the right-hand leafs of the decision tree. Assuming a risk-neutral decision-maker, we can calculate the expected values of TCF and TCNF. For a positive investment in flexibility-to-change, $E(\text{TCF}) = 0.25 \times 1,708.3 + 0.50 \times 1,324.7 + 0.25 \times 813.6 = 1,292.8$. Accordingly, $E(\text{TCNF}) = 1,325.8$. The expected value of flexibility-to-change is then determined by the difference $c^* = E(\text{TCNF}) - E(\text{TCF}) = 32.2$. This number is larger than it was in the fully deterministic base case above, where $c^* = 30.4$. The result is plausible because the positive impact of the flexibility-to-change option is large in the upward scenario, while the impact is rather small in the downward scenario, nonetheless not zero because $c = 0$ in all scenarios.

As an alternative to decision tree analysis (DTA), real option analysis (ROA) allows us to calculate the value of flexibility c^* without explicit reference to scenario probabilities. Using financial option pricing theory (OPT) as an analogy, more specifically the pricing of a call option, we interpret the investment decision as follows (Figure 4): $TCNF_b = 1,355.1$ is viewed as the “current” price of a given stock; $TCNF_u = 1,770.3$ depicts the “future” price of the stock in the upward scenario and $TCNF_d = 819.5$ depicts the “future” price of the stock in the downward scenario, if flexibility-to-change were not available. The respective upward (U) and downward (D) movements of the stock are given as $U = 1,770.3 / 1,355.1 = 1.306$ and $D = 819.5 / 1,355.1 = 0.605$, respectively. Of course, the analogy is somewhat limited because of the fact that we do not distinguish between “current” and “future” status. Instead, all three scenarios relate to the same underlying lifetime of the IS of five years in our numerical example.

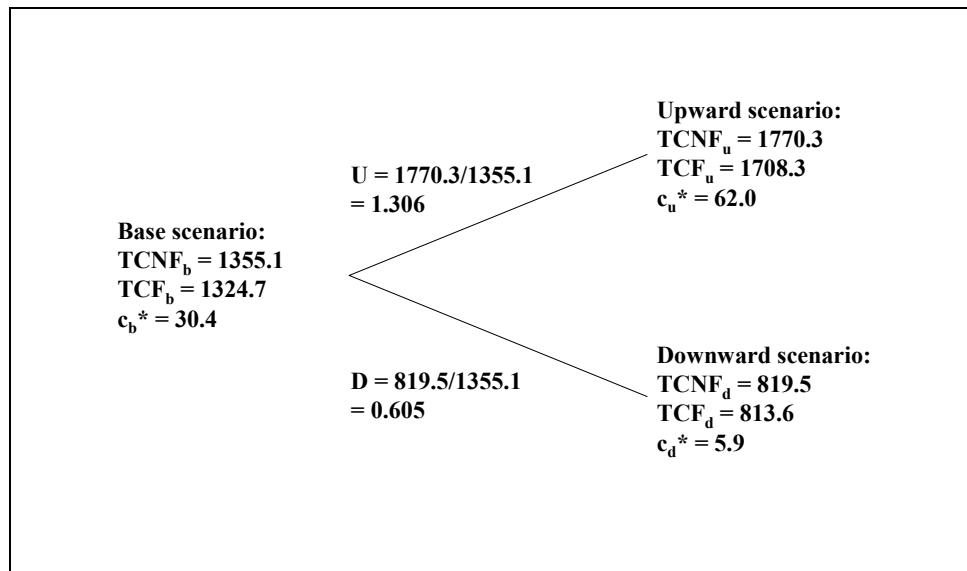


Figure 4: Interpretation as Real Option

As is depicted in Figure 4, ROA provides the following results for our numeric example: If the option of flexibility-to-change was available, we expect a profit of $c_u^* = TCNF_u - TCF_u =$

62.0 in the upward scenario and a profit of $c_d^* = \text{TCNF}_d - \text{TCF}_d = 5.9$ in the downward scenario.

Extending the analogy of financial markets, let us assume that there exists a market where one could buy a certain amount m of options to hedge the base scenario—a situation that is similar to the hedging of a stock investment in OPT. For this purpose, a portfolio is constructed that contains one stock and m options that are written against the stock. The value of the portfolio for the upward scenario is $\text{TCNF}_u - m c_u^*$. For the downward scenario, the value is $\text{TCNF}_d - m c_d^*$. In addition, a portfolio for the base scenario is constructed with a value $\text{TCNF}_b - m c^*$ that contains the yet unknown value of the flexibility option c^* . As in OPT, we choose m and c such that the values of all three portfolios are identical:

$$(13) \quad \text{TCNF}_u - m c_u^* = \text{TCNF}_b - m c^* \quad \text{and} \quad \text{TCNF}_d - m c_d^* = \text{TCNF}_b - m c^*.$$

By doing so, it is assumed that a risk-neutral decision-maker tries to hedge the risk that is inherent in either the upward or the downward scenario.

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

$$(14) \quad m = (\text{TCNF}_u - \text{TCNF}_d) / (c_u^* - c_d^*)$$

and

$$(15) \quad c^* = P c_u^* + (1-P) c_d^* \quad \text{with } P = (1-D) / (U-D); (1-P) = (U-1) / (U-D) \\ \text{and } U = \text{TCNF}_u / \text{TCNF}_b; D = \text{TCNF}_d / \text{TCNF}_b.$$

Equations (14) and (15) correspond with the well known formulas of OPT in the binomial form (COPELAND, WESTON and SHASTRI 2007, 219), with the exception that no reference is made to the risk-free interest rate because there is no delay between now and time to maturity as in OPT. In fact, the risk-free interest rate is 1 in our analogy.

Applied to our numerical example, equations (14) and (15) result in $m = (1,770.3 - 819.5) / (62.0 - 5.9) = 16.9$ and $c^* = \{ (1-0.605) / (1.306-0.605) \} \times 62.0 + \{ (1.306-1) / (1.306-0.605) \} \times 5.9 = 0.563 \times 62.0 + 0.437 \times 5.9 = 37.5$. 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” in OPT) that is different from the weights P_u , P_b and P_d that are used in DTA. For this reason, c^* also has a different value. As an obvious advantage of ROA, no explicit probabilities have to be provided. Instead, the hedging probabilities are calculated implicitly by assuming a hedging strategy according to equation (13). Table 1 shows flexibility values that result from ROA for various combinations of upward and downward scenarios.

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

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

Extension of Real Options Analysis to Include Several Model Parameters

So far, only one of the model parameters—process load—has been treated in stochastic form. We are now ready to extend the analysis, and apply non-deterministic forms to the three business process parameters p (uncertainty), v (variability) and r (time-criticality) as well. While the various cost parameters could be treated stochastically, we will keep these parameters deterministic in order to limit the complexity of the analysis.

Both, DTA and ROA can be applied to handle this more complex situation, but we consider ROA to be the more interesting analysis. DTA leads to a rather straight-forward explosion of the decision tree that requires additional assumptions regarding the various probabilities of occurrence. In the following, we demonstrate ROA for a model in which all of the process parameters are treated as stochastic variables (Figure 5). Both, the upward and downward scenarios are constructed for all four parameters that are included in the analysis. The process load scenarios are depicted with the parameter L , where $L = 1.4$ denotes an upward move of 40 percent and $L = 0.5$ a downward move of 50 percent as in the examples before.

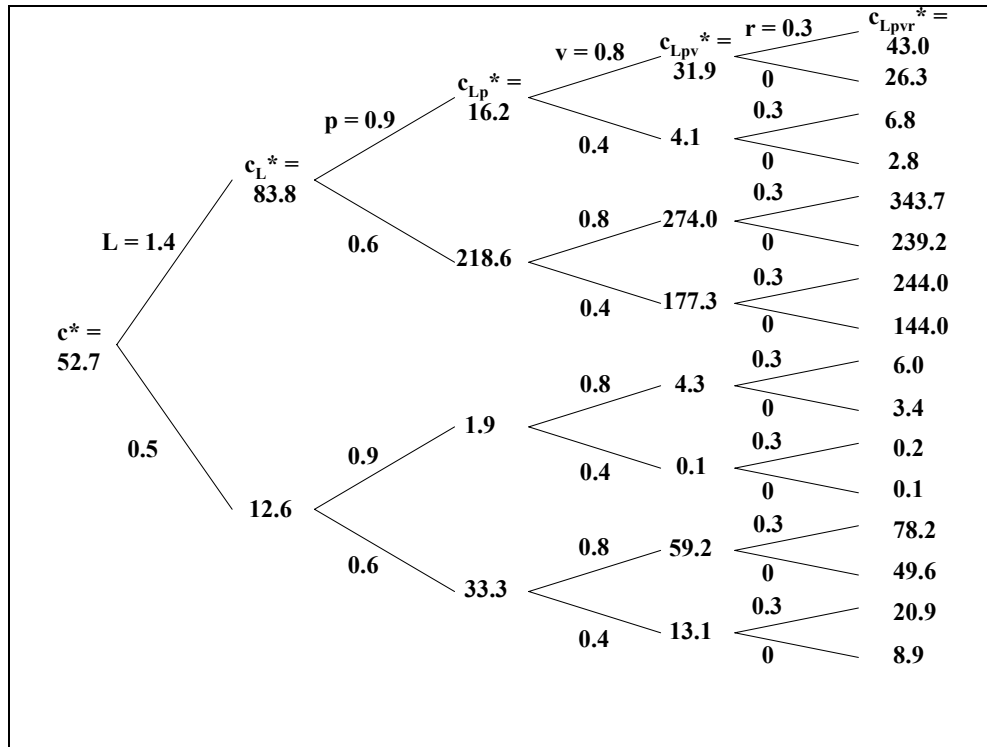


Figure 5: Real Options Analysis Extended to Several Parameters

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 $c_{Lpv}^* = 43.0$ 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 $c_{Lpv}^* = TCN_{Lpv} - TCF_{Lpv}$ with the corresponding parameter settings in both model runs. Accordingly, $c_{Lpv}^* = 26.3$ is the profit for the parameter constellation $L = 1.4$, $p = 0.9$, $v = 0.8$ and $r = 0$. On the next level to the left, both profit values are consolidated using binomial ROA and following equation (15), resulting in $c_{Lp}^* = 31.9$. The iterative application of binomial ROA continues until we reach the final node $c^* = 52.7$ on the highest level of 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.

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 analysis between the full risk-structure of the problem on the one hand and the individual 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 simplicity, however, we chose to approximate the beta distributions with normal distributions and means that reflect the averages between the upward and downward scenarios. For example, for parameter p we used the value $E(p) = (p_u - p_d) / 2$. For standard deviations we followed the 3-sigma rule and used $\sigma(p) = (p_u - p_d) / 6$. Similar approaches were used for $E(v)$, $E(r)$, $E(L)$, $\sigma(v)$, $\sigma(r)$, and $\sigma(L)$. The substitution of the normal distributions for beta distributions results in a small chance that a random draw for 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 only with a small probability of less than 1 percent. Even though we did not encounter any outliers in our current simulation runs, one could truncate a random outlier to its boundary value.

It is plausible to assume that the parameters L , p , v and r are statistically independent. For the simulation, we conducted 100 experiments by drawing a normally distributed sample (L , p , v and r) with mean and standard deviations as defined above, and calculating the corresponding value of flexibility c^* based on equation (12). Figure 6 shows the results.

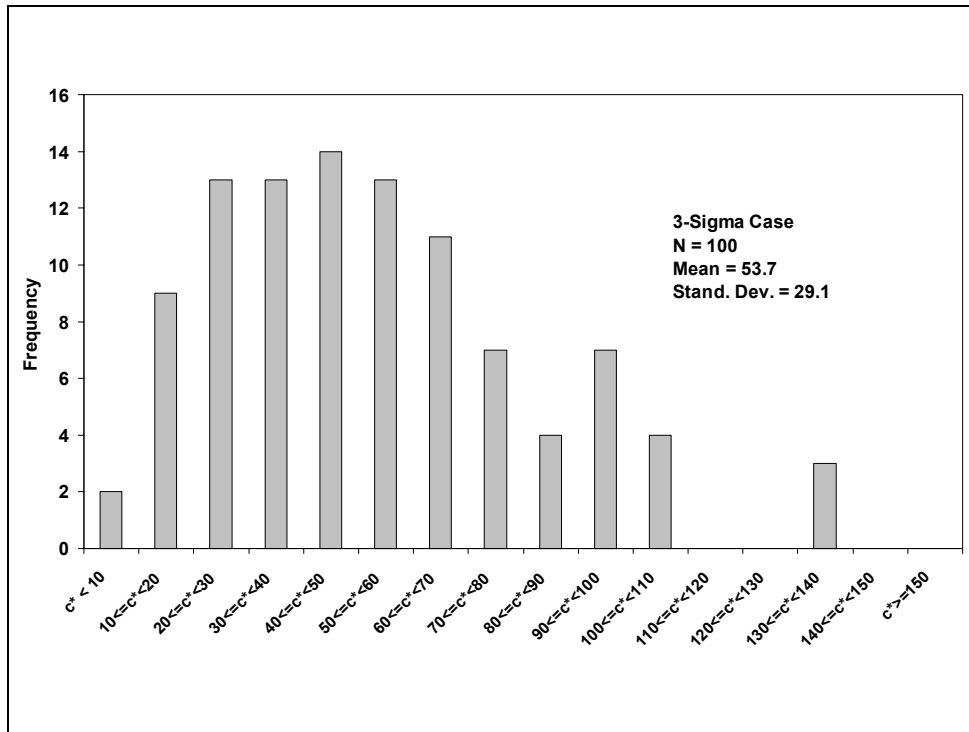


Figure 6: Distribution of the Value of Flexibility

The results exhibit a mean value of flexibility of 53.7 monetary units, a value that is noticeably similar to the result that we obtained from compound ROA earlier, where $c^* = 52.7$. With 29.1 monetary units, the standard deviation is relatively large for all values, as well as for a calculation that excludes the three outliers in the interval $130 \leq c^* < 140$ and that results in 27.2 monetary units.

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 is 63 percent, and the probability that c^* is larger than 50 monetary units is 49 percent.

Level	Probability that value of flexibility exceeds level
10	98 (%)
20	89
30	76
40	63
50	49
60	36
70	25
80	18
90	14
100	7

Table 2: Risk Assessment for the Investment into Flexibility

Conclusions

In this paper, we used an extended version of the model proposed by GEBAUER and SCHOBBER (2006) to measure the value of IS flexibility. The proposed procedures explicitly considered the stochastic nature of the situation and included decision tree, real options and risk analyses, the latter by means of stochastic simulation experiments.

For the specific numerical example that we used throughout the paper, a deterministic view on the value of flexibility underestimates this value. This result is not surprising because of the asymmetric risk structure in the model that arguably corresponds with the underlying reality: The benefit of flexibility-to-change in an upward scenario may be quite substantial while the benefit in a downward situation may be comparatively small.

We conclude that the practical measurement of the value of flexibility should include non-deterministic scenarios that can provide valuable information to management. Of course, more generally speaking, our conclusion may be considered trivial because it is the

unforeseen future that leads us to consider flexibility in the first place. Still, general wisdom and concrete measurement are two different things, and we are hopeful that our paper contributes to the second.

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