Information System Flexibility and the Performance of Business Processes

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Abstract

While insufficient flexibility of an information system to support a business process precludes the use of the system in certain cases, excessive flexibility of an information system can limit the usability of the system (Silver 1991), in addition to presenting an unnecessary investment. Despite a wealth of research on flexibility and its impacts on organizations and business processes (esp. manufacturing), the value of flexibility of an information system and the price at which it comes have rarely been included into the analysis, with the result that guidelines to determine an appropriate level of flexibility of an information system to support a given business process have not been developed. To support decisions regarding information system flexibility, the current paper presents an optimization model to relate business process characteristics (uncertainty, variability, and time−criticality) with two basic types of information system flexibility (built−in flexibility to use the information system and flexibility to change the information system). Based on an analysis of the model, we conclude that the focus of information system management should be on flexibility to change the information system in order to support processes of high uncertainty, while situations of low uncertainty tend to call for a focus on built−in flexibility to use the information system. The model also shows that very high process variability can limit the value of investments in an information system altogether, thus, improving the importance of careful flexibility and investment management, while a high level of time−criticality generally tends to increase the benefits of using an information system over manual processing.

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Abstract

While insufficient flexibility of an information system to support a business process precludes the use of the system in certain cases, excessive flexibility of an information system can limit the usability of the system (Silver 1991), in addition to presenting an unnecessary investment. Despite a wealth of research on flexibility and its impacts on organizations and business processes (esp. manufacturing), the value of flexibility of an information system and the price at which it comes have rarely been included into the analysis, with the result that guidelines to manage the flexibility of an information system to support a given business process have not been developed.

To support decisions regarding information system flexibility, the current paper presents an optimization model to relate business process characteristics (uncertainty, variability, and time-criticality) with two basic types of information system flexibility (flexibility to use the information system and flexibility to change the information system). Based on an analysis of the model, we conclude that the focus of information system management should be on flexibility to change the information system in order to support processes of high uncertainty, while situations of low uncertainty call for a focus on flexibility to use the information system. The model also shows that high process variability can limit the value of investments in an information system altogether, thus, improving the importance of careful flexibility management, while a high level of time-criticality generally tends to increase the benefits of using an information system over manual processing.

Keywords: information system flexibility, information system design and development decision support, business process performance, optimization model.

1. MOTIVATION

In order to be effective, an information system needs to be flexible and be able to accommodate a certain amount of variation regarding the requirements of the supported business process. For example, for an electronic procurement system to allow for the processing of actual purchasing requests it needs to include a reasonable amount of product categories and approval procedures. Insufficient flexibility can limit the success of an information system by preventing its use in certain circumstances and by making exception handling necessary. In addition, insufficient flexibility can reduce the overall lifespan of a system in cases where it prevents system changes in order to accommodate changes of the supported business process. Excessive flexibility, however, can also limit the success of an information system by increasing system complexity, investment requirements, implementation time, and subsequent operating and maintenance costs, and by reducing usability (Anonymous 2004, Koste and Malhotra 1999, Silver 1991, Soh, Sia, Boh, and Tang 2003).

In addition to the extent of flexibility, the type of flexibility that is built into an information system impacts system performance, in particular regarding the extent to which the system can be changed after its initial implementation. Choices range from turnkey systems with little room for subsequent changes, to architectures (e.g., based on web services) that provide ample room for changes yet also call for a disciplined design and development effort, including complexity management (see the extensive research work on object-oriented software design).

To date, managers of information system design and development have little guidance regarding the appropriate, let alone optimal extent and type of information system flexibility. In fact, information system flexibility is rarely considered explicitly as a factor of information system design and development decisions. Rather, such decisions tend to be dominated by short-term political considerations, often at the expense of longer term consequences. For example, risk aversion in times of economic uncertainty and limited budgets may result in limited investments in information system flexibility, whereas "me-too"-decisions and the perceived need to follow recent trends in information technologies may result in information systems characterized by extensive flexibility and complexity. The situation is unsatisfactory economically, from a competitive perspective, and with respect to information system usability. Furthermore, research in the area of system requirements engineering has long pointed out that non-systematic and unstructured analyses of system requirements may lead to suboptimal results (Robinson and Pawlowski 1999).

The current research study is motivated by the advent of modern information systems and technologies, such as component-based and service-oriented software architectures, autonomous computing concepts (Horn 2001), web services, and mobile applications that promise to be more flexible than the legacy, mainframe- and client/server-based systems they are meant to replace, yet also require significant investments (Whiting 2003, see also Duncan 1995). We hope to contribute to information system design and development by providing guidelines regarding the optimal extent and type of flexibility of an information system in support of a given business process ("design quality" according to Swanson 1988, Ch. 1). From a theoretical perspective, we address tensions related to information system design (Poole and Van de Ven 1989) that are manifested in the need to find a balance between information system rigidness and variability, i.e., complexity (Silver 1991).

In the following, we particularly draw on earlier research work on flexibility in manufacturing (Sethi and Sethi 1990) and information system infrastructure (Byrd and Turner 2000, Duncan 1995), and on earlier research in organization and management on business processes and business process performance (Gebauer, Shaw, and Gribbins 2005) to *develop an economic optimization model intended to guide investment decisions in the flexibility of an information system to support a given business process*. Based on a systematic variation of the model variables, we then derive a set of propositions regarding the recommended focus of information system flexibility for different types of business processes. Given the high level of abstraction, the model presented in the current paper and the derived propositions are not presented as a closed model to be applied in a concrete situation without further specification. Rather it is our hope that the model can provide the basis for the development of a structured approach to the management of information system flexibility and a starting point for a general discussion on the value and conceptualization of information system flexibility.

2. FLEXIBILITY OF INFORMATION SYSTEMS

Despite significant interest in the concept of flexibility by scholars of various research areas, including economics (Carlson 1989, Maier 1982), strategic management (Evans 1991), and manufacturing (Gupta and Goyal 1989, Sethi and Sethi 1990, Vokurka and O'Leary-Kelly 2000), and information systems (Byrd and Turner 2001, Duncan 1995, Newell, Huang, Galliers and Pan 2002, Palanisamy and Sushil 2003, Robey and Boudreau 1999), there is not much specific guidance on how to manage the flexibility of an information system, let alone how to determine the economically optimal level of information systems flexibility in support of a given business process. In order to fill this gap and to develop guidelines for the management of information system flexibility, we refer to the research area of manufacturing, where research studies have shown that dedicated, single-purpose machines typically operate at lower costs than multi-purpose machines and processes (i.e., single-purpose machines exhibit greater efficiency), yet they provide less flexibility and there is a risk that not all requirements are met (Duimering, Safayeni, and Purdy 1993, also Stigler 1939).

There is evidence that information systems exhibit relationships between flexibility and efficiency that are similar to the ones found to exist for manufacturing systems. For example, Silver (1991) showed that both, an extremely flexible and an extremely restrictive (=inflexible) design of a decision support system can inhibit system use and with it system success. While the extremely restrictive decision support system evidently limits the user to only certain types of procedures and precludes the use of others, the extremely flexible system can discourage usage by being too overwhelming for the inexperienced user. Soh, Sia, Boh, and Tang (2003) pointed out that increasing flexibility of an enterprise resource planning system leads to an increase in complexity. We propose that similar to the management of manufacturing technology, information system managers need to strike a balance between efficiency effects from automation provided by an information system and the flexibility required to adequately perform a given business process over time, acknowledging that flexibility generally is not a "free good" (Stigler 1939) but comes at the price of complexity and additional required investment efforts.

In this context, we point out that the focus of our analysis is on *a specific information system to support a given business process*. Consequently, changes of a business process and business process re-engineering, performed for example in preparation for the implementation of an information system are not discussed in the current research paper. In cases where a business process is supported by more than one information system, the management of interdependencies between the individual systems becomes necessary to ensure overall process performance, yet in order to limit the scope of the current paper, we suggest to focus on the particular tasks of a business process that are supported by the information system in question. Furthermore, in cases where one information system supports more than one business process, we treat all business process characteristics as an average over the set of processes, without loss of generality.

With Hanseth, Monteiro, and Hatling (1996), we include into the analysis two types of flexibility: (1) the "flexibility in the pattern of *use*" that an information system provides before major changes have to be made (in the following termed as *flexibility to use an information system*); and (2) the "flexibility for further *changes*" of a given system, e.g., provided by a modular architecture and built on open standards (in the following termed as *flexibility to change an information system*). Hanseth, Monteiro, and Hatling's (1996) distinction roughly corresponds with Stigler's (1939) distinction between flexibility and adaptability of production plants (p. 315), with Klein's (1977) distinction between Type I flexibility as built into production processes and Type II flexibility as the ability to make good use of newly disclosed opportunities (p. 47), and with Bahrami and Evans's (2005) distinction between robustness, i.e., the ability of an organization to endure variations and perturbations of its environment, and modifiability, i.e., the ability of an organization to make adjustments to its systems in order to cope with the occurrence of less foreseeable events (see also Tan and Sia 2005). The two types of flexibility, i.e., flexibility to use an information system and flexibility to change an information system are discussed next.

2.1 Flexibility to Use an Information System

Based on an extensive literature review, Sethi and Sethi (1990) identified a number of different types of flexibility of manufacturing processes and generally implied that manufacturing flexibility was determined by the range of possibilities that are provided by a given system until a major change was required. For example, Sethi and Sethi (1991) defined machine 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, emphasis added) and to be measured by the "number of operations that a machine can perform without requiring more than a *specified amount of effort*" (p. 299, emphasis added); process flexibility as being related to the "set of part types that the system can produce *without major setups*" (p. 302, emphasis added) and to be measured by the volume of the set of part types that the system can produce "*without major setups*" (p. 303, emphasis added); and production flexibility as "the universe of part types that the manufacturing system can produce *without adding major capital equipment*" (p. 311, emphasis added) and to be measured as the "size of the universe of parts the system is capable of producing" (p. 312).

Applying Sethi and Sethi's (1990) general understanding of flexibility to information systems, we define *flexibility to use an information system as the range of possibilities that is provided by an information system until a major change is required*. For example, the flexibility to use an electronic procurement system refers to the scope of different products and procurement procedures that is built into the system. The next question is how to operationalize the flexibility to use an information system. Research work by Silver (1991) as well as by Soh, Sia, and Tay-Yap (2000) provide good starting points to accomplish the task of describing the scope of an information system.

In order to assess the flexibility and restrictiveness of decision support systems, Silver (1991) grouped the elements of a decision support system into: *operators*, including data, models, parameters and responses, and visual representations; *sequencing rules*; *adaptors*, i.e. components that allow creating or modifying operators; and *navigational aids* to help users structure decision making processes. In a study of structural misfits of enterprise resource planning systems and organizational requirements, Soh, Sia and Tay-Yap (2000) identified three broad categories as sources for misfits: data, including data format and relationships among entities, function, including processing procedures, and output, including presentation format and information content.

Focusing on the features related to the use of an information system that can be determined by designers and project managers of information systems in general (and not just decision making processes, see Silver 1991) we suggest to build on the research work by Silver (1991) and Soh, Sia, and Tay-Yap's (2000) to include into our description of flexibility to use three features: system functionality, scope of the underlying database, and user interface. As an additional factor of flexibility to use, we suggest to include the processing capacity of an information system into our analysis. The four factors are described next.

Functionality refers to the different features a system provides the user with, 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 included in an inter-organizational system (e.g., EDI-messages and RosettaNet-PIPs), and the different models and analysis techniques that are provided by a decision support system. The notion of functionality of an information system as just described, corresponds with Soh, Sia, and Tay-Yap's (2000) concept of functional/process misfit, and Silver's (1991) range of operators (including models, parameters and responses), sequencing rules, and adaptors.

As a second factor to describe the flexibility to use an information system we consider the *scope of the database* underlying the system, referring for example to the number of product categories that can be purchased through the catalog of an electronic procurement system, and the number of reports and analyses contained in a data warehouse. Our notion of the scope of the database to describe the flexibility to use an information system corresponds with Soh, Sia, and Tay-Yap's (2000) concept of data misfits and with Silver's (1991) data operators. In general, the larger the database, the more expensive it is to set up and maintain, as is evidenced by the difficulty to deploy and maintain large data warehousing projects (Wixom and Watson 2001).

User interface as a third factor of flexibility to use an information system refers to the different features and methods an information system provides to a user to interact with it, and comprises the number and type of access channels that are available, including personal computer desktop, and mobile access, as well as soft factors, such as the range of input schemes and output presentation formats. Our notion of user interface encompasses Silver's (1991) concept of navigational aids, as well as Soh, Sia, and Tay-Yap's (2000) concept of output. While a greater number of interface elements allows to support users in a broader variety of use situations without having to revert back to manual processing or time delays in cases where a use situation cannot be covered by the current system (e.g., user is out of the office), the provisioning of additional interface elements can be costly and difficult to manage (Gebauer and Shaw 2004).

As a fourth factor to describe the flexibility to use an information system, we include the *processing capacity* that is provided by an information system before major performance losses are experienced. Processing capacity refers for example to the number of users an information system can accommodate concurrently, and the number of transactions and user requests an information system can process without major performance losses, measured for example in response times.

Similar to Sethi and Sethi (1990), we assume that the actual measurement of flexibility to use an information system and the determination of the limits of this type of flexibility depend on the individual circumstances. For example, a real-time financial trading system will have a different threshold of what constitutes acceptable performance than an information system providing access to archived accounting data. In addition, we note that 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.[1] Acknowledging these limits that need to be addressed explicitly upon applying the suggested flexibility model in a specific situation, we still view flexibility to use as the pre-determined scope of an information system for instances of "regular" use.

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[1] We thank an anonymous reviewer for pointing this out.

2.2 Flexibility to Change an Information System

Besides the decision regarding the level of flexibility to use an information system as a result of the combined choices in respect to functionality, data base, user interface, and processing capacity, system designers and project managers also face a decision regarding an investment in the *flexibility to change, i.e., the effort required to change a given information system after its initial implementation*. Choices range from systems that cannot be changed, upgraded, or expanded in any way (off-the-shelf, turnkey systems), to arrangements that provide many opportunities for change after the initial system has been put to use, based for example on decomposition and modularization (Hanseth, Monteiro, and Hatling 1996), and on the use of open standards, such as web services. To distinguish flexibility to change from flexibility to use, it needs to be determined what constitutes a major change as we determined earlier that flexibility to use covers the scope of the system *before* a major change occurs. Acknowledging system-specific differences, we associate a major change with information system adjustments and changes that require a fresh system setup, including re-installation and re-testing, whereas the activation of pre-installed parameters that cause only minor disruptions in system availability are not being associated with a major change, and, thus be subsumed under flexibility to use. Typically, information systems exhibiting a high level of flexibility to change require greater investment efforts regarding system setup and maintenance, as compared to their more proprietary counterparts.

To operationalize the concept of flexibility to change an information system, we build on research studies on information system infrastructure as provided by Byrd and Turner (2000) and Duncan (1995). Information system infrastructure has been defined as a general-purpose information technology resource that is shared throughout the organization, that is of long-term use, and that provides a basis for more specific applications (Byrd and Turner 2000 and 2001, Weill 1993).

Although our notion of an information system pertains to individual applications rather than to the more encompassing concept of information system infrastructure, research on information system infrastructure is relevant for our purpose as it emphasizes the part of an information system architecture that has been designed specifically with the purpose to contribute to future developments and changes.

In an attempt to capture the flexibility of information technology infrastructure and to improve the understanding of what makes information technology infrastructure flexible, Duncan (1995) identified four basic components of information technology infrastructure, namely platform technology (i.e., hardware and operating systems), network and telecommunication technologies, key data, and core data-processing applications. In addition, Duncan (1995) included three information system planning issues into the analysis, such as "(1) the alignment of IS plans to business objectives, (2) information technology plans or architecture and (3) the skills of all personnel involved in IT resource management" (p. 40), and further stressed the fact that the flexibility of an infrastructure encompasses the degree to which resources are sharable (defined in terms of "reach" and "range") and reusable, in other words "modular." Duncan (1995) finally presented the results of a Delphi study that provided the following factors as most important for an information technology consultant to characterize infrastructure flexibility: (1) compatibility rules for communications and networks, data, and applications; (2) business management leadership in long-term planning for applications; (3) connectivity of systems across physical locations; and (4) interface standardization.

Building on Duncan's (1995) work, Byrd and Turner (2000) carefully identified three factors as relevant to describe the flexibility of information technology infrastructures: (1) the flexibility of the information technology *personnel*, as manifested in a variety of skills and attitudes of the information technology staff; (2) 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 compatibility of applications across platforms; and (3) *modularity*, as provided by the use of re-usable software modules, vendor-independent database connectivity, and object-oriented development tools.

In the current paper, we apply Byrd and Turner's (2000) construct of information technology infrastructure to individual information system applications to operationalize flexibility to change an information system with the three elements: *Personnel*, *integration of data and functionality*, and *modularity of system components*. Each element impacts the ability of the organization to provide new (and re-combined) information system functionality, to recombine and reorganize access to various data sources, to allow for changes of the user interface, and to change the available processing capacity. In addition, we assume that the three elements personnel, integration of data and functionality, and modularity also impact the actual efforts required to make the desired changes. In general, flexibility to change an information system has the character of a real option, i.e., an optional investment in addition to the (mandatory) investment in flexibility to use that provides the possibility to be executed in the future but not the obligation (Amram and Kulatilaka 1999).

3. BUSINESS PROCESS CHARACTERISTICS

Information systems are used to support business processes, such as procurement and customer relationship management. To perform a business process, a number of individual activities need to be performed, such as requesting an item, approving a request, compiling a purchase order, managing customer contacts, and schedule services. Since our focus is on the management of information system flexibility with the objective to improve business process performance, we need to (1) operationalize business process performance; and (2) operationalize the characteristics of business processes to be included into the analysis as being impacted by information system flexibility.

Researchers have identified many factors to determine the performance of business processes, including: efficiency, effectiveness, customer satisfaction, bottom line impact, and shareholder value (Hammer and Champy 1993). In order to avoid over-complication of our model from dynamically changing processes, we focus our attention on a given process, for example purchasing, and measure *performance as process efficiency over time*. We consequently want to assume the target process outcome to remain steady in terms of quality and processing time. The assumption of a fixed process outcome does not necessarily preclude intermittent changes of the underlying process structure. Yet the process structure as such is not at the focus of attention and effectively treated a "black box" in the current paper. In cases where a process cannot be performed in time and where the quality of outcome is not adequate, we assume additional operational costs as a penalty for late and for poor performance.

To operationalize business process characteristics, we now turn to earlier research studies on managerial processes that have been performed in research areas, such as organization and management. We focus on three process characteristics: uncertainty, variability, and time-criticality.

3.1 Uncertainty

The uncertainty associated with a business process refers to the difficulty to predict the tasks and resources required to perform the business process in a particular instance. Business process uncertainty results from a combination of *environmental uncertainty*, i.e., uncertainty of exogenous input variables, that determines what process tasks are required to perform a future business process, and *structural uncertainty* that determines to which extent a process task can be supported by a given information system.

The concept of structural uncertainty is part of the discussion of task difficulty by scholars of organization and management, in particular managerial tasks (Anthony 1965, Gorry and Scott Morton 1971, Perrow 1967, Simon 1960, see also Gebauer, Shaw and Gribbins 2005). Terms related to task uncertainty include the degree of (non)-routineness (Anthony 1965, Gorry and Scott Morton 1971), structuredness (Simon 1960), and analyzability (Perrow 1967) of a task and with it the business process of which the task is a part. In general, higher level management tasks tend to be characterized by a higher level of uncertainty than lower level management and administrative tasks, making a prescription of specific activities problematic for higher level management tasks. The result of high structural uncertainty is a situation where even at the time of process occurrence a significant amount of individual judgment is required regarding the most appropriate measures to be taken.

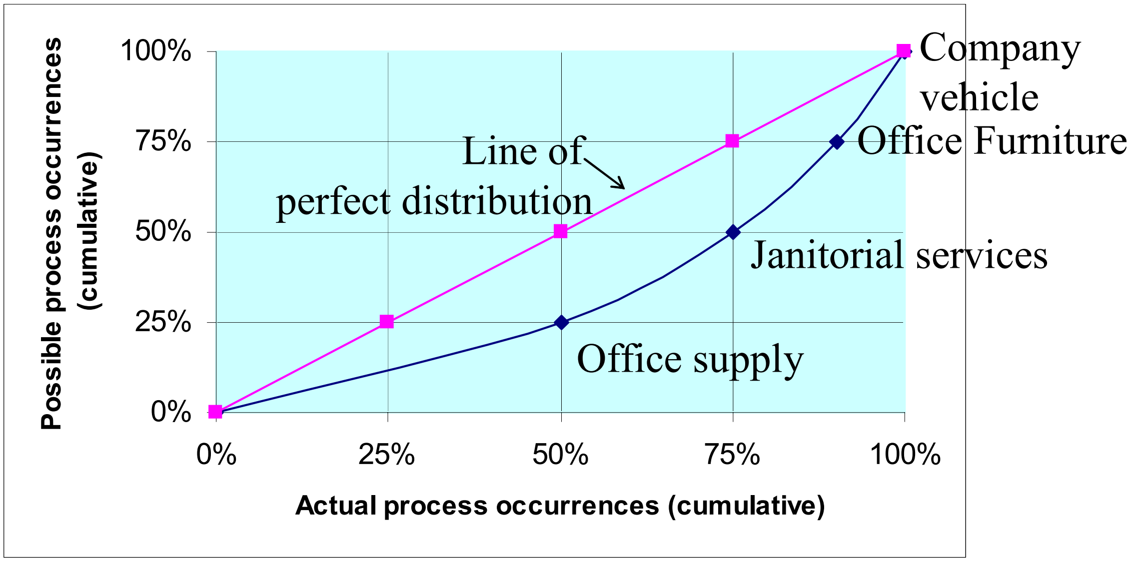
Both environmental and structural uncertainty, contribute to the overall difficulty of predicting system requirements. A business operating in a highly volatile environment (high environmental uncertainty) will find it difficult to predict system requirements even for processes and tasks that can be structured easily (low structural uncertainty), whereas a business operating in a relatively stable environment (low environmental uncertainty) will at times find it difficult to predict the specific system requirements for highly unstructured tasks and processes (high structural uncertainty).

3.2 Variability

As a second factor to impact the requirements of an information system in support of a given business process, we suggest to consider the variability of process requirements. Variability has been key to the identification and discussion of various flexibility concepts, in particular in the research area of manufacturing. Sethi and Sethi’s (1990) analysis of manufacturing flexibility for example centers around the question of what factors vary or should be varied with respect to manufacturing processes, e.g., machine configuration, market and production volumes, and production procedures.

In the current study, we summarize the different, varying aspects of process requirements into one concept of variability, describing for example the different product categories requested for purchase in a procurement process and the different modes that are required to access an information system as requested by a user group.

The variability of a business process over time can be operationalized with the concept of the Lorenz curve (Lorenz 1905), traditionally a graphical representation of income distribution that can be used, however, to measure any form of (uneven) distribution. Following the concept of the Lorenz curve, we characterize the variability of a business process with two dimensions (Figure 1). As the first dimension (horizontal axis in Figure 1), the frequency of *actual* process occurrences (e.g., actual number of requests for different product categories over a certain period of time) is depicted cumulatively in decreasing order, with the most frequent occurrence depicted first and the least frequent occurrence depicted last, such that the range is from zero percent at the far left to one hundred percent at the far right. As the second dimension the frequencies are then related to all *possible* occurrences, e.g., all product categories available for purchase during the period of observation, again ranging from zero to one hundred percent. Each point of the resulting Lorenz curve combines the cumulative share of a set of *actual* process occurrences (e.g., actual purchasing requests for various product categories) with the cumulative share of *possible* process occurrences (e.g., list of all product categories available for purchase).



Product category	Share of possible process occurrences (cumulative)	Actual purchasing requests = share of actual process occurrences (cumulative)
Office supply	25%	50%
Janitorial services	50%	75%
Office furniture	75%	90%
Company vehicle	100%	100%

Figure 1 – Concept of the Lorenz curve applied to measure process variability

In cases of extreme variability all possible process occurrences have equal probability during a certain period, which means that there is a low concentration of process occurrences. For example, the probability of a specific product category to be requested through an electronic procurement system is the same across the entire range of categories, depicted by the line of perfectly equal distribution in Figure 1. In contrast, low process variability corresponds with a strong concentration of process occurrences, where some processes have a higher probability to occur than others. The table in Figure 1 shows that office supplies account for 50% of all purchasing requests, janitorial services for 25%, office furniture for 15% and company vehicles for 10%. In the extreme case of zero process variability one hundred percent of purchasing requests would be made for one single product category, and no requests would be made for all other product categories.

3.3 Time-Criticality

Time-criticality is included in the analysis as a third factor to characterize business processes, referring to the question of how urgent it is to perform a business process promptly. Although the concept of time-criticality has traditionally found relatively little attention in the research areas of management and organization, the ability of organizations to respond quickly to changing market requirements has recently been discussed in the context of agile organizations operating in fast-paced economic environments (Bradley and Nolan 1998, D'Aveni 1994). In addition, time-criticality has captured the attention of scholars of mobile information systems (Balasubramaniam, Peterson, and Jarvenpaa 2001, Junglas and Watson 2003, Siau, Lim and Shen 2001).

In reality, many business processes are in fact time-critical and a failure to perform a business process in time can result in penalty charges. Penalty charges can occur literally, e.g., as part of a contractual arrangement, or be viewed as opportunity costs from delayed strategic choices. Processes of low time-criticality allow for certain delays in performance without significant additional operational costs. We assume that time criticality in particular affects processes that are handled outside the system, e.g., manually or by using older, legacy systems, as those tasks typically take longer to be performed, e.g., using paper forms or requiring duplicated data entry. This assumption not withstanding we note, however, that business processes are in fact often performed outside of an information system for the stated reason that following "proper," that is information system-based procedure would result in too much of a delay. Conceptually, we address this argument by including into the analysis the opportunity costs from duplicate data entries and from non-consistent process handling that a company has to incur as a consequence from such behavior.

4. A MODEL TO SUPPORT INFORMATION SYSTEM FLEXIBILITY DECISIONS

Based on the previous discussion we are now ready to model the different decisions regarding the allocation of investments for the different types of information system flexibility and information system upgrades. Figure 2 depicts the general structure of the model showing business process characteristics as the combined independent variable, information system design and usage as the combined decision variable, and overall business process performance as the dependent variable.

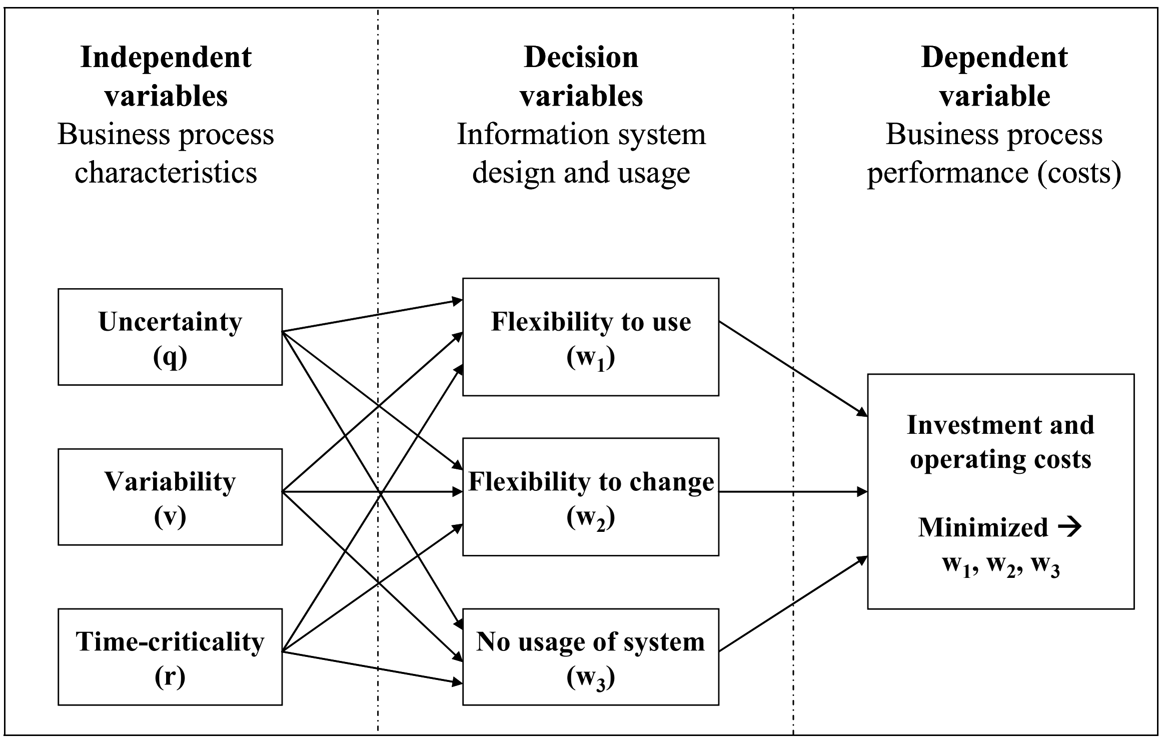


Figure 2: General model structure

More specifically, a business process is characterized by uncertainty, variability and time-criticality and each characteristic is measured by a specific parameter: q denotes the probability that a certain process occurrence is anticipated at the time of system specification, v denotes process variability and drives the Lorenz curve, and r denotes the share of time-critical process occurrences. In the model, the business process parameters influence the recommended investments in flexibility to use the information system and in flexibility to change the information system, as expressed by the shares w_1 and w_2 in Figure 2. The share $w_3 = 1 - w_1 - w_2$ denotes the amount of process occurrences that are handled outside of the system by manual operations or by the use of older legacy systems (in the following we simply speak of “manual operations”). In the model, the shares w_1, w_2 and w_3 are calculated such that the objective function, comprising the total investments and operating costs, is minimized over the lifetime of the considered information system.

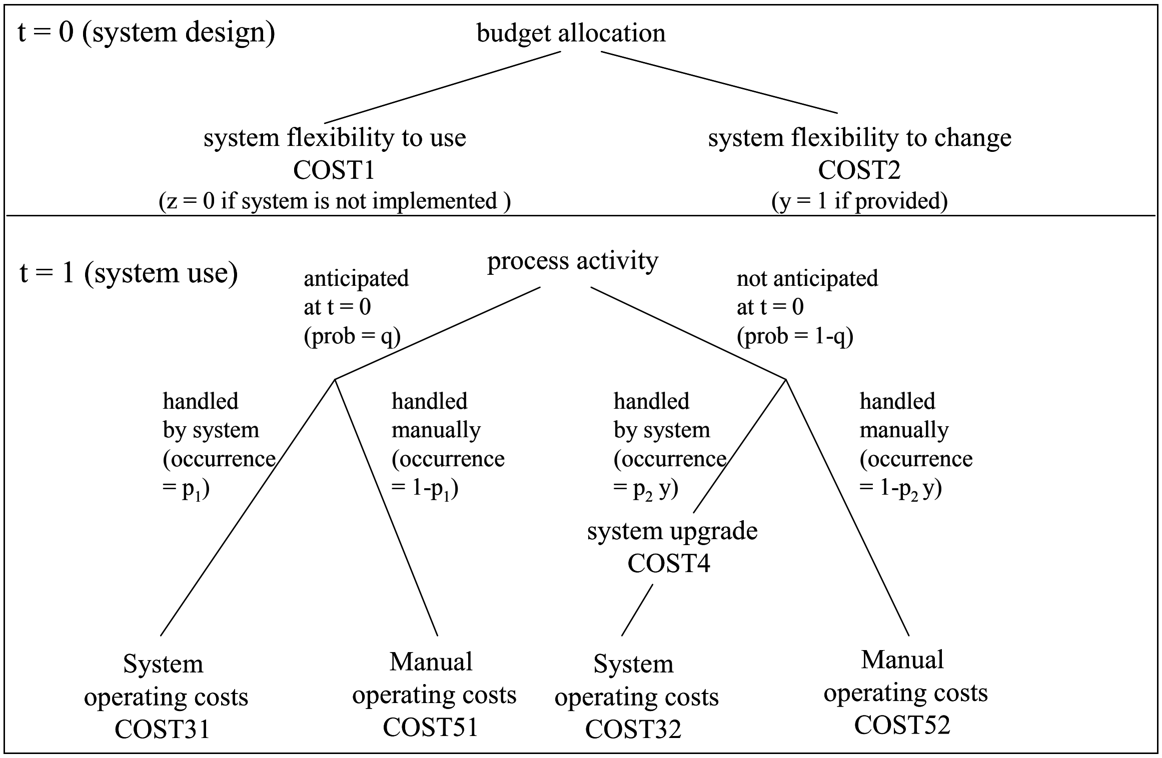


Figure 3: Two-stage decision process

Figure 3 exhibits the specific decisions to be made and their sequence in time, assuming a two-period decision process. Initial budget allocations for flexibility to use and for flexibility to change are made in the first period of system design ($t = 0$). The investment in flexibility to use is reflected in the cost factor *COST1*, while the investment in flexibility to change is reflected in the additional and optional cost factor *COST2*. System use takes place in the second period ($t = 1$), covering the entire operational lifetime of the system.

In the period of system use ($t = 1$), four different situations are included into the analysis. (1) A process activity occurs in $t = 1$ that has been anticipated in $t = 0$ (the probability is q, see Figure 3) and that can be handled by the information system given the level of flexibility built into the information system. Flexibility to use is measured with p_1 as the share of the actual process occurrences in $t = 1$ that were included in the information system. The share p_1 is one of the decision variables to be determined by the model based on the uncertainty parameter q, on the variability parameter v, and on the time-criticality parameter r, and it effectively determines w_1. The incurred costs are *COST31*. (2) A process occurs in $t = 1$ that has been anticipated in $t = 0$ and that can not be handled by the information system, e.g., because the required functionality and data have not been included into the information system. Such a process occurrence must be performed manually, leading to a cost factor of *COST51*. (3) A process occurs in $t = 1$ that has *not* been anticipated in $t = 0$ (probability is $1 - q$), and that has consequently not been included in the initial investment to set up the system, but that will lead to a system upgrade. Generally, upgrading can only occur if an investment in flexibility to change has been made in $t = 0$. This decision is expressed with a binary variable y with $y = 1$ if flexibility to change has been provided for in $t = 0$ and $y = 0$ if not. If upgrading can be done, it is assumed that it will be performed for a share of all process occurrences p_2 only, depending again on the uncertainty parameter q, the variability parameter v, and the time-criticality parameter r, and effectively determining w_2. This part of the decision tree leads to cost factor *COST32*. (4) A process occurs in $t = 1$ that has *not* been anticipated in $t = 0$ and that will *not* lead to a system upgrade. Such a process but must consequently be performed manually, leading to cost factor *COST52*.

We include into the model also the extreme situation that in the period $t = 0$ the information system will not be designed and implemented at all, thus allowing for manual process handling only in the subsequent period $t = 1$. In this case, we set $z = 0$. In detail, the model has the following form:

(1) $COST1 = c_{10}\, z + c_{11}\, L_1(p_1).$

To determine the total investment in flexibility to use c_{10} denotes a fixed cost component of system development that has to be incurred independent of the level of flexibility to use. We multiply c_{10} with a binary variable z, with $z = 0$ if no system is developed in the period $t = 0$ and all process occurrences in $t = 1$ are handled manually. In this case, flexibility to use ($L_1(p_1)$) is assumed to be zero, leaving the cost factor *COST1* at zero as well. If the system is in fact implemented in $t = 0$, then $z = 1$. The coefficient c_{11} expresses development costs for the case that the flexibility built into the information system covers every process occurrence in the period of $t = 1$ that is anticipated in t = 0, i.e. the case where full flexibility to use is provided. Assuming that in most cases full flexibility to use is cost prohibitive, $L_1(p_1)$ depicts the cumulative percentage of all possible process occurrences that can be handled by the system, where $L_1(p_1)$ is the value on the Lorenz curve that corresponds with the cumulative share of actual process occurrences p_1.

(2) $COST2 = c_{20}\, y$.

The coefficient c_{20} measures the presumably fixed cost required to provide flexibility to change in $t = 0$. Provision happens if $y = 1$, otherwise $y = 0$ and $COST2 = 0$.

(3) $COST31 = c_{31}\, p_1\, q$.

To determine cost factor *COST31*, the coefficient c_{31} expresses the cost for system operation that is required to perform one hundred percent of process occurrences in $t = 1$ with the information system. Full coverage of process occurrences, however, is typically not feasible for two assumed reasons. First, uncertainty limits the share of process occurrences anticipated in $t = 0$ to q, leaving a share of $1\text{-}q$ process occurrences to be unplanned for. Second, investment decisions as part of the model further limit the level of flexibility (p_1) that is built into the system in $t = 0$. As a result, only the portion $p_1\, q$ of all process occurrences can be performed in $t = 1$ by using the information system.

(4) $COST32 = c_{31}\, p_2\, y\, (1\text{-}q)$.

Cost factor *COST32* is determined by c_{31}, the same cost coefficient for system operation that was used in (3), now applied, however, to the share of process occurrences that have *not* been anticipated in $t = 0$, (i.e., $1\text{-}q$) and that have been included in a system upgrade in $t = 1$ (p_2). As explained before, a system upgrade in $t = 1$ requires flexibility to change to be present (i.e., $y = 1$). Exercising the upgrade option determines cost factor *COST4*:

(5) $COST4 = c_{41}\, L_2(p_2)$.

The coefficient c_{41} determines the costs to implement all process activities not anticipated in period $t = 0$ ($1\text{-}q$) during the upgrade in period $t = 1$. However, as in (1), we assume that for cost reasons the upgrade is provided to cover only the most frequent process occurrences (p_2), expressed by the value $L_2(p_2)$ on the Lorenz curve.

Cost factors *COST51* and *COST52* describe the costs for all process occurrences that are performed outside of the information system. Manual operations lead to:

(6) $COST51 = c_{51}\ (1+r\ d)\ (1-p_1)\ q$

and

(7) $COST52 = c_{51}\ (1+r\ d)\ (1-p_2\ y)\ (1-q)$.

In equations (6) and (7), the coefficient c_{51} expresses the operating costs for the case that all process occurrences are handled outside the information system. To derive cost factors *COST51* and *COST52*, the coefficient c_{51} is multiplied by the share of actual process occurrences that are using this option, i.e., $(1-p_1)\ q$ and $(1-p_2\ y)\ (1-q)$, respectively. Manual operating costs are further inflated by the share r of time-critical activities assumed to incur an overhead cost share of d, i.e. we assume that time-criticality only has an impact on the performance of process occurrences outside the information system.

Concerning the form of the Lorenz curve $L(p)$, we follow a proposal of Ortega, Martin, Fernandez, Ladoux, and Garcia (1991) and define $L(p) = p^a\ (\ 1-(1-p)^b\ )$ with $a > 0$ and $0 < b < 1$. We specifically set $a = v$, $b = 1 - v$, and $0 < v < 1$, describing a fairly symmetric shape of the Lorenz curve that we believe provides a good representation of the variability of process activities if nothing else is known (Figure 4). We get

(8) $L_1(p_1) = p_1^{v_1}\ (\ 1-(1-p_1)^{1-v_1}\ )$

and

(9) $L_2(p_2) = p_2^{v_2}\ (\ 1-(1-p_2)^{1-v_2}\ )$,

where the coefficients v_1 and v_2 measure different levels of variability. Small values of v_1 and v_2 represent high variability, whereas large values of v_1 and v_2 represent low variability. In the numeric examples below we assume that all process occurrences exhibit the same level of variability, be they anticipated or not anticipated, and set $v_1 = v_2 = v$ in (8) and (9).

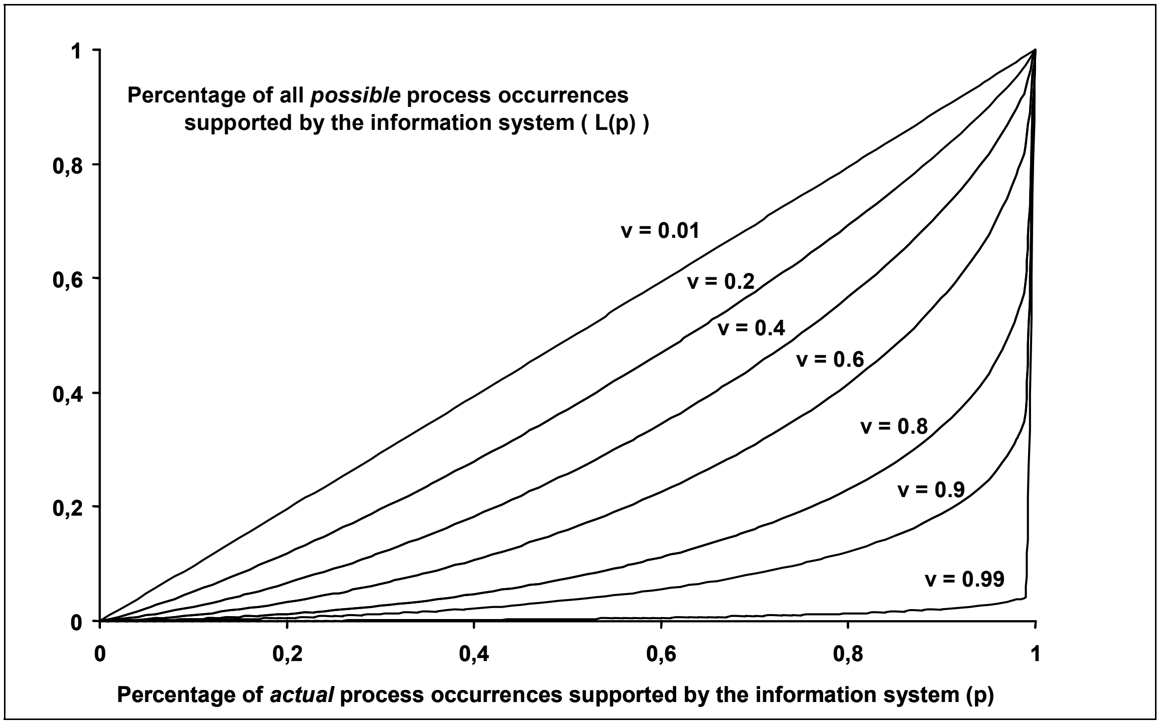


Figure 4: Lorenz Curve

Finally, we include the following auxiliary constraint into the model. To ensure that $z = 0$ in (1) if all activities are handled manually, we state

(10) $2z \geq p_1 + y$.

If all activities are handled manually the right-hand side of (10) becomes zero. In addition and given that we minimize costs (see equation 11) $z = 0$; otherwise $z = 1$.

Equations (1) to (10) describe the decision space of the model. By solving the model decision variables p_1, p_2, y and z are determined such that total costs are minimized, i. e. we apply the objective function

(11) Min $TCOST = COST1+COST2+COST31+COST32+COST4+COST51+ COST52$

with $0 \leq p_1, p_2 \leq 1$ and $y, z \in \{0,1\}$.

This completes the model. It is non-linear containing continuous variables p_1 and p_2 as well as discrete variables y and z. After solving the model the shares w_1, w_2 and w_3 in Figure 2 can be directly calculated as

(12) $w_1 = p_1{}^* q,$

(13) $w_2 = p_2{}^* y^* (1-q),$

and

(14) $w_3 = 1-w_1-w_2,$

where $p_1{}^*$, $p_2{}^*$ and y^* indicate the model solutions for the variables p_1, p_2 and y.

5. MODEL ANALYSIS AND PROPOSITIONS

We now analyze the behavior of the proposed decision model for different combinations of the business process parameters uncertainty (q), variability (v), and time-criticality (r) and for a set of pre-determined cost coefficients. The model analysis provides the basis for a number of propositions to guide investment decisions in information system flexibility. The analysis was performed using the modeling language LINGO, in particular the global solver feature of LINGO for non-linear optimization (LINDO 2003).

We start by presenting the results of different combinations of business process uncertainty (q) and variability (v) while omitting time-criticality. Table 1a presents the results for the case of low uncertainty ($q = 0.8$, i.e., 80% of actual process occurrences in period $t = 1$ are anticipated in period $t = 0$) for various settings of the variability parameter v and the assumption $r = 0$, i.e. no process occurrence is time critical.

Table 1a: Low uncertainty, varying levels of variability, and no time-criticality

Cost assumptions: $c_{10} = 100$, $c_{11} = 300$, $c_{20} = 50$, $c_{31} = 800$, $c_{41} = 300$, $c_{51} = 1500$, $d = 0.7$
Low uncertainty (q = 0.8), no time-criticality (r = 0)

Variability (v)	Flex to use (w_1)	Flex to change (w_2)	Manual (w_3)	TCOST
0.01= high	0.80	0	0.20	1340
0.2	0.78	0	0.22	1337
0.4	0.73	0	0.27	1311
0.6	0.72	0	0.28	1266
0.8	0.74	0.13	0.13	1195
0.9	0.76	0.16	0.08	1116
0.99 = low	0.80	0.20	0	982

The results show that for the conditions modelled in the experiment, business processes of low uncertainty ($q = 0.8$) and of high variability ($v = 0.01$, i.e., the Lorenz curve is very close to the line of perfectly equal distribution) should be supported by an information system with flexibility to use sufficient to cover about 80% of all actual process occurrences (w_1), while the remaining 20% of actual process occurrences would be handled manually and outside the information system (w_3). No flexibility to change would be provided ($w_2 = 0$). With decreasing variability ($v \geq 0.8$) flexibility to change the information system starts to play a role. At $v \geq 0.8$, the model recommends an investment in flexibility to use sufficient to cover 74% of all process occurrences (w_1). In addition, it is now recommended to invest in flexibility to change and to upgrade the system in $t = 1$ such that after the upgrade another 13% of process occurrences (un-anticipated in $t = 0$ but known in $t = 1$) can be handled with the information system (w_2). The remaining 13% of actual process occurrences would still be handled manually (w_3). For very low variability ($q = 0.99$, i.e., the Lorenz curve is very close to the line of perfectly unequal distribution) the recommendation to handle any process occurrences manually (w_3) drops to zero. Overall, flexibility to use plays a dominant role in the described scenario of low uncertainty.

Table 1b presents the situation of medium uncertainty ($q = 0.5$). All other parameters remain unchanged compared to the situation of low uncertainty.

Table 1b: Medium Uncertainty, varying levels of variability, no time-criticality

Cost assumptions: $c_{10} = 100$, $c_{11} = 300$, $c_{20} = 50$, $c_{31} = 800$, $c_{41} = 300$, $c_{51} = 1500$, $d = 0.7$
Medium uncertainty (q = 0.5), no time-criticality (r = 0)

Variability (v)	Flex to use (w_1)	Flex to change (w_2)	Manual (w_3)	TCOST
0.01= high	0	0	1	1500
0.2	0	0	1	1500
0.4	0.37	0.37	0.26	1427
0.6	0.39	0.39	0.22	1339
0.8	0.43	0.43	0.14	1221
0.9	0.46	0.46	0.08	1130
0.99 = low	0.50	0.50	0	984

For the situation of medium uncertainty and very high variability the model recommends to forego the investment in an information system altogether and to handle all process occurrences outside of the system ($w_3 = 1$). At a level of variability $v = 0.4$, however, the recommendation changes to a level of flexibility to use sufficient to handle about 37% of process occurrences (w_1) and an investment in flexibility to change that will allow to handle another 37% of process occurrences after system upgrade (w_2). At a level of very low process variability the model recommends to split investments in flexibility to use and flexibility to change such that each would cover half of process occurrences ($w_1 = 0.5, w_2 = 0.5$). Overall, the model recommends approximately equal investments in flexibility to use and flexibility to change for the scenario of medium uncertainty, except for the case of very high process variability where manual processing becomes the recommended strategy. Note that this surprising result is a consequence of the comparatively attractive costs of manual operations in the case of very high variability. An increase in the costs of manual operations from $c_{51} = 1500$ to the threshold value of $c_{51} = 1550$ changes the results significantly with $w_1 = w_2 = 0.50$; $w_3 = 0$;

TCOST = 1550 for *v = 0.01*, and $w_1 = w_2 = 0.41$; $w_3 = 0.18$; *TCOST = 1516* for *v = 0.2*. A similar change occurs when we introduce time-criticality along with its impact on manual costs, see Table 2b.

Table 1c presents the case of high uncertainty (*q = 0.2*, i.e., 20% of actual process occurrences in *t = 1* are anticipated in *t = 0*). All other parameters remain unchanged.

Table 1c: High Uncertainty, varying levels of variability, no time-criticality

Cost assumptions: $c_{10} = 100$, $c_{11} = 300$, $c_{20} = 50$, $c_{31} = 800$, $c_{41} = 300$, $c_{51} = 1500$, d = 0.7
High uncertainty (q = 0.2), no time-criticality (r = 0)

Variability (v)	Flex to use (w_1)	Flex to change (w_2)	Manual (w_3)	TCOST
0.01 = high	0	0.80	0.20	1390
0.2	0.01	0.78	0.21	1386
0.4	0.04	0.73	0.23	1353
0.6	0.08	0.72	0.20	1291
0.8	0.13	0.74	0.13	1195
0.9	0.16	0.77	0.07	1116
0.99 = low	0.20	0.80	0	982

For the situation of high variability, the model recommends an investment into flexibility to change and a system upgrade in t = 1 sufficient to cover approximately 80% of process occurrences (w_2) and no investment in *t = 0* into flexibility to use, resulting in manual processing for about 20% of process occurrences (w_3). For situations of lower variability, the model recommends to gradually replace manually handled situations with flexibility to use (w_1). Overall, the model recommends investments in flexibility to change for the scenario of high uncertainty.

The model results indicate that uncertainty plays a critical role. For situations of low uncertainty the model suggests flexibility to use to be the dominant option of system design (Table 1a), whereas for situations of high uncertainty flexibility of change becomes dominant (Table 1c). For medium uncertainty both flexibility options are of equal importance (Table 1b). We further observe that as variability decreases (higher values of v) information system use gradually replaces manual operations. The obvious reason is that because of the high concentration of a few different process occurrences in the case of low variability the scope of the system can be low at system setup (*t = 0*) as well as at system upgrade (*t = 1*). In the case of medium uncertainty and high variability ($v \leq 0.2$), however, the experiment shows that the manual option proves to be dominant and the system will not be implemented at all. In this case $z = 0$ in equation (1), resulting in $TCOST = c_{51} = 1500$.

These results are not surprising as they reflect the inner logic of the model. For instance, in the case of low uncertainty (Table 1a) the use of flexibility to change is restricted to the 20% of actual process occurrences not already anticipated in $t = 0$ ($1\text{-}q = 0.2$), which means that flexibility to use naturally becomes the dominant option. Similarly, in the case of high uncertainty (Table 1c), flexibility to change becomes the dominant option, given that it pertains to the large share of actual process occurrences that cannot be anticipated in $t = 0$. Based on the results of the experiment we state the following general propositions:

Uncertainty:

Proposition 1a: Processes that are characterized by *low uncertainty* should be supported with an information system of *high flexibility to use* (= dominant flexibility strategy) and *low flexibility to change* for best overall cost performance (Table 1a).

Proposition 1b: Processes that are characterized by *medium uncertainty* should be supported by an information system with an *equal mix of flexibility to use and flexibility to change* for best overall cost performance (Table 1b).

Proposition 1c: Processes that are characterized by *high uncertainty* should be supported with an information system of *high flexibility to change* (= dominant flexibility strategy) and *low flexibility to use* for best overall cost performance (Table 1c).

Variability:

Proposition 2a: Processes that are characterized by *high variability* should be supported by an information system using the *dominant system flexibility strategy* according to Proposition 1a (*low uncertainty*) and Proposition 1c (*high uncertainty*), as well as a *sizable capacity for manual operations*, for best overall cost performance (see upper parts of Tables 1a and 1c). In the case of *medium uncertainty* where no dominant flexibility strategy exists, *all three operating modes* should be considered for best overall cost performance (upper part of Table 1b).

Proposition 2b: Processes that are characterized by *low variability* should be supported by an information system using an *appropriate mix of system flexibility strategies* according to Propositions 1a to 1c and only a *very marginal capacity for* *manual operations* for best overall cost performance.

We are now ready to include the impact of time-criticality into the experiment. Tables 2a to 2c provide the results of an experiment similar to the one presented earlier with a fairly high rate of process occurrences that are time-critical: $r = 0.5$ (i.e., 50 %).

Table 2a: Low uncertainty, varying levels of variability, and high time-criticality

Cost assumptions: $c_{10} = 100$, $c_{11} = 300$, $c_{20} = 50$, $c_{31} = 800$, $c_{41} = 300$, $c_{51} = 1500$, d = 0.7
Low uncertainty (q = 0.8), high time-criticality (r = 0.5)

Variability (v)	Flex to use (w_1)	Flex to change (w_2)	Manual (w_3)	TCOST
0.01 = high	0.80	0	0.20	1445
0.2	0.80	0	0.20	1445
0.4	0.78	0	0.22	1434
0.6	0.77	0.13	0.10	1366
0.8	0.77	0.16	0.07	1245
0.9	0.78	0.18	0.04	1145
0.99 = low	0.80	0.20	0	986

Table 2b: Medium uncertainty, varying levels of variability, and high time-criticality

Cost assumptions: $c_{10} = 100$, $c_{11} = 300$, $c_{20} = 50$, $c_{31} = 800$, $c_{41} = 300$, $c_{51} = 1500$, d = 0.7
Medium uncertainty (q = 0.5), high time-criticality (r = 0.5)

Variability (v)	Flex to use (w_1)	Flex to change (w_2)	Manual (w_3)	TCOST
0.01 = high	0.50	0.50	0	1550
0.2	0.49	0.49	0.02	1546
0.4	0.47	0.47	0.06	1500
0.6	0.46	0.46	0.08	1411
0.8	0.47	0.47	0.06	1269
0.9	0.48	0.48	0.04	1158
0.99 = low	0.50	0.50	0	987

Table 2c: High uncertainty, varying levels of variability, and high time-criticality

Cost assumptions: c_{10} = 100, c_{11} = 300, c_{20} = 50, c_{31} = 800, c_{41} = 300, c_{51} = 1500, d = 0.7
High uncertainty (q = 0.2), high time-criticality (r = 0.5)

Variability (v)	Flex to use (w_1)	Flex to change (w_2)	Manual (w_3)	TCOST
0.01 = high	0	0.80	0.20	1495
0.2	0.06	0.80	0.14	1480
0.4	0.10	0.78	0.11	1439
0.6	0.13	0.77	0.10	1366
0.8	0.16	0.77	0.07	1245
0.9	0.18	0.78	0.04	1145
0.99 = low	0.20	0.80	0	986

The experiment shows that for the situation of a large number of time-critical process occurrences, it becomes more important to provide sufficient system flexibility at all levels of business process uncertainty and variability (compare Tables 2a, 2b, and 2c to Tables 1a, 1b, and 1c respectively). Of particular interest is the case of medium process uncertainty, where the model recommends that the system should cover all activities and manual operations should practically be reduced to zero. The results of the experiment lead us to state the following propositions concerning time-criticality:

Time-criticality:

Proposition 3a: For processes that are characterized by *high time-criticality and either low or high uncertainty* a *reduced, but still sizable capacity for manual operations* should be provided for best overall cost performance (compare Table 2a and Table 2c with Table 1a and Table 1c respectively).

Proposition 3b: For processes that are characterized by *high time-criticality and medium uncertainty* only a *very marginal capacity for manual operations* should be provided for best overall performance (compare Table 2b with Table 1b).

A sensitivity analysis with different cost parameters shows that the derived propositions remain valid as long as the cost parameters are changed within a meaningful range, i.e. within a range where all three operating alternatives of flexibility to use, flexibility to change and manual operations remain interesting options. To provide an example, let us consider a variation of the costs of system operation, c_{31}. Using the scenario depicted in Table 2a, we consider a low level of uncertainty ($q = 0.8$), medium variability ($v = 0.6$) and high time-criticality ($r = 0.5$). For $c_{31} = 800$, for example, the recommended level of flexibility to use is $w_1 = 0.77$, flexibility to change is as $w_2 = 0.13$ and manual operations are $w_3 = 0.10$. The result indicates that flexibility to use is the major option, but that flexibility to change and manual operations are important as well. The result remains valid for $0 \leq c_{31} \leq 1049$ (Figure 5). For values of $c_{31} > 1049$, however, flexibility to change becomes too expensive and drops out of the recommended configuration. This situation holds for $1049 < c_{31} \leq 1681$. For very high system operating *costs* $c_{31} > 1049$, the model recommends a focus on manual operations only.

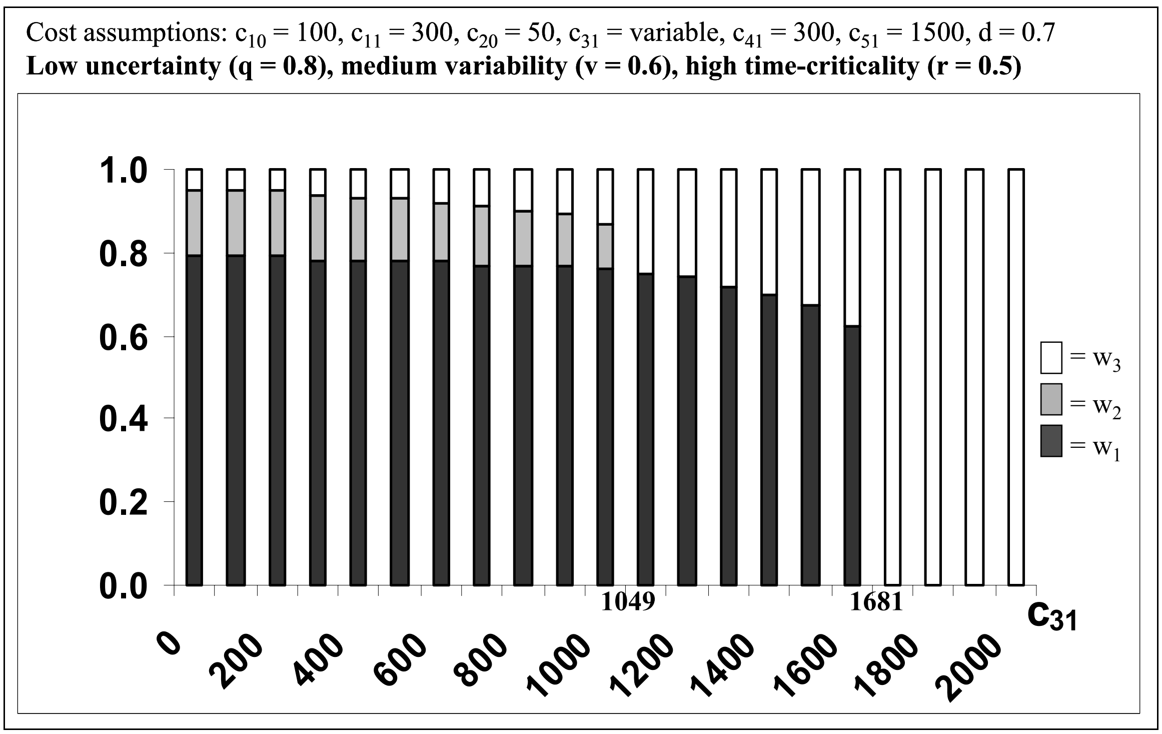


Figure 5 – Sensitivity analysis: Impact of variation of system operation costs c_{31} on recommended budget and use allocations (w_1, w_2, w_3), all other parameters unchanged from the scenario depicted in Table 2a

Summarizing the findings from the model and the derived propositions, Figure 6 shows graphically the gradual shift from a recommended focus on flexibility to use for situations of low uncertainty to a recommended focus on flexibility to change for situations of high uncertainty. The recommended shift to perform processes outside of the information system (manual operations) for cases of high variability is evident as well in Figure 6.

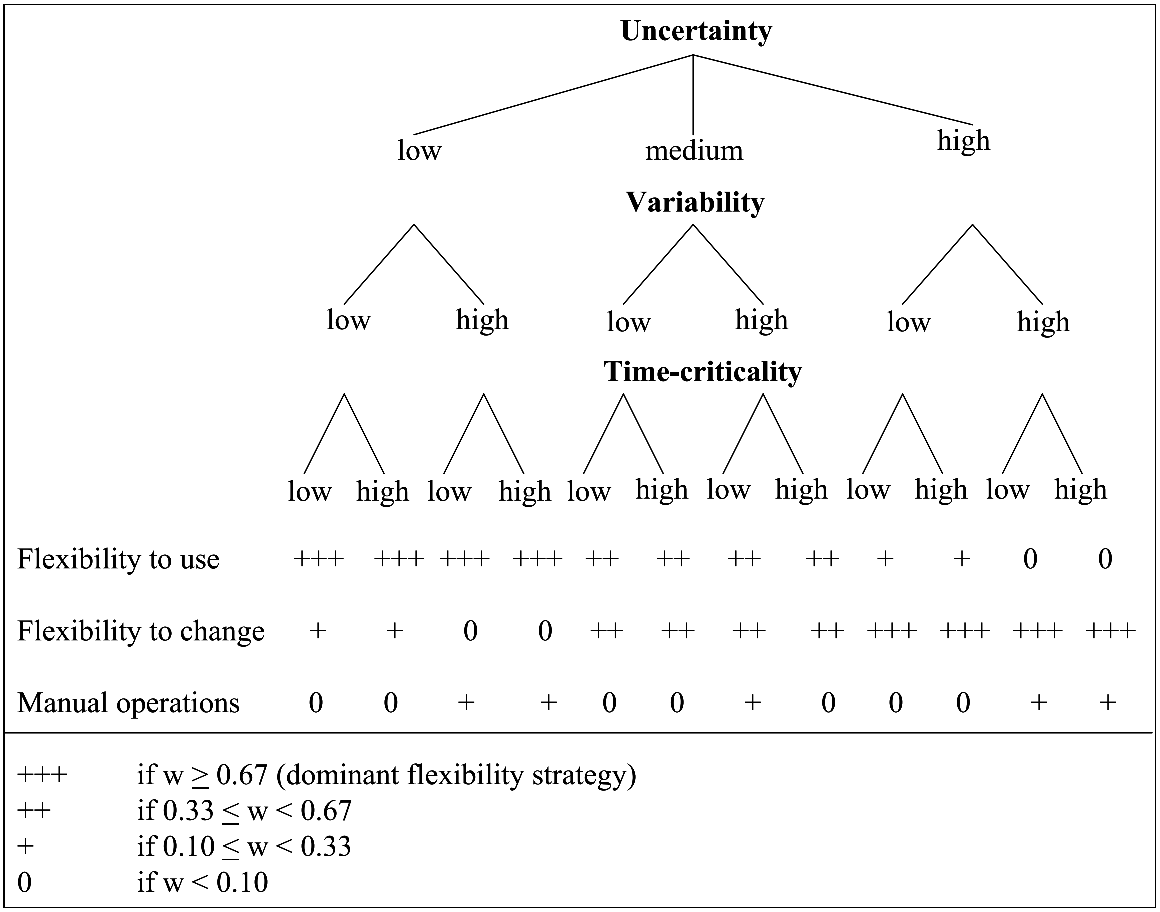


Figure 6: Summary of model results

6. APPLICABILITY AND LIMITATIONS

The objective of the current research study was to improve the management of information system flexibility in support of a given business process. We presented a decision model to guide the investment in two types of information system flexibility, namely flexibility to use, manifested for example in information system functionality, data base, user interface and processing capacity, and flexibility to change, manifested for example in technical staff, system integration and modularity, and for the subsequent operations, including the use and upgrade of the information system, and manual operations outside of the information system. We used as independent variables the business process characteristics of uncertainty, variability and time-criticality, while the minimization of the overall investment and operational costs of the information system throughout the system lifetime comprised the objective function, subject to decisions regarding investments in information system flexibility and regarding subsequent use.

An analysis of the model shows that within a reasonable range of pre-set parameters a focus on flexibility to use is recommended for situations of low uncertainty where most process requirements can be predicted upfront, whereas situations of high uncertainty would call for a focus on flexibility to change. A situation of medium flexibility calls for a balanced approach integrating flexibility to use and flexibility to change. Furthermore we found that in the case of high process variability, i.e., a situation where many different process requirements are equally likely to occur, the careful management of a supporting information system in general and of information system flexibility in particular becomes critical, given that the relative value of the information system tends to decrease compared to process performance outside of the information system. In other words, alternative means to perform a business process that at the point of decision making require lower investments than the design and development of an information system, such as manual operations, use of legacy systems and outsourcing, can have a comparative advantage in cases where process requirements exhibit high variability. Finally, we found that time-criticality of business processes can put a premium on process performance outside of the information system, thus, increasing the value of the information system and with it the value of both types of flexibility.

Regarding its applicability, the abstract model presented in the current paper is to be considered less as a closed theory applicable to most practical situations without further specification, but rather as a starting point for discussion on the economic value of a structured and longer-term approach to investment decisions in information system flexibility as compared to current practice. For example, the model can help identify the process characteristics that managers should consider in practical situations, such as uncertainty, variability and time-criticality. Even if a precise measurement of the process characteristics (e.g., uncertainty) may be 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 the catalog of an electronic procurement system. In addition, the general approach laid out in the current paper promises to be of value for decision makers by generating awareness of the relevance of information system flexibility and the benefit of applying an inclusive approach to information system and design that includes the expected lifespan of the system. The concept should also be of interest for software vendors, such as vendors of enterprise resource planning (ERP) systems, 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 (i.e., flexibility to change), not just for one individual implementation but for an entire range of customer implementations.

In practice, the relative importance of the different components of flexibility to use (e.g., functionality, database, user interface, and processing capacity) and of flexibility to change (e.g., staff, integration and modularity) are to be determined by factors such as the key drivers of the information system 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 determinants 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 information system architecture applicable to the current situation.

Beyond its support for the design and development of a specific information system, the current model can also be applied to assess the impact of emerging information technologies. For example, in the model we assumed a cost premium for process performance outside of the information system (manual operations) as a result of processing delays in addition to the assumption of zero time effort for information system upgrades. New technological developments, however, can result in changes of those assumptions the effect of which can be assessed with the model. For example, the availability of innovative solutions to outsourcing will impact the assumed cost to perform a process outside of the information system with implications for the proposed recommendations. In addition, advances in technology, such as the availability of affordable web services and open source software can change the relative importance of the different forms of flexibility, and for example lower the cost for flexibility to change, and, thus increase the attractiveness of this option.

The current model can furthermore be applied to risk management. In particular, the model component flexibility to change has all characteristics of a real option (Amram and Kulatilaka 1999), the value of which can be determined with the current model, as the following example demonstrates.

For a given set of the model parameters q, v and r, expressing uncertainty, variability and time-criticality, we set $\hat{c}_{20}$ as the threshold value for the cost parameter c_{20} in equation (2) beyond which flexibility to change becomes unattractive. Table 3 exhibits these threshold values $\hat{c}_{20}$ for all model results of Section 5.

Table 3: Option prices ($\hat{c}_{20}$) for providing flexibility to change

Cost assumptions: c_{10} = 100, c_{11} = 300, c_{31} = 800, c_{41} = 300, c_{51} = 1500, d = 0.7

Option prices		r = 0			r = 0.5	
	q = 0.8	q = 0.5	q = 0.2	q = 0.8	q = 0.5	q = 0.2
v = 0.01*)	-	-	156	-	312	579
0.2	0.6	45	164	15	315	595
0.4	8	112	197	45	337	636
0.6	24	156	259	80	382	709
0.8	51	215	355	127	453	803
0.9	76	260	434	165	508	865
0.99*)	126	333	542	229	594	959

*) Option prices for v = 0.01 and v = 0.99 are partly approximated due to instabilities of the optimal solution for these extreme values of the Lorenz curve.

For example, in the case of low uncertainty ($q = 0.8$), medium variability ($v = 0.6$) and no time-criticality ($r = 0$) the threshold value is $\hat{c}_{20} = 24$, meaning that if flexibility to change could be provided at a cost of 24 monetary units instead of the originally assumed cost of 50, this flexibility option would become part of the optimal solution. On the other hand, in the case of low uncertainty ($q = 0.8$), low variability ($v = 0.9$) and no time-criticality ($r = 0$) flexibility to change would become unattractive if c_{20} exceeds 76 monetary units. Thus, the threshold value $\hat{c}_{20}$ can be interpreted as the "option price" for providing flexibility to change. Option prices in Table 3 are below 50 in all cases where flexibility to change was not part of the recommended solution (costs for providing flexibility to change have to be cut to the threshold to make this flexibility option attractive) and above 50 in all cases where flexibility to change was part of the recommended solution (costs can even be increased to the threshold to keep flexibility to change attractive). The option prices provide a measure for the importance of providing flexibility to change. High option values correspond with a high importance of providing flexibility to change and low option values correspond with a low importance of providing flexibility to change. Table 3 indicates once more, that flexibility to change becomes particularly crucial in the case of high uncertainty, low variability and/or high time-criticality.

The managerial implications of improved guidelines to handle information system flexibility in a structured way can be substantial. In times of tight information system budgets and economic uncertainty, information system managers understandably tend to opt for conservative investment strategies that primarily focus on flexibility to use and that provide little room for additional investments in flexibility to change. Yet, examples exist where firms were able to gain substantial competitive advantage from the deployment of an information system that allowed for affordable and quick extensions based on a powerful system architecture, whereas the competition faced the challenge of tedious and lengthy updates of various homegrown systems. A situation, however, where a firm hastily deploys a new and powerful technology in order to follow current trends in the marketplace, may turn out to be problematic as well when the challenge to manage an overly complex system subsequently arises. Even if at times stating the intuitive, the current model can show the sub-optimality of short-term oriented seat-of-the-pants decisions and provides the ground for structured procedures to help a manager explore and better understand the specifics of the decision making situation. A more substantiated justification of particular investment decisions may be the result, e.g., investments in a modular architecture and competent information system staff with the intent to provide flexibility to change in lieu of excessive flexibility to use.

Before we conclude, several limitations of the current study should be mentioned. An optimization model such as the one presented here, always presents a simplification from reality, and, thus has its natural limits that define the valid range of application to specific instances and situations.

To begin, the current model is not very specific with respect to the lifetime of an information system. Still the lifetime of an information system is a critical component for the evaluation of flexibility-related decisions as it determines the point in time where the replacement of the information system is considered, effectively determining the end of period $t=1$. It has been noted elsewhere that the lifetime of an information system cannot necessarily be considered a pre-determined factor as it is itself subject to decision making (Swanson and Dans 2000). The concept of system lifetime is relevant for a second reason and insofar as flexibility generally has to be considered with respect to the aspect of time: While in the long run, most features of an information system can be considered flexible, the concept of flexibility to use an information system tends to be associated with a rather short time frame. As outlined above, we use the concept of a major change, associated for example with system re-installation and re-testing, to distinguish between flexibility to use and flexibility to change, all with respect to the lifetime of the information system.

To summarize, we acknowledge the simplification regarding the lifetime of an information system made in the current paper, yet refer to the fact that at the outset of the design and development of an information system, managers need to have some timeframe in mind as a guiding factor for the required investment effort. In general, the lifetime of the information system will depend on factors such as the environmental uncertainty of the supported business process, the rate of technical innovations and the rate of change of the underlying business process that may render the current information system obsolete. While outside of the scope of the current paper, the factors that determine the lifetime of an information system should be included in future extensions of the model, in particular as other parameters of the model are affected. For example, situations of low uncertainty (q) should be associated with a shorter system lifetime and, therefore, lower total operating costs (c_{31}, c_{51}) throughout period $t=1$ than situations of high uncertainty.

Another limitation stems from the fact that the current model assumes time-criticality to affect only manual processes and that system upgrades can be performed with zero time-effort. A future expansion of the model should loosen this condition to account for the fact that (1) system upgrades can in fact take time, and that (2) there are cases where process performance outside of the information system can be faster in the short term and might, thus, be the method of choice in day-to-day operations. We suggest including opportunity costs into the analysis, the nature of which, however, needs to be determined in more detail in future research studies.

Furthermore, the current analysis is based on the assumption that the business process supported by an information system does not change in terms of its outcome, i.e., the underlying business process structure is essentially treated as a black box. As a result, the question of whether the business process and its structure actually match the organizational needs remains outside of the current study. There typically is a relation though between the structure of a business process and the structure of a supporting information system, as changing business requirements (e.g., increased competition, changes in market dynamics) can lead to changes of the business process and subsequently also impact the outcome of the process (e.g., higher outcome quality, overall faster processing). In the current model, a change in process outcome conceptually requires the setup of a new information system.

7. OUTLOOK

The model presented in the current paper provides a general way of thinking about flexibility of an information system to support a given business process, rather than a closed body of theory. A number of propositions have been derived as guidelines for the evaluation and management of information system flexibility. Given the normative orientation of the research study and the general openness of the current model, we now provide several starting points for improvement and further development.

First, to validate and improve upon the general structure of the model it is necessary to address the question of whether critical aspects were omitted, such as time aspects and specific characteristics of business processes, and to analyze the implications of those omissions. In this context, empirical research work should seek to establish evidence for the validity of the propositions, addressing questions such as: How are managers actually addressing the question of flexibility to use versus flexibility to change? How are managers selecting (1) the components to be included in an information system (flexibility to use) and (2) the type of level of flexibility to change by offsetting setup and operational costs for the information system on the one hand, with additional investments in flexibility to change, change costs, and exception handling costs on the other hand? The identification and analysis of differences between actual managerial behavior and the recommendations provided in the current paper will help to strengthen the model, and help to improve information system management.

Second, we suggest applying the model to critically assess the actual flexibility of new technologies and to determine the price at which the flexibility comes. Recent innovations, such as web services, service oriented architectures, and business process orchestration concepts have resulted in bold promises regarding information system flexibility and regarding the ease with which changes of an information system can be implemented. We suggest trying to find out whether recent innovations are bound to change a fundamental assumption underlying our conceptual model, i.e., the effective need to carefully calibrate information system flexibility to use and flexibility to change.

Third, we suggest taking the concept presented in the current paper to the next level by improving our understanding about the relationship between the flexibility of an information system and the performance of the supported business process. The model should be extended such that in addition to efficiency of a business process more complex performance measures could be assessed, such as customer satisfaction, profitability, and shareholder value.

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