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Valuing IT through Virtual Process Measurement

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ABSTRACT

The so called "productivity paradox" associated with information technology remains the focus of active research in information systems. One explanation involves the dearth of useful measures to assess the value of IT investments. A review of the predominant approaches to such measurement reveals a number of serious weaknesses and fundamental limitations. The research described in this paper addresses these limitations through a complementary methodology termed *virtual process measurement* (VPM). Through VPM, assessments of IT value are determined through the measurement of computer-based process representations (i.e., virtually), as opposed to measuring their real counterparts in ongoing organizations; this approach affords a number of advantages that are unattainable through extant techniques. In this paper, the VPM methodology is discussed in considerable detail, and examples from industry practice are used to demonstrate the use and utility of this approach. The paper closes with a set of conclusions and some possible directions for continued research.

1. IT PRODUCTIVITY PARADOX

A trillion dollars have been invested in information technology (IT) through the decade of the eighties, yet marked improvement in business productivity remains illusive (Rothschild 1993). This so called "productivity paradox" has been cited in the information systems (IS) literature as a lingering dilemma (Boehm 1981), and represents the focus of current research in academics (e.g., Abdel-Hamid 1993; Glazer 1993; Keen 1993; Weill 1992). According to one IS journal editor, a key aspect to this dilemma pertains to the manner in which productivity is measured, exacerbated by the lack of good measures for the value of IT (King 1992). Given the deep and rapid proliferation of IT through the business environment, this need for useful IT-valuation measures will certainly grow through time; moreover, to the extent that measures for IT valuation fail to capture the "true" economic benefit of IT investments, business managers risk serious misallocation of capital to IT-based investments.

The search for IT valuation measures is not new to IS research. Traditional financial techniques (e.g., ROI, IRR) have been employed for decades and measures have been developed to estimate IS functionality and cost (e.g., function point analysis, COCOMO). The key limitation of these approaches is that they fail to capture *intangible* costs and benefits, many of which are inherently qualitative, very difficult to quantify, and nearly impossible to reduce to measures expressed in terms of dollars, complexity, and lines of code (Hall 1992). Other approaches take a strategic view of IT, discarding valuation measures for the promise of attaining competitive advantage; however, the sustainability of IT-based competitive advantages is arguable, so valuation remains key to analysis and decision making. Further, IS textbooks (e.g., Fertuk 1992) now include guidance on subjective valuation, but this approach is asystematic and suffers from inconsistency and bias.

Many researchers now argue for methodological pluralism (e.g., Hall 1992; Kanevsky and Housel 1993), through which multiple simultaneous approaches are employed in an attempt to "triangulate" on the underlying IT value. In this paper, we too adopt this multiple-methodology approach, for the measures and approaches developed to date have considerable utility and merit; however, we strive to overcome the residual limitations of this ensemble of approaches through a methodology termed *virtual process measurement* (VPM). Virtual process measurement derives from a more comprehensive methodology employed for business process reengineering.

In this methodology, which is currently being actively and effectively employed in a number of organizations, processes from the field are represented in our knowledge-based modeling environment. This environment also supports symbolic simulation, in which dynamic process measures are taken from the *represented process*. A validation step ensures that the behavior of this representation is consistent with the real-world process in the field, so that value-based measurements can be made regarding *virtual processes*. These include the obvious measures of process performance (e.g., cost and cycle time), in addition to a battery of measures with heuristic value that are useful for identifying process weaknesses and generating redesign alternatives.

These measures are also useful for IT valuation and can be used, for example, to compare the performance of an organizational process *with* the proposed IT investment against that of its counterpart *without* the IT implementation. Moreover, the rich, high-fidelity, dynamic process representation supports detailed measurement at the level of the *organizational microprocess* (Nissen 1994). This unit of analysis provides a context-specific view into the workings of alternative process designs with particular emphasis on *how* IT implementations affect the manner in which work is performed.

In the next section, we discuss the predominant approaches toward IT valuation and then describe virtual process measurement in considerable detail. Section 4 includes two examples of this methodology applied to an important process captured from the field. The paper closes with a set of conclusions and some possible directions for continued research.

2. IT VALUATION

The predominant approaches to the valuation of IT can be classified in four major categories: 1) financial, 2) functional, 3) strategic, and 4) subjective. Table 1 provides a summary of the key strengths and weaknesses of each to provide a backdrop for discussion of virtual process measurement.

2.1 Financial Measures

Financial measures can be effectively employed to quantify *tangible costs and benefits* associated with IT investments. These approaches can be found in standard finance textbooks (e.g., Welsch and Anthony 1977) and also include the time-based measures employed in the practice of industrial engineering (Barnes 1980). Use of financial measures requires dollar-denominated measurement of costs and benefits, generally in terms of cost and revenue streams over time. These approaches have the advantage of precision supported by quantitative measures and their strong theoretical basis supports unambiguous decision rules regarding investment. Examples include net present value (NPV), internal rate of return (IRR), and payback period.

The fundamental limitation of financial measures derives from their (time- and) dollar-denominated, quantitative nature: many important costs and benefits associated with IT investments are qualitative, intangible, and difficult or impossible to measure quantitatively. Such limitation is very well recognized in the field of artificial intelligence (AI) (Rich and Knight 1991), in which powerful symbolic representational techniques are employed to obviate this problem.

2.2 Functional Measures

Functional measures were developed in the context of information systems analysis and design, in which the objective was to estimate the complexity of an IS early in the systems development life cycle (SDLC). Such measures directly address IS costs associated with software engineering (SE). Examples include function point analysis (Albrecht and Gaffney 1983; Dreger 1989), which represents a systematic approach to estimating source lines of code (SLOC), the McCabe Measure of IS complexity, and *COCOMO* (Boehm 1981), which entails the use of a multivariate statistical model to estimate SE costs.

Although these measures address SE *costs*, they do not address the important dimension of *benefits*. This represents a fundamental limitation of methods in this class. Moreover, these functional measures focus only upon *software engineering*; hence, they ignore costs for hardware and the potentially huge costs associated with implementation, training, and usage are left unaddressed.

2.3 Strategic Measures

A number of publications have addressed IS strategy and *strategic information systems* (Henderson and Venkatraman 1993; Kambil, Henderson and Mohsenzadeh 1993; Konsynski 1993; Porter and Millar 1985; Westland 1993; Wiseman 1988), the latter of which entail IS used to shape or enable a firm's business strategy; hence, strategic IS are described in terms of a unique class of importance (Wiseman 1988, p. 18). The key argument is that the precise costs and benefits of strategic IS are relatively unimportant, certainly when the IS affords a company the opportunity to dominate a competitive arena or is required for a firm's survival. A number of consultants begin with the assumption that an IS is indispensable (and, hence, must be developed). Examples include using the competitive forces model (Porter and Millar 1985) to change the nature of competition for a firm (e.g., by raising IT-enabled barriers to entry) or the theory of strategic thrusts (Wiseman 1988) to outline IT-based means for achieving competitive advantage (e.g., through product differentiation, innovation, or competitive alliance).

Table 1. Key Strengths and Weaknesses

	Strengths	Weaknesses
Financial	Quantify tangible costs and benefits Precise, accurate measures Theoretical decision rules	Poor at qualitative concepts Poor at addressing intangibles Limited to "dollarized" variables
Functional	Assess costs early in SDLC Facilitate software engineering	Do not address benefits Limited to software engineering costs
Strategic	Focus upon competitive advantage Align IS with business strategy	Competitive advantage not sustainable Do not address fundamental economics
Subjective	Focus upon lean, responsive process Focus upon managing risk Focus upon value added	How to measure? How to relate to IT investments?

However, cases like the computerized airline reservation systems (Hopper et al. 1994) suggest that IT-enabled competitive advantages may not be sustainable. Once a competitive advantage has been mitigated, strategic IS lose some of their special status and importance and the fundamental economics of cost versus benefit and risk versus return are re-imposed as key determinants of IT value.

2.4 Subjective Measures

The Subjective Measures category represents something of a "catchall" for techniques not addressed in the categories above, many of which have been proposed in the trade literature. For example, the chief information officer (CIO) of a major U.S. corporation adduced, "When IT is seen as part of the process of making organizations leaner and more responsive to the marketplace, the issue of placing a dollar value on systems starts to become irrelevant" (Freedman 1990, p. 35). In a related example, an IT consultant suggests that "managing risk" represents the key to effective IT investment. Additionally, much has been written regarding the necessity of valuation within the rubric of Total Quality Management (TQM), with its emphasis on value added (Flood 1993; Hoffherr, Moran and Nadler 1994). However, a critical question remains without answer: How does one measure aspects such as "leanness," "responsiveness," "risk," "value added," and other qualitative concepts in a manner that captures the contribution from investment in IT?

Virtual process measurement provides an approach to measuring some of these concepts and has been developed to help overcome the limitations inherent in the approaches summarized above. From the weaknesses identified in Table 1, we propose that VPM should minimally address seven measurement issues: 1) non-"dollarized" variables, 2) qualitative concepts, 3) intangibles, 4) IT-related benefits as well as costs, 5) organizational costs above software engineering, 6) fundamental economics, and 7) a measurement procedure. We shall see that VPM addresses a number of issues beyond this minimal set.

3 VIRTUAL PROCESS MEASUREMENT

It is important to note that virtual process measurement has been developed as a *complement* to the ensemble of measurement approaches currently available. Hence the objective is to augment the portfolio of capabilities supported at present with a methodology that addresses the weaknesses inherent therein. Our discussion of VPM follows each of the three elements in the term: 1) virtual, 2) process, and 3) measurement.

3.1 Virtual

The term *virtual* is commonly used to describe phenomena or effects that exist or occur in or through the computer. For example, the concept of the *virtual organization* (Hammer and Champy 1993, p. 67; Schroth and Mui 1991) represents computer-supported communication, coordination, and processing sufficient to enable an "organization" of workers to function, without the necessity of collocation or even belonging to a common organizational entity (e.g., firm, department, workgroup); thus the "organization" exists virtually, although its output could be indistinguishable from that of its corporeal counterpart. Similarly, the concept of the *virtual marketplace* (Malone, Yates and Benjamin 1987) represents computer-supported information, communication, and commitment/transaction processing sufficient to enable buyers and sellers to conduct commerce without meeting personally or requiring a physical marketplace (e.g., store, market, stock exchange); thus the "marketplace" exists virtually, although the economic transactions may be indistinguishable from those of other market modes.

In our present context, the concept of *virtual IT valuation* represents computer-supported representations, simulations, and visualizations of the effects produced by IT in the organizational context (e.g., decreased cost, improved quality, shorter cycle time) without actually introducing the IT into the processes of an ongoing organizational concern (e.g., corporation, government agency, military unit); thus the "IT valuation" is assessed virtually, although the measurements used for assessment could be indistinguishable from those obtained from ongoing organizations in the field.

The key to virtual IT valuation is consistency between the behavior of a computer-based process representation and its ongoing organizational counterpart in the field. Representational validation is central to AI, through which a number of effective techniques have been developed. For example, logic can be employed to verify that the represented process is internally consistent and possible given the set of organizational constraints corresponding to the process in the field. Additionally, the representation can be validated against its real-world counterpart by ensuring that the number of organizational agents, their roles, task assignments, tools, coordinative structures, work environment, and like attributes match. Further, simulation can be employed to validate the dynamic behavior of the represented process — for example, to ensure that the time required for agents to perform tasks, the number and types of agents required to perform these tasks, the throughput and quality of products/services through the process, and like attributes are consistent between the real process and its virtual counterpart. Finally, visualization can be employed to provide process experts with the means to witness the mechanics of represented processes and with sufficient fidelity to make detailed comparisons with observable process mechanics in the field.

A number of advantages accrue from virtual IT valuation. For example, the operations of an ongoing organization do not need to be interrupted while the IT-valuation effort is being conducted. Additionally, a wide diversity of (good and bad) processes can be examined virtually, without the requirement to physically implement or pilot the process changes in the field organization. Further, because of the time compression enabled by simulation (Senge 1990) a very large number of alternative process designs can be observed and evaluated in a relatively short period of time (i.e., much shorter than the cycle time required for the process in the field). Moreover, process operations can be replicated again and again via computer, whereas each "live" process instance is unique in some regard (e.g., time sequence, exogenous factors, measurement error). Finally, related to replication, experimental controls can be imposed upon the study of a virtual process: through computer support, the experimenter can selectively modify one variable at a time, as well as variables in any combination, to observe and measure the effects on performance of the represented organization. Together these advantages enable IT valuation imbued with high internal validity (through experimental controls) while simultaneously preserving the external validity of the represented process. No existing valuation approach offers such important advantages.

3.2 Process

The process represents a key element of VPM. With this approach, the value of IT is assessed by measuring the impact of a proposed investment in IT on the affected organizational processes. The term *process* has been defined by Hammer and Champy (1993, p. 35) as "a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer." Viewing a process systems-theoretically (Von Bertalanffy 1968) it can also be described in terms of inputs, outputs, a boundary, transfer function, and mission or goal. This facilitates a number of representational economies, for nearly every organizational process can be represented via this systems scheme, and "families" of reusable process models can be organized through object-oriented meta-models (Mi and Scacchi 1993).

Processes are necessarily cross-functional (Hammer 1990) and dynamic Davenport 1993, p. 6), so they provide a rich representation of organizational operations; that is, not only do they describe *who* (e.g., organizational agent/role) does *what* (e.g., organizational activities/tasks), but also *how* (e.g., with which kinds of tools and communication modes) this work is accomplished and *when* the various agents, tasks, and tools come together to add value. Additionally, the process represents the central unit of analysis for *business process reengineering* (BPR) (Hall, Rosenthal and Wade 1993), for which IT represents a key enabling technology (Davenport 1993, p. 37).

Additionally, the systems-process scheme supports high-fidelity computer representation (Gasser, et al. 1993) because very detailed process models can be represented through *attributed directed graphs* (A-digraphs); the A-digraph constitutes the fundamental data structure employed in support of VPM, for not only can it be used to link process inputs and outputs through value creation, but it can also be used to capture the rich organizational details associated with the process task environment. Using the A-digraph for process representation affords several key advantages.

First, many important qualitative and intangible concepts associated with modeled processes can be represented symbolically, defined with rigor Nissen 1994), and analyzed through *qualitative simulation* (Weld and de Kleer 1990). Additionally, graph theory provides a powerful set of mathematics to support systematic analysis and reliable measurement of organizational processes. Further, embedding the A-digraph process representation within a knowledge-based system (KBS) enables measurements and analyses to be performed automatically; not only does this support the VPM methodology, but it also represents a step toward reengineering the process of reengineering itself.

3.3 Measurement

The direct or *fundamental* measures have been developed through the procedure of *extension* (Roberts 1979). This enables measures to be defined with sufficient rigor, and measurements to be obtained with sufficient precision, to support the use of *ratio scales* in our measurement methodology. Ratio scales are very desirable in terms of their information content and inferential power, but are generally quite difficult to obtain in the social sciences (Kranz, et al. 1971).

Process measures can be conveniently classified according to three categories: 1) static, 2) dynamic, and 3) improvement. Static attributes include direct measures such as length, breadth, IT-based processes/communications, organizational handoffs, and others, in addition to a number of derived metrics such as parallelism, bushiness, IT-processing/communication density, and Value Chain fraction, among many others. These measures have the advantage of being *domain independent*, in that any process can be described in terms of such metrics and compared with other (even cross-industry) processes.

Similarly, dynamic attributes can be defined and measured directly through computer simulation. For example, the cost, cycle time, throughput, quality, and other dynamic constructs can be simulated and measured at any level of detail in a represented process. Such measurements support performance comparisons between alternative process designs, which can include, for example, the specific incorporation of an IT investment under consideration.

A number of improvement attributes are being developed for incorporation into VPM. One use of improvement attributes would be to represent the time-based derivatives of their dynamic counterparts (e.g., cycle time *improvement*, cost *reduction*, risk *mitigation*). Quantum improvement measures have been employed to gage the degree to which a reengineering proposal is "radical" (Hammer and Champy 1993) (e.g., 100% cycle time improvement) and continuous improvement measures such as learning curves (Wright 1936) can be used to capture an important dimension of organizational learning (Epple, Argote and Devadas 1991); additionally, improvement attributes such as process *adaptability, flexibility*, and *repairability* provide the opportunity to represent an organization's *potential* for improvement, deemed to be important in today's competitive environment (Stalk and Hout 1990). Work on improvement measures is just beginning, but the static and dynamic measures are relatively well-established and play a key role in the VPM methodology developed and employed to date.

3.4 Summary

To summarize, the approach of virtual process measurement includes a methodology for the representation, simulation, and visualization of organizational processes in terms of static, dynamic, and improvement attributes that are domain-independent and which can be measured with rigor and precision. This methodology approaches the task of IT valuation through comparison: the performance of a validated, high-fidelity model of a real process in the field is measured with respect to any number of modified processes that reflect implementation of various IT investments under consideration. Differences are attributed to the IT investments, and IT value is assessed on the basis of organizational process performance. As such, VPM can be used to complement other available IT-valuation methods.

Table 2 provides a summary of the weaknesses identified above for current valuation methods and the manner in which VPM addresses their limitations.

Provided that the structure and behavior of an organizational process model is consistent with that of the represented process in the field (consistency which is ensured through model validation), VPM can be employed to effectively address the deficiencies identified above for current IT-valuation methods. This approach not only extends our capabilities for valuing IT, but it provides a rich, high-fidelity model of the organization and its processes, which can be used for reengineering, training, process documentation, and a number of other purposes.

Table 2. Issues Addressed through VPM

Issue	VPM Approach
Non-"dollarized" variables	Model variables not limited to dollars
Qualitative concepts	Symbolic modeling supports qualitative concepts. Qualitative simulation projects behavior of qualitative characteristics
Intangibles	Qualitative variables can represent intangible costs and benefits AI techniques enable inference regarding intangibles Detailed process models can be visualized for intangible aspects
IT-related benefits	Multidimensional performance benefits are projected through simulation Benefits such as process simplicity and improvement can be assessed
Costs above software	Process models address agents, organizations, tasks, tools, and communications related to process performance, not just software
Fundamental economics	Costs and benefits can be measured Elements of risk and return can be assessed VPM output can support analysis by other valuation methods
Measurement procedure	VPM obtains measurements from process models Process models are validated against processes in the field Process measurements are calibrated against field processes

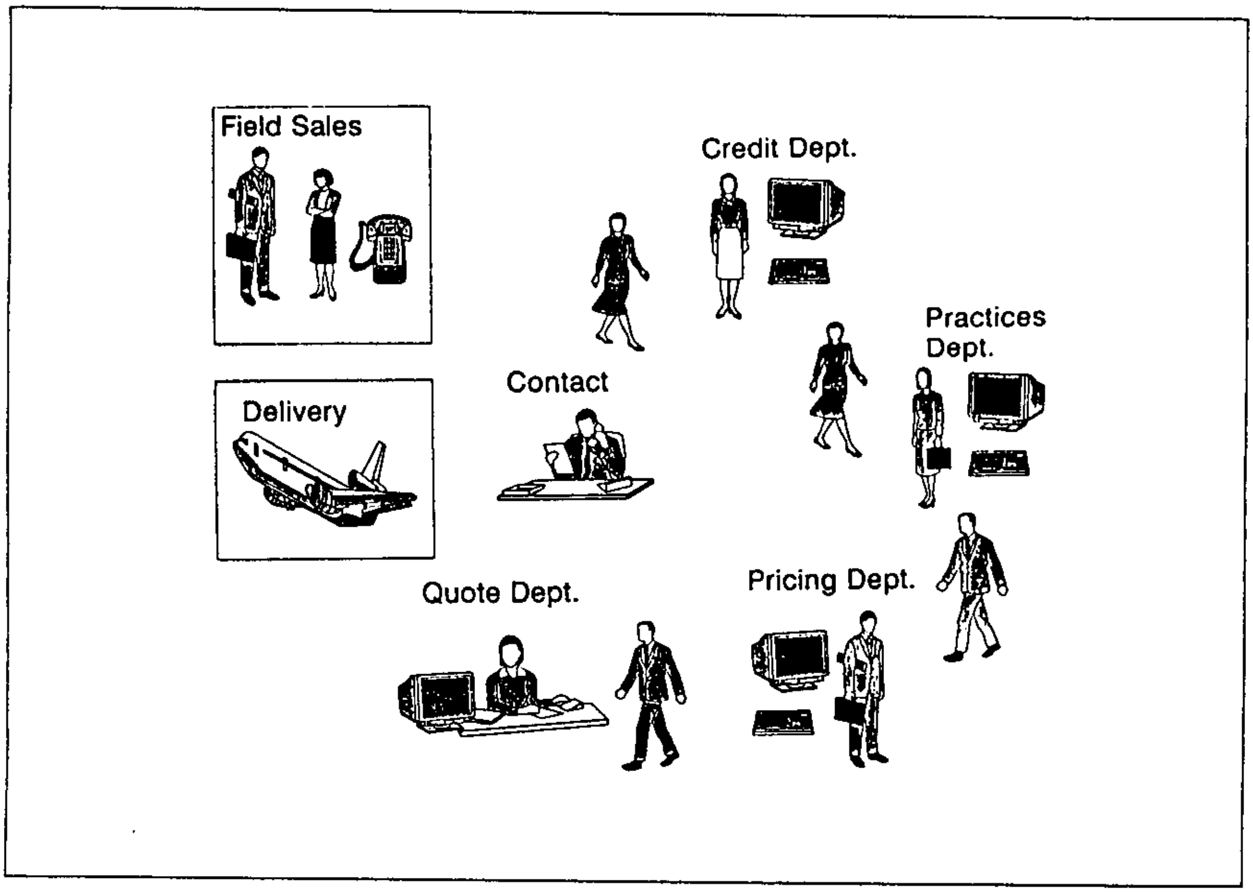

Figure 1. Rich Pictures Representation — Baseline

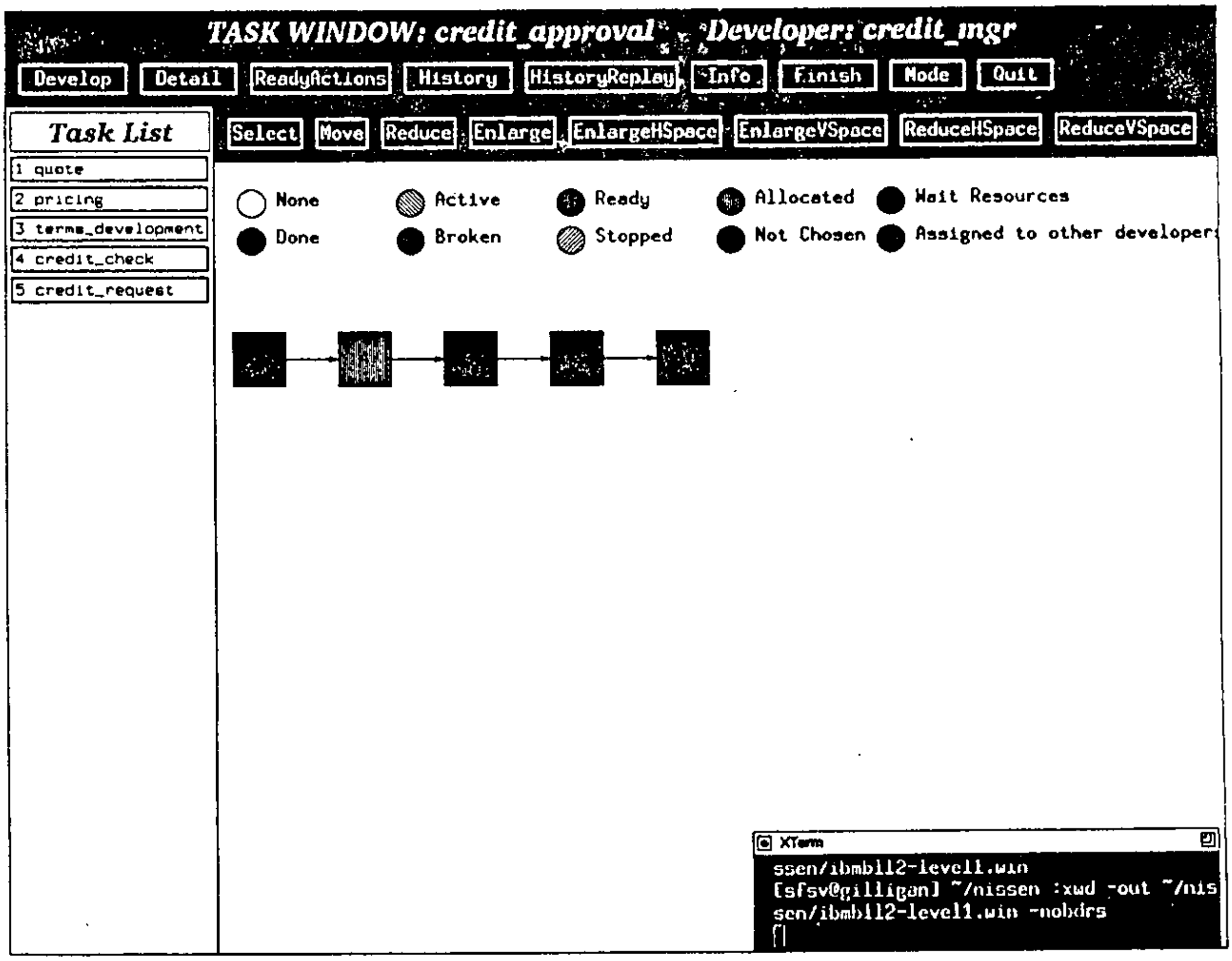

Figure 2. Attributed Diagraph Representation — Baseline

4. MEASUREMENT EXAMPLE

This example is taken from the order fulfillment process of a major U.S. corporation and focuses upon the specific sub-process of credit approval, which represents a key element of order fulfillment for many companies; a similar case is discussed in Hammer and Champy (1993, pp. 36-39) in a reengineering context, which serves to highlight the close coupling of IT valuation and reengineering. However, the purpose of this example is to explicate VPM, not to discuss an exemplar of "radical" reengineering.

4.1 The Credit Approval Process

Figure 1 presents a *rich pictures* (Davies and Ledington 1991) view of the baseline credit approval process. A field sales representative with a new customer lead contacts the credit approval organization by telephone to request a credit proposal for the potential customer; the relevant customer and sale information is written down by a contact person in the credit organization, who then carries the information to the Credit Department. Four primary departments participate in the credit approval process: 1) Credit, 2) Practices, 3) Pricing, and 4) Quote Agents from each department perform the credit check, terms development, payment calculation, and proposal preparation activities serially. From the rich pictures representation, notice the isolated presence and usage of IT in each department and note that all communication is accomplished via telephone and paper. Notice also that a third party is contracted for delivery. In this baseline case, work within each department must be approved by the department manager before being sent to the subsequent department for processing. This model captures the "command and control" behavior exhibited in many organizations.

4.2 Representation

The first step required for virtual process measurement is to represent a process via A-digraph. A level-1 schema is presented in Figure 2. This schema indicates that the baseline level-1 process is comprised of five tasks, which are represented as process-activity nodes connected by task-precedence edges. Attached to this digraph (but not shown) are a number of relevant attributes associated with this process, including the *organization* (credit approval in this case), *role* (agent specialty or job description), *processing mode* (tools used for accomplishing work), *communication mode* (method of communication), and *Value Chain*.

In Figure 3, we present the sequence of level-2 activities for the *quote* task from above. Notice the feedback loop which captures an aspect of output quality: unless the *quote_letter* reflects acceptable quality, this task chain must be repeated until quality meets the modeled threshold. Elements of quality are determined during the modeling process and quality checks are performed dynamically during simulation.

4.3 Measurements and Redesign

Measurements. Table 3 presents descriptions of some static measures that can be applied to the baseline credit approval process, along with the direct measurements that were obtained from the level-2 process schemata.

These direct measurements provide some summary information regarding the baseline process and also provide the basis for a set of derived measures, some of which are listed in Table 4. The derived measurements provide additional static information and are useful to generate process redesign heuristics. A selection of process measurements and heuristics generated for the baseline process is presented in Table 5 and discussed below.

First, the *parallelism* measurement of 1.00 indicates that the process is entirely sequential; heuristically, this suggests the

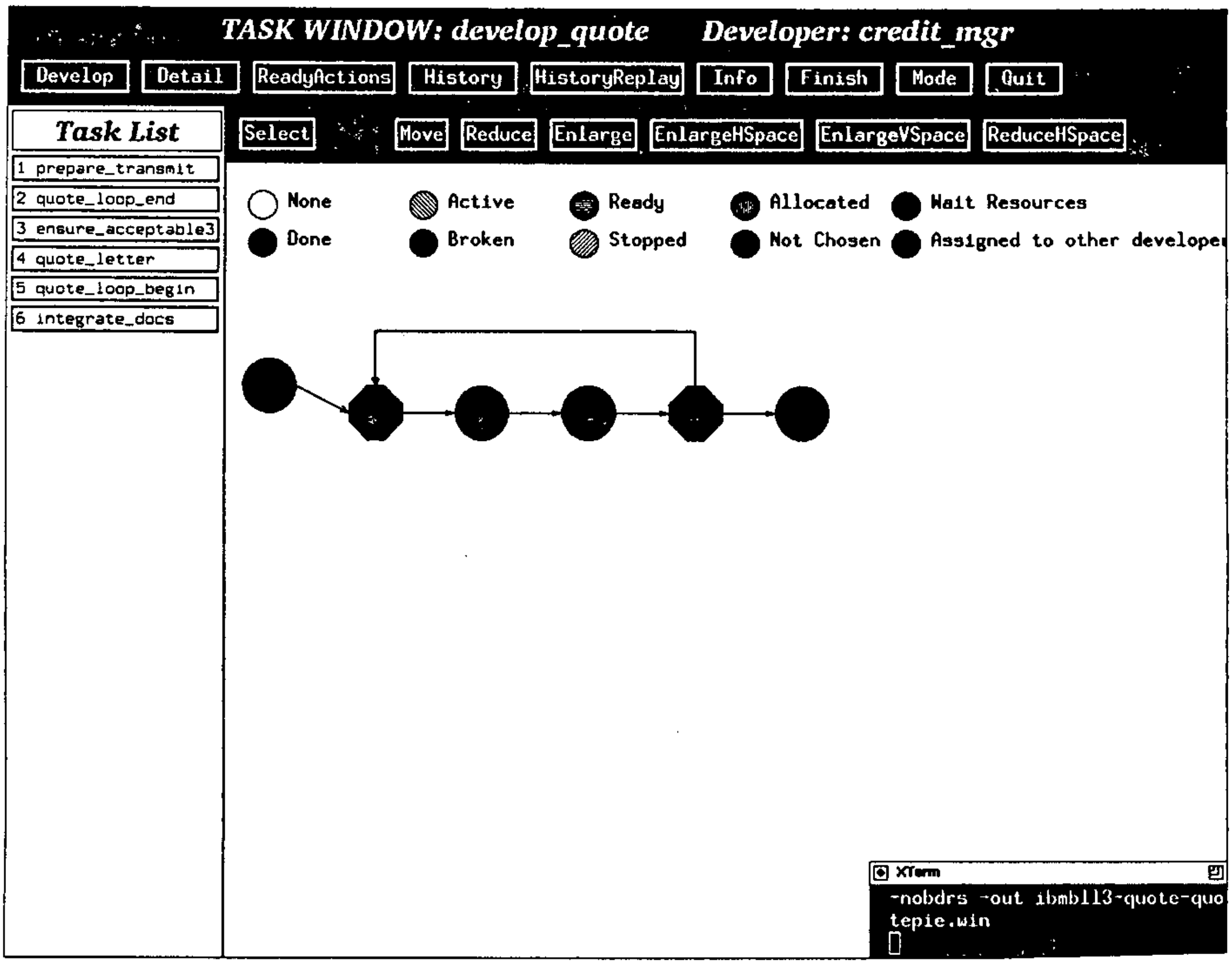

Figure 3. Level-2 Representation — Quote Task

Table 3. Static Process Measures (Direct)

Measure	Calculation	Base
Steps	Total number of nodes	24
Length	Nodes in longest path	24
Leaves	Number of automatic activities	18
Levels	Levels of decomposition	2
Breadth	Distinct paths	1
Handoffs	Organizational traverses	6
IT Activities (IT-A)	Processing steps supported by IT	7
IT Communications (IT-C)	Communications supported by IT	0
Value Chains (VCs)	Value Chain traverses	3

Table 4. Static Proces Measures (Derived)

Measure	Calculation	Base
Parallelism	Steps divided by length	1.00
Bushiness	Breadth divided by length	0.04
Handoff Fraction	Handoffs normalized by steps	0.25
IT-A Fraction	IT-A normalized by steps	0.29
IT-C Fraction	IT-C normalized by steps	0.00
VC Fraction	VCs normalized by steps	0.13
Footprint	Levels multipled by leaves	36

Table 5. Measurement-Based Redesign Heuristics

Measure	Value	Redesign Heuristic
Parallelism	1.00	Parallel processing of tasks
Handoff Fraction	0.25	Case manager/team or empowerment
IT-A Fraction	0.29	IT tools to support tasks
IT-C Fraction	0.00	IT tools for communication
VC Fraction	0.13	Forward or backward integration

possibility of reconfiguring the workflow so that one or more of these steps are processed in parallel, as opposed to serially. Second, the *handoff fraction* measurement of 0.25 indicates that the process is highly-departmentalized; heuristically, this suggests the possibility of employing a *case manager* (Hammer and Champy 1993, p. 36) or *case team* (Davenport 1993, p. 97) approach, or *empowerment* can also be instituted to decentralize and accelerate decision making (Stohr and Konsynski 1992). Third, the values for *IT-A fraction* and *IT-C fraction* indicate that the IT density of the process is relatively low; heuristically, this suggests that one or more process activities and communications may be better accomplished with IT support. Finally, the measured *Value Chain fraction* indicates considerable complexity in the *Value Stream*, as three separate Value Chains are involved in this relatively small process; heuristically, this suggests that forward or backward integration may be used to eliminate one or more Value Chain interface.

Redesign. For our first process redesign alternative, we hypothesized that three of the level-1 activities could be performed in parallel, so the tasks assigned to specialists in Credit, Practices, and Pricing are conducted concurrently. Further, an IT investment is made to couple the separate IT systems through an integrated database and enable work to flow electronically through the four departments. Additionally, some empowerment is introduced so that work can flow between departments without *managerial* approval, provided that it meets quality requirements. This reflects a process redesign that does not require changes to the organization chart. We refer to this alternative as "Redesign-1."

For our second process redesign alternative, which we refer to as "Redesign-2," we extended the process design from above by making an additional investment in IT-supported processing and communication in the field. This enables the field sales representative to contact the credit organization electronically, as well as to view the status of proposal requests as they move through the process. Electronic communication also enables forward integration of the delivery task as electronic communication obviates the need for a third party.

Figure 4 illustrates the rich pictures representation of Redesign-2 for comparison with the baseline and Figure 5 serves to delineate the redesigned (level-1) workflow configuration; notice that the process design is now visibly shorter.

4.4 IT Valuation

To determine the value of these IT investments, we need to compare the process *before* IT implementation with its post-redesign counterparts. Table 6 provides a comparison of some key static measurements obtained from the three process designs. The reader can see that both redesigned processes are smaller, shorter, and involve fewer steps (i.e., simpler); Redesign-2 also reflects the forward integration of a Value Chain. Notice that both redesigned processes reflect greater parallelism and have much higher IT densities in terms of both activities and communications. Results such as these (e.g., process size, simplicity, forward integration, parallelism, IT density) reflect some of the intangible benefits deriving from the IT investments; other,

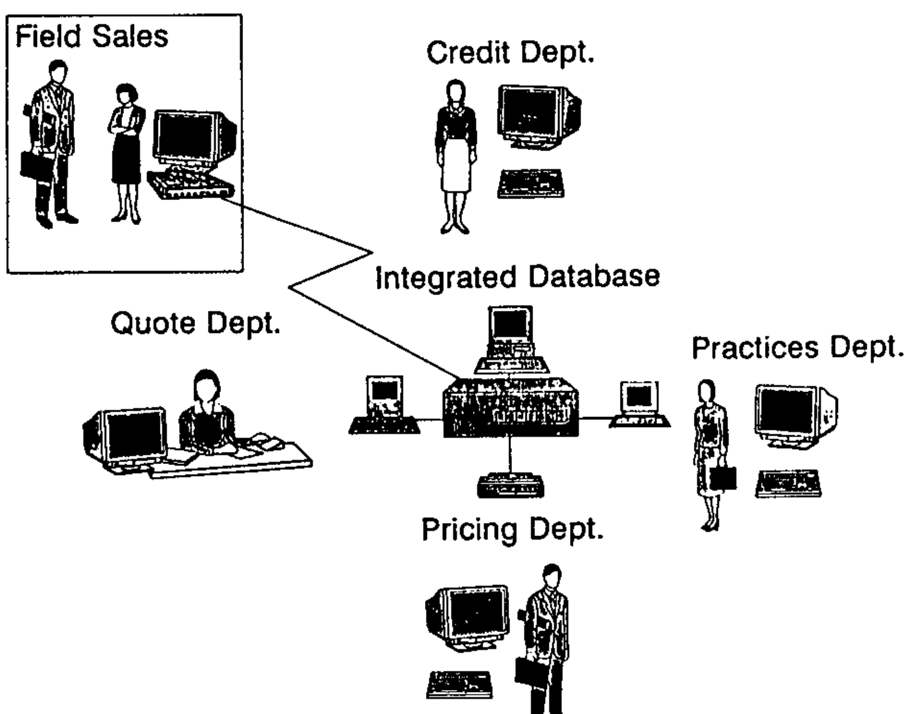

Figure 4. Rich Pictures Representation — Redesign 2

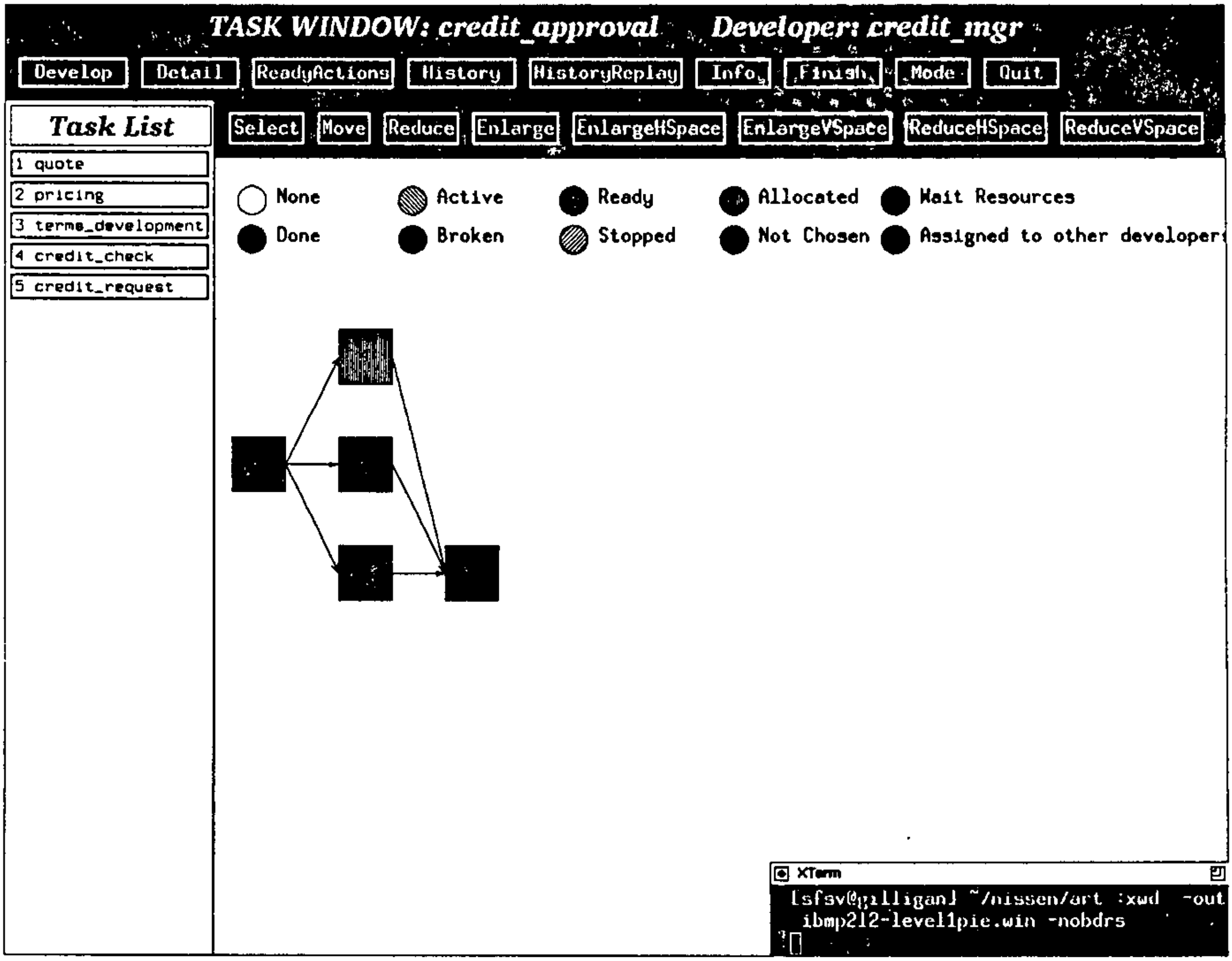

Figure 5. Attributed Digraph Representation — Redesign-2

Table 6. Comparative Static Measures

Measure	Baseline	Redesign 1	Redesign 2
Steps	24	18	17
Length	24	14	13
Footprint	36	24	22
Breadth	1	3	3
Value Chains	3	3	2
Parallelism	1.00	1.29	1.31
IT-A Fraction	0.29	0.72	0.88
IT-C Fraction	0.00	0.44	0.59

Table 7. Comparative Dynamic Measures

Measure	Baseline	Redesign 1	Redesign 2
Agent Cost	18	12	11
IT Cost	9	21	25
Overhead Cost	27	6	5
Supplier Cost	1	1	0
Cycle Time	27	17	15
Communications	19	17	5
Risk	9	15	17
Throughput			

Table 8. Quantum Improvement Measures

Measure	Baseline	Redesign 1	Redesign 2
Total Cost	27%	25%	-3%
Cycle Time	37%	44%	12%
Communications Risk	11%	74%	88%

more tangible benefits like dynamic performance improvements were projected and measured through simulation.

Table 7 provides a comparison of some key dynamic measurements obtained from the three process designs. In the qualitative simulations, token resource units were projected through the modeled process to measure various performance categories, including cost, cycle time, throughput, and risk. Qualitative simulation is powerful, because it supports dynamic process measurement with minimal information, and it can be conducted at a very early stage of process understanding and redesign. However, unlike the ratio scales supported by the static measures above, qualitative simulations used to obtain these dynamic measurements support only *ordinal* relations between process design alternatives. Although ordinal relations are not as powerful as their ratio counterparts (Roberts 1979), they provide for useful comparisons and interesting results.

One interesting result can be seen regarding the tradeoff between the costs of agents ("Agent Cost") and those associated with investments in IT ("IT Cost"). This tradeoff represents the known economic phenomenon of *labor-capital substitution* (Douglas 1983) and its simulation signifies the kind of high-fidelity process models supporting VPM. Also, differences in (allocated) overhead cost reflect the shorter cycle times and higher throughput rates of the redesigned processes: shorter process cycle times decrease period costs per cycle and higher throughput rates increase the volume of output used for allocation. This result is consistent with measurements obtained through most accounting systems in practice.

Another interesting result pertains to communications risk. This measure captures the management heuristics that telephone communications are more error-prone, and paper-based disseminations are harder to keep current, than those conducted through electronic media. Notice that the hybrid of electronic communications and telephone/paper-based systems in Redesign-1 barely affected communications risk, even though they contributed toward substantial improvements in cost, cycle time, and output. Simulation of this risk-return relationship indicates another aspect of the IT-valuation problem that is difficult to explore through existing valuation methods.

Many additional measures, results, and comparisons would be required to use VPM for IT valuation in practice, but the IT investments assessed in this section should suffice to convey the use and utility of VPM, along with its potential to complement extant IT-valuation methods. Table 8 summarizes a few quantum improvement measurements obtained from these examples; the "Redesign 2M" column reflects *marginal* improvements over Redesign-1.

5. CONCLUSIONS

Through our discussion of virtual process measurement, and the examples above, a number of conclusions can be drawn and several opportunities for future research emerge. First, using VPM, we were able to analyze and compare a number of alternative process designs, each reflecting a different level of investment in IT. We were able to assess the relative, multidimensional value of IT across the various designs, in a manner that overcame the limitations of current valuation methods. This satisfies the primary objective of the present research effort. However, continued research will be required to determine the relative efficacy of various measurement constructs, to extend static and dynamic measures to capture domain-specific factors, to define and test improvement metrics, and to validate that virtual process measures are consistent with measures obtained directly from ongoing processes in the field.

Second, we were able to see how IT valuation and VPM are closely coupled with reengineering. For example, our static measurements were employed to conceive of the IT investments and redesign alternatives examined above. This measurement-based approach to redesign has the potential to introduce a considerable amount of *engineering* into the process of "reengineering." Additional research can be conducted to develop a theoretical framework for process redesign, say in terms of a process-transformation model, and to test such a model in both laboratory and field environments. Research oriented toward the automation of the redesign process is already underway in the laboratory, but the use and evaluation of this knowledge-based engineering methodology in practice will be indispensable.

Finally, the measures and examples from above have an apparent internal focus, as they are oriented primarily toward efficiency as opposed to effectiveness. However, nothing associated with the VPM methodology, KBS, or other support tools precludes the modeling and simulation of *competitive arenas*, for example, which could be employed to measure and assess the effects of alternative IT investments *and strategies*. Basic research into issues such as the representational ontology, units of analysis, and epistemology associated with such use of VPM is only now being contemplated. These questions suggest a number of opportunities for continued research along the lines discussed in this paper.

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