Journal of the Association for Information Systems

Volume 7 | Issue 3 Article 8

3-18-2006

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Recommended Citation

Gebauer, Judith and Schober, Franz (2006) "Information System Flexibility and the Cost Efficiency of Business Processes," *Journal of the Association for Information Systems*, 7(3), .
DOI: 10.17705/1jais.00084
Available at: https://aisel.aisnet.org/jais/vol7/iss3/8

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RESEARCH ARTICLE

Information System Flexibility and the Cost Efficiency of Business Processes [1]

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Abstract

In order to be effective, an information system (IS) needs to be flexible, that is, it must be able to accommodate a certain amount of variation regarding the requirements of the supported business process. Despite many previous studies on the flexibility of organizations, processes, and various organizational technologies, the economics of flexibility are not yet well understood. The current paper contributes to IS theory building with a focus on the impact of IS flexibility on the cost efficiency of a given business process. We present a theoretical model that details the economics of two generic strategies of IS flexibility (i.e., flexibility-to-use regarding the IS features that are provided at the time of implementation, and flexibility-to-change regarding the IS features that constitute an option for later system upgrade), and that also includes the possibility of process performance outside of the IS (manual operations). Based on an analysis of the model, we conclude that IS flexibility-to-change is cost efficiently deployed to support a business process characterized by a high level of structural and environmental uncertainty, whereas a low level of process uncertainty corresponds efficiently with IS flexibility-to-use. The model also indicates that high process variability can improve the importance of IS flexibility management in general, as it tends to limit the value of an IS over manual operations, whereas a high level of time-criticality of process requirements tends to increase the value of an IS over manual operations.

Keywords: Business processes, cost efficiency, economics of IS flexibility, IS flexibility, Lorenz curve, theory-building research, theory of IS flexibility

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[1] Robert Kauffman was the accepting senior editor. Qizhi Dai, Xiaotong Li, and one anonymous reviewer reviewed this paper. This paper was submitted on March 19, 2005, and went through four revisions.

Introduction

To be effective, an information system (IS) needs to be flexible, that is, it must be able to accommodate a certain amount of variation regarding the requirements of the supported business process (Applegate et al., 1999). For example, a decision support system needs to include reasonable capabilities to enable data entry, analysis, and presentation (Silver, 1991; Zmud, 1979), while an electronic procurement system needs to include a reasonable number of product categories and approval procedures to support the purchasing process (Killen and Kamauff, 1995). Insufficient flexibility can limit the success of an IS by preventing its use in certain circumstances and by making exception handling necessary. In addition, insufficient flexibility can reduce the overall lifetime of a system. Excessive flexibility, however, can also limit the success of an IS by reducing usability (Silver, 1991) and increasing complexity (Economist, 2004), thus requiring higher investments, implementation time, and subsequent operating and maintenance costs (Soh et al., 2003).

Today's IS managers face a great variety of choices regarding IS flexibility, ranging from turnkey systems with little room for subsequent change, to IS architectures with many options for future change (Rumbaugh et al., 1991). In addition, information technology (IT) innovations, such as component-based and service-oriented software architectures (Bieberstein et al., 2006), Web services (Whiting, 2003), autonomous computing concepts (Horn, 2001), and mobile applications (Siau et al., 2001) promise greater flexibility than the mainframe, client/server, and non-mobile systems they are meant to replace, yet require significant upfront investments. Practical evidence as reported to the authors by a number of IS managers and consultants in Europe and the United States suggests that in lieu of clear guidelines regarding the economic management of IS flexibility, IS investment decisions may be based on factors such as short-term political considerations, risk aversion, tight budgets, and "me-too" desires, all at the expense of IS flexibility that may only pay out in the longer term.

IS research has addressed the effects of IS on organizational flexibility and competitive advantage (Palanisami and Sushil, 2003), and the typically contradictory effects of IS on organizational flexibility and efficiency (Allen and Boynton, 1991; Robey and Boudreau, 1999), yet the *economics of IS flexibility* have received comparatively little attention. Research in systems requirement engineering, however, has long pointed out that non-systematic and unstructured analyses of IS requirements can lead to suboptimal results (Robinson and Pawlowski, 1999).

The current paper contributes to IS theory building with a focus on *the effects of IS flexibility on the cost efficiency of a given business process*. Besides proposing a theory of IS flexibility, a more general goal of the paper is to establish the relevance of IS flexibility for successful IS management. Figure 1 outlines the theoretical framework that we use throughout the paper to determine the cost efficient mix of flexibility strategies in support of a given business process (see the Appendix for a summary of the notations). The paper proceeds as follows. After describing relevant business process characteristics and flexibility strategies, we outline a formal, quantitative model. To begin the development of a theory of IS flexibility we then analyze the model and derive propositions regarding the cost efficient match between business process characteristics and flexibility strategies. In conclusion, we point out applications of the proposed theory and suggest a number of refinements.

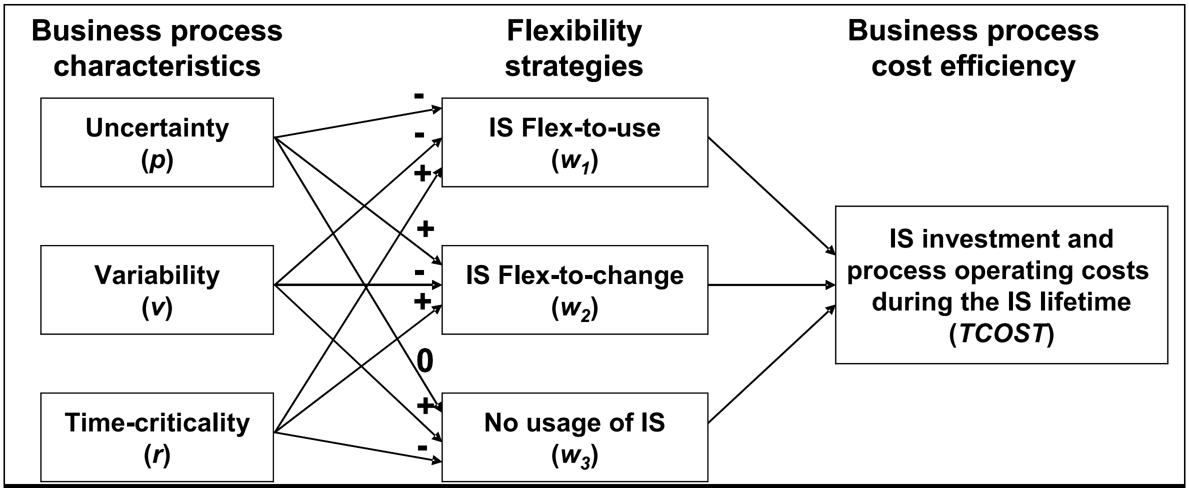


Figure 1. Theoretical framework

Business Process Characteristics

A business process (e.g., budget decision making or procurement) consists of a number of tasks, such as collecting and analyzing financial data (Silver, 1991), requesting an item from a procurement catalog, approving a request, and compiling a purchase order (Killen and Kamauff, 1995). The individual tasks possess characteristics, such as structuredness, variety, expectancy, and urgency, that impact the type and level of flexibility required to provide adequate IS support. To describe and operationalize the characteristics of a business process with respect to IS flexibility, we consider three dimensions: (i) uncertainty, (ii) variability, and (iii) time-criticality.

Process Uncertainty

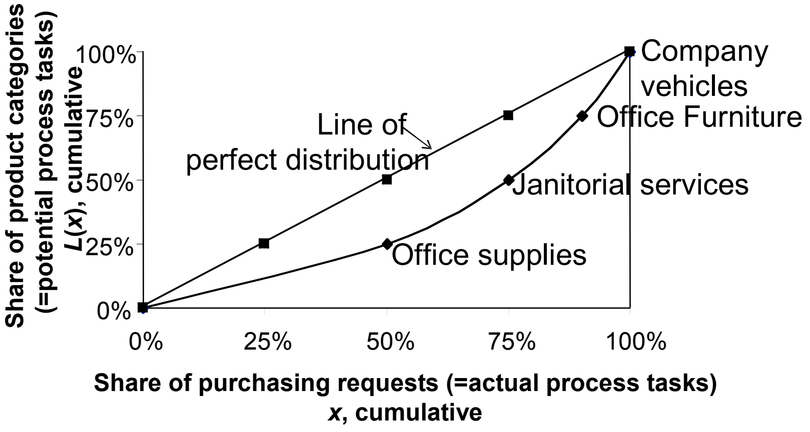
Uncertainty of a business process refers to the difficulty to predict the exact tasks and resources that are required to perform a particular process. Hereby, environmental and structural uncertainty can be distinguished. *Environmental uncertainty* is determined by the predictability of dynamic changes in the business process environment that result in changes of the requirements to adequately support the business process (Applegate et al., 1999). Environmental uncertainty is typically related to process-external factors such as the level of dynamic change prevailing in a particular industry. *Structural uncertainty* relates to process-internal characteristics like non-routineness (Anthony, 1965; Gorry and Scott Morton, 1971), unstructuredness (Simon, 1960), and non-analyzability (Perrow, 1967). Generally, higher level management tasks tend to have a higher level of structural uncertainty than lower level management and administrative tasks.

The number of process tasks with high uncertainty and the degree of these uncertainties determine the overall uncertainty of a business process. We operationalize process uncertainty by considering the probability p that a process task can be foreseen and described at the time of IS implementation. Hence, we characterize the risk of being able to describe a task at the time of system implementation by a binomial distribution with probabilities p (anticipated) and $1-p$ (not anticipated). Conceptually, the uncertainty factor p that is included in the decision model is derived based on an aggregation of all process tasks that occur during the IS lifetime. Processes with low overall uncertainty are associated with high values of *p,* and processes with high uncertainty are associated with low values of *p* ($0 < p < 1$).

Process Variability

As a second factor to impact IS flexibility requirements, we consider the variability of tasks that are required to perform a certain business process. *Process variability* is considered to be low, when a business process concentrates on a small number of distinct types of tasks, while process variability is considered to be high if many different types of tasks need to be performed with about the same frequency. To operationalize variability, we apply the *Lorenz curve* (Lorenz, 1905), a concept of concentration and distribution frequently used in descriptive statistics.

To demonstrate our application of the Lorenz curve, Figure 2 exhibits the statistics of a simple purchasing process where all purchasing requests (actual process tasks *x*, depicted cumulatively) concern one of four product categories (potential process tasks *L*(*x*), depicted cumulatively). Figure 2 shows that the product category of office supplies accounts for an individual share of 50% of all purchasing requests, whereas janitorial services, office furniture, and company vehicles account for 25%, 15%, and 10% of all purchasing requests, respectively. The business process depicted in Figure 2 is characterized by fairly low variability (i.e., high concentration), given that an IS that included only the one product category of office supplies (i.e., a fourth of all possible product categories) could account for as much as one half of all actual purchasing requests. In contrast, a situation of extreme variability (i.e., zero concentration) resulted if all four product categories account for equal shares of purchasing requests (25%), in which case the Lorenz curve owes the diagonal line of perfect distribution. The curvature



	Share of product categories (= potential process tasks) *L*(*x*), cumulative	**Share of purchasing requests (= actual process tasks) *x*, cumulative**
Office supplies	25%	50%
Janitorial services	50%	75%
Office furniture	75 %	90%
Company vehicles	100%	100%

Figure 2. Lorenz curve as a measure of process variability

of the Lorenz curve v (with $0 \leq v \leq 1$) defines our measure of process variability. A large curvature v characterizes a process of low variability, while a low curvature v corresponds with high variability. We will introduce an exact definition of v later, along with a more precise functional representation of the Lorenz curve.[2]

Process Time-Criticality

Though rarely included in earlier organization and management studies of business processes, the aspect of time-criticality has recently found attention in the context of newly-emerging information and communication technologies. For example, organizations are now required to respond quickly to the changing market requirements of fast-paced economic environments (Bradley and Nolan, 1998; D'Aveni, 1994). Most recently, time-criticality has been included in research studies of mobile IS as one key characterizing feature (Balasubramaniam et al., 2002; Siau et al., 2001).

In the current paper, we define *time-criticality* by the percentage r of time-critical tasks of a business process. Based on the observation that the shortening of processing times constitutes a core feature of an IS, we assume that IS-supported business processes can deal more efficiently with time-critical tasks than processes that are not supported by an IS.

Flexibility Strategies

The concept of flexibility is of significant interest to scholars of various research areas, most notably manufacturing (Gupta and Goyal, 1989; Vokurka and O'Leary-Kelly, 2000), economics (Carlson, 1989), strategic management (Evans, 1991), and IS (Allen and Boynton, 1991). Research efforts have focused on the phenomenon of flexibility (Byrd and Turner, 2000; Sethi and Sethi, 1990), and on the impact of flexible technologies on organizations (Byrd and Turner, 2001; Palanisamy and Sushil, 2003) and organizational processes (Maier, 1981; Stigler, 1939). Throughout the 1970s, researchers conducted substantial amount of empirical works on desirable IS features, including flexibility requirements (Zmud, 1979).

Even though scholars of flexibility typically (and often implicitly) agree that flexibility comes at a price, the economics of flexibility have rarely been studied in detail (Koste and Malhotra, 1999). Still, research studies of manufacturing flexibility have shown that dedicated, single-purpose machines typically operate with greater cost efficiency than multi-purpose machines and processes, yet they provide less flexibility and carry the risk that important requirements are not met (Duimering et al., 1993). IS scholars have investigated such often contradictory effects of IS on organizational flexibility and

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[2] The curvature v of the Lorenz curve is closely related to the variance of different tasks because a larger curvature (lower variability) corresponds with a lower variance. This relationship is obvious from the non-cumulative frequencies of the tasks, as the frequencies become more concentrated with increasing curvature, while the spread (100%) remains the same. The largest variance is associated with the line of perfect distribution; in this case the square root of the variance (standard deviation) is 28.0% for our example of four product categories. For the more concentrated case in Figure 2 with lower variability, the standard deviation is 25.3%.

efficiency (Allen and Boynton, 1991; Robey and Boudreau, 1999), and on various aspects of usability (Silver, 1991).

To develop a theory of IS flexibility that can help assess the impacts of IS flexibility on the cost efficiency of business processes, we follow Hanseth et al. (1996) who describe two types of flexibility: (i) *flexibility in the pattern of use* (short: flexibility-to-use) and (ii) *flexibility for further changes* (flexibility-to-change). Similar distinctions have been made elsewhere (Bahrami and Evans, 2005; Klein, 1977; Stigler, 1939).

IS Flexibility-to-Use

Hanseth et al.'s (1996) flexibility in the pattern of use is conceptually similar to Sethi and Sethi's (1990) understanding of the flexibility of a manufacturing machine. Sethi and Sethi characterize flexibility as being related to the “various types of operations that the machine can perform without requiring a prohibitive effort in switching from one operation to another” (p. 298). Further, such flexibility is measured by the “number of operations that a machine can perform without requiring more than a specified amount of effort” (p. 299). Total process flexibility is related to the “set of part types that the system can produce without major setups” (p. 302), and is measured by the volume of part types that the system can produce “without major setups” (p. 303).

Analogously, we define *IS flexibility-to-use* as the range of process requirements supported by the IS without requiring a major change of the IS. For example, the flexibility-to-use of an electronic procurement system includes the ranges of products categories and procurement procedures that are built into the system. Building on earlier work by Silver (1991) and Soh et al. (2000), who discuss the features of decision support systems and of enterprise resource planning systems, respectively, we suggest operationalizing IS flexibility-to-use with four factors: (i) system functionality, (ii) scope of the underlying database, (iii) user interface, and (iv) processing capacity.

System functionality refers to the different features a system provides to a user, such as the range of procurement procedures covered by an electronic procurement system, the range of functional modules included in an enterprise resource planning system, the different types of interactions between an organization and its business partners as part of an inter-organizational system, and the different models and analytical techniques included in a decision support system.

The *scope of an IS database* refers, for example, to the number of product categories that can be purchased through the catalog of an electronic procurement system, or the number of analyses and reports provided by a data warehouse application. In general, the larger the database, the more expensive and difficult it is to set up and maintain (Wixom and Watson, 2001).

The *user interface* describes the different features and methods an IS provides to a user to interact with the system, and includes the number and type of available access channels, such as desktop computer and mobile devices, and the range of input schemes and output presentation formats. While a higher number of interface elements increase the coverage of use situations, the provisioning of additional interface elements can be costly and difficult to manage (Gebauer and Shaw, 2004).

Processing capacity refers to the number of users an IS can accommodate concurrently. It also refers to the number of transactions and user requests an IS can process without major performance losses, measured, for example, in response times.

It should be noted that the actual measurement of flexibility-to-use and the determination of the limits of this type of flexibility depend on individual circumstances (Sethi and Sethi, 1990). For example, a real-time financial trading system must have a different threshold of what constitutes acceptable performance from an IS that provides access to archived accounting data. In addition, it will at times be difficult to determine exactly when a major loss of performance has been reached, given that loss in performance typically occurs gradually. In the following, w_1 denotes the share of all process tasks that are to be supported by the IS based on the flexibility-to-use that was built into the IS at the time of implementation ($0 \leq w_1 \leq 1$).

IS Flexibility-to-Change

Besides the level of IS flexibility-to-use with respect to functionality, data base, user interface, and processing capacity, IS managers face a second decision regarding an (additional) investment that will allow the IS to be changed, upgraded, and expanded after its initial implementation. Choices range from systems that cannot be changed in any way (off-the-shelf, turnkey systems) to arrangements that provide a large variety of opportunities for change, based for example, on the modularization of system components (Hanseth et al., 1996).

To distinguish flexibility-to-change from flexibility-to-use, we must establish what constitutes a major change, just as we determined earlier that flexibility-to-use covers the scope of the system without requiring a major change. Acknowledging system-specific differences, we associate a major change with IS adjustments and modifications that require a fresh system setup, including re-installation and re-testing, on the other hand, the activation of pre-installed parameters that causes only minor disruptions in system availability is not considered a major change, and, is subsumed under flexibility-to-use.

Flexibility-to-change is conceptually related to *IT infrastructure*, defined as a general-purpose technological resource that is shared throughout the organization, is of long-term use, and provides a basis for more specific applications (Byrd and Turner, 2000 and 2001; Weill, 1993). Although our notion of an IS pertains to individual applications rather than to the more encompassing concept of IT infrastructure, research on IT infrastructure is relevant for the current study because it emphasizes the part of an IS architecture that has been designed specifically with future modifications in mind.

To operationalize IS flexibility-to-change, we build on the research results of Byrd and Turner (2000), who carefully identified three factors as relevant to describe the flexibility of IT infrastructures: (i) the flexibility of the IT personnel, as the variety of skills and attitudes of the IT staff; (ii) the integration of data and functionality, as provided by an open network architecture, a multitude of interfaces with transparent access to platforms and applications and the compatibility of applications across platforms; and (iii) modularity, provided by re-usable software modules, vendor-independent database connectivity, and object-oriented development tools. For individual IS applications, we operationalize *flexibility-to-change* with three categories: (i) personnel, (ii) integration of data and functionality, and (iii) modularity of system components. Each category impacts the ability of an organization to change the level of IS flexibility-to-use, manifested as the ability to provide new IS functionalities, to recombine and reorganize access to various data sources, to allow for modifications of the user interface, and to change the available processing capacity. Hence, IS flexibility-to-change can be viewed as a real option, expressing an optional investment in addition to the investment in flexibility-to-use. It creates the possibility, but not the obligation, of future changes of the IS (Amram and Kulatilaka, 1999).

With reference to our theoretical framework, we denote with w_2 ($0 \leq w_2 \leq 1$), the share of tasks of a given business process that are to be performed by the IS following a system upgrade based on the embedded flexibility-to-change capability. Besides the shares of tasks to be performed based on flexibility-to-use (w_1) and based on flexibility-to-change (w_2), we also consider w_3 as the share of tasks that are to be performed manually outside of the IS in question (termed manual operations), an option that conceptually also includes the use of outsourcing arrangements and legacy systems. Even though $w_3 = 1 - w_1 - w_2$, the share of manual tasks is not considered a given residual, but part of the overall strategy for IS flexibility, as we point out in detail below.

Economic Model to Assess the Impact of IS Flexibility on Process Cost Efficiency

Depending on the object of analysis, business process performance can be expressed by a variety of targets and measures, including cost efficiency, customer satisfaction, output, profit or shareholder value (Hammer and Champy, 1993). A supporting IS can contribute to all of these targets, yet in our quest to develop an economic theory of IS flexibility, we abstract from structural and competitive consequences of IS flexibility and assume that the variation of flexibility strategies mainly impacts the costs of process performance but not the process outcome (e.g., customer satisfaction). We consequently focus on the impact of IS flexibility on process efficiency, measured by the overall cost to perform a given business process (Kauffman and Walden, 2001).

Our goal is to identify the mix of flexibility strategies that promises cost efficiency of a given business process, taking into consideration the three strategies of flexibility-to-use, flexibility-to-change, and manual performance of process tasks outside of the IS. Based on the descriptions of business process characteristics and flexibility strategies, we now lay out a set of preliminary propositions.

Preliminary Proposition A (Uncertainty Effect, *p*):

- A business process characterized by low uncertainty (high value of p) can be supported cost efficiently based on IS flexibility-to-use.
- But a business process characterized by high uncertainty (low value of p) can be supported cost efficiently based on IS flexibility-to-change, given the higher payout of the extra investment.

Preliminary Proposition B (Variability Effect, *v*):

- A business process characterized by low variability (high value of v) can generally be supported cost efficiently with an IS (independent of the flexibility strategy).

- But the cost efficient performance of a business process characterized by high variability (low value of *v*) may not warrant the inclusion of all different process tasks into the IS, making it efficient to perform some process tasks outside of the system.

Preliminary Proposition C (Time-Criticality Effect, *r*):

- A business process characterized by high time-criticality (high value of *r*) can be performed cost efficiently with an IS (independent of the flexibility strategy).
- But in a business process characterized by low time-criticality (low value of *r*), the IS investment may not outweigh the cost premium to be paid for tasks that are performed outside of the system.

The preliminary propositions are reflected by the signs on the arrows in Figure 1. For example, high uncertainty (low value of *p*) corresponds with a low share w_1 of flexibility-to-use (-) and with a high share w_2 of flexibility-to-change (+). An entry of “0” in Figure 1 indicates that the impact is yet undetermined. In order to advance the theory-building process and to derive more precise propositions regarding the relative impacts of flexibility strategies on process cost efficiency, we now introduce a formal decision model.

The general model structure is shown in Figure 3 with the notation detailed in the Appendix. The model outlines a two-stage decision process. IS design takes place in the

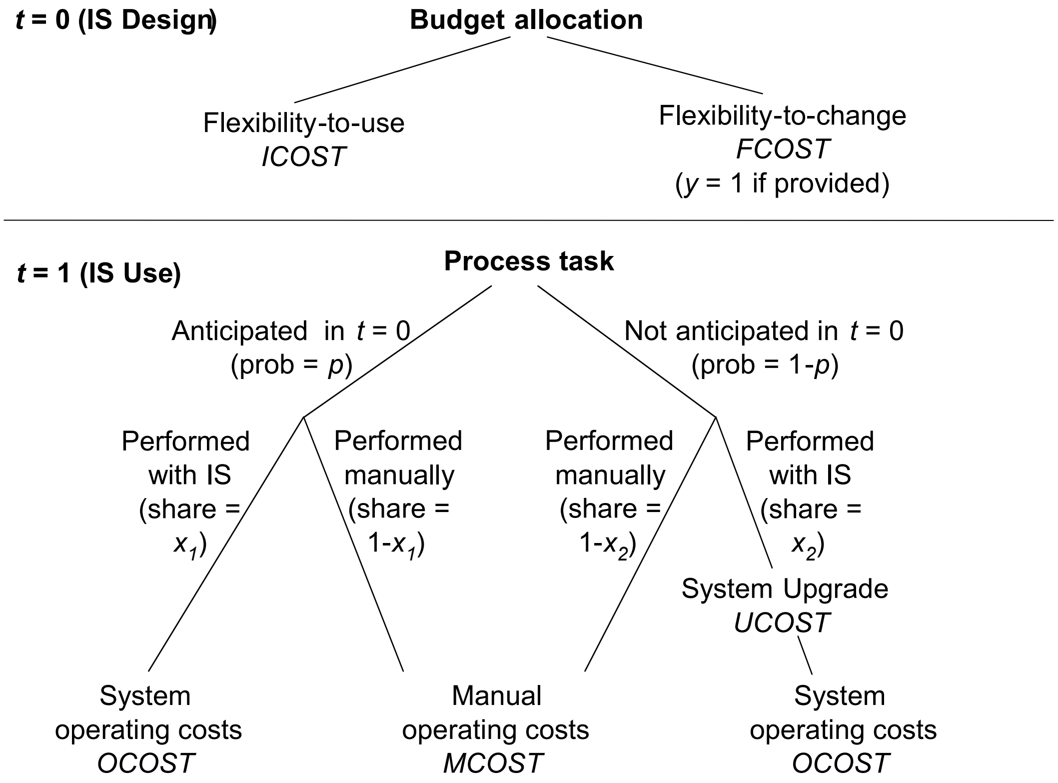

Figure 3. Two-stage decision process regarding IS flexibility

first stage ($t = 0$) and encompasses decisions regarding budget allocation for IS flexibility-to-use and for IS flexibility-to-change, resulting in investment costs of *ICOST* and *FCOST*, respectively. Since flexibility-to-change is optional, our first decision variable is y, with $y = 1$ if flexibility-to-change is provided, and $y = 0$ if not.

IS use takes place in the second stage ($t = 1$), where the three strategies flexibility-to-use, flexibility-to-change, and manual performance, come into effect resulting in the three cost types of system operating costs, manual operating costs, and upgrade costs. In $t =1$, four use situations can be distinguished. (i) A process task to be performed in $t = 1$ has been anticipated in $t = 0$ and has been included in the IS allowing the use of the IS and resulting in system operating costs *OCOST*; (ii) a process task to be performed in $t = 1$ has not been anticipated in $t = 0$, but can be performed with the IS after system upgrade based on the flexibility-to-change option resulting in system operating costs *OCOST* in addition to system upgrade costs *UCOST*; (iii) a process task to be performed in $t = 1$ has been anticipated in $t = 0$ but has not been included in the IS, thus precluding the use of the IS in $t = 1$ and resulting in manual operating costs *MCOST*; and (iv) a process task to be performed in $t = 1$ has not been anticipated in $t = 0$ and is not included in an IS upgrade in $t = 1$, thus again precluding the use of the IS in $t = 1$ and resulting in manual operating costs *MCOST*.

The decisions regarding the extent of system use are denoted by two additional decisions variables: x_1 and x_2. For tasks that are anticipated in $t = 0$, x_1 denotes the share that is to be included in the IS in $t = 0$; whereas x_2 denotes the share of tasks not anticipated in $t = 0$ that are to be included in the IS in $t = 1$ via system upgrade ($0 \leq x_1, x_2 \leq 1$). As a main outcome of the model, the actual mix of flexibility strategies resulting from the decisions in $t = 0$ and $t = 1$ is denoted by w_1, w_2 and w_3, and includes the impact of uncertainty p on the decision variables x_1 and x_2 (see the loads on the four different branches in Figure 3), as follows:

$$
\begin{aligned}
(1) \qquad & w_1 = p\, x_1 \\
& w_2 = (1\text{-}p)\, x_2 \\
& w_3 = p\, (1\text{-}x_1) + (1\text{-}p)\, (1\text{-}x_2) = 1 - w_1 - w_2.
\end{aligned}
$$

The share x_2 can only be positive in $t = 1$ if flexibility-to-change has been provided in $t = 0$, which leads to the logical inequality

$$(2) \qquad y \geq x_2.$$

We can now specify the different cost categories. Beginning with the costs to implement flexibility-to-use in $t = 0$ (*ICOST*), we model

$$(3) \qquad ICOST = a + b\, L(x_1).$$

The cost parameter a denotes a fixed cost component that is independent of the particular process tasks to be included in the IS, such as the costs required to set up the general structures of the database and of the user interface and to provide for basic system functionality and processing capacity. The second term in Equation 3 measures the costs that are associated with the particular tasks to be included in the IS. b expresses the costs to include in the IS *all* tasks that are anticipated in $t = 0$ (complete anticipated IS flexibility-to-use). However, depending on the variability of the supported business process, it often makes economic sense to limit the share of tasks to be included in the IS to the types of tasks that occur most frequently.[3] The share of potential tasks to be included in the IS is denoted by $L(x_1)$ and corresponds with the value of x_1 on the Lorenz curve, as is explained in more detail in Equation 8.

To provide flexibility-to-change in $t = 0$, we assume a fixed cost component c associated with the provision of sufficient personnel resources, integration of data and functionality, and modularity of system components, and state

$$(4) \qquad FCOST = c\,y.$$

System operating costs $OCOST$ in $t = 1$ are modeled as

$$(5) \qquad OCOST = d\,(\,w_1 + w_2\,).$$

The cost parameter d is an estimate of the operating costs over the life-time of the system if *all* tasks of the supported business process were performed with the IS, whether the tasks had been anticipated in $t = 0$ or not. d depends on the expected number of process tasks to be performed during the entire lifetime of the system.[4] To obtain the actual system operating costs OCOST, we multiply d by the share of tasks that are to be performed with the IS (i.e., $w_1 + w_2$).

System upgrade costs $UCOST$ in the case of unanticipated process activities are denoted by

$$(6) \qquad UCOST = e\,L(x_2),$$

where $L(x_2)$ indicates the point on the Lorenz curve that corresponds with the share of tasks that are included in the upgrade. The parameter e is similar in concept to the parameter b in Equation 3. It expresses the upgrade costs required to include *all* process tasks that were not anticipated in $t = 0$ but known to occur based on new information available in $t = 1$.

Manual costs $MCOST$ are expressed by

$$(7) \qquad MCOST = f\,(1{+}r\,g)\,w_3.$$

Similar to the parameter d in Equation (5), the cost parameter f measures operating costs if *all* process tasks were performed manually in $t = 1$. Therefore, we multiply f with the share of manual operations, w_3. The parameter r represents the share of time-critical activities, while g indicates a cost markup for time-critical activities.

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[3] The inclusion of tasks according to frequency is a simplification made in the model that is based on the assumption of task homogeneity regarding IS investment requirements (Equations 3 and 6) and operating costs (Equations 5 and 7). IS implementation should consider the tasks that provide the biggest bottom line impact (e.g., net present value) if performed with the IS, a requirement that needs to be addressed upon applying the model to situations with heterogeneous tasks.

[4] Although we do not know the exact nature of tasks unanticipated in $t = 0$, we make an assumption on the total volume when determining the value of the uncertainty parameter p.

Concerning the form of the Lorenz curve in Equations 3 and 6, we follow a proposal by Ortega et al. (1991) and define

(8) $L(x) = x^{v} (1 - (1-x)^{1-v})$,

with $x = x_1$ in Equation (3) and $x = x_2$ in Equation 6.[5] The parameter v measures the curvature of $L(x)$ to denote variability in our model, as outlined earlier. $L(x)$ fulfills the typical requirements of a Lorenz curve with $L(x) \geq 0$, $L(0) = 0$, $L(1) = 1$, and $L(x)$ convex. For $v = 0$ we get $L(x) = x$ (i.e., the highest possible variability); for $v = 1$ we get $L(x) = 0$ for all $x < 1$ (i.e., the lowest possible variability). See Figure 4.

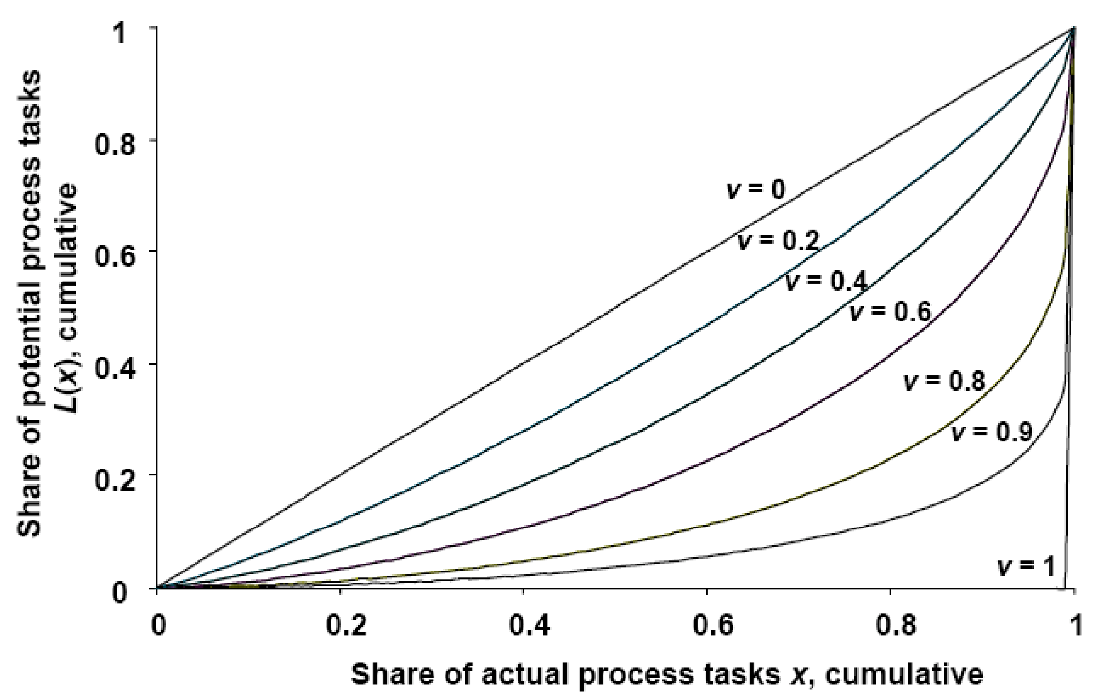

Figure 4. Lorenz curves for different levels of variability *v*

Total costs *TCOST* over both stages of the decision process are given by

(9) $TCOST = ICOST + FCOST + OCOST + UCOST + MCOST.$

To minimize the total costs for IS investment and process performance we need to solve the decision model for the decision variables x_1, x_2 and y:

(10) Minimize *TCOST*
subject to $0 \leq x_1, x_2 \leq 1$ and $y \in \{0,1\}$.

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[5] Several different functional forms have been proposed in the literature (Cheong, 2002). The decision on the proper form can be only made by an empirical comparison for a specific situation on hand. Not wanting to pose any situational assumptions, we propose Equation 8 mainly for reasons of computational efficiency.

Because of Equation 8, the model is non-linear in the decision variables x_1 and x_2. Since the solution space is convex for a given value of y, the model can be solved, yet the solution that we find may not be unique, a situation that is relatively common for mathematical programming problems.[6] After solving the model for the decision variables x_1 and x_2 and y, the optimal mix of flexibility strategies can be determined by w_1, w_2 and w_3, according to Equation 1.

Model Analysis and Proposition Refinement

We now present the results of an analysis of the model that we performed in order to refine the preliminary propositions put forward earlier and to assess in greater detail the impact of IS flexibility on business process cost efficiency. During the analysis, we systematically changed the business process characteristics of uncertainty (p), variability (v), and time-criticality (r). To solve the model for a given set of IS and process cost parameters, we used LINGO (LINDO, 2003), a non-linear optimization software package, including its global solver feature. In the following, we first present the results for business processes where time-criticality does not play a role ($r = 0$), followed by the results for business processes that are characterized by a certain level of time-criticality ($r > 0$). In each case, we solved the model for different levels of variability, while keeping process uncertainty at low, medium, and high levels, respectively.

For the case of low process uncertainty without time-criticality, the model results indicate IS flexibility-to-use as the dominant recommended flexibility strategy (Table 1), which is in line with the Uncertainty Effect Proposition (Preliminary Proposition A). It is interesting, however, to see how flexibility-to-change comes into play for lower levels of variability (i.e., higher levels of the curvature v of the Lorenz curve). The model results indicate that the economic benefits to invest in flexibility-to-change and to upgrade the system in $t = 1$ following the availability of additional information regarding task requirements only come into effect with increasing concentration of the business process on a small number of tasks. The model also recommends the gradual replacement of manual operations for situations of reduced variability, whereas for situations of very high variability, the model recommends a significant share of manual operations. Obviously, it is the precise nature of the *combination* of uncertainty and variability that determines the efficient mix of flexibility strategies.

Table 1. Low uncertainty, different levels of variability, no time-criticality

Cost assumptions: $a = 100$, $b = 300$, $c = 50$, $d = 800$, $e = 300$, $f = 1{,}500$, $g = 0.7$

Low uncertainty ($p = 0.8$), no time-criticality ($r = 0$)

Variability (v)	Flex-to-use (w_1)	Flex-to-change (w_2)	Manual (w_3)	Total Cost (*TCOST*)
0 = high	0.80	0.00	0.20	1,340
0.2	0.78	0.00	0.22	1,337
0.4	0.73	0.00	0.27	1,311
0.6	0.72	0.00	0.28	1,266
0.8	0.74	0.13	0.13	1,195
0.9	0.76	0.16	0.08	1,116
1 = low	0.80	0.20	0.00	950

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[6] For example, see Table 2 for $v = 0$.

The model yields similar results for the case of medium process uncertainty and varying levels of variability (Table 2), insofar as we see the importance of manual operations diminish with decreasing variability. The model indicates equal weight for flexibility-to-use and flexibility-to-change, which is due to the meaningful assumption of identical values for the cost parameters *b* and *e* throughout the model runs. For extremely high process variability ($v = 0$) we obtain an ambiguous solution, with either 50% flexibility-to-change or 50% manual operations, both resulting in total costs $TCOST = 1{,}550$.[7]

Table 2. Medium uncertainty, different levels of variability, no time-criticality

Cost assumptions: $a = 100$, $b = 300$, $c = 50$, $d = 800$, $e = 300$, $f = 1{,}500$, $g = 0.7$

Medium uncertainty ($p = 0.5$), no time-criticality ($r = 0$)

Variability (v)	Flex-to-use (w_1)	Flex-to-change (w_2)	Manual (w_3)	Total Cost ($TCOST$)
0 = high	0.50	0 (0.50)	0.50 (0)	1,550 (1,550)
0.2	0.37	0.37	0.26	1,505
0.4	0.37	0.37	0.26	1,427
0.6	0.39	0.39	0.22	1,339
0.8	0.43	0.43	0.14	1,221
0.9	0.46	0.46	0.08	1,130
1 = low	0.50	0.50	0.00	950

The case of high process uncertainty provides the counterpart to the case of low process uncertainty (Table 3). Now flexibility-to-change becomes the main recommended strategy for IS flexibility, whereas flexibility-to-use becomes more prominent with decreasing process variability at the expense of manual operations.

Table 3: High uncertainty, different levels of variability, no time-criticality

Cost assumptions: $a = 100$, $b = 300$, $c = 50$, $d = 800$, $e = 300$, $f = 1{,}500$, $g = 0.7$

High uncertainty ($p = 0.2$), no time-criticality ($r = 0$)

Variability (v)	Flex-to-use (w_1)	Flex-to-change (w_2)	Manual (w_3)	Total Cost ($TCOST$)
0 = high	0	0.80	0.20	1,390
0.2	0.01	0.78	0.21	1,386
0.4	0.04	0.73	0.23	1,353
0.6	0.08	0.72	0.20	1,291
0.8	0.13	0.74	0.13	1,195
0.9	0.16	0.77	0.07	1,116
1 = low	0.20	0.80	0.00	950

Following the analysis of business processes that are not time-critical, we restate our preliminary propositions as follows.

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[7] In fact, in this situation it would have been cost efficient to not invest in an IS at all, resulting in $TCOST = f = 1{,}500$. Given our focus on IS flexibility, we excluded the case without IS investments, yet point out that the model can easily be expanded to include this case.

Uncertainty and variability propositions:

- **Proposition 1a (Low Process Uncertainty and High Variability Proposition):** A business process characterized by low uncertainty and high variability can be supported cost efficiently with an IS that is based predominantly on flexibility-to-use and that is complemented by manual operations (Table 1, upper part).

- **Proposition 1b (Low Process Uncertainty and Low Variability Proposition):** A business process characterized by low uncertainty and low variability can be supported cost efficiently with an IS that is based predominantly on flexibility-to-use and that is complemented by IS flexibility-to-change (Table 1, lower part).

- **Proposition 2a (Medium Process Uncertainty and High Variability Proposition):** A business process characterized by medium uncertainty and high variability can be supported cost efficiently with an IS that is based equally on flexibility-to-use and on flexibility-to-change and that is complemented by manual operations (Table 2, upper part).

- **Proposition 2b (Medium Process Uncertainty and Low Variability Proposition):** A business process characterized by medium uncertainty and low variability can be supported cost efficiently with an IS that is based equally on flexibility-to-use and on flexibility-to-change strategies with a negligible share of manual operations (Table 2, lower part).

- **Proposition 3a (High Process Uncertainty and High Variability Proposition):** A business process characterized by high uncertainty and high variability can be supported cost efficiently with an IS that is based predominantly on flexibility-to-change and that is complemented by manual operations (Table 3, upper part).

- **Proposition 3b (High Process Uncertainty and Low Variability Proposition):** A business process characterized by high uncertainty and low variability can be supported cost efficiently with an IS that is based predominantly on flexibility-to-change and that is complemented by flexibility-to-use (Table 3, lower part).

In the following, we present the results of the model for time-critical processes. To highlight the implications of time-criticality, we assume a situation of high time-criticality where 50% of the tasks are time-critical (r = 0.5) and where the cost markup for the manual performance of a time-critical task is 70% (d = 0.7). Tables 4, 5, and 6 present the results for situations of low, medium, and high process uncertainty, respectively.

As we expected, the experiments show that in the presence of time-criticality it becomes more important to provide sufficient IS flexibility for all levels and combinations of business process uncertainty and variability. Of particular interest is the case of medium process uncertainty for which the model recommends that the IS should cover all tasks and that manual operations should practically be reduced to zero. In addition, the ambiguity that occurred in Table 2 for very high variability (v = 0) has now disappeared, given that manual operations have become considerably more expensive ($TCOST$ =

1,813) when compared to flexibility-to-use (*TCOST* = 1,550). The model results lead us to state the following propositions regarding time-criticality.

Time-criticality propositions:

- **Proposition 4 (High Time-Criticality and Low Uncertainty Proposition):** A business process characterized by high time-criticality and low uncertainty can be supported cost efficiently with an IS according to Propositions 1a and 1b, yet with a reduced but still sizable share of manual operations in the case of high variability (Table 4).
- **Proposition 5 (High Time-Criticality and Medium Uncertainty Proposition):** A business process characterized by high time-criticality and medium uncertainty can be supported cost efficiently with an equal mix of flexibility-to-use and flexibility-to-change with a negligible share of manual operations, independent of the level of process variability (Table 5).
- **Proposition 6 (High Time-Criticality and High Uncertainty Proposition):** A business process characterized by high time-criticality and high uncertainty can be supported cost efficiently with an IS according to Propositions 3a and 3b, yet with a reduced but still sizable share of manual operations in the case of high variability (Table 6).

Table 4. Low uncertainty, different levels of variability, high time-criticality

Cost assumptions: $a = 100$, $b = 300$, $c = 50$, $d = 800$, $e = 300$, $f = 1{,}500$, $g = 0.7$

Low uncertainty (p = 0.8), high time-criticality (r = 0.5)

Variability (v)	Flex-to-use (w_1)	Flex-to-change (w_2)	Manual (w_3)	Total Cost ($TCOST$)
0 = high	0.80	0	0.20	1,445
0.2	0.80	0	0.20	1,445
0.4	0.78	0	0.22	1,434
0.6	0.77	0.13	0.10	1,366
0.8	0.77	0.16	0.07	1,245
0.9	0.78	0.18	0.04	1,145
1 = low	0.80	0.20	0.00	950

Table 5. Medium uncertainty, different levels of variability, high time-criticality

Cost assumptions: $a = 100$, $b = 300$, $c = 50$, $d = 800$, $e = 300$, $f = 1{,}500$, $g = 0.7$

Medium uncertainty (p = 0.5), high time-criticality (r = 0.5)

Variability (v)	Flex-to-use (w_1)	Flex-to-change (w_2)	Manual (w_3)	Total Cost ($TCOST$)
0 = high	0.50	0.50 (0)	0 (0.50)	1,550 (1,813)
0.2	0.49	0.49	0.02	1,546
0.4	0.47	0.47	0.06	1,500
0.6	0.46	0.46	0.08	1,411
0.8	0.47	0.47	0.06	1,269
0.9	0.48	0.48	0.04	1,158
1 = low	0.50	0.50	0.00	950

Table 6. High uncertainty, different levels of variability, high time-criticality

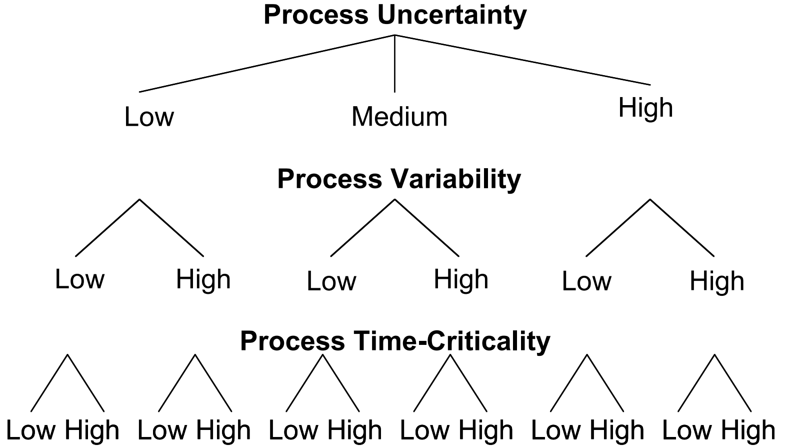
Cost assumptions: $a = 100$, $b = 300$, $c = 50$, $d = 800$, $e = 300$, $f = 1{,}500$, $g = 0.7$

High uncertainty ($p = 0.2$), high time-criticality ($r = 0.5$)

Variability (v)	Flex-to-use (w_1)	Flex-to-change (w_2)	Manual (w_3)	Total Cost ($TCOST$)
0 = high	0.00	0.80	0.20	1,495
0.2	0.06	0.80	0.14	1,480
0.4	0.10	0.78	0.11	1,439
0.6	0.13	0.77	0.10	1,366
0.8	0.16	0.77	0.07	1,245
0.9	0.18	0.78	0.04	1,145
1 = low	0.20	0.80	0.00	950

It turns out that for the cases of low and of high process uncertainty, the aspect of time-criticality does not dramatically change the mix of recommended flexibility strategies compared to the situation without time-critical process tasks. For the case of medium process uncertainty and high time-criticality, however, the model results practically indicate the elimination of manual operations.

Figure 5 summarizes the refined propositions. Following the systematic analysis of the model, we have now arrived at a differentiated picture regarding the interrelations among business process characteristics and flexibility strategies with respect to process cost efficiency.



	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Flexibility-to-use	+++	+++	+++	+++	++	++	++	++	+	+	0	0
Flexibility-to-change	+	+	0	0	++	++	++	++	+++	+++	+++	+++
Manual operations	0	0	+	+	0	0	+	0	0	0	+	+

+++	if $w \geq 0.67$ (dominant flexibility strategy)
++	if $0.33 \leq w < 0.67$
+	if $0.10 \leq w < 0.33$
0	if $w < 0.10$

Figure 5. Summary of model results

During the refinement, the propositions have become more situation-specific and are now more dependent on the values of the various cost parameters. Nevertheless, sensitivity analysis for our parameter set shows that the model results are robust within reasonable limits.

For example, Figure 6 demonstrates the impact of a change in IS operating costs *d* on the recommended mix of flexibility strategies for processes of low uncertainty (p = 0.8), medium variability (v = 0.6), and high time-criticality (r = 0.5), with all other cost parameters unchanged (Table 4). The combination of all three flexibility strategies remains cost-efficient up to a level of d = 1,049 (i.e., a factor of 1.3 of the assumed level of d = 800), the combination of flexibility-to-use and manual operations remains cost-efficient up to a level of d = 2,024 (i.e., a factor of 2.5 of the assumed level of d = 800). For even higher system operating costs, the use of the IS becomes unattractive.

Cost assumptions: a = 100, b = 300, c = 50, d = variable, e = 300, f = 1,500, g = 0.7

Low uncertainty (q = 0.8), medium variability (v = 0.6), high time-criticality (r = 0.5)

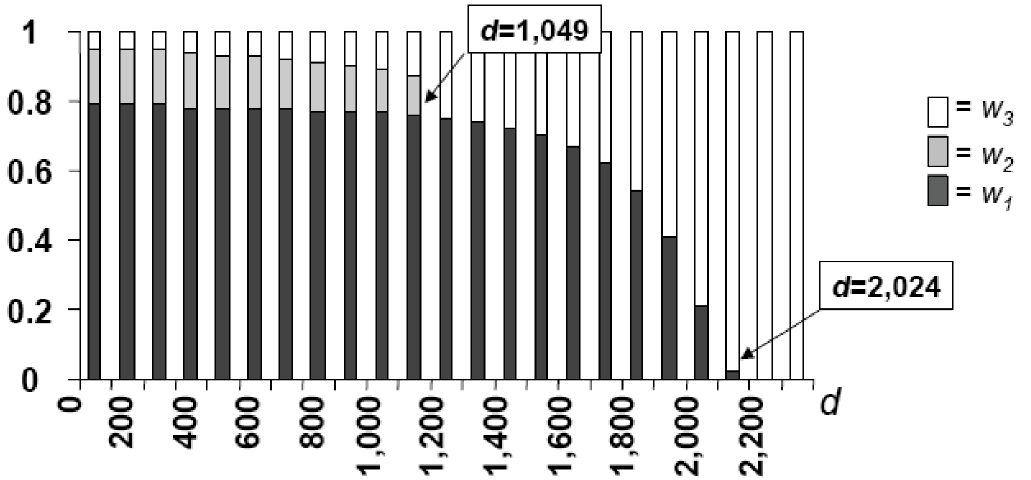


Figure 6. Impact of the variation of IS operating costs (*d*) on the recommended mix of flexibility strategies

Discussion and Conclusions

The main objective of this paper was to present a theory of the impact of IS flexibility on the cost efficiency of a given business process. In addition, we hoped to establish the importance of IS flexibility as a success factor of IS management. To specify the relationships between relevant variables of analysis (Dubin, 1978), we distinguished among three strategies to perform a process task: IS flexibility-to-use, IS flexibility-to-change, and task performance outside of an IS (manual operations). We then outlined a general framework to discuss the impact of the three flexibility strategies on business process cost efficiency, whereby we proposed that the impact is contingent upon process characteristics, such as uncertainty, variability, and time-criticality. Following the presentation of a preliminary set of propositions, we systematically analyzed a formal, quantitative decision model, which allowed us to obtain a refined set of propositions that included combinatorial effects of business process characteristics, yet that at the same time also became more situation-specific (i.e., dependent on the particular parameter values used during the analysis). In particular, we found that IS flexibility-to-change is cost efficiently deployed to support a business process characterized by a high level of uncertainty, whereas a low level of uncertainty corresponds efficiently with IS flexibility-to-use. In addition, the model indicates that high process variability tends to limit the value of an IS over manual operations, whereas a high level of time-criticality of process requirements tends to increase the value of an IS over manual operations.

In the words of Dubin (1978), the current model stands at the intersection between theory and research, and will now benefit from empirical testing in order to determine its general adequacy, to further improve our understanding of the proposed relationships between IS flexibility and business process cost efficiency, and to eventually develop a tool of practical applicability. To conclude the current paper, we point out a number of application areas for the proposed theory as well as directions for refinement.

First, our *theory of IS flexibility* promises to be of value for decision makers by generating awareness of the general relevance of IS flexibility and the benefit of applying a long-term approach to IS investment decisions that covers the expected lifetime of the IS. An improvement of current IS management practices will be the expected result.

Second, the theory can help identify the business process characteristics that managers should consider, such as uncertainty, variability, and time-criticality. Even if a precise measurement of the process characteristics (e.g., uncertainty) is difficult, rough estimations are already, albeit often implicitly, included in the decision making process, such as when past purchasing patterns are analyzed in order to determine the number and type of product categories and suppliers to be included in an electronic procurement system.

Third, the theory should be of interest for software vendors who need to calibrate ready-to-use software features (flexibility-to-use) with the extensibility of the product, as well as effective service concepts and release management (flexibility-to-change), not just for one individual implementation but for an entire range of customer implementations.

Beyond applying the theory to manage a specific IS it could also be used to assess the impact of emerging technologies. For example, in the current model we assumed cost and time premiums for process performance outside of the IS (manual operations). New technical developments, however, such as the availability of innovative solutions to outsourcing and of powerful (Web) service-oriented architectures, will most certainly impact the relative costs of the different flexibility strategies, the effect of which can be assessed with the model.

To refine the theory we suggest a more rigorous inclusion of risk, given that the investment in flexibility-to-change (parameter c in the current model) has all the characteristics of a real option (Amram and Kulatilaka, 1999). The model could be used to calculate for each specific setting of business process characteristics a threshold value γ where $c > \gamma$ prohibits the investment in flexibility-to-change from a cost efficiency point of view, while for $c \leq \gamma$, flexibility-to-change would be part of the cost-efficient solution. The threshold parameter γ can be interpreted as a form of real option value.[8]

A second suggested refinement relates to the treatment of time, which is not very specific in the current theory. Time actually concerns two different yet, in practice, interconnected aspects. First, from a dynamics perspective, time refers to the fact that process characteristics such as uncertainty or variability may change during the lifetime of the IS. Second, from an IS management perspective, the lifetime of the IS itself (t = 1) should arguably be subject to decision making (Swanson and Dans, 2000). To begin with the second aspect, lifetime decisions are affected by process characteristics, particularly by process uncertainty and the corresponding emphasis on IS flexibility-to-change, but also by the expected progress of IT. A refined model might associate uncertain processes with a shorter IS lifetime and, thus, lower estimated operating costs. Time in the dynamics sense takes into account the fact that in the long run most features of an IS will be subject to change, while in the short run flexibility-to-use prevails. This aspect would require a dynamic model that explicitly discounts all time-dependent costs.

Third, it will be necessary to address the limitations stemming from the various assumptions the current theory is based upon. For example, we assumed that time-criticality of business processes puts a cost premium on manual operations only, yet in practice it may actually be faster to perform a complicated task manually rather than with the IS. Without reference to a particular case, we could argue that the situation just described indicates an insufficient amount of IS flexibility-to-use without the option of flexibility-to-change. In general, the situation of a task that occurs very rarely and that is therefore not supported by the IS, is included in the model with the concepts of variability and the Lorenz curve.

Fourth, to develop the theory into a tool of practical relevance, the relative importance of the different components of flexibility-to-use (through functionality, database, user interface, and processing capacity) and of flexibility-to-change (via staff, integration, and modularity) have to be determined by factors such as the key drivers of the IS and relative component costs. For example, a customer relationship management system may be driven by the scope of the underlying database and analytic capabilities, resulting in a situation where the two components of database and functionality would be the main determinants of flexibility-to-use. In comparison, for an order processing system, the two components of processing capacity and variability of access methods (user interface) may be the main drivers of flexibility-to-use. The relative costs of the different options will be determined by the specifics of the underlying business process, but also exhibit path dependency to the extent that previous investments in flexibility-to-change determine the availability of knowledgeable staff, and modularity and integration of the IS architecture applicable to the current situation.

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[8] In fact, γ is the option value for the case of complete market certainty. Market uncertainty could be introduced into the model by considering optimistic and pessimistic volumes of the business process load and corresponding optimistic and pessimistic estimates of the system and manual operating costs and calculating the corresponding option value γ using binomial option price theory.

Acknowledgements

The first author acknowledges support from the College of Business and the University of Illinois at Urbana-Champaign. Valuable input was received from participants at two research seminars at the University of Illinois at Urbana-Champaign, at two theory development workshops sponsored by the Journal of the AIS, and at the 3rd Big Ten IS Research Symposium, University of Wisconsin, Milwaukee; from a number of practitioners in the United States and in Europe; from the *Journal of the AIS* senior editor Rob Kauffman; and from a number of anonymous reviewers. We also thank University of Illinois at Urbana-Champaign Doctoral Student Fei Lee for her help to prepare this paper. All errors remain our own.

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Appendix: Modeling Notation

Decision process	
t	Stage of the decision process with $t = 0$ denoting IS design stage and $t = 1$ denoting IS use stage
Decision variables (direct)	
y	Binary variable with $y = 1$ if flexibility-to-change is provided in $t = 0$, else $y = 0$
x_1	Share of process tasks anticipated in $t = 0$ and using flexibility-to-use in $t = 1$
x_2	Share of process tasks not anticipated in $t = 0$ and using flexibility-to-change in $t = 1$
Decision variables (derived)	
w_1	Share of total process tasks performed based on flexibility-to-use in $t = 1$
w_2	Share of total process tasks performed based on flexibility-to-change in $t = 1$
w_3	Share of total process tasks performed based on manual operations in $t = 1$
Process characteristics	
p	Probability that a process task occurring in $t = 1$ is anticipated in $t = 0$ (measures process uncertainty)
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 in $t = 1$ (measures time-criticality)
Cost parameters	
$ICOST$	Total investment in flexibility-to-use in $t = 0$
a	Base investment in flexibility-to-use in $t = 0$
b	Additional investment in flexibility-to-use in $t = 0$, if all task types anticipated in $t = 0$ were supported by the IS
$FCOST$	Actual investment in flexibility-to-change in $t = 0$
c	Investment in flexibility-to-change in $t = 0$ if provided (i.e., if $y = 1$)
$OCOST$	Actual system operating costs in $t = 1$
d	System operating costs in $t = 1$ if all process activities were supported by the system
$UCOST$	Actual system upgrade costs in $t = 1$ using the flexibility-to-change option provided in $t = 0$
e	System upgrade costs if all process activities not anticipated in $t = 0$ were included in the upgrade in $t = 1$
$MCOST$	Actual costs for manual operations in $t = 1$
f	Manual operating costs in $t = 1$ if all process tasks were performed manually
g	Cost markup for manually performing time-critical process tasks in $t = 1$
$TCOST$	Total costs over both stages $t = 0$ and $t = 1$ (i.e., the entire lifetime of the system)

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Judith Gebauer holds both masters' and doctoral degrees from the University of Freiburg, Germany. Her research focuses on the management and assessment of emerging technology to support organizational processes and interorganizational relationships. Current research projects address the issues of task-technology fit for mobile IS, IS flexibility, and the impact of IT on product modularity. She has published in such journals as the *International Journal of Electronic Commerce*, *Electronic Markets*, *Information Technology and Management*, and *Informatik Forschung & Entwicklung.* For more information, please see www.judithgebauer.com.

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Journal of the Association for Information Systems

ISSN: 1536-9323

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