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A WORKFLOW ANALYSIS AND DESIGN ENVIRONMENT (WADE)

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ABSTRACT

This paper presents the architecture of a *Workflow Analysis and Design Environment* (WADE) that will provide robust support for simulation-based design of next-generation workflow systems. The architecture's utility will be illustrated by showing its use to design and analyze material ordering and control system workflow.

1 INTRODUCTION

The utility of simulation for the design and analysis of complex systems has been well documented (Pegden et al. 90). Workflow systems are an emerging infrastructure technology that facilitates the execution and control of work in real time. There are several advanced tools that support simulation and workflow. However, there is a dearth of robust support to integrate simulation with workflow systems. This paper presents the architecture of a *Workflow Analysis and Design Environment* (WADE) that will provide robust support for simulation-based design of next-generation workflow systems. We will illustrate the architecture's utility by showing its use to design and analyze the workflow of a material ordering and control system.

Workflow systems provide operational semantics to process descriptions. In a word, they "execute" process models. Different workflow "engines" execute different process models. Different process models focus on different aspects of processes. Some are designed for complex decision making and therefore encapsulate rules and logic needed for decision support, while other process models work with relatively routine and recurring processes and incorporate greater detail about individual activities within the process. Workflow systems are limited by the nature of the process models they support: highly repetitive tasks vs. ad-hoc kinds of processes. Workflow systems also provide varying levels of both exception handling and monitoring and management reporting capabilities. Some workflow systems are integrated with Graphical User Interfaces (GUIs) or forms packages, some with imaging systems. Some workflow systems manage application data while others do not. No one workflow system is equally strong in all areas (Bußler and Jablonski 1994, Cleetus 1994, McCarthy et al. 1993).

Workflow systems can be divided into what we can call "departmental" systems and "enterprise" systems. Departmental systems are usually built around a central workflow server which contains a database of process descriptions and the workflow engine. Clients execute the activities in the workflow process as specified by the workflow process description at the server. Enterprise systems are more often Electronic Mail based. Often, the workflow process description is passed from client to client along with the specific work.

Despite rapid advances in the past few years, contemporary workflow software systems have been observed to have several limitations:

- Limited knowledge acquisition and knowledge representation support: lack of mechanisms for acquiring knowledge (especially process knowledge) and representing this knowledge in a form that is computer-processable (for automated reasoning).
- Inadequate graphical support: graphical support provided by existing systems is unsophisticated, non standard, and often difficult to understand.
- Inadequate design support: there is little automated support to assist the design and development of workflow applications.
- Limited analysis support: there is a lack of support for the (qualitative and quantitative) analysis of workflow system performance.
- Lack of integration: workflow systems are not integrated with business process analysis and design tools, resulting in workflow process designs that are incompatible with the business processes they are supposed to support.

Workflow and simulation technology are important enabling technologies for the effective application of Business Process Reengineering (BPR) and Continuous Process Improvement (CPI) techniques (Hammer and Champy 1993). Simulation plays an important enabling role in BPR and CPI and has been successfully used to assist process improvement efforts in several different tasks including 1) measuring the performance of existing systems, 2) identifying improvement opportunities, 3) evaluating the effect of alternative operational policies on system performance (*what if* analysis), and 4) comparing alternative system designs. The role of simulation as a BPR enabler has been well documented (Mayer et al. 1995). Recent advances in information technology, such as workflow, have opened up new opportunities to use simulation more effectively to facilitate process improvement and change management.

Workflow technology appears to have the potential to leverage the benefits of simulation for the design and analysis of work. Because the study of processes (in essence, how things work) is an integral part of BPR and CPI efforts, there is much to be gained by combining the power of these two technology areas. Motivated by this opportunity, we have leveraged the results of our research on knowledge based simulation to formulate an architecture that embeds a simulation-based expert system within a workflow environment (Mayer 1988, Benjamin et al. 1993, and Erraguntla et al. 1994). The resulting WADE software has significant application potential in many areas including BPR and CPI, production systems design and analysis, workflow design and analysis, and change management systems.

2 WADE PHILOSOPHY AND CONCEPT OF OPERATION

WADE is intended to support the design and analysis of workflow systems in the context of continually evolving business processes. Just as the industry has recognized the need for concurrent engineering of products and manufacturing processes that produce those products, WADE supports a philosophy of concurrent design of the business process with the workflow process that must support the business process. In today's environment, the business process is developed by process owners or business stakeholders, whereas the workflow process is developed by the information systems engineers and programmers. Bringing concurrency to these activities results in business processes that take maximum advantage of the workflow automation and workflow processes that conform to the business goals. Workflow simulation models are used to analyze and improve workflow processes. Workflow execution models are used to execute the work within the context of an information system (a set of applications). The relationship between business process models, workflow models and the analysis data generated from these models is summarized in Figure 1.

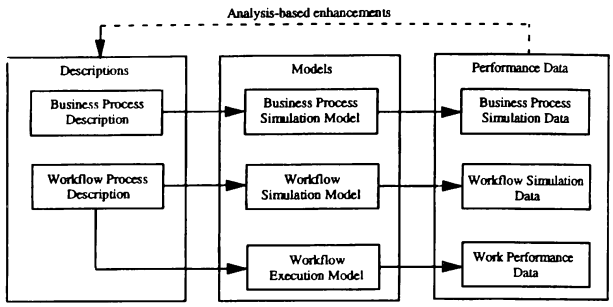

Figure 1: Relationships Between Business Models and Workflow Models

WADE is a design and engineering analysis environment intended to support concurrent engineering of the business process and the workflow process which supports that business process. This section describes the concept of operation of WADE, that is, the activities performed by a typical WADE user while designing and analyzing business process workflows. A simple material acquisition process is used to illustrate the concepts and structure the discussion.

Consider the (simplified) procurement process for inventory material at Enterprise XYZ. Material is requested by different functional areas within the organization. Material requests are routed to the procurement department. If the requested item is available (that is, in "stock"), the item is issued out and the inventory records are updated. If, on the other hand, the material is not available, a vendor is identified and a purchase order is generated and sent out to the supplier(s). Once the ordered material is received, it is sent to the requester. The finance department then makes payment for the purchased material.

Suppose that the purchase manager at XYZ would like to 1) model the procurement process, 2) analyze the process for determining improvement opportunities, 3) design an enhanced procurement process based on the simulation-based analysis, 4) model the workflow process, 5) use simulation analysis to improve the workflow process, 6) build a workflow execution model to automate the process, 7) use data generated through the execution of work (and recorded by the workflow "engine") to control the work, and 8) analyze the work data (generated by the execution of work) to determine potential improvements to the workflow process. Figure 2 summarizes the activities involved in designing and analyzing workflows in the context of a business process.

Note that although the diagram suggests a precedence ordering between the activities, these analysis and design activities are invoked iteratively and opportunistically in actual workflow analysis and design situations, depending on the context of application.

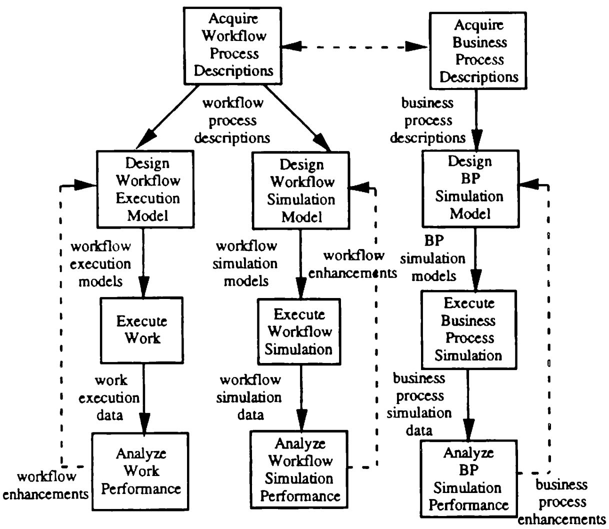

Figure 2: WADE Concept of Operation

The following sections describe the type of support that WADE provides for these activities.

2.1 Acquire Business Process Descriptions

The knowledge of the focus business processes must be acquired from domain experts and stored in a representation format. WADE facilitates the acquisition of this information using the IDEF3 process description capture language (KBSI 1992). IDEF3 provides intuitive and structured mechanisms to acquire knowledge about how things work in a system. Also, IDEF3 has a graphical language that provides a standard format for displaying and communicating such process knowledge. As noted earlier, XYZ's procurement manager would like to determine how to improve the procurement process. Discrete event simulation is a powerful technique for analyzing business processes (Pegden et al. 1990). WADE supports the design of simulation models starting from process descriptions.

It is important to make the distinction between descriptions and models. Descriptions are recordings of belief and are either *true* or *false* (that is, they have "truth value"). Models on the other hand, are idealizations of the world that are developed for a particular purpose (or to address a specific set of goals) (Mayer 1988). Models are not true or false, rather they are *valid* or *invalid*, with respect to the modeling goals. A valid model is one that satisfies the goals for which it is built. With reference to the WADE concept of operation, the product of the description acquisition activity is independent of the modeling goals. In the procurement example, the goal of building the business process model is to analyze the process to determine improvement opportunities. Here, we use business process model to refer to the discrete-event simulation model developed from the business process description.

2.2 Design Business Process Simulation Model

Designing a business process simulation *model* starting from a business process *description* involves several inter-related model design activities such as identifying the relevant activities that need to be modeled and specifying their attribute values, designing the model flow logic, designing the model control logic, etc. The BP Model Designer component of the WADE architecture (Section 3) provides support for these (business process) simulation model design tasks. An IDEF3-based model of the procurement business process is shown in Figure 3. The labeled boxes (Request Material, etc.) represent distinct real-world activities that are individuated for the simulation model design. The box with an "X" in Figure 3 represents a decision situation: in the XYZ example, the decision logic is:

if the inventory level is greater than the requested material quantity
then (perform) Transfer Material
else (perform) Generate Purchase Order

This logic specification will be subsequently encoded in the language of the target simulation engine. The bordered text box beneath the "Receive Material" activity box (Figure 3) shows the kinds of additional information that may be recorded about the an activity. Thus, the name of the entity that participates in this activity is "Material," the name of the Resource that is needed to perform this activity is "Receiving Officer," and the duration of the activity is 10 minutes.

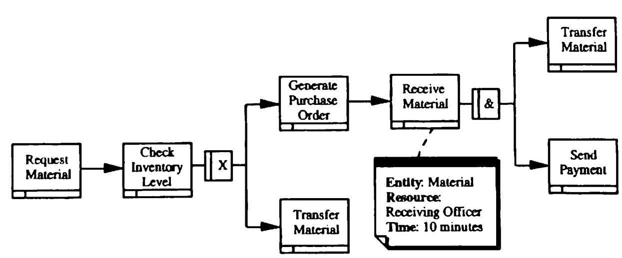

Figure 3: IDEF3-Based Description of the XYZ Procurement Process

After the simulation model has been designed, it is converted to a target simulation language.

2.3 Execute Business Process Simulation

The business process model is executed under a set of pre-specified experimental conditions. The executions yield output data that is recorded and compiled. These tasks are supported by the Simulation Engine component of the WADE architecture. Other WADE functions include accessing and editing model information, viewing key performance metrics while the simulation executes, and observing animations of the model.

The output data from the simulation is analyzed and interpreted with reference to the modeling goals. For example, if the specific objective of the XYZ manager was to determine bottleneck resources in the procurement process, the manager might examine the resource utilization statistics produced by the simulation. Resources with very high utilization are candidate bottlenecks. Bottleneck resources, will, in turn suggest ways to improve the business process through resource re-assignment, job enrichment training, etc.

The results of the simulation output analysis are often used to make process reengineering decisions. Suppose that the utilization of the Receiving Officer is found to be 97%. Suppose further that there are two Purchase Agents assigned to the activity Generate Purchase Order and that their average utilization is only 30%. The situation suggests that one of the Purchase Agents is re-assigned (with some retraining, if necessary) to the Receive Material activity.

2.4 Acquire Workflow Process Descriptions

Workflow processes are normally distinguished from the more general business process in that they are generally centered around the flow of a single information artifact (work-item) that triggers, enables, or controls an instance of the business process. In more complex cases, a work-item in a workflow may tie together multiple business processes. Thus, workflow processes support the execution of the business process. In WADE, knowledge about the workflow processes is acquired using the IDEF3 process description capture method. Workflow process descriptions contain information about the workflow applications that are used within the enterprise operational environment, the information needed to launch these applications, and routings between these applications. Workflow processes are subsumed by the business processes that they support. Often, business process descriptions are acquired prior to the workflow process descriptions (see the dotted arrow in Figure 2). In fact, following a re-engineering of the business processes the workflow processes must often be designed from scratch.

A distinguishing feature of WADE is that it provides automated support for the generation of workflow models, starting from workflow process descriptions. WADE supports the generation of two kinds of workflow models: 1) workflow simulation models (Section 2.5) and 2) workflow execution models (Section 2.7). The first enables the quantitative analysis of the workflow process design. The second enables the automatic programming of the workflow controllers in the enterprise information infrastructure.

We describe the difference between workflow process models and business process models. Recall that there are two kinds of workflow models that are generated by WADE: workflow simulation models and workflow execution models. We will describe the difference between 1) business process simulation models and Workflow simulation models and 2) workflow simulation models and workflow execution models.

A business process simulation model is a specification of a business process that can be executed by a discrete event simulation engine. It must thus encode enough structure and contain enough information that simulation executions will produce sufficient data to answer the simulation analysis questions. Therefore, in the context of a BPR situation, the business process model must have sufficient fidelity to generate metrics such as resource utilizations, mean process times, mean wait times, etc. A workflow simulation model, on the other hand, is developed to execute a simulation that mimics that flow of work between different workflow applications. The data generated by such models must enable the answering of questions about performance measure of the workflow applications, such as mean processing time for an application, mean queue time of a document at an application, etc. The main difference between business process simulation models and workflow process simulation models is the difference in the kinds of analysis questions they seek to answer. Business process simulations generate data to answer questions about the performance of a business process; workflow process simulations provide data to answer workflow application performance questions.

Workflow execution models are workflow specifications that are executable by a workflow engine. They contain enough information so that the flow of work between the applications occurs as required of the operational environment in real time. The main difference between a workflow simulation model and a workflow execution model is the kind of information contained in these models and the level of detail. A workflow execution model will contain information such as the routing of work between applications, the information needed to launch applications (such as input data passed to an application), exception handling information (for example, if an application "crashes," send a notification to the system administrator). Workflow execution models are often "human in the loop" models, requiring human involvement during an execution cycle. A workflow simulation model contains information such as processing times and resource requirements for various workflow process steps. Their execution typically requires little human intervention (for non mission critical workflow applications).

2.5 Design Workflow Simulation Models

A workflow simulation model is a representation of a process that can be directly executed by a discrete-event simulation engine. Workflow simulation models are useful in analyzing and designing workflow systems. Activities of workflow simulation model design supported by WADE are similar to those listed in Section 2.2 (for the BP simulation model design), the difference being in the type of information specified to support the workflow system-specific analysis goals. Workflow simulation model design is supported by the Workflow Model Designer component of the WADE architecture.

2.6 Execute Workflow Simulations

Workflow simulation models are executed under controlled experimental conditions. The executions yield output data that is recorded and compiled. These task are supported by the Simulation Engine component of the WADE architecture. Commercially available workflow simulators allow model editing, animation, and graphical display of performance statistics.

Analysis of the workflow simulation data is performed to identify potential improvements to (or problems in) the workflow description. Such analysis may be performed 1) for the design of new workflow systems and 2) for the redesign of existing workflow systems.

2.7 Design Workflow Execution Models

A workflow execution model is a representation of a workflow process that can be directly executed by a workflow engine. An IDEF3-based description of the workflow execution model specification for the "Generate Purchase Order" activity is shown in Figure 4. Note, that in general, workflow systems will cut across multiple business functions. Thus, the workflow specification illustrated in this example may need to be extended to include accounts receivable and invoicing (business) processes associated with activity boxes "Receive Material" and "Send Payment" in Figure 3.

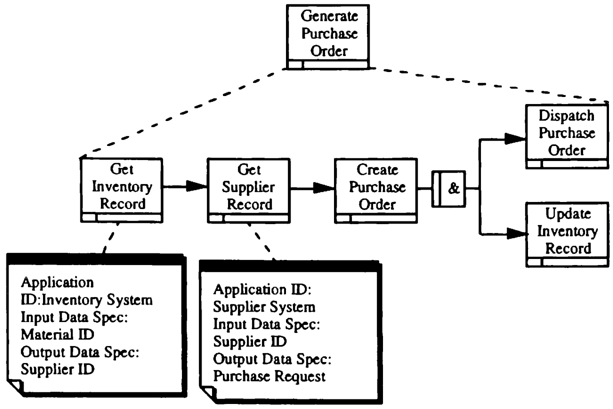

Figure 4: Example of a Workflow Execution Model

Therefore, the design of a workflow model starting from a business process description thus involves specifying sufficient information to enable the encoding of the workflow application. In particular, workflow model design involves activities such as identifying the information objects that are managed by the work and their attributes, identifying the sequence of the workflow, characterizing the information transformations that are performed during the work performance, etc.

2.8 Execute Workflow

The workflow model specifications are used to generate the workflow system. The workflow system is used to automate the flow of work. A sample sequence of work activities that will be invoked by XYZ's procurement process workflow system are: 1) receive the material request information, 2) determine that a purchase order must be placed, 3) retrieve material information from the Inventory Database, 4) retrieve supplier information from the Supplier Database, 5) merge information from 3) and 4) to create a purchase order, and 6) dispatch the electronic purchase order through XYZ's Value Added Network (VAN) to suppliers.

Note that these activities may only be partly automated. For example, the decision to place an order (Step #2) may require a human to "sign-off."

While the work is being executed by the workflow system, data is collected to measure the performance of work. For example, the durations (times to complete) of the activities are recorded.

Statistical analysis such as distribution fitting and determination of mean and standard deviations are performed on the workflow data (for example, on the activity time data). This type of data is then fed back for use by the workflow simulation models (Figure 2). The analysis of performance data may also lead to the identification of workflow and business process improvement opportunities. Data analysis activities are supported by the Data Analyzer component of WADE.

3 WADE ARCHITECTURE

The conceptual architecture of WADE is shown in Figure 5. WADE is a distributed software system that provides intelligent assistance for the design and analysis of workflow systems. WADE can be "plugged in" to different enterprises. The enterprise information systems that WADE supports are shown in Figure 5. (Note that several WADE components have been implemented.) The main components of the WADE architecture are described in the following paragraphs.

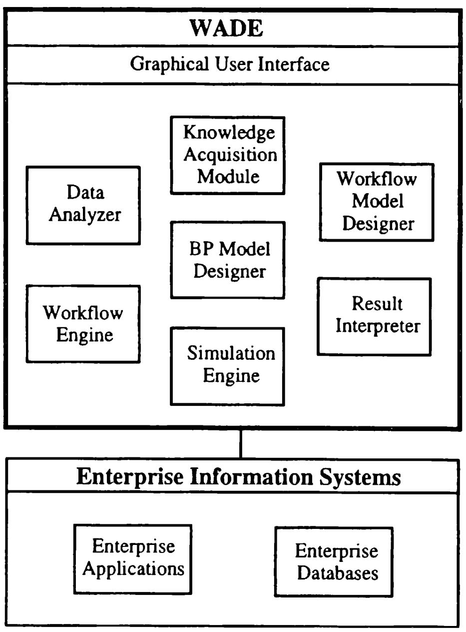

Figure 5: WADE Architecture

The Knowledge Acquisition Module facilitates the capture and maintenance of process knowledge about the business processes and the associated workflows. This component is based on the IDEF3 process description capture language. It allows for the description of activities, the precedence and logical relationships between activities, and the objects that participate in these activities. The knowledge captured by this module will be used as the basis for subsequent business model and workflow model design activities. This module has been implemented as a commercial tool, PROCAP™.

The Business Process (BP) model designer provides assistance for the design of a business process (simulation) model starting with an IDEF3-based process description and a set of analysis questions to be answered. The activities involved in simulation model design are described in Section 2. This module has been implemented as a commercial tool, PROSIM™.

The Simulation Engine provides support for the execution of discrete event simulation and the compilation of simulation output for analysis. AT&T's simulation tool, WITNESS™, executes code that is automatically generated by the PROSIM model designer. The simulation engine can be used to simulate both business process simulation models and workflow process simulation models.

The Workflow Model Designer provides intelligent assistance for the design of 1) workflow simulation models and 2) workflow execution models, starting from IDEF3-based descriptions of the workflow processes.

The Workflow Engine provides support for the execution of workflow. This component will execute the specifications generated by the Workflow Model Designer. The activities supported by the Workflow Engine include 1) invoking different work applications, 2) routing work between different work applications, 3) maintaining work status information, and 4) performing other process control functions such as error notification, failure recovery, etc.

The Data Analyzer provides different kinds of data analysis support. Data analysis is used for 1) analyzing work performance data generated by the workflow systems and 2) analyzing output data generated from workflow simulations and business process simulations.

The Result Interpreter assists in the interpretation of the simulation data and the presentation of the analysis results in a form that facilitates decision making.

The Enterprise Information Systems box shown in Figure 5 refers to the set of software applications and databases that are invoked by the Workflow Engine. The Workflow Engine automatically manages the invocation of these application services in a distributed computing environment. Note that these applications and databases are not part of WADE or the workflow system itself. Rather, they are part of the user enterprise environment. The workflow system manages the sequencing and often the marshaling of necessary data for the applications.

4 BENEFITS AND POTENTIAL APPLICATIONS

Implementations of the WADE architecture have the potential to benefit different kinds of users. Potential WADE applications include:

1. **Enterprise Planning:** WADE facilitates model-based planning of enterprises. Process models can be used as the basis for analysis and planning tasks relevant to enterprise planning.
2. **Business Process Reengineering:** The model based analysis capabilities of WADE help with 1) identifying opportunities for BPR and 2) evaluating alternative business process designs.
3. **Enterprise Change Management:** Real time data collected by the workflow and feedback to the analysis and design components of WADE provide powerful mechanisms for change management at the enterprise level. With WADE, tomorrow's enterprise engineers can use models of the business to monitor and control operations of the business on an ongoing basis.
4. **Workflow Systems Engineering:** Process modeling and simulation technology can be used synergistically in the WADE environment to design and "engineer" workflow systems. WADE will help with both the rapid prototyping of new workflow systems and the reengineering of existing workflow systems in response to a rapidly changing business environment.

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