An Ontology-Based Dynamic Enterprise Model for Managerial Planning and Control

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ABSTRACT: In this paper we propose an ontology-based dynamic enterprise model to facilitate managerial control. Management control systems serve to implement enterprise strategies, and formal management control systems typically include strategic planning, budgeting, performance measurement, and performance evaluation processes (Anthony and Govindarajan 2004). We focus on the portion of the process wherein managers assess complex business environments, changing competitive forces and uncertain futures, and then make significant resource allocation decisions. Managers often rely on traditional capital budgeting techniques, such as discounted cash flow or internal rate of return models, in making these resource allocation decisions (e.g., Accola 1994, Adams et al. 2004). Critics argue, however, that such techniques fail to consider non-linear relationships, discontinuities, and uncertainty (e.g., Accola 1994, Boquist et al. 1998). System dynamics provides an alternative approach that specifically considers business complexities and uncertainties. Since Forrester (1956), system dynamics methods have been extensively applied to business problems, but to our knowledge, there is no general system dynamics model of integrated business processes to support business strategy (see Warren 2005). We therefore propose the use of system dynamics models based on an established enterprise domain ontology to facilitate reuse of and learning from these models in a variety of business contexts. An enterprise domain ontology, such as the resource-event-agent (REA) framework, supports an integrated and holistic view of enterprise processes and risk factors. Such a view would further the development of dynamic models of enterprise processes that explicitly consider process complexity, non-linear interactions, uncertainty, and the consequences of time delays. An ontology-based dynamic model thus allows managers to better assess the consequences of alternative resource allocation decisions and determine appropriate performance indicators. To illustrate the concepts, we use the REA framework to establish a generic system dynamics model and provide an example of how that model could be used to plan internal control procedures.

Key Words: REA framework; ontology; system dynamics; management control systems; enterprise planning

Data Availability: not applicable.

I. INTRODUCTION

In this paper we propose an ontology-based dynamic enterprise model to facilitate managerial control. The strategic planning process includes two parts: 1) strategy formulation, and 2) strategy implementation (e.g., Anthony 1965; Kaplan and Norton 2004; Anthony and Govindarajan 2004). Management control systems serve to implement enterprise strategies, and formal management control systems typically include strategic planning, budgeting, performance measurement, and performance evaluation processes (Anthony and Govindarajan 2004). We focus on that portion of the management control process commonly termed capital investment analysis or capital budgeting, wherein managers must first assess complex business environments, changing competitive forces and uncertainties, and then make significant resource allocation decisions.

The strategy implementation process results in a set of resource allocation decisions expected to best implement the enterprise's strategy and deliver shareholder value (Anthony and Govindarajan 2004). Kaplan and Norton (1996) argue, however, that traditional management systems create barriers that limit managers' ability to assess the cumulative impact of cross-functional or inter-related investment opportunities. For example, capital investment analysis techniques such as net present value (NPV) or internal rate of return (IRR) typically consider one or a few investments in isolation. Others also argue that traditional capital investment analysis techniques fail to adequately consider risks and uncertainties, and a number of researchers therefore advocate the use of real options techniques to address sources of uncertainty (e.g., Accola 1994; Arya et al. 1998; Childs et al. 1998; Amram and Howe 2002). Yet, advanced quantitative techniques such as real options analyses remain limited in their ability to consider nonlinearities and incorporate qualitative factors (e.g., Drew 2006).

One tool, scenario planning, allows managers to combine information from multiple sources and consider the interactions of alternative investments under uncertainty. Scenario planning combines traditional analytical methods with management judgment and opinion to analyze multiple views and different perspectives on the future Schwartz 1996; Senge 1990). It can include such unstructured approaches as storytelling and strategic conversation. While scenario planning is now widely-used—the Bain and Company 2006 annual management tools survey indicates that over 70% of their respondents report the use of scenario planning[1] for investment decisions—it has been criticized for a lack of rigor (Miller and Waller 2003). Additionally, the process can perpetuate management biases, since there are seldom formal tests of the expected outcomes.

System dynamics offers an approach to capital investment analysis that retains the benefits but overcomes the limitations of scenario planning. System dynamics[2], which originated with Jay Forrester's work at MIT in the 1950s, is the study of complex systems through an examination of system stocks, flows, and feedback loops through computer simulation models. System dynamics methods provide "useful insight into situations of dynamic complexity," especially when experimentation with real systems is impractical or infeasible (Sterman 2000, 39). In conjunction with scenario planning, it provides formal models to evaluate the expected outcomes of relevant investment alternatives and provides a basis for informed management discussion (Warren 2005).

[1] See http://www.bain.com/management_tools/tools_scenario_contingency.asp.

[2] Forrester originally termed these methods "industrial dynamics" as in the title of his 1961 book on the subject.

Although Anthony (1965, 60) noted Forrester's potential contribution to strategic processes over 40 years ago and Senge's (1990) popular management book gave it visibility, system dynamics is still not widely used in enterprise management (Warren 2005).

There are several possible reasons for the limited use of system dynamics tools. Warren (2005) notes that system dynamics in not commonly included in business school curriculums. Consequently, many managers either are not aware of or do not understand the capabilities of system dynamics tools. Furthermore, there are relatively few business consulting firms with the requisite skills to support broad use of system dynamics models for enterprise capital investment planning (Warren 2005).[3]

We argue that another reason that system dynamics tools are not widely used for capital investment analysis is the lack of easily generalizable generic system dynamics models of business processes. As Kaplan and Norton (1996, 2004) describe, managers need to consider the cross-functional impact of the major initiatives to achieve the enterprise's strategic objectives. Change efforts must be directed at enterprise business processes. Thus, any model must be able to describe current business process performance and expected changes in performance over time. Despite the number of academic articles that present system dynamics models (e.g., Gary 2005; Oliva and Sterman 2001; Sterman 1989), to our knowledge no researchers have offered easily generalizable models of business processes with the exception of the supply chain models in Sterman's (2000, Part V) text.

[3] We searched the web sites of the big 4 accounting firms and several major business consulting firms, e.g., Accenture, and found no reference to system dynamics.

The development of appropriate models is a systems design issue, and systems design can be facilitated when there are standard semantic structures for these models (e.g., Geerts and McCarthy 2000a). We propose the use the resource-event-agent (REA) framework as an enterprise domain ontology from which we develop generic system dynamics models of enterprise processes. Ontologies provide a formal specification of the concepts and relationships that can exist for an agent or a community of agents (Gruber 1993). Thus, ontologies enable knowledge sharing and information integration and provide a consistent basis for understanding and communicating domain phenomena. They facilitate what Geerts and McCarthy (2000a) term *augmented intensional reasoning*, which allows the sharing of concepts across functional boundaries and the reuse of those concepts in various applications. An ontology-based approach establishes a standard semantic structure for a dynamic enterprise models and facilitates reuse of these models for capital investment planning in a variety of business contexts.

We select the REA framework as an enterprise domain ontology for several reasons. First, since the REA framework has been published in peer-reviewed accounting journals, it has undergone extensive analysis. It has proven to be a faithful representation of the objects and relationships between those objects that exist in an enterprise accounting context (e.g., McCarthy 1982; Geerts and McCarthy 1999, 2000b, 2002; Dunn et al. 2005). Second, the REA framework supports an integrated view of enterprise processes. Third, recent research extends the REA framework to the broader enterprise domain, effectively modeling both enterprise economic and management activities (e.g., Church and Smith 2007).

We describe how the REA ontology can be used to define a dynamic model[4] of enterprise processes to support enterprise capital investment planning. Business problems are often complex and changing over time. An ontology-based dynamic model addresses the complexities of the planning process but overcomes the limited generalizability of existing system dynamics models. We expect that such a model has broad application for many enterprise planning purposes, as well as broad application for research, which we will outline later. To illustrate the concepts, we describe how to use the REA framework to specify a system dynamics model of business processes. We then provide an example of how that model could be used in a managerial planning system to plan internal controls procedures to comply with section 404 of the Sarbanes-Oxley Act.

We proceed as follows. In the next section, we briefly outline management control processes and the complexities of the business environment. We discuss system dynamics and describe how system dynamics models address the complexities of the business environment. We also describe the benefits of ontologies and the use of the REA framework as an enterprise domain ontology. In section three, we describe how to use the REA framework to develop generic system dynamics models of business processes and how managers would use those models for enterprise capital investment planning purposes. In section four, we provide an example that applies the model to a managerial investment planning in an internal control context. We then conclude and provide recommendations for future research.

II. BACKGROUND ON MANAGEMENT CONTROL SYSTEMS, SYSTEM DYNAMICS, AND THE REA FRAMEWORK

[4] We use the term dynamic model to indicate a model developed with system dynamics methods.

Management control systems and strategic planning

Anthony and Govindarajan (2004) describe management control systems as processes for strategy implementation. Managers make capital investment decisions based on enterprise goals and objectives. They base their plans on the expected impact of their decisions on enterprise performance, while also considering how the changes in external factors, such as the general level of economic activity or the competitive environment, as well as the changes in internal factors, such as process or products, will affect future performance.

Additionally, managers must consider process complexity and uncertainty. For example, projects may not be completed on time, competitors may react to product changes, the general economic conditions may change, and outcomes may depend on synergies delivered by other initiatives. Bounded rationality indicates that managers will not be able to anticipate and consider all the possible ramifications of their plans (Barber et al. 2003). Thus, capital investment planning becomes an iterative process of resource allocation (Noda and Bower 1996). Better planning should result in less iteration and deliver greater shareholder value.

Scenario planning is widely used in capital investment planning to support the development of major resource allocation plans and the communication of these plans to key employees (Winch 1999). Scenario planning combines traditional analytical methods, such as discounted cash flow analyses, with management judgment and opinion to analyze multiple views and different perspectives on the future (Schwartz 1996; Senge 1990). The success of scenario planning depends on the mental models of the participating managers (Senge 1990), but those mental models can be flawed.

Managers can have biased views of business relationships, underestimate the dynamic nature of the business environment, or fail to consider the uncertain consequences of a change. System dynamics provides a powerful tool to overcome potential biases and address the dynamics and uncertainties of the business context. It supports a dynamic view of the business environment and expected scenarios and enables managers to evaluate the expected changes in those environments.

System dynamics

According to Sterman (2000), system dynamics is an interdisciplinary approach to examining complex systems, such as business processes. It uses stock and flow models to simulate the behavior of complex systems over time. It offers tools to represent difficult problems such as those managers face in the capital investment planning process.

Proponents of system dynamics argue that simulation models using these building blocks overcome deficiencies in other planning tools, which often fail to consider feedback, time delays, and nonlinearities (Sterman 2000). Simulation models therefore offer the only practical way to evaluate how conjectured causal relationships might influence the performance of complex, dynamic systems, such as business processes.

Skeptics argue that formal simulation models are constrained by the assumptions upon which they are based (Sterman 2000). However, all planning systems share this problem, and there is an extensive body of literature that indicates that system dynamics modeling provides a rigorous approach that helps managers understand—and improve decisions about—complex business problems when experimentation with real systems is impractical (e.g., Sterman 1989; Oliva and Sterman 2001; Gary 2005, Forrester 1957, 1961, 1968). For example, the journal *System Dynamics Review* publishes peer-reviewed articles on the applications of system dynamics to business and other problems.

Despite the number of academic articles that present system dynamics models, to our knowledge only Sterman's (2000) supply chain models provide easily generalizable models of business processes. We incorporate features of those models in our proposed models. The development of appropriate models is a systems design issue, and systems design can be facilitated when there are standard semantic structures for these models (e.g., Geerts and McCarthy 2000a). We therefore propose the use the resource-event-agent (REA) framework as an enterprise domain ontology from which we develop generic system dynamics models of enterprise processes. Generic, ontology-based, dynamic models of business processes would allow managers to formalize the expected impact of both qualitative and quantitative factors on business process performance. These models could be readily adapted to new investment decisions and changing circumstances over time.

REA Framework as an ontology

Ontologies define the common words and concepts used to describe and represent an area of knowledge (Obrst 2003; Schreiber 2003; Linthicum 2004). Ontological theories impose order on domain phenomena and help us describe the structure of the domain and relations between objects therein (Weber 2003; Zuniga 2001). Thus, ontologies should facilitate the accurate communication of business process events, resources, agents, relationships and management information structures critical to the successful implementation of enterprise systems (Linthicum 2004; Uschold et al. 1997; Weber 2003) by providing the architecture necessary to design effective systems. Systems design ontologies enable what Geerts and McCarthy (2000a) term *augmented intensional reasoning*, which allows the sharing of concepts across functional boundaries and the reuse of those concepts in various applications.

The REA framework depicts business processes in terms of the events and related agents and resources (e.g., McCarthy 1982; Dunn et al. 2005). McCarthy (1982) presents the original REA framework as a general model of “the stock-flow aspects of accounting object systems” by characterizing accounting phenomena in terms of economic events and the associated enterprise resources and agents as shown in Figure 1. *Resources* are defined as things of economic value that are provided or consumed by an enterprise’s activities and operations. *Events* reflect the potential (commitment) or actual increment or decrement of economic resources. *Agents* are the persons, organizations, or organizational units that control or participate in events. Stockflow relationships link resources to events. Participation relationships link the agent to events. The Duality relationship links the non-cash economic event (e.g., sales) with a corresponding cash economic event (e.g., cash receipt).

Through ongoing research in the field of design science, the REA framework has been extended to specify broadly the set of objects and relationships among the objects that exist in the accountability infrastructure for an enterprise domain (Geerts and McCarthy 1999; Church and Smith 2007; Dunn et al. 2005). The REA framework has proven robust to critical analysis for over 25 years. Geerts and McCarthy (1999, 2000b, 2002) argue that the extended REA framework meets the definitions of an enterprise domain ontology; it supports an integrated view of enterprise processes. We therefore chose to use the REA ontology as a blueprint for strategic information architectures and enterprise systems.

III. CONVERTING AN REA MODEL TO A DYNAMIC MODEL

Dynamic model stocks and flows

Stocks and flows are the basic building blocks of dynamic models.[5] Stocks represent accumulations, such as inventory value. Flows represent changes in stocks, such as shipments from inventory or receipts into inventory. Stocks characterize the state of a system at a particular time, and flows characterize the changes in the stocks during any period. The relationship between stocks and flows can be described mathematically:

$$\text{Stock}(t) = \int_{t0}^{t} [Inflow(s) - Outflow(s)]ds + \text{Stock}(t_0) \qquad (1)$$

where Inflow(s) is the value of the inflow and Outflow(s) is the value of the outflow from the stock at any time, s, between the initial time, t_0, and the current time, t.

We employ *iThink* software from ISEE Systems, Inc. Although there are other similar software products, e.g., *Vensim* from Ventana Systems, Inc., the *iThink* product is widely used in system dynamics academic research. We follow the conventions for modeling stocks and flows described in Sterman (2000), Richmond (1997), and *iThink* and *Vensim* tutorials, as shown in Figure 2. Sterman's (2000) text summarizes the system dynamics research over the last five decades.

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[5] See Sterman (2000) for a complete description of stocks and flows in system dynamics modeling.

As described in Figure 2, stocks are represented by rectangles. Inflows are represented by a pipe pointing into a stock. Outflows are represented by a pipe pointing out of a stock. Biflows (flowing either in or out depending on the value of the flow) are represented by pipes pointing both ways. The valves on the pipes regulate flow rates. The clouds at the end of some flow pipes represent sources or sinks for the flows (outside the boundary of the model). The circles represent converters, which define external inputs to the model, calculate algebraic relationships, or hold constants. Converters are linked to valves to determine the flow rates over time, i.e., the *Inflow(s)* and *Outflow(s)* values in Equation (1). The curved arrows, e.g., from converters to flows, connect model elements and indicate that mathematical relationships exist between those elements.

Principles for mapping REA models to dynamic models

We propose rules for converting an REA model to a dynamic model in Figure 3. In developing these rules, we mapped the REA structure to the basic system dynamic building blocks. Unlike REA models, however, dynamic models do not represent detailed transactions; instead they represent summary level data. The dynamic models are therefore similar to other planning tools, such as budgets, while offering the flexibility to investigate complex causal relationships, handle nonlinearities and uncertainties, and plan across multiple periods. Like REA models, they can be integrated across processes via shared resources.

First, we present some basic principles underlying our proposed rules. Stocks represent accumulations and thus model levels information. Flows represent the change in stocks for each time period, and thus model changes information. Sterman (2000,

Table 6-1 and Figure 6-3) gives examples of stocks that represent inventories, balance sheet items, employees, populations, and prices. Flows represent cash flow, income statement items, periodic borrowing, periodic repayments, hire rates, quit rates, and customer order rates. Following Sterman's conventions, we model REA resources and agents as stocks. We model events, such as periodic sales, purchases, cash receipts, and cash disbursements, as flows.

The REA duality and fulfillment relationships denote the timing difference between related events, for example, the duality between sales and related cash receipt events or the fulfillment relationship between customer orders and subsequent sales. Since duality relationships typically represent balance sheet items (e.g., accounts receivable or accounts payable), we propose to model that relationship as a stock.[6]

REA participation relationships take on a different meaning in the dynamic model. In the REA framework, the participation relationship specifies control by identifying the parties to a particular event. In the dynamic model, the link between agent stocks and event flows specifies influence. That link establishes how the level of the stock determines the rate of event flow. For example, the productivity of employees or the customer demand determines sales rates. Thus, both the level of the agent stock, such as number of employees, and the expected influence, such as productivity per employee, help determine the periodic event flow, such as sales per period.

The REA framework incorporates the impact of business policies, process risks, process constraints, or process technology through their impacts on the enterprise accounting records, but it does not necessarily specifically model those factors. For

[6] Although REA Fulfillment relationships do not have corresponding balance sheet items, the purpose of these relationships is similar to that of Duality relationships and the same modeling conventions apply.

example, the delay between sales and subsequent cash receipts results from the enterprise's cash management policies, but those policies are not typically shown in an REA model. To the extent that the capital investment decision depends on those factors, the dynamic model must include them. Since these factors affect rates of change, e.g., the cash management policies affect the cash collection rates, we model business policies, risks, constraints, and technological influences as converters and link those converters to the flows to which the policy applies.

In summary, REA resources, agents, and duality and fulfillment relationships become stocks. REA events and stockflow relationships become inflows and outflows. REA Participation relationships become connectors that link stocks with corresponding inflows and outflows. We overlay that basic pattern with the converters that influence the flows and change the levels of stocks. Thus, the converters become the vehicle for considering alternative investment decisions. The changes in stocks represent the costs and benefits of those decisions.

Creating REA-based dynamic models of business processes

Figure 4 portrays the mapping of an REA model to a dynamic model following the rules described in Figure 3. We use the sales/collection process as an example, as follows:

- The REA resources (inventory and cash) become stocks that represent the accumulated values.
- The REA events (sales and cash receipts) become stock inflows and outflows. Specifically the REA sales event becomes an inflow to the receivables stock and the REA cash receipt event becomes an outflow from

the receivables stock. Note that we assume a traditional model with collections at some point after the sales. The REA cardinalities for the relationship between sales and cash receipt indicate whether the cash is received before or after the sale and would determine the appropriate dynamic model. For the planning model, we are not interested in tracking individual transactions, but rather the rate of sales transactions. In the REA model, the value of receivables can be computed from the transaction detail. In the system dynamics model, we specifically compute the value of receivables by including a stock.

- The REA agents (customers and sales employees) become stocks, because dynamic modeling is interested in the number of customers and employees at any time. We add biflows to model changes in the number of customers and employees over time.[7]
- The REA stockflow-out relationship (between inventory and sales) becomes an outflow from the Inventory stock. The REA stockflow-in relationship (between cash Receipt and cash) becomes an inflow to the Cash stock. These flows represent the periodic changes in the stocks, and they implement the effect of the REA duality relationship on resources.
- The REA duality relationship (between sales and cash receipts) becomes a stock (receivables) to accumulate receivable balances.
- The REA participation relationships (between sales and cash receipts events and corresponding employee and customer agents) become connectors that

[7] Instead of biflows, we could model this with an inflow and a separate outflow. We would separate the two flows if the decision alternative depended on those separate values.

link the stock with the corresponding flows. Specifically the REA employee and customer are linked to the sales inflow by connectors.

- Business policies are represented as converters: the time-to-collect converter describes the expected length of time to collect receivables, and the sales-discount-rate converter describes the expected discount. The customer-demand-factor converter describes expected sales per customer per period. The sales-employee-productivity converter describes the expected sales per employee. Thus, the periodic sales are a function of the number of customers, the demand per customer, the number of employees, and the employee productivity.[8]

The dynamic sales model allows us to establish initial values for stocks and simulate the sales process for a number of periods. We can then examine the effect of assumptions or policies on future performance. For example, we can change the customer demand or employee productivity assumptions and see the effect on inventory or cash. More importantly, we can use this process to create an integrated, dynamic model of business processes and tailor the model to specific business situations.

Figure 5 illustrates a similar system dynamics model for purchase/cash disbursements processes. Figures 6 and 7 present extended sales order event for the sales/cash receipts process that include commitments, i.e., agreements to execute an economic event at a specified future time, which will result in either an increase or decrease of resources. Figure 6 shows the sales order event for the sales/cash receipts process, and Figure 7 shows the purchase order event for the purchase/cash

[8] Other factors may also influence the demand and constrain the business process, but this example represents a generic model, like the basic REA pattern. We will discuss enhancements to the model in section five.

disbursements process. The purchase process creates a stock inflow to the Inventory stock and the sales process creates a stock outflow from the Inventory stock. Cash receipts create stock inflow to the cash stock, and cash disbursements create cash outflows from the cash stock.

IV. EXAMPLE MODEL

Dynamic models of capital investment planning

When managers consider anticipated changes to enterprise processes, they must also consider the hypothetical effect of possible options. By considering multiple options, managers can also evaluate which options deliver the desired benefit at the least cost. Thus, managers need a planning tool with which they can evaluate dynamic changes in cost and benefits.

In this example, we illustrate how the REA ontology can be combined with the procedural elements of system dynamics to produce an model of enterprise processes to support investment planning for Sarbanes-Oxley Section 404 compliance. Business problems, such as capital budgeting, outsourcing, mergers and acquisitions, and regulatory compliance, can be complex and changing over time. Our model provides a theory-based approach to solving situations of dynamic complexity. This example applies the generic model to a specific management planning situation: enterprise risk management in compliance with section 404 of the Sarbanes-Oxley Act (SOA).

Sarbanes-Oxley Act section 404 compliance process

Since compliance with SOA section 404 is an important challenge faced by a large number of managers, we propose an example of how an ontology-based dynamic model could facilitate managers' compliance decision-making. First, we have to understand how managers implement section 404 requirements. A number of accounting firms have issued guidance for managers. In all cases, the guidance follows the Committee on Sponsoring Organizations (COSO) framework. We select the guidance from PricewaterhouseCoopers (PWC) (2004) as our reference, since it is consistent with guidance from the other major accounting firms but more comprehensive.[9]

PWC (2004) provides guidance for "evaluating and testing the design and operational effectiveness of control over financial reporting that will be conducted in the future and (ii) affirm or initiate a reassessment of established work plans or processes." They outline several steps for an effective compliance project. We focus on the steps that require an evaluation of controls and risk at the business process level, the scope and evaluate functions. The four major steps of scoping are as follows (PricewaterhouseCoopers 2004, 9):

1. Identify significant accounts and disclosures by considering Items separately disclosed in the consolidated financial statements, and the materiality at the consolidated financial statement level.
2. Identify business processes and sub-processes and map them to significant accounts and disclosures.
3. Identify the relevant financial statement assertions for each significant account and disclosure.
4. Perform a risk assessment of the business sub-processes.

[9] We compared the following documents from the big 4 accounting firms and others: Deloitte 2004, 2005a, 2005b; Ernst & Young 2005; KPMG 2005; PricewaterhouseCoopers 2004, 2005a, 2005b; Protiviti 2005.

Firms carry out these four steps for every location or business unit that are “individually important” or “financially significant” as defined in the PCAOB’s Auditing Standard No. 2. In other words, firms have to make a risk-based evaluation of internal control for each business process expected to have a material effect on the financial statements. PWC recommends that firms use the most recent annual financial reports, current budgets, or a combination of recent quarterly and annual data to select which processes at which locations to assess. While this recommendation addresses the requirements of the auditing standard, it may not allow managers to react to dynamic changes in business processes and anticipate future risks. PWC goes on to recommend that budget or prior year data should be updated to reflect significant anticipated changes, but they do not offer any systematic way for managers to test and evaluate anticipated changes. Thus, managers need a planning tool with which they can evaluate dynamic changes in process risk.

After determining the scope of SOA compliance efforts, managers must evaluate whether their system of internal controls is suitably designed to prevent or detect misstatements (PricewaterhouseCoopers 2004, 46) by determining if the controls are effective in managing risk. When managers consider anticipated changes, they must therefore also consider the hypothetical effect of possible control options. By considering multiple control options, managers can also evaluate which set of controls provides the desired benefit at the least cost.

A model for planning Sarbanes-Oxley section 404 compliance

We use the sales/cash receipts process to provide an example of how a dynamic model can be used to plan and manage SOA compliance. Development of a complete

SOA compliance model is beyond the scope of this paper and would require modeling across multiple processes. We provide a simplified example for proof of concept.

For section 404 compliance, PWC recommends that managers set priorities based on an assessment of the impact of process risk factors on the possibility of material financial misstatements (PricewaterhouseCoopers 2004, 98-99). Following the PWC recommendations, we select the sales/cash receipts process, because of the substantial effect that this process has on firms' financial statements. To simplify this example, we focus on three basic control objectives 1) sales are accurately recorded, 2) cash collections are accurately recorded, and 3) shipments from inventory are accurately recorded and reflect sales actually made to customers.

The benchmark for this process is the basic Sales/Cash Receipts process model (Figure 4). We add three converters to the model necessary to assess the three basic control objectives: *Risk of Inaccurate Sales Recording*, *Risk of Inaccurate Cash Collections*, and *Risk of Inaccurate or Inappropriate Shipments* as shown in Figure 8. Each converter corresponds to one of the three basic control objectives and represents the likelihood that the control objective will be violated. The values that each of these three converters takes on over time is a function of the five COSO[10] internal control components: control environment, risk assessment, control activities, information and communication, and monitoring. For this example, we model these five components as single converters as shown in Figure 8, although we expect these components to be broken down into appropriate subcomponents in more refined models. For example, the

[10] The PriceWaterhouseCoopers (2004) guide describes the five COSO elements. Recently, COSO specified an ERM framework with eight components. The COSO revision adds additional complexity to the model while distracting from the intent of the simplified example.

Control Environment converter could be a set of converters that describe the influences of organizational culture, enterprise values, the regulatory environment, and so on.

There are several options for modeling the values that each COSO component takes on. For this example, we set the value of each component as a percentage of best practice, i.e., optimal compliance with all objectives for that component. To apply the model to a real business situation, managers would make those determinations based on familiarity with the company, the business unit, the location, and the business process. For this example only, all five components affect each of the three converters that correspond to the three control objectives as shown in Figures 8 and 9. We assume that each component has the same weight. Again, managers would modify these relationships to reflect the real business situation. Finally, the COSO components may affect the converter value if management believes that the level of risk is the most important factor (lower component percentages drives a higher level of risk of misstatement), or they may affect the variance in the converter value if management believes that fluctuations in risk are of particular concern (lower component percentages drives a higher variance in the risk of misstatement). For this example we arbitrarily select the second option for this example; the COSO components affect the variance in the three "Risk" converters.

Table 1 describes the parameters for this example and compares simulation results for this model against the no-risk benchmark model over 20 fiscal quarters using *iThink* software. Table 1 shows the impact of COSO component deficiencies and how those deficiencies might interact in a business process. The difference in recorded sales is less than 3 percent, but the differences in both cash receipts (stockflow in) and inventory shipments (stockflow out) exceeds 5 percent of the benchmark values. The results also show that the assumed 2 percent sales growth rate increases the level of differences, but the random variation in the "Risk" converters sometimes tends to hide the growth. Table 1 therefore provides the results for one alternative. Management could estimate the effect of different investments to decrease specific risks and then run the model again, producing new results. The costs of the specific investments could then be compared against the benchmark (no-risk model) to determine an optimal combination of costs and benefits.

Appendix A presents the initial values and equations for each model. Although *iThink* provides a graphical interface, it also documents the underlying equations and setup values for the model to facilitate validation. For example, Appendix A shows that the Cash stock had an initial value of 0 and the level of Cash at any time t is the level of Cash at time t-1 plus the change in Cash during t (Stockflow_In). The "dt" shown in the equations represents the selected time increment, e.g., hour, day, month, quarter, and year.

In our simplified example we measure the absolute difference between the benchmark and risk models. We assume the risk of recording sales, cash, and inventory accurately will always provide values below the benchmark, but this may not always be the case. It is equally reasonable to model the variance from the target and track the number of times the value exceeds an inappropriate threshold.

Clearly, this sort of information is important to managers in evaluating dynamic changes in process risk and the tradeoff between the costs and benefits of internal control initiatives. For example, the cost of an investment to improve monitoring can be compared to the benefit achieved by improving that COSO component value and thereby reducing the difference between the simulation results and the no-risk benchmark shown in Table 1. Managers can also examine the impact of sales growth on related account values and how sales growth exacerbates the effect of internal control deficiencies. Importantly, although the dynamic model allows managers to quantify the potential impact of decision alternatives, Lyneis (1999) argues that the role of the such models is to extend management debate rather than provide specific answers. The models force managers to make explicit predictions of the impact of alternatives.

V. CONCLUDING REMARKS AND RECOMMENDATIONS FOR FURTHER RESEARCH

We propose an ontology-based dynamic enterprise model to facilitate capital investment planning. Enterprise management control systems require managers to predict future performance in a complex and dynamic business environment. Yet, many enterprises rely heavily on quantitative techniques such as discounted cash flow analysis, which fail to adequately consider uncertainty. Furthermore, projects are often considered in isolation, which fails to adequately consider cross-functional impacts and project synergies.

To overcome the limitations of such quantitative techniques, enterprises also employ scenario planning techniques that incorporate management judgment and opinion. System dynamic models enjoy the advantages of both approaches; they incorporate quantitative analysis augmented by management's qualitative assessments. However, there is little evidence that system dynamics models are heavily used in capital investment planning or other similar circumstances. Although there are several possible reasons for the limited use, we argue that the presence of generic, ontology-based dynamic models of business processes would advance the use of a powerful management tool.

We therefore use the REA framework as an enterprise domain ontology from which we develop a dynamic model of enterprise processes. System dynamics methods allow managers to assess risks and consider and debate the effect of external and internal changes on enterprise process performance. Although system dynamics have been extensively applied to business problems, there is little evidence that any dynamic models of enterprise processes have been based on established ontologies, which limits the reusability of dynamic models. Our approach employs an established ontology, i.e., the REA framework, which facilitates reuse of and learning from these models in a variety of business contexts.

We provide only a few, limited examples of dynamic models. We recommend further research to integrate and expand these models into a complete dynamic model of the firm. Such a model would have broad application to a variety of business problems and support academic research into those problems. We recognize that our dynamic models must be tailored to specific business situations. McCarthy's (1982) basic REA pattern has proven robust. It describes the features of business processes necessary to support accounting systems in a database environment. We argue that REA-based dynamic models provide the basic patterns necessary to support a variety of management planning contexts.

Recommendations for further research

We also suggest that REA-based dynamic models could provide a model of the firm for a variety of research purposes. For example, management accounting research often attempts to address complex, dynamic business phenomena. Advances in management accounting research are constrained by the lack of publicly available data (Zimmerman 2001), the limits of statistical methods (Luft and Shields 2003), and the lack of theory (Ittner and Larcker 2001; Zimmerman 2001). We propose that some of these limitations can be overcome by the appropriate use of technology.

An REA-based model provides a structure or architecture for the enterprise domain using established frameworks, e.g., Porter's (1985) value chain and McCarthy's (1982) resource-event-agent (REA) framework. Through ongoing research in the field of design science, the REA framework has been extended to specify broadly the set of objects and relationships among the objects that exist in the accountability infrastructure for an enterprise domain (Geerts and McCarthy 1999, 2002; Church and Smith 2007). The REA framework also incorporates Porter's value chain and has been extensively analyzed and shown to support an integrated view of enterprise processes necessary to place management accounting issues in context. The REA framework has also been expanded to incorporate interfirm relationships as well as nonfinancial information requirements (Church and Smith 2007).

The approach we describe integrates and expands individual process models into a complete dynamic model of the firm. Such a model would have broad application to a variety of business problems and support academic research into those problems. We recognize that our dynamic models must be tailored to specific business situations, management accounting research questions, as well as behavioral and sociological objects and relationships. Our approach, however, requires that researcher make explicit any assumptions necessary for that tailoring. An REA-based dynamic model of the enterprise therefore provides a potential research tool that can change and grow through continued use.

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APPENDIX A
Initial Values and Equations for the Benchmark and Risk-Assessed Models

BENCHMARK MODEL:

Cash(t) = Cash(t - dt) + (Stockflow_In) * dt
INIT Cash = 0

INFLOWS:
Stockflow_In = Cash_Receipts*(1-Sales_Discount_Rate)
Customers(t) = Customers(t - dt) + (chg_Customers) * dt
INIT Customers = 100

INFLOWS:
chg_Customers = .02*Customers
Inventory(t) = Inventory(t - dt) + (- Stockflow_Out) * dt
INIT Inventory = 50000

OUTFLOWS:
Stockflow_Out = Sales*.75
Receivables(t) = Receivables(t - dt) + (Sales - Cash_Receipts) * dt
INIT Receivables = 1000

INFLOWS:
Sales = MIN(Customers*Customer_Demand__Factor,
Sales_Employees*Sales_Employee__Productivity)
OUTFLOWS:
Cash_Receipts = Receivables/Time_to_Collect
Sales_Employees(t) = Sales_Employees(t - dt) + (chg_Employees) * dt
INIT Sales_Employees = 100

INFLOWS:
chg_Employees = 0
Customer_Demand__Factor = 10
Sales_Discount_Rate = .01
Sales_Employee__Productivity = 15
Time_to_Collect = 1

RISK-ASSESSED MODEL:

Cash(t) = Cash(t - dt) + (Stockflow_In) * dt
INIT Cash = 0

INFLOWS:
Stockflow_In = Cash_Receipts * (1-Sales_Discount_Rate) * (1 -
Risk_of_Innacurate_Cash_Collections)
Customers(t) = Customers(t - dt) + (chg_Customers) * dt
INIT Customers = 100

INFLOWS:

chg_Customers = Customers*.02
Inventory(t) = Inventory(t - dt) + (- Stockflow_Out) * dt
INIT Inventory = 50000

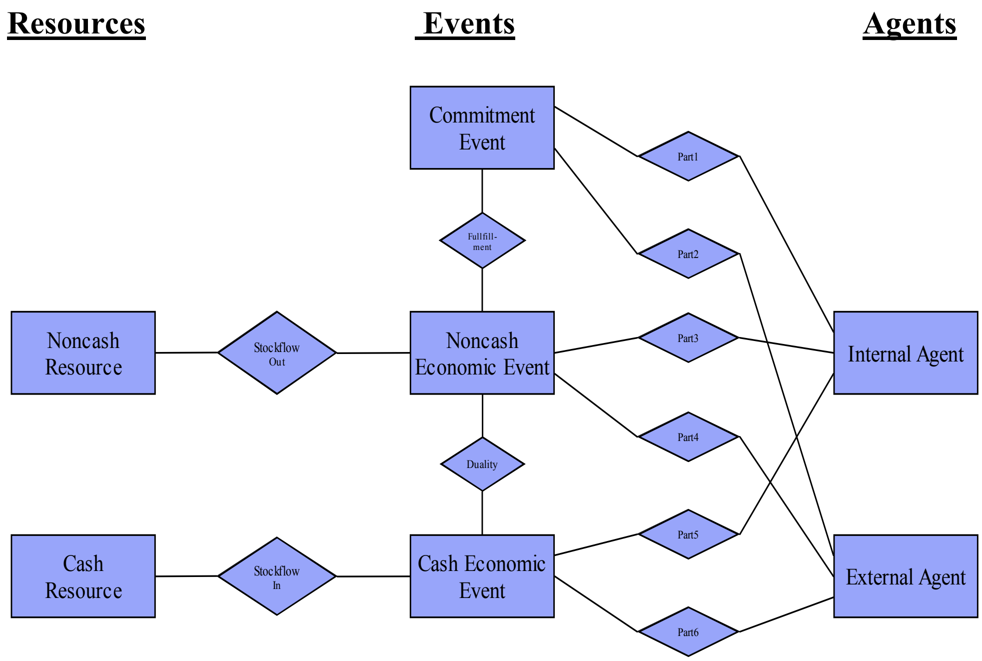
OUTFLOWS:
Stockflow_Out = Sales*(1-Risk_of_Inaccurate_or_Inappropriate_Shipments) * .75
Receivables(t) = Receivables(t - dt) + (Sales - Cash_Receipts) * dt
INIT Receivables = 1000

INFLOWS:
Sales = MIN(Customers*Customer_Demand__Factor,
Sales_Employees*Sales_Employee__Productivity) * (1-Risk_of_Inaccurate_Sales_Recording)

OUTFLOWS:
Cash_Receipts = Receivables/Time_to_Collect
Sales_Employees(t) = Sales_Employees(t - dt) + (chg_Employees) * dt
INIT Sales_Employees = 100

INFLOWS:
chg_Employees = Sales_Employees*0
Customer_Demand__Factor = 10
Control_Activities = .95
Control_Environment = .95
Information_and_Communication = .95
Monitoring = .95
Risk_Assessment = .95
Risk_of_Inaccurate_or_Inappropriate_Shipments = 1 - RANDOM(MIN(Control_Activities, Control_Environment, Information_and_Communication, Monitoring, Risk_Assessment), 1, 12321)
Risk_of_Inaccurate_Sales_Recording = 1 - RANDOM(MIN(Control_Activities, Control_Environment, Information_and_Communication, Monitoring, Risk_Assessment), 1, 12345)
Risk_of_Inaccurate_Cash_Collections = 1 - RANDOM(MIN(Control_Activities, Control_Environment, Information_and_Communication, Monitoring, Risk_Assessment), 1, 54321)
Sales_Discount_Rate = .01
Sales_Employee__Productivity = 15
Time_to_Collect = 1

FIGURE 1
REA Model Building Blocks



Resources: resources are things of economic value that are provided or consumed by an enterprise's activities and operations (i.e. cash or inventory).

Events: events reflect the stock inflows and stock outflows of economic resources. (i.e. sales or cash receipts)

Agents: agents are the persons, organizations, or organizational units that control or participate in economic events (i.e., employees or customers).

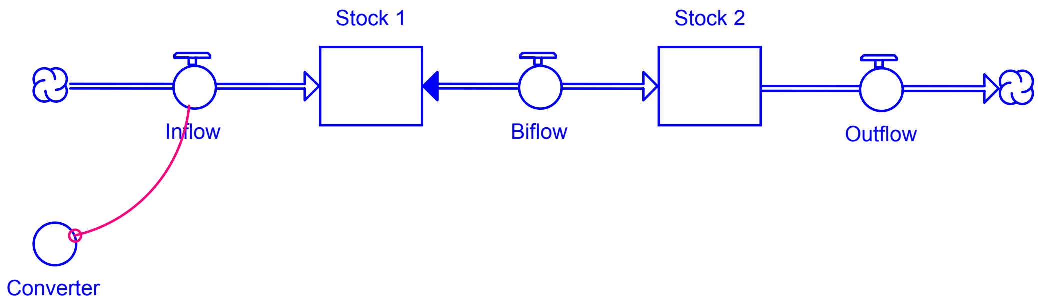
Commitments: commitment events represent agreements to execute an economic event at a specified future time that will result in either an increase of resources or a decrease of resources

Stockflow Relationship: stockflow relationships are an association between an economic event and a resource, which indicates either an increment or decrement to the resource.

Duality Relationship: duality relationships link economic events that increment economic resources with corresponding economic events that decrement economic resources

Participation Relationship: participation relationships are an association between an event and an internal or external agent.

FIGURE 2
System dynamics Models Building Blocks



Inflow and Outflow: flows fill and drain accumulations (stocks). The unfilled arrow head on the flow pipe indicates the direction of positive flow, e.g., inventory receipts or shipments.

Biflow: biflows combine inflow and outflow in the same flow depending on the value (positive or negative) of the flow for the time period.

Stock: stocks are accumulations. They collect whatever flows into them, net of whatever flows out of them, e.g., inventory.

Converter: the converter serves a utilitarian role in the software. It holds values for constants, defines external inputs to the model, and calculates algebraic relationships, e.g., sales. Converters connect to either inflows or outflows.

Connector: the connector (curved line between the converter and the inflow) connects model elements, allowing the user to define algebraic relationships between the elements that affect the rates of changes in the model.

Clouds: clouds represent the end of flows when flows do not connect to other stocks.

Valves: valves regulate flow rates on the flow pipe. i.e., determine the periodic change in stocks, and are adjusted by links from converters.

FIGURE 3
Rules for mapping REA to Stockflow

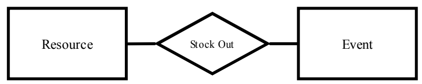
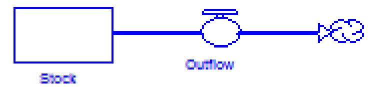
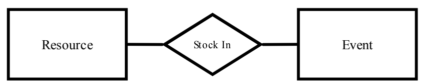
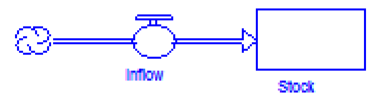
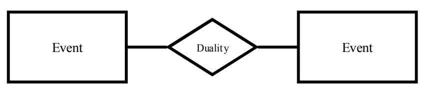
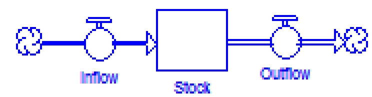
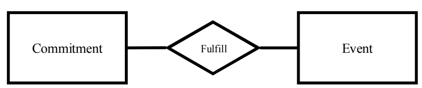
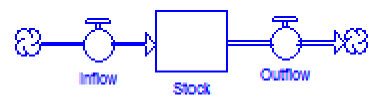
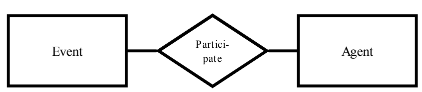
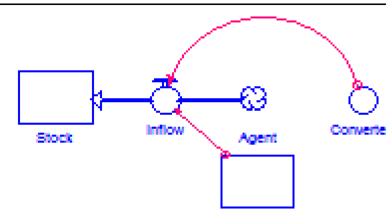
REA Description	REA Model Elements	Stock-Flow Model Elements	Stock-Flow Model Description
Stockflow Out relationship exists between an event (e.g., sales) giving something up and the resource (e.g., inventory) being given up.			An accumulated stock (e.g., inventory) reduced by periodic flows out of the stock (e.g., sales) regulated by the outflow valve.
Stockflow In relationship exists between an event (e.g., purchases) taking something in and the resource (e.g., inventory) being acquired.			A stock (e.g., inventory) increased by the periodic flow into the stock (e.g., purchases) regulated by the inflow valve.
Duality relationship is the causal relationship between an increment event (e.g., cash receipts) and a decrement event (e.g.,sales).			A stock (e.g., accounts receivable) increased by a periodic inflow (sales) and simultaneously decreased by periodic outflows (cash receipts).
Fulfillment relationship represents associations between economic events and the commitment (e.g., sales order) leading up to the economic event (e.g., sales).			A stock (e.g., unfilled orders) increased by a periodic inflow (e.g., orders received) and simultaneously decreased by periodic outflows (e.g., orders filled or sales).
Participation relationship represents associations between an event (e.g., purchases) and the associated internal (e.g., employee) and/or external (e.g., vendor) agent.			A stock (e.g., total purchases) increased by periodic inflows (e.g., purchases) that are regulated as a function of another stock (e.g., number of employees) and a rate (e.g., productivity per employee).

Figure 4
Mapping an REA Model to a Dynamic Model of the Sales/Cash Receipts Process

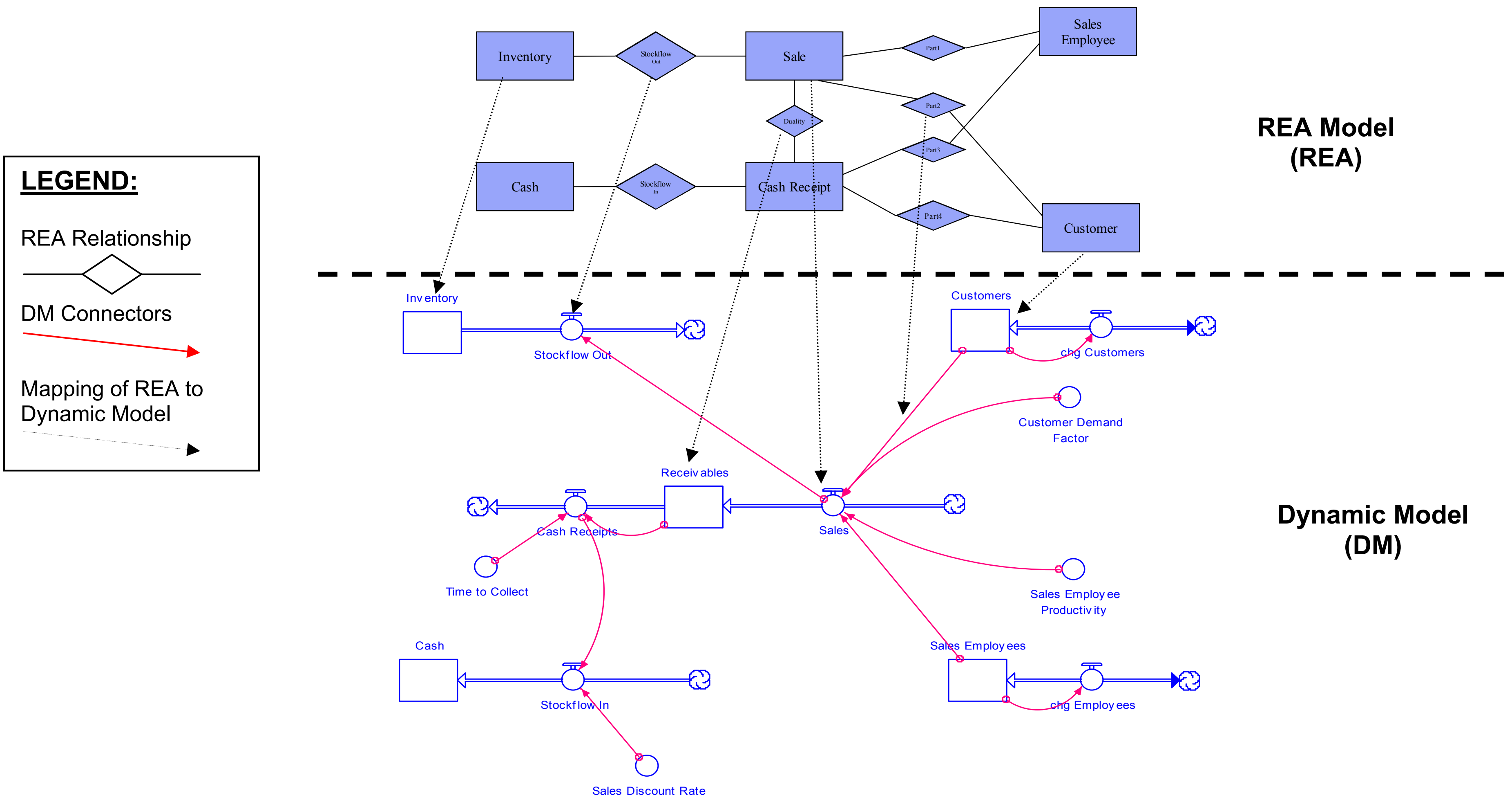


FIGURE 5
Purchases/Cash Disbursement Process Dynamic Model

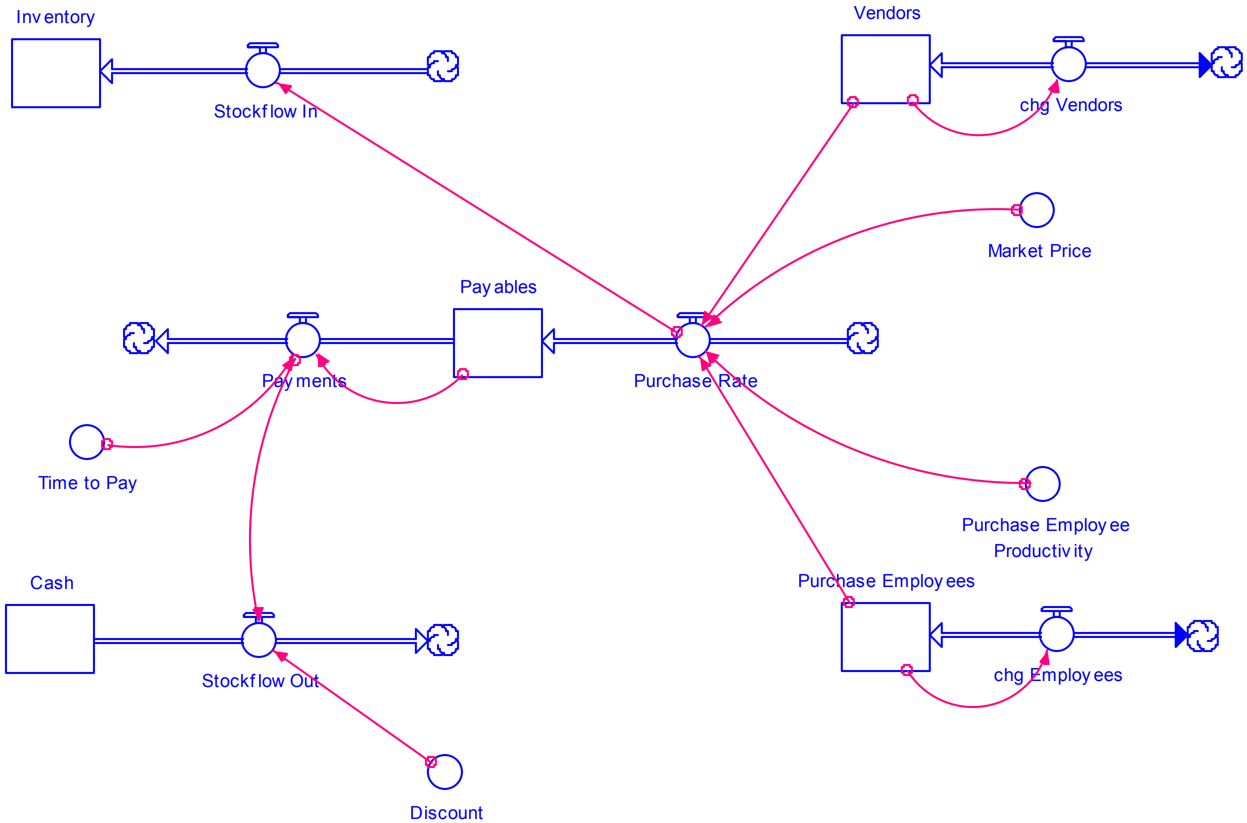


FIGURE 6
Sales/Cash Receipts Process with Commitments

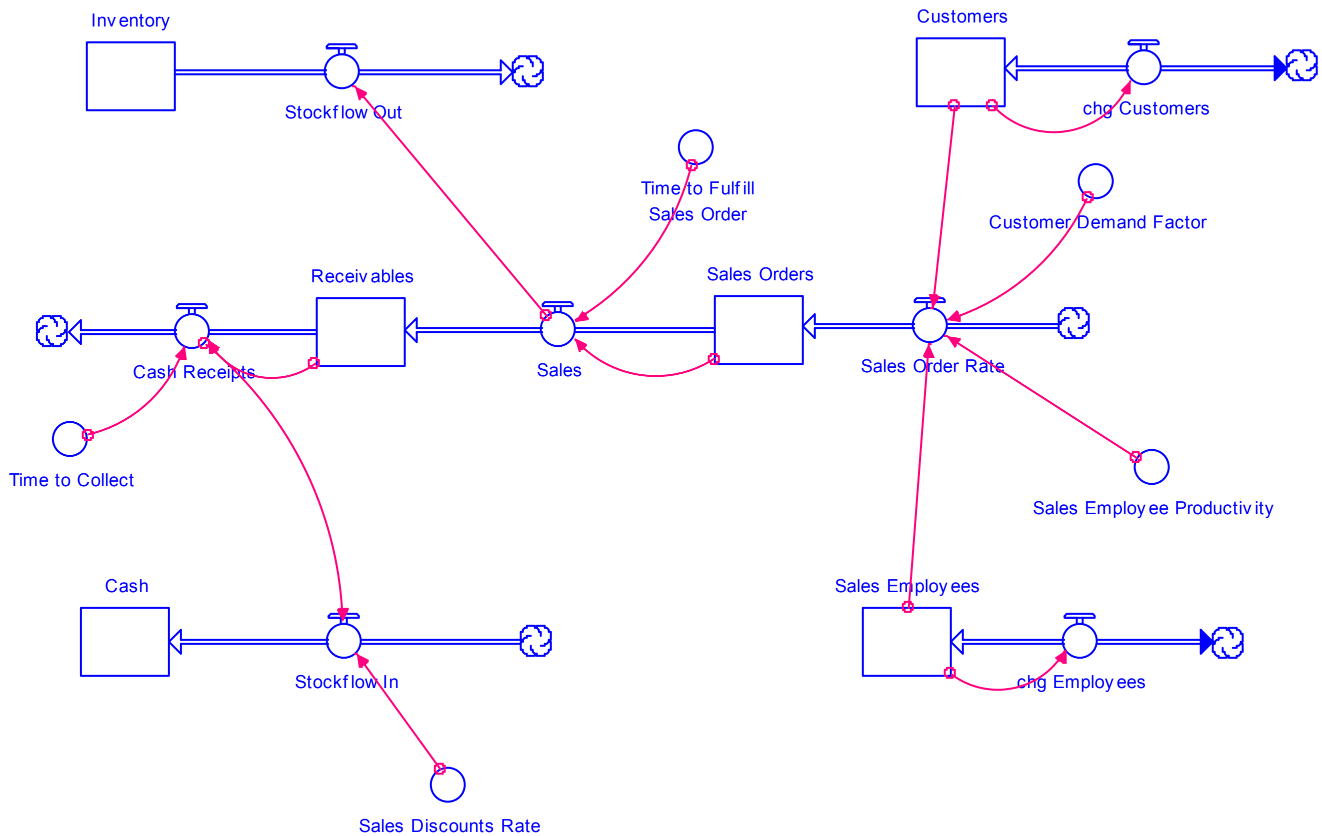


FIGURE 7
Purchase/Cash Disbursement Process with Commitments

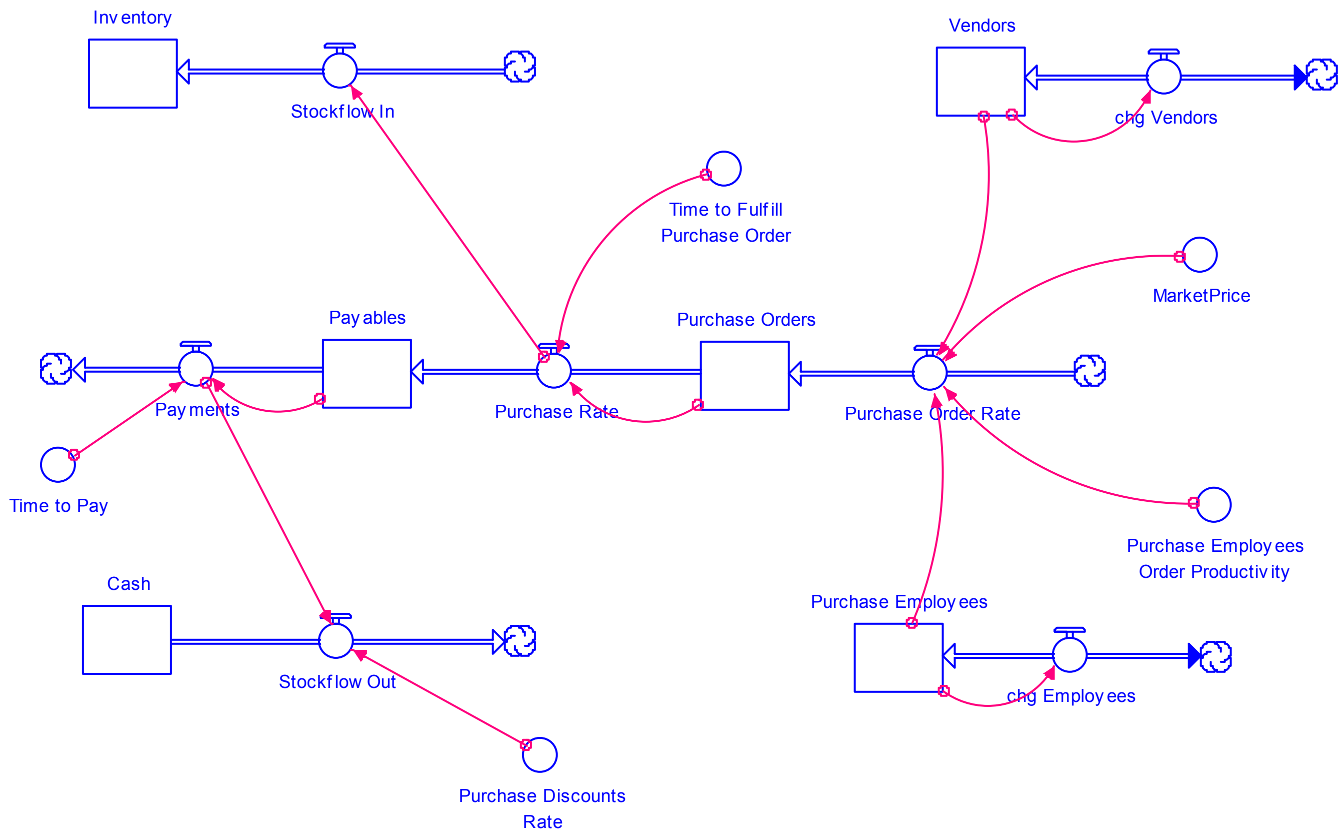


FIGURE 8
Sales/Cash Receipts Process with Risks

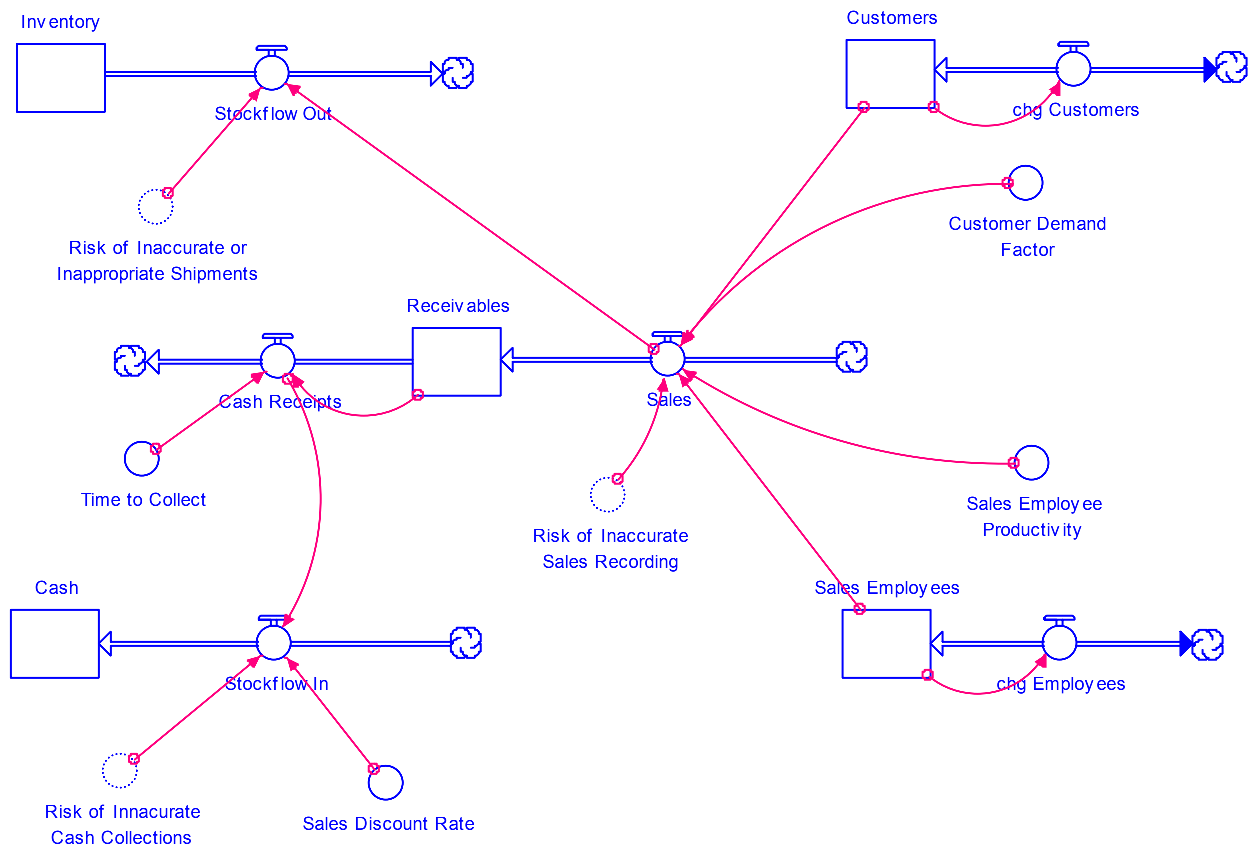


FIGURE 9
Linking COSO Model Components to Process Risk Converters

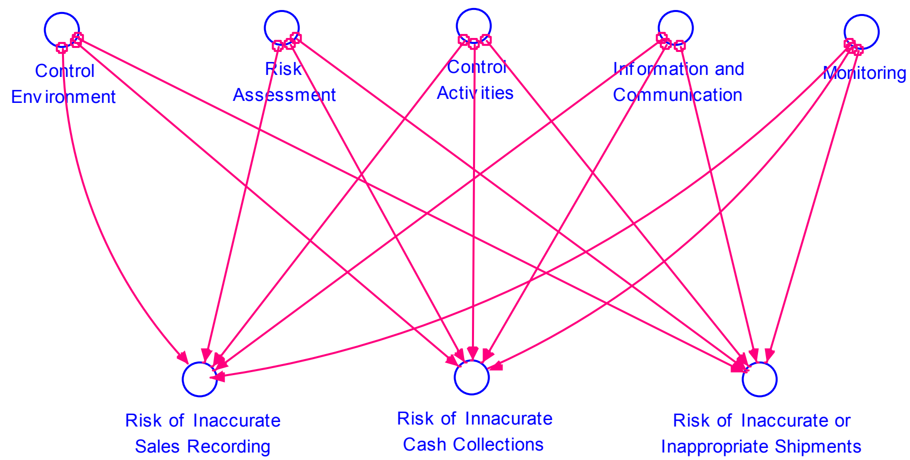


TABLE 1
Comparing Benchmark Results with Risk-Assessed Results
Over 20 Quarters

	SALES			STOCKFLOW (CASH) IN			STOCKFLOW (INV) OUT		
Period	Benchmark	Risk	Difference	Benchmark	Risk	Difference	Benchmark	Risk	Difference
1	1008	981	26	991	950	41	756	714	41
2	1028	995	33	1002	947	54	771	727	44
3	1049	1025	23	1019	960	59	786	748	38
4	1070	1046	24	1039	998	41	802	769	33
5	1091	1048	44	1059	1004	55	818	763	55
6	1113	1089	25	1081	1015	65	835	809	26
7	1136	1119	17	1102	1052	50	852	817	34
8	1159	1129	30	1124	1069	56	869	815	54
9	1182	1166	16	1147	1096	51	886	852	35
10	1206	1180	26	1170	1125	46	904	867	37
11	1230	1195	35	1194	1124	69	922	871	52
12	1255	1232	23	1218	1138	80	941	898	43
13	1280	1249	31	1242	1196	46	960	904	56
14	1306	1268	37	1267	1202	65	979	925	54
15	1332	1290	42	1293	1218	75	999	931	68
16	1359	1331	28	1319	1247	72	1019	967	52
17	1386	1333	54	1346	1268	78	1040	972	68
18	1414	1362	52	1373	1300	72	1061	987	74
19	1443	1406	37	1400	1309	91	1082	1022	60
20	1472	1431	41	1429	1356	73	1104	1049	55
Total	24517	23872	645	23815	22575	1241	18388	17407	981
% Bench			3%			5%			5%

Initial parameters: Both models: Customers = 100; Employees = 100; Customer Demand Factor = 10; Sales Employee Productivity = 15; Time to Collect = 1; Receivables = 1000; Sales Discount Rate = .01; Gross Margin = .25. Risk-Assessed model: Control Activities = .95; Control Environment = .95; Information and Communication = .95; Monitoring = .95; Risk Assessment = .95.