Technology and Tools for Comprehensive Business Process Lifecycle Management

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Abstract. *Business processes* are collections of one or more linked activities which realize a business objective or policy goal, such as fulfilling a business contract, and/or satisfying a specific customer need. The *lifecycle* of a business process involves everything from capturing the process in a computerized representation to automating the process. This typically includes specific steps for measuring, evaluating, and improving the process. Currently, commercially available *workflow management systems* (WFMSs) and *business process modeling tools* (BPMTs) provide for complementary aspects of business process lifecycle management. Furthermore, new concepts and interoperating tools in these categories are emerging to provide comprehensive support for managing the entire business process lifecycle. In this paper we provide an overview and an evaluation of the process modeling, analysis, automation, and coordination capabilities provided by integrated BPMTs and WFMSs. We also discuss how state of the art WFMSs and BPMTs can interoperate to provide complete support for the entire business process lifecycle. Although we occasionally discuss research issues, we mainly focus on the state of the art in commercially available technology.

Introduction

Business processes are market-centered descriptions of an organization's activities. That is, business processes are collections of activities that support critical organizational functions in realizing an objective or policy goal, such as fulfilling a business contract, and/or satisfying a specific customer need. Business processes are typically implemented by designing corresponding information and/or material processes [MWFF 92].

Information processes relate to automated activities (i.e., activities performed by programs) and partially automated activities (i.e., activities performed by humans interacting with computers) that create, process, manage, and provide information. Typically an information process involves distributing and coordinating work activities among human and information system resources. In addition, effective coordination must deal with throughput delays, achieve efficient human and system resource allocation, provide reliability and consistency, and improve the quality of the resulting products (whether information service or matter).

Material processes are related to the assembly of physical components and the delivery of physical products. That is, material processes relate human or machine activities that are rooted in the physical world. Such activities include, moving, storing, transforming, measuring, and assembling physical objects.

Capturing business processes allows reasoning about the efficiency of an organization's activities. Implementing and automating business processes (by designing and implementing corresponding information and material processes) provides for the actual coordination of the organization's activities.

Business process reengineering (BPR) is the activity of capturing business processes starting from a blank sheet of paper, a blank computerized model, document, or repository. Once an organization captures its business in terms of business processes, it can measure each process to improve it or adapt it to changing requirements. *Continuous (business) process improvement* (CPI) involves explicit measurements, reconsideration, and redesign of the business process.

Reasons cited for business process redesign include increasing customer satisfaction, improving efficiency of business operations, increasing quality of products, reducing cost, and meeting new business challenges and opportunities by changing existing services or introducing new ones. BPR is performed before information systems and computers are used for automating a process. CPI may be performed after BPR and before information systems and computers are used for automating a process. However, typically CPI occurs after a process has been automated. Furthermore, CPI takes into account measurements of the process automation effectiveness.

Information process reengineering and *continuous information process improvement* are complementary activities of BPR and CPI, respectively. They involve determining how to use legacy and new information systems to automate the business processes produced by BPR and CPI. These activities can be performed iteratively to provide mutual feedback. While business process redesign can explicitly address the issues of customer satisfaction, information process reengineering can address the issues of information system efficiency and cost, and take advantage of advancements in technology.

In many organizations the term *workflow* is used to refer to a specific category of automated business processes. The main characteristic of such processes is that they are specified and/or implemented in two tiers. The top tier consists of a single process, which we refer to as the *workflow process*, and it is implemented by a corresponding (workflow) application. The workflow application automates the coordination, control, and communication of the basic process activities. These activities and the information systems or humans that perform them comprise the lower tier. During the workflow process enactment information or tasks are passed from one participating human or system to another for action, according to a set of procedural rules that implement and automate the business rules defined by the workflow process. Workflows are discussed further in Sections 0, 0, and 0.

The *business process lifecycle* involves everything from capturing a business process in a computerized representation to automating the business process (e.g., by implementing a workflow process). These typically include explicit process measurement, analysis, and improvement activities as required by BPR and CPI. The need to manage the business process lifecycle effectively, i.e., to perform *business process management*, has led to the development of new concepts and interoperating tools that support complementary aspects of business process management. Currently, commercially available products that support business process management can be characterized as *workflow management systems* (WFMSs) and *business process modeling tools* (BPMTs)[1]. Both WFMSs and BPMTs support business process definition or specification. However, while the scope of process definition in BPMTs is to provide for process understanding and analysis that can lead to process improvement, the scope of process definition in WFMSs is to support process automation. Therefore, the capabilities and the level of detail of the process definition typically captured by the WFMSs and BPMTs may vary, as needed to support respective automation or analysis purposes. More specifically, WFMSs manage the enactment of processes through the use of software that directly interprets the process definition and coordinates human and system participants that perform process related activities. On the other hand, BPMTs facilitate process evaluation and improvement by analyzing process definitions, simulating process enactment, and analyzing simulation measurements. Although BPMTs may be also capable of analyzing process measurements that are collected while the process is enacted by a WFMS, BPMTs usually lack functional capabilities and process definition detail needed for support process enactment. Therefore, to provide for the entire business process lifecycle, BPMTs and WFMSs must interoperate.

This paper provides an overview and an evaluation of the process modeling, analysis, and coordination capabilities of BPMTs and WFMSs. It also discusses how interoperability between WFMSs and BPMTs can provide complete support for the management of the entire business process lifecycle. More specifically, the rest of paper is organized as follows: Section 0 provides a characterization of business processes. Section 0 describes the business process lifecycle and its management, while Section 0 discusses commercially available BPMT and WFMS technology for supporting the business process lifecycle. The impact of using BPMTs and WFMSs on the business process lifecycle, as well as an

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[1] BPMTs are often referred to as BPR tools.

evaluation of current BPMT and WFMS technology are then discussed respectively in Sections 0, 0 and 0. One of the major issues in using BPMTs and WFMSs is their integration. This is described in Section 0. Finally, we conclude this paper by discussing critical factors for the success of using BPMTs and WFMSs in supporting BPR, CPI and process implementation. Although we occasionally discuss research issues, we mainly focus on the state of the art in commercially available BPMTs and WFMSs.

Characterizing business processes

As yet, there is no commonly agreed way to characterize business processes. However, the workflow literature often distinguishes between four kinds of processes (e.g., such a characterization is given by [McC92]): ad hoc, administrative, collaborative, and production. The basic dimensions along which these kinds of processes are characterized include:

- repetitiveness and predictability of the process and its activities
- mission criticality and value for the organization

A*d hoc* and *collaborative* processes have no set pattern for coordinating activities and for moving information among (typically human) process participants Kor 94, Bla94]. Ad hoc and collaborative processes typically involve small teams of professionals performing both synchronous and asynchronous activities. Examples include many office processes, such as business tax returns, product documentation, and sales proposals. In such processes, the ordering of activities is controlled and coordinated by humans [SZ91]. Furthermore, the ordering and coordination decisions are made while the process is performed. The basic difference between ad hoc and collaborative processes is their relative value for the organization that uses them. In particular, collaborative processes are mission critical and have high value for the organization, since process imperfection or disruption may result in violation of critical business objectives (e.g., significant loss of revenue or inability to offer critical customer services). On the other hand, ad hoc processes are generally not mission critical, since periodic imperfection and disruption can be tolerated (e.g., by repeating the process until it produces the desired result).

Administrative and *production processes* are repetitive and predictable. Therefore, the ordering and coordination of activities in such processes can be specified before they are performed. Administrative processes, such as routing an expense report or travel request for authorization, are generally not mission critical. On the other hand, typical production processes, such as loan application processing, insurance claim processing, or service order and fulfillment in telecommunications are mission critical. Therefore, unlike administrative processes, production processes have high business value.

Currently only administrative and production processes may be effectively supported by commercial BPMTs and WFMSs. Ad hoc and collaborative processes currently receive limited support from *groupware* technology and tools. However, groupware tools lack theoretical foundation, explicit process modeling, and corresponding infrastructure. In addition, they do not interoperate with WFMSs and BPMTs. Due to these problems, in the rest of this paper we focus mainly on administrative and production processes.

To discuss a more specific example of a production process, consider the processes depicted in Figure 1.

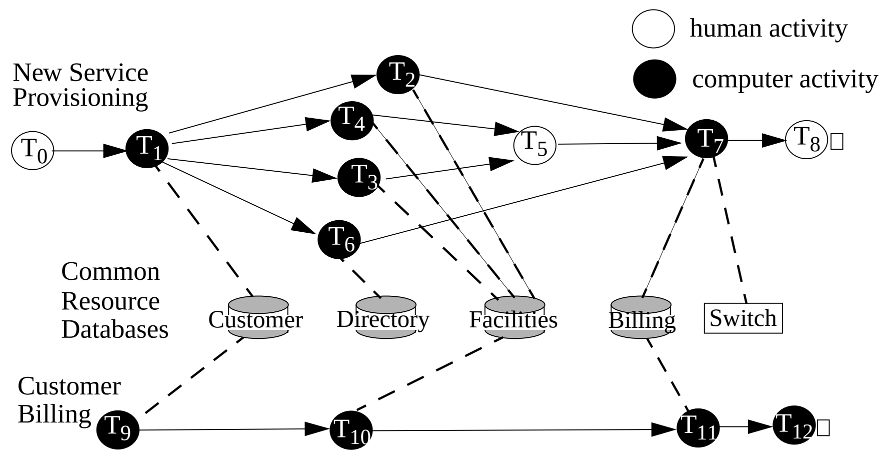

Figure 1. Examples of production processes in telecommunications.

The New Service Provisioning process captures the activities of telephone service provisioning for a new customer. The process takes place when a telephone company customer requests telephone service installation. Activity T_0 involves an operator collecting information from the customer. When sufficient customer data are collected, activity T_1 is performed to:

1. verify that the information provided by the customer is accurate, and
2. create a corresponding service order record.

On completion of T_1, activities T_2, T_3, and T_4 are initiated to perform three circuit provisioning activities. The objective of a provisioning activity is to construct a circuit from a customer location to the appropriate telephone switch and allocate equipment to connect the circuit. Only one of these provisioning activities should be allowed to complete, as all will result in a completed circuit, i.e., a set of lines and equipment that connects the customer to a telephone network (this requirement is not depicted in Figure 1). T_2 attempts to provide a connection by using existing facilities such as lines and slots in switches. If T_2 succeeds, the cost of provisioning is minimal, i.e., the requested connection can be established by allocating existing resources. However, a successful completion of this activity may not be possible if the facilities are not available. T_3 and T_4 achieve the same objectives as T_2 but involve different paths for physical installations of new facilities. T_5 requires manual work for facility installation. The human activity T_5 is initiated by providing installation instructions to the engineers (e.g., via mobile computers) and is completed when the human engineers provide the necessary work completion data. Activity T_6 involves changes in the telephone directory, while T_7 updates the telephone switch to activate service and then generates a bill. Finally, activity T_8 involves a human operator who calls the customer to inform him of the establishment of the requested service and verify that the provided service meets the customer needs.

In addition to the activities involved, the process defines the following activity ordering and dataflow between activities:

1. T_1 waits for data from T_0,
2. T_2, T_3, T_4, and T_6, wait for data from T_1 but do not exchange data, i.e., they can be performed concurrently after activity T_1 is completed,
3. T_5 needs data from T_3 and T_4,
4. T_7 waits from data from T_2, T_5, and T_6, and
5. T_8 needs completion data from T_7.

These dependencies are depicted as arcs in Figure 1. The other process depicted in Figure 1 has explanation similar to that of the New Service Provisioning process.

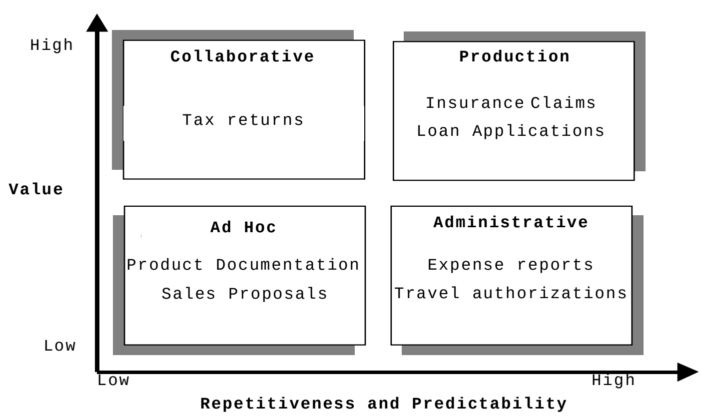

Figure 2. Characterization of Processes

The relationship of ad hoc, collaborative administrative, and production processes is illustrated in Figure 2 using process value and mission criticality versus process repetitiveness and predictability.

In the following sections we describe the business process lifecycle and discuss its management by contrasting traditional approaches with novel approaches using state of the art BPMTs and WFMSs.

Traditional Business Process Lifecycle Management

The business process management approach started in the 1980's when companies began several initiatives to improve performance with an emphasis on quality. This led to the realization that all work activities are business processes (i.e., related decisions and activities required to manage and administer resources of the business). Then, quality objectives were introduced to improve the effectiveness and efficiency of cross functional business processes. In particular, the process lifecycle includes the following:

- Capturing Process Definition
- Reengineering a Process
- Implementing a Process
- Performing Continuous Process Improvement

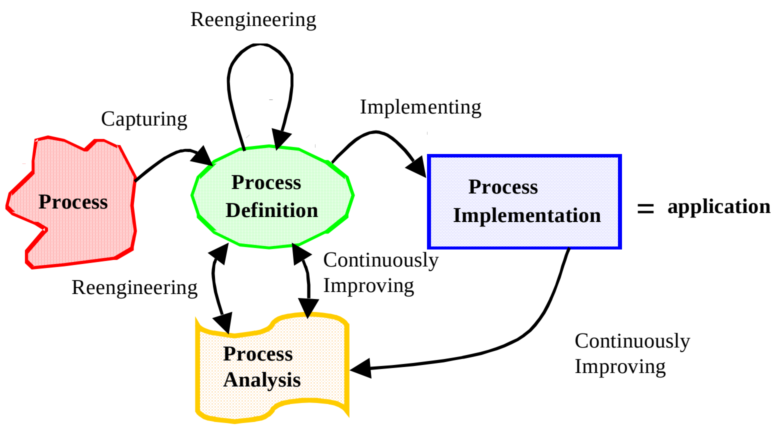

Figure 3. The business process lifecycle.

The process lifecycle elements are illustrated in Figure 3 and they are discussed further in the following sections.

Capturing Process Definition

In order to capture a process, we need to understand it. This usually involves interviewing people with expert knowledge about the process. Interview methodologies such as those used for expert system design are appropriate for conducting such interviews. When enough knowledge about the process is obtained, the process is captured in process definition.

A process definition is a process abstraction. The process abstraction level in a definition depends on the intended use of the definition. For example, a definition may describe a process at the highest conceptual level necessary for understanding, evaluating, and redesigning the process. On the other hand, another definition may describe the same process at a lower-level of detail required for performing process implementation.

Performing process definition requires a process model. A model typically includes a set of concepts that are useful to describe processes, their activities, the coordination of the activities, and the required *roles* (i.e., skills of the individuals or information systems) that can perform the specified activities. These concepts are embodied in a process definition language.

Validation of the process definition is necessary to determine if the process definition actually represents the intended process. This can be accomplished through behavioral simulation (showing what "happens next?") and/or static analysis (which can be used to answer such questions as: is a certain activity on all paths through this process?), assuming that the process model is rich enough to support this.

Reengineering a Process

Process reengineering involves design of a new process which is intensive, revolutionary, top down, supported by system solutions and results in dramatic improvements. Process reengineering should be guided by clearly stated business objectives, such as increasing customer satisfaction, reducing the cost of doing business, reducing the time for producing new products and services. Reengineering methodologies are currently an art. Process definition provides a high-level description of a process that facilitates high-level reasoning about business process efficiency; this reasoning may be supported through process simulation and analysis.

Implementing a Process

Implementation involves realizing a process using computers, software, and information systems. (This does not require that all activities in the process be automated, since there may be some performed by people with no computer support). No implementation or automation is required when the only reason for process definition is to capture business processes and reason about their efficiency. Otherwise, process definitions are used to implement and automate the processes.

Process implementation has traditionally been accomplished indirectly by embedding parts of the process in software systems and relying on human actions to provide adherence to the rest of the process. In this case, the process definition serves as a design for system functions and human behavior. The IT staff typically do the implementation, which often happens without discussions with the business staff specifically about the process.

Implementing a process (new or improved) traditionally includes suitable training and carefully thought-out work instructions to guide the process performers in their intended roles.

Performing Continuous Process Improvement

Improving a process involves making small course corrections rather than engaging in radical redesign. Measurement of the process execution is the basis for improving the process (and its definition). Measurements can show how often certain paths are taken, what elapsed cycle times are, what costs have been incurred, and similar results. Analysis of this data can lead to ideas for process improvement based on actual process results. In contrast, improvements made after a process is defined but before it is implemented are based on human intuition and possibly simulation with estimated data.

Traditionally, measurement is accomplished by adding instrumentation to software systems and devising ways to measure human activity. Typically, such data must be gathered from multiple sources.

Technology and Tools for Business Process Lifecycle Management

In this section we discuss commercially available technology and software systems/tools that has been specifically developed to support aspects of the business process lifecycle. In particular, we focus on the technology and capabilities of commercial BPMTs and WFMSs. Furthermore, we show how BPMTs and WFMSs may together provide comprehensive support for the management of the business process lifecycle. BPMTs are introduced in Section 0. An introductory discussion of WFMSs is provided in Section 0. Levels of integration between BPMTs and WFMSs are described in Section 0. The roles of BPMTs and WFMSs in the business process lifecycle are discussed in Section 0.

Business Process Modeling Technology and Tools

As we mentioned earlier, BPMTs provide for capturing, understanding, evaluating, and improving (redesigning) business processes. Typical BPMT objectives include [Hol97]:

1. Ease of use for the business end-user.
2. Well-defined process model objects for accurate measurements.
3. Simulation and analysis techniques.
4. Automated reports to expedite production of high quality outputs.
5. Integration capabilities with WFMSs.

To support these objectives, BPMTs provide the following tools:

- Business process definition tools to produce visual business process models by using one, or more, process modeling methodologies
- Analysis tools to measure long term performance, and facilitate process reengineering or improvement efforts
- Simulation tools to determine the short term impact of a model, and address practical concerns such as "bottlenecks"
- Integration tools to export, translate or share process definitions with WFMSs

Typical BPMT capabilities and data are depicted in Figure 4.

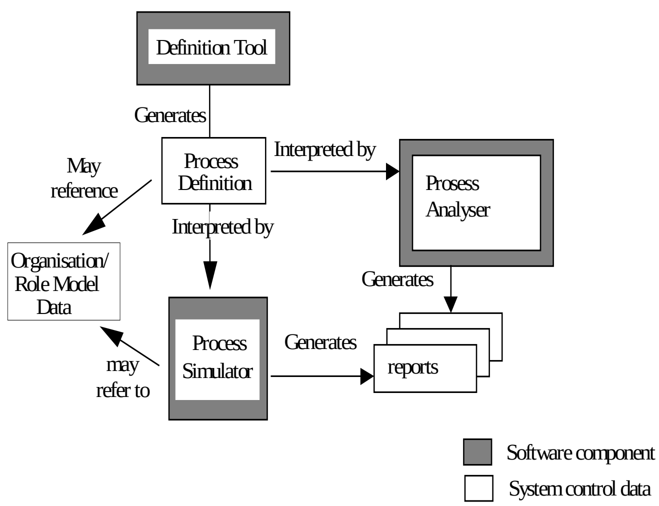

Figure 4. BPMT capabilities and data.

Business process definition/specification is the single most important founding principle of a BPMT. All analysis and subsequent benefits are based on the existence of “good” business process models. For example, if a process is not accurately modeled in a BPMT, no analysis tool can serve any useful purpose. Additionally, a BPMT without sufficient modeling depth can be counter-productive, since conclusions will be reached based on incomplete or inaccurate information.

"Good" process models and corresponding specifications must have the following properties [Hol97]:

1. Models must show how objects are transferred and where they are going.
2. A process is chronological, i.e., there no loops and activities are partially ordered
3. Conditions select one of many possible paths when interpreting the specifications of a process.
4. Alternate paths in a process must be separated for measurement.

Business process analysis and simulation measure possible business process outcomes. In particular, since business processes can often have multiple variations (or process cases), to support process analysis a BPMT must measure each possible outcome with a probability of occurrence. The resources required for each possible case can be aggregated and factored by their probabilities to obtain data that are essential for accounting and resource allocation. State of the art BPMTs include predefined reports geared to this purpose.

Another BPMT capability is process simulation. By varying rates of input, a BPMT can simulate activities and assess short-term performance issues, such as "bottlenecks" in a process. Procedures can be developed based on these simulations to successfully plan for and manage uncontrollable variations of input.

BPMTs do not provide business process automation. Instead, BPMTs rely on WFMSs for this purpose. We introduce WFMSs next. In Section 0, we discuss the integration of BPMTs with WFMSs. The role of BPMTs in the business process lifecycle is discussed further in Section 0. The capabilities and limitations of commercial BPMTs are discussed in Section 0.

Workflow Management Technology and Systems

In many organizations the term *workflow* is used to refer to an automated business process, which means that the coordination, control and communication of activities is automated, but the activities themselves can be either automated by information systems or performed by people. *Human activities* include interacting with computers closely (e.g., providing input commands) or loosely (e.g., using computers only to indicate activity progress). Examples of activities include updating a file or database, generating or mailing a bill, and laying a cable. Therefore, workflows are *loosely coupled* (i.e., they are built by linking together human and system activities).

As mentioned above, a business process definition is a process abstraction that depends on the intended use of the definition. In the rest of this paper, when a process definition is intended for process implementation and automation we will call it a *workflow process definition.* When a definition is intended for business process analysis, improvement, reengineering, we will call it a *business process definition.* This terminology differs slightly from the Workflow Management Coalition's (WfMC) terms [WfM97], which do not make this distinction.

Figure 5, depicts typical capabilities and data in a WFMS as they are defined by the Workflow Management Coalition (WfMC).

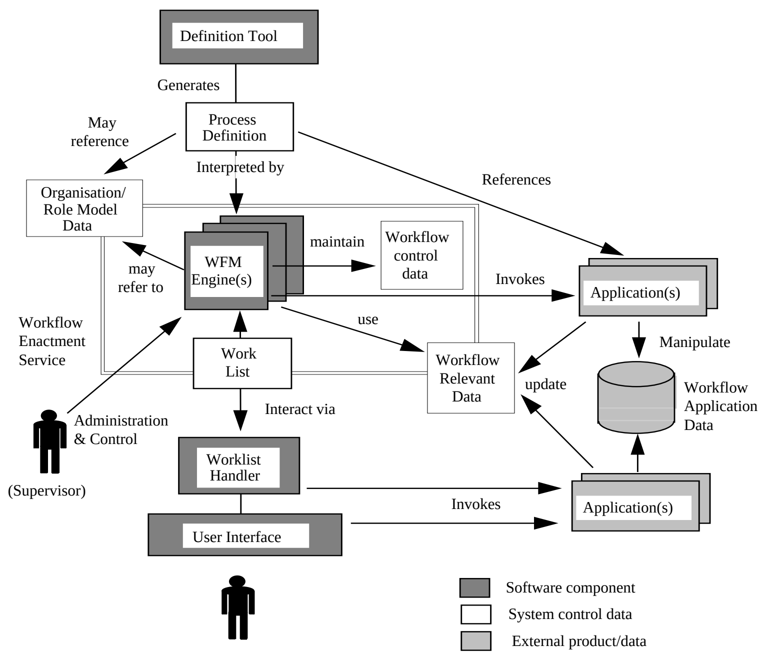

Figure 5. WFMS capabilities and data as defined by theWfMC Reference Model

Definition of workflow processes involves the specification of the *control flow* and *dataflow* dependencies between activities. These dependencies are implemented by a *workflow engine*, which is controlled by a computerized representation of the workflow processes and the corresponding dataflow and control flow dependencies. Each execution instance of a process is called a *workflow process instance*. From the perspective of a workflow processes definition, users play organizational *roles*. Each workflow activity specifies the *resources* it requires, i.e., the application(s) or the organizational role(s) of the users that can perform it. Whenever the workflow engine initiates such an activity, it dynamically selects a specific user form those supporting the role(s) specified in the activity. Users communicate with workflow engines by means of *workflow clients*, programs that provide an integrated user interface to all workflows supported by the WFMS. To request work from a user, the engine places an item in the *worklist* of this user. Workflow clients allow participating users to pick up worklist items and indicate the completion status of the work specified by each work item they have picked.

The role of WFMSs in the business process lifecycle is discussed further in Section 0. The capabilities and limitations of commercial WFMSs are described in Section 0. Next, we discuss the integration of BPMTs and WFMSs.

Interoperability between BPMTs and WFMSs

To provide for implementation and automation of business processes, state of the art BPMTs may export, translate, or share process definitions with WFMSs. For example, consider a situation where the business process model used by a BPMT is different than the workflow process model utilized by a WFMS. Their integration involves filtering business process model objects, translating them into appropriate workflow process model objects, validating the resulting workflow process model, and placing it in the representation used by the WFMS engine. Once this is accomplished, the translation process can be automated. In general, the level of integration between BPMT and WFMS can be characterized as follows:

- Level 0: Includes BPMTs that export business process definitions using a proprietary BPMT model and/or representation. WFMSs (or related software) must translate such heterogeneous process models and process representations into the native workflow process and the corresponding process definitions, and import them to the WFMS.
- Level 1: Includes BPMTs that export business process definitions using a workflow process model and representation that can be directly used by a WFMS. BPMTs in this category must translate their business process definitions into the workflow process definitions supported by a target WFMS.
- Level 2: Includes BPMTs and WFMSs that share process models and definitions. BPMTs (WFMSs) in this category must automatically export (import) such definitions or share a common process model repository.

In this paper we consider only BPMTs in Levels 1 and 2. However, it should be noted that even BPMTs and WFMSs at Level 2 may not interoperate fully. For instance, this may occur if the process definition in a BMPT does not contain sufficient level of detail for automation (e.g., it may not specify which application implements each automated activity and how to invoke it). Further decomposition of Levels 1 and 2 is possible. However, it is outside the scope of this paper.

The role of BPMT and WFMS integration in the business process lifecycle is discussed further next. Issues related to the integration of commercial BPMTs with WFMSs are discussed in Section 0.

Role of BPMT and WFMS Technology in the Business Process Lifecycle

In this section we discuss the impact of using BPMT and WFMS technology on the process lifecycle. The changes from the traditional lifecycle management in Section 0 are illustrated in Figure 6.

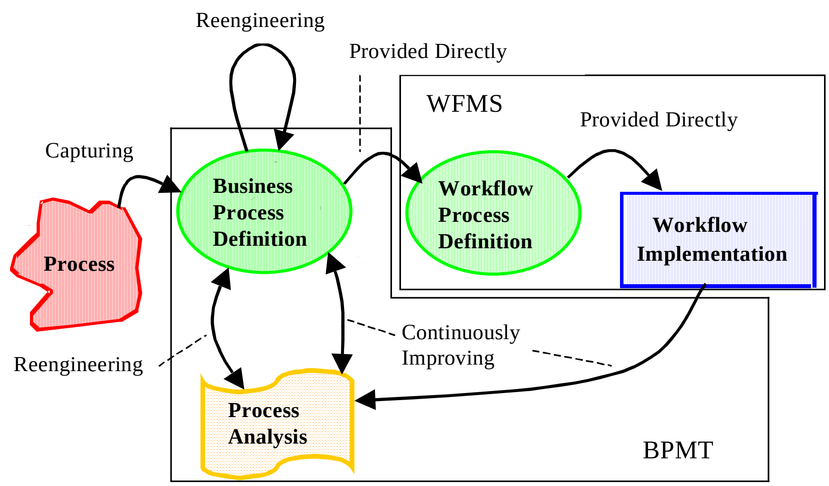

Figure 6. Process Lifecycle with BPMT and WFMS Technology.

The specific impact of BPMT and WFMS technology on the elements of the business process lifecycle is discussed further in the following sections.

Capturing Process Definition

In Sections 0 and 0, we discussed that a process definition is a process abstraction that depends on the intended use of the definition. Furthermore, we noted that both BPMTs and WFMSs provide models and technology for capturing business processes. Therefore, the value of these technologies in capturing a process depends on how well they support the intended use of the process definition. More specifically, BPMTs provide better support than WFMSs in situations where the process definition is intended for business process understanding, reengineering, and improvement. On the other hand, if the objective of process definition is process implementation and automation, a WFMS should be used instead of a BPMT. Thus, business process definition involves the capturing of a process by using a BPMT, while workflow process definition requires use of a WFMS.

To provide comprehensive support for the entire business process lifecycle, we must develop an approach for allowing an organization to transition between its business process definitions in a BPMT and its workflow process definitions in the model of a WFMS product. This is a more complicated issue than it might appear for the following reasons:

- The business process model may not provide sufficient detail so that the process implementation can be based directly on the process definition.
- The workflow process model (and the definition language provided by the WFMS) may be heterogeneous with the business process model (and corresponding definition language) used by the BPMT.

In any of these holds, the business process definition and the workflow process definition are two different entities, as depicted in Figure 6. This category includes commercial BPMTs and WFMSs offered by different vendors that currently interoperate at Level 1.

In an ideal situation from the perspective of supporting the entire process lifecycle, the business process definition used for general business process reengineering and improvement purposes will be exactly what is needed as a workflow process definition for workflow implementation. However, even in this situation business process definitions may differ from workflow process definitions for the following reasons:

- Business process reengineering and improvement neither require that the business process definition be at a working level of detail, nor they require exact correspondence of automated activities with the interfaces of legacy and new systems needed to support the process. Achieving this requires IT knowledge, in addition to business knowledge, and may not simply be a matter of adding detail to the business process definition.
- The models used by WFMSs are in general more comprehensive, requiring information and design decisions that are best made by IT

personnel with knowledge of legacy systems and how to achieve workflow throughput, scalability, monitoring, etc.

- Some business process definition languages are best suited for human, not machine, understanding; for example, it may be obvious to humans based on activity titles that two activities are alternatives to each other, but this cannot be detected by a automated algorithm.
- Sometimes process reengineering is focused primarily on the “normal” path through a process. Thus, the business process definition may lack detail on exceptional conditions, error handling, and other details that must be present in a workflow process definition.

Despite these problems, working with a single process definition (whether for understanding, reengineering, improvement, or implementation) is clearly the desirable case. To provide for this, some vendors have begun offering toolkits that include Level 2 integration between the provided BPMTs and WFMSs.

Reengineering a Process

Reengineering is not affected by introducing WFMS technology. BPMTs provide process models and analysis tools that can support one or more BPR methodologies. These are discussed further in Section 0.

Implementing a Process

Implementation is not affected by introducing BPMT technology. However, this is where the many advantages of WFMS technology are achieved. WFMSs provide for direct process implementation, driving process automation through the workflow process definition. Here, the process definition is actually part of the implementation. We believe that workflow process implementation will still be a collaboration between business staff and IT staff, with communication between them centered on the process definition. The IT staff will design the optimal implementation.

Performing Continuous Process Improvement

When BPMT and WFMS technologies are utilized, improving a business process involves making changes to:

- The business process definition, based on process measurements performed when the business process was analyzed by the BPMT.
- The workflow process definition, based on changes in the corresponding business process definition (assuming that the business and workflow process definitions are different).

- The business process definition, based on measurements made when the workflow process definition is enacted by the WFMS.

Logging functions are provided within a WFMS to record activity starts and stops. Thus, BPMTs can introduce monitoring applications to collect measurements from process enactment in WFMSs.

Evaluation of Current Business Process Modeling Technology

Commercial BPMTs currently support business process modeling and evaluation for improvement and reengineering purposes. Evaluation is performed by means of analysis, simulation, and report generation techniques. In the following sections, we discuss related BPMT capabilities and limitations.

Business Process Models and Methodologies

From the perspective of BMPT technology, the modeling of an existing or a proposed process involves the selection and use of:

- a *business process model* (and a BPMT that provides/supports it)
- a *methodology* (that promotes the specific process reengineering and/or improvement goals)

A business process model is a set of business process model objects, we refer to as *core business process objects*, and their relationships [TJ95]. These encapsulate the most important pieces of information that must be captured by the process definition.

A business process modeling methodology provides a set of rules and techniques for guiding process definition and establishing criteria for process evaluation. The methodologies we consider here include various BPR (e.g. [Dav93, HC93]), CPI, and object-oriented methodologies (e.g. [JEJ95]). From the perspective of business process modeling and evaluation, the purpose of such a methodology is to provide a set of guidelines and techniques for accomplishing specific process design, reengineering, or improvement goals.

Currently, commercial BPMTs provide process models that can be classified as goal-oriented, activity-oriented, or hybrid.

Goal-oriented models provide core business objects that explicitly support goal-based work. Models in this category are needed to ensure that a process achieves one or more organizational goals. However, goal-oriented models do not necessarily capture how to coordinate all the activities in the process.

Activity-oriented models provide core business objects that capture how to coordinate the process activities, but offer no explicit support for modeling anything else beyond this.

Hybrid models are both goal-oriented and activity-oriented.

Figure 7 depicts the relationship between models in these categories, and examples of goals such models may support.

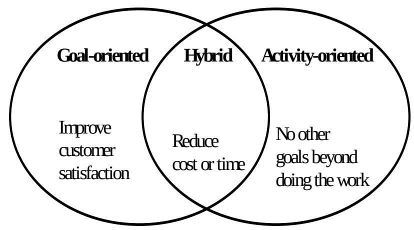

Figure 7. Classification of process models with respect to support for process goals.

Typical examples of goal-oriented models are conversation-based models (and corresponding methodologies) that stem from the Winograd/Flores Conversation for Action Model [MWFF92]. A conversation-based model assumes that the objective of a business process is to improve customer satisfaction. It reduces every action in a process to four phases based on the communication between a customer and a performer:

- *preparation* - a customer requests an action to be performed or a performer offers to do some action
- *negotiation* - both customer and performer agree on the action to be performed and define the terms of satisfaction
- *performance* - the action is performed according to the terms established
- *acceptance* - the customer reports satisfaction (or dissatisfaction) with the action

The four phases in the loop, their actions, the loops they form, and the customer and performer roles are the core business objects this model provides. Processes are modeled by defining such loops between a customer and performer, and joining each loop with other workflow loops to complete the business process. The performer in one loop can be a customer in another loop.

Examples of BPMTs that support this model include, the ActionWorkflow Analyst tool [MWFF92] from Action Technologies [Act97] and the Business Transformation Management tool from Business Transaction Design [Mar94].

Activity-oriented process models focus on modeling the work instead of modeling the rules and human commitments for achieving specific goals. Activity-oriented process models typically support the following core business objects for process modeling:

- *activity*: a logical step, or unit of work that an individual, a machine, or a group can perform

- *control flow*: the execution order of activities
- *resource*: an object necessary for the execution of an activity, e.g., a document, a data item, an application, a role, a fax machine, a phone, etc.
- *resource flow*: the path of resources between activities, i.e., the source and target activities of each resource and the method of transfer
- *role*: a placeholder for a person or organizational unit assigned to a particular activity.
- *organizational structure*: organizational units, roles, people competence, etc.

As an example of an activity based-model consider the telecommunications process in Figure 1. Although there are some BPMTs that support pure goal-oriented or activity-oriented models, most state of the art BPMTs typically provide hybrid models. Figure 8 depicts a classification of the process models offered by five hybrid BPMTs.

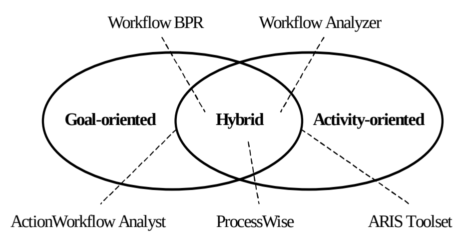

Figure 8. A classification of sample hybrid BPMTs.

More specifically, the ActionWorkflow Analyst tool from Action Technologies lies in the line between goal-oriented and hybrid BPMTs. This is because ActionWorkflow provides a conversation-based model for the higher levels of (abstraction in) the process definition. An activity-based model is used only at the lowest level of the process (e.g., to define the actions in each phase in a loop).

The ARIS Toolset [Ids97] lies at the opposite end of the spectrum, i.e., on the dividing line between activity-oriented and hybrid process models. In ARIS, business processes are defined top-down or bottom-up using Event-driven Process Chains (EPCs) [KNS92]. Process Chains are based on an activity-oriented model, referred to as the control view in the ARIS documentation. In addition, each Process Chain may have a goal associated with it. ARIS provide no functionality to validate, evaluate, or enforce goals. Goals specifications are basically text annotations on activity-based (sub) process specifications.

In addition to the control view, ARIS supports the construction of complementary functional, data, and organizational views/models (according to the integrated information systems approach [Sch92]). Furthermore, it allows the sharing of modeled objects between these views and ensures their consistency. The control view integrates parts of the other views, since it models business processes using information from the functional, data, and organizational views. For the description of the functional, data, and organizational views, established models can be used, e.g. the ER-model can be used for data modeling.

Mainstream hybrid BPMTs include those that provide activity-oriented models that capture additional core business objects. These typically include activity execution time, elapsed time, and cost. By capturing these in combination with their activity-based models, these BPMTs can support a variety of methodologies that aim to improve process efficiency, e.g., by reducing process cost, improving resource utilization cost and/or time, minimizing process execution and elapsed time, etc.. The modeling of such information is important, since the evaluation of a business process often depends heavily on combining such information to reason about its efficiency.

More specifically, the WorkflowBPR by Holosofx [Hol97] uses Activity Decision Flow (ADF) diagrams for process modeling. ADF diagrams can be nested to support top-down process definition. ADF diagrams provide an activity-oriented model that incorporates attributes for modeling activity cost, execution time, and elapsed time (as needed by various methodologies).

The Workflow Analyzer toolset by Metasoftware [Met97] offers the Workflow Modeler tool (formerly Design/IDEF) which supports the IDEF0 methodology and the IDEF modeling standard IDEF1X [Bru92]. IDEF (Integrated DEFinition method) is a model used to describe information systems. IDEF0 is very similar to SADT (Structured Analysis and Design Technique) [MG88, MG91] which was developed by SofTech Corporation in the 1970’s. IDEF is used here to describe complex business processes in sufficient detail. This top-down model is basically a hierarchical activity-oriented model that provides process cost and duration attributes. Just like in WorkflowBPR, these attributes can be used for process analysis and simulation.

ProcessWise Workbench by ICL & Fujitsu [IF97] provides a default set of core process objects (which are represented by pictures or images) for defining business processes. In addition to being activity-oriented, the process model provided by ProcessWise is object-oriented and hierarchical (so that different levels of details can be specified). Process evaluation information, such as cost, time or volume can be added as attributes to core objects of the model. These can be subsequently used for process analysis and simulation.

Business Process Analysis

Analysis of the modeled process is performed to identify the process strengths and weaknesses, and determine if the process should be redesigned or proceed to its implementation. Analytical tools used by the various BPMTs include:

- *Case analysis:* measures and analyzes only a specific process path, as directed by the process designer/evaluator. Case analysis typically estimates process cost and/or time attributes. The analysis calculations use probabilities and parameters assigned to the process conditions and activities. These are assigned by the process designer/evaluator.
- *Weighted average analysis*: calculates mean cost and cycle time using data taken from case analysis. It takes into account all potential execution paths and their relevant probabilities of execution, and gives higher weights to paths with the higher execution probabilities.
- *Critical path analysis*: identifies the critical path in a process. The critical path is the series of activities on which the overall completion schedule of the process depends. Any delay in the completion of any activity in the critical path will cause process delays.
- *Throughput analysis*: identifies the process throughput that can be achieved, assuming that all necessary or a specified level of resources is available.
- *Resource utilization*: given a specific workload, assesses the degree of resource utilization a process can achieve.
- *Value chain analysis*: identifies which activities in a process are critical for providing value to the customer, i.e., achieving a process goal.
- *Activity based costing*: allows the process designer/evaluator to associate cost information to the process definition objects, and then performs financial analysis.
- *Process simulation analysis*: this very important analysis technique is discussed further in the following section.

The WorkflowBPR by Holosofx supports three types of analysis: case analysis, weighted average analysis and process simulation analysis. Case analysis is supported by the use of Gantt Charts, Communication Diagrams, Activity Cost Graphs, and Resource Cost Charts.

The Workflow Analyzer by Metasoftware supports activity based costing analysis. To provide this, Workflow Analyzer integrates a financial analysis tool (the EasyABC Plus) where cost and process information is exported for more detailed analysis.

ProcessWise WorkBench provides no specific support for process analysis.

The ARIS Toolset supports case analysis, critical path, and value chain analysis. Also, the ARIS Promt component (fully integrated into ARIS Toolset) enables the evaluation and monitoring of business process costs by supporting activity based costing. Various cost management requirements are supported, including process cost controlling, optimization, benchmarking, and resource management.

Business Process Simulation

Simulation is very important for evaluating a business process (either new or redesigned) before implementing it. Many BPMTs provide for simulation of business processes and assess performance issues by varying rates of simulation input. For example, these include a wide variety of statistical distribution types ranging from ‘normal’ (bell shaped curves), trinomial (most, least, average), exponential to pre-assigned volumes at different times of day. BPMTs typically provide statistics on resource utilization, and support for animation so that the user can visualize how work moves through the model. In addition, BPMTs often provide facilities to identify blockages or bottlenecks in the process definition. These occur at activities or conditions where work consistently builds up awaiting for resources or other activities to complete. Finally, some BPMTs, provide facilities for pausing the process simulation during a run, handle concurrent processes (i.e., several processes running simultaneously competing for resources), and maintain queue load statistics for assessing the overall number of worklist items and resources that may build up in process queues maintained by the BPMT.

The simulation component of WorkflowBPR supports discrete simulation and provides for most of the above mentioned aspects. Calendars providing the availability of resources are used during simulation, so the simulation output is based on real schedules. The simulation analysis information can also be exported to other analysis tools, such as Microsoft’s Excel.

The Workflow Analyzer of Metasoftware incorporates the Workflow Simulator which automatically translates the process model to a dynamic analysis model. This approach provides a smooth transition from modeling to simulation. Simulation results are displayed graphically and allow the visual assessment of key factors such as bottlenecks, idle resources and operating costs. A variety of graphic formats, from pie charts to bar charts and spreadsheets are provided. Costing statistics can also be produced using the resource costs specified in the process model. Another feature of Workflow Analyzer is that the process model can be exported in a form that is readable by the Design/CPN Simulator [PS90]. This provides powerful simulation capabilities using information that has been inserted as annotations to the process definition. Design/CPN is based on hierarchical colored Petri nets.

The ProcessWise WorkBench supports both time based and event based discrete simulation. It also provides for arrival rate distribution, animation, queuing statistics, and concurrent processes.

ARIS Promt (the integrated simulation component of the ARIS Toolset mentioned before) allows the simulation of ARIS process models. It provides various simulation scenarios, capacity-oriented evaluation of business processes, discovery of performance gaps, identification of resource bottlenecks, evaluation of process using according to time and cost criteria.

Business Process Evaluation Reports and Documentation

BPMTs can typically generate reports for analysis data. In particular, process designers/evaluators can compose ad-hoc, user-defined analysis reports, as needed. In addition, BPMTs provide a set of pre-defined, pre-formatted analysis reports. Both types of reports typically include charts and diagrams.

WorkflowBPR offers a variety of reporting options, providing flexibility in reviewing analysis data from different perspectives. For example, a process designer/evaluator can generate reports to evaluate a process from an enterprise perspective, a resource flow perspective, or an activity perspective that includes scheduling and costing information. Also, ‘as is’ process and ‘to be’ process reports can be generated. These provide analysis information on resource utilization and costs associated with resources. Various charts and diagrams, e.g., Gantt charts for viewing scheduling information or resource requirement charts, can be generated. An interesting feature of this tool is the automatic generation of a Process Improvement Document. This uses real data from modeling and analysis activities and assembles them into a Microsoft Word document. Such a document is very useful for justifying BPR and CPI initiatives.

ProcessWise provides similar user-defined and pre-defined reporting.

The ARIS Toolset provides for entire documentation of business processes. The ARIS documentation can be used for other purposes too, like management presentations, user training or ISO 9000 certification.

Evaluation of Current Workflow Management Technology

In the following sections we discuss the features and capabilities currently supported by WFMSs. These include commercially available products and home-built applications currently in use in various organizations. However, although a combination of BPMT and WFMS technology currently provides the most comprehensive support to the business process lifecycle, commercial WFMSs are sometimes not the only (and in some cases not the best) infrastructure technology that can be used to implement and automate business processes. Therefore before we describe any specific WFMS capabilities, we first discuss the perspective of commercial WFMSs and their vendors. In particular, in the following paragraph we characterize WFMSs from the perspective of process implementation and automation requirements. In addition, we discuss the relationship of WFMS technology to other infrastructure technologies that can support process implementation and automation.

Seen from the process implementation and automation perspective, process requirements can be characterized by considering the degree to which a process depends on humans or software for performing and coordinating activities. Such a characterization is depicted in Figure 9. On the one extreme, human-oriented processes requires humans collaborating in performing activities and coordinating activities. The requirements for process implementation in this environment are to support the coordination and collaboration of humans and to improve human throughput. Humans, however, must ensure the consistency of process objects and results.

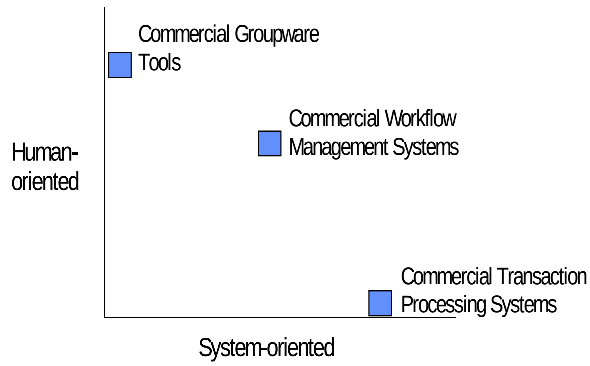

Figure 9. Processes with respect to software and human supported activities

On the other extreme, system-oriented processes require computer systems that perform computation-intensive operations and automated activities. In addition to being highly automated, system-oriented processes access heterogeneous, autonomous, and/or distributed (HAD) information systems. While human-oriented process implementations often control and coordinate human activities, system-oriented process implementations control and coordinate automated activities (typically with little or no human intervention). Consequently, system-oriented process implementations must include software for various concurrency control and recovery techniques to ensure consistency and reliability.

In human-oriented process, the main issues to address include:

- human-computer interaction matching human skills to activity requirements
- changing office culture, i.e., how people need or prefer to work

In systems-oriented process, the issues to address include:

- matching business process requirements to functionality and data provided by existing information system and/or their applications
- interoperability among HAD systems
- finding appropriate software activities to perform process activities
- determining new software required to automate business processes
- ensuring correct and reliable system execution

Issues such as exception handling, user overrides, prioritization, and deadline may appear in different forms in both types of process, and need to be addressed. Also depicted in Figure 9 are points indicating process characteristics and issues that are addressed by:

- groupware systems,
- commercial WFMSs, and
- commercial transaction processing (TP) systems (e.g., distributed DBMSs, TP monitors).

Groupware systems are typically used to support the implementation of processes involving predominantly human activities. Commercial TP systems are used to provide for the implementations of system-oriented processes involving activities submitted as DBMS or TP monitor transactions. Although, WFMSs overlap with groupware and TP monitors, most commercial WFMSs are designed to address the requirements of processes in the center of the process space depicted in Figure 9.

Having provided this general perspective, in the following sections we discuss the workflow process models, tools, and infrastructure provided by commercial WFMSs. We use examples from actual WFMS products, as needed.

Workflow Model

Workflow management systems typically support activity-oriented models. Some toolkits that provide tightly integrated BPMTs and WFMSs (i.e., Level 2 integration), also provide hybrid process models through the BPMT model. Examples of toolkits in this category include the ARIS toolkit, the ProcessWise toolkit, and the ActionWorkflow Process Builder – Analyst and Developer editions [Act97].

Activity-oriented workflow and business process models typically support similar core process objects. In particular, activity-oriented workflow models typically support the following:

- *activity*
- *control flow*
- *workflow resource*: a workflow data object, an application, and/or a role necessary for the execution of an activity
- *workflow data*: e.g., a scanned or electronic document, a spreadsheet, a graphics image, a voice message, a fax, an email, etc.
- *dataflow*: the path of workflow data between activities

- *organizational structure and roles*
- *participant/performer*: person, group or application that fills roles and interacts while performing activities in a particular workflow instance.

There are two basic differences between core process objects in workflow and business process models. The first is the scope of resources which in workflow process models is limited to computerized resources (i.e., data, applications, and human roles) and resource flow is basically dataflow. The second difference is the notion of participant that implies assignment of “real” human resources and applications for performing each workflow instance. This is not required for business process modeling, since process evaluation either does not depend on participants or they can be probabilistically simulated.

To provide different levels of abstraction, activity-oriented models (and the WFMSs that provide them) typically support the nesting of workflow processes. Higher levels of abstraction help in capturing the business process as it relates to the operations and the organization (sub)units that participate in carrying out the process. Modeling at these higher levels is typically devoid of implementation, technology or software. These levels can be imported from a BPMTs. The lower levels of abstraction are required to capture a variety of details about the actual information systems and applications required to support the implementation of workflow activities.

Examples of commercial WFMSs that provide activity-oriented workflow models include IBM’s FlowMark [Ibm97], FileNet’s Ensemble and Visual Worklow [Fil97], InConcert [InC97] and EASTMAN SOFTWARE Workflow [Eas97] (the latter originated from Wang’s Open/Workflow).

In the following paragraphs we describe the core process objects in the Workflow Process Definition Language (WPDL) defined by the WfMC [WfM97]. Although WPDL is currently incomplete, it is an attempt for defining industry standard scripting language for representing workflow processes. We discuss WPDL because it supports a set of specific core process objects that provide the workflow engine with the details of the process to be executed. Furthermore, this is a specific example of a process representation that can be use to communicate process definitions between a BPMT (or a workflow process definition tool) and a WFMS. WPDL provides the following core process objects:

Workflow Process Definition: describes the process itself, i.e. name and/or ID of process, etc.. The workflow process definition optionally contains a reference to an external organizational model.

Workflow Process Activities: each activity is defined through four dimensions, the who, the what, the how and the when:

1. The activity is assigned to one or more workflow participants, who are permitted to play the role in this activity.
2. The activity is assigned to an application, which will be invoked during runtime.

3. Activities are related to one another via transition conditions. Transition conditions are usually based on workflow data.
4. Optionally an activity depends on a time frame (earliest begin, deadline, etc.).

Workflow Participant Definition: describes the performer of an activity in terms of a reference to an (external) organizational model. The definition of such a performer does not necessarily refer to a single person, but also to a function or any other organizational entity.

Transition Information: describes the navigation between different process activities, which may involve sequential or parallel operations. Thus activities are connected to each other by transition information.

Workflow Application Definition: defines one to n applications that are assigned to an activity. These applications will be invoked during run time by the WFMS. The workflow application definition reflects the interface between the workflow engine and the application.

Workflow Process Relevant Data: data used by a WFMS to determine particular transition conditions and may affect the choice of the next activity to be executed. Such data is potentially accessible to workflow applications for operations on the data and thus may need to be transferred between activities.

Organizational/Role Model Data: (possibly external) data that may be referenced by the process definition data to describe the identify and relationships of human and automated resources associated with workflow activities. The organizational/role model data may contain information about the identity of human and automated resources, organizational structure of resources, role information identifying the function that resources can perform.

Workflow Control Data: internal control data maintained by the workflow engine. They are used to identify the state of individual process or activity instances. These data may not be accessible or interchangeable outside of the workflow engine but some of the information content may be provided in response to specific commands (e.g. query process status, give performance metrics, etc.).

Dataflow

Some WFMSs (e.g., HP's AdminFlow [Hew97]) support the flow of only process relevant data. Others (e.g., IBM's FlowMark [Ibm97]) support the flow of any data specified in the workflow process definition (i.e., independently of whether such data is referenced in a transition condition). In practice, the ability to pass data among the participants is what determines the effectiveness of a WFMS. For example, during the processing of an international patent, each patent application involves a significant number of documents referencing other information sources and patents. Each existing patent is also a large collection of documents. Additional attached information such as articles and scientific papers are smaller in size but can be numerous. To the application itself, related patents and relevant articles are included as part of the documentation. Hence, transferring the case from the initial stages to the evaluation stages involves moving a great deal of information around (often from country to country as is the case with the European Patent Office).

The typical support provided for data flow is to ensure the existence of all information objects before an activity is started, and to locate and retrieve these objects. This typically requires no specific action on the part of the user, who will experience that all activities on the worklist come with all documents and information needed to do the work. Current WFMSs achieve this by allowing the process designer to specify whether the WFMS should provide dataflow by moving data references rather than the data itself. Some WFMSs rely on specialized external systems to perform dataflow. For example, the EASTMAN SOFTWARE Workflow [Eas97] relies on Microsoft Exchange and an imaging system for storing and routing data involved in dataflow, including scanned or faxed images, spreadsheets, graphics, voice, email, and multimedia objects. HP's AdminFlow [Hew97] uses a CORBA Object Request Broker (ORB) [OMG97] to perform dataflow by moving object references. Other WFMSs, such as FlowMark [Ibm97] and InConcert [InC97], integrate imaging systems with the workflow engine to handle the movement of scanned documents. However, such integration is often poor and the engine has minimal control over the flow of data, complicating dataflow synchronization with control flow.

Workflow Process Definition Tools

Most WFMSs provide tools for graphical specification of workflow processes. The available tools for workflow process design typically support the iconic representation of activities. Definition of control flow between activities is accomplished by:

1. connecting the activity icons with specialized lines/arrows which specify the activity precedence order, and
2. composing the transition conditions which must hold before the workflow execution moves from one activity to another.

Dataflow between activities is typically defined by filling up dialog boxes that specify the input and output data to and from each activity. In some WFMSs, such as FlowMark, dataflow definition involves using specialized lines/arrows to draw dataflow paths between activities.

Assuming that BPMTs are used to model business processes and that BPMTs and WFMSs interoperate, the role of workflow process definition tools is limited, since either the entire workflow process definition or a significant part of it is usually performed at the BMPT.

Analysis, Simulation, and Animation Tools

Most workflow products provide workflow process animation tools, but depend on external BPMTs for simulation and analysis. Therefore, the sophistication of analysis and simulation provided by BPMTs, as well as the degree of integration and interoperability between BPMTs and WFMSs have a direct impact on the ability to validate and evaluate workflow processes.

Workflow Monitoring and Tracking Tools

Workflow monitoring tools can present different views of workflow process execution. They illustrate which activity or activities are currently active, by whom they are performed, the priorities, deadlines, duration, and dependencies. Administrators can use such monitoring tools to compute statistics such as activity completion times, workloads, and user performance, as well as to generate reports and provide periodic summary of workflow process executions. In Section 0, we discussed that workflow execution data and statistics may be fed back to a BPMT to facilitate process evaluation and improvement.

Basic WFMS Infrastructure: Architecture, GUIs, and APIs

Many commercial WFMSs have loosely-coupled, client-server architectures that divide and distribute the WFMS functionality in components similar to those illustrated in Figure 5. Examples of WFMSs having such architectures include FlowMark, FileNet's Visual Workflow, and EASTMAN SOFTWARE Workflow. In such WFMSs, the WFMS engine is typically the central component, and it is often referred to as the WFMS server. Process Definition data, workflow control data, workflow relevant data, and organization/role data are usually kept in a centralized database (or a set of such databases) under the control of the WFMS engine, its (client) tools, and/or the external applications invoked by the workflow process. Most WFMS engines and tools take advantage of the data manipulation capabilities of a commercial database management system (DBMS), such as ORACLE, Informix, Sybase, and ObjectStore.

WFMSs typically offer proprietary GUIs and (client) tools for graphical process specification, process monitoring, process invocation, and interaction with human participants. However, the advent of the Web has made many workflow product designers consider Web browsers and GUIs for WFMS (client) tools. Using the Web as a front-end platform allows for workflow processes that are geographically spread out. Since many users already use Web-browsers, there is no need to distribute client software, thus enabling a wider class of WFMS applications. Many WFMSs currently support web-enabled tools for starting and monitoring workflow process instances, including among others FileNet's Ensemble and Visual Workflow, IBM's FlowMark, UES' KI Shell

[Ues97], and ActionWorkflow's Metro [Act97]. Web-enabled client tools are becoming a de facto standard in current WFMS.

Many state-of-the-art WFMSs, including FlowMark and InConcert, have complete application programming interfaces (APIs). This allows everything that can be done through the user interface also to be done via an API. In addition, the API can be used to introduce specialized user interfaces and tools designed to meet specific application requirements.

Advanced WFMS Infrastructure: Distribution, Scalability, and Component Redundancy

Commercial WFMS currently may not support more than several hundred workflow instances per day if they are used directly off the shelf (i.e., all the clients and server components provided by the vendor are utilized, and the default settings and configurations are used). However, there are processes, such as the one illustrated in Figure 1, that require handling of a larger number of workflow instances. In addition, the use of more powerful computers may not necessarily yield corresponding improvements in WFMS throughput. These problems are due to limited (or lack of) engine and worklist handler scalability, distribution and component redundancy for dealing with load balancing and engines failures.

Workflow vendors have realized some of these limitations in earlier versions of their products, and they are currently introducing improvements to address them. In particular, the latest WFMSs versions from several vendors (including FlowMark, InConcert, and Plexus) allow the use of multiple WFMS engines for supporting distributed workflow process execution. In addition, vendors (such as IBM) currently provide capacity planning tools that can estimate the number of WFMS engines required to support the execution requirements of a given process. However, in WFMSs like FlowMark distributed workflow process execution requires manual replication of the process definition in all engines that may be involved in the process execution. This approach suffers form potential configuration problems. For example, consider the process in Figure 1. Suppose that a capacity planning tool has estimated that several dozens of engines needed to support a realistic version of this process. In the event of a process update, all engines must have consistent process definitions before the process can be executed. However, currently WFMSs do not provide process configuration management and do not ensure the consistency of process definition in different engines.

Another serious limitation in the current approaches for distributed workflow execution is the lack of automatic load balancing. In the following paragraphs we discuss server (engine) scalability and component redundancy issues, and describe approaches for addressing these problems.

Just like any other client-server system, the architecture of a WFMS typically corresponds one of the client-server architectures shown in Figure 10 through

Figure 13 [GE95]. Figure 10 shows an architecture in which there is a server process for each client. Suppose that each of the X clients uses Y applications and that each application opens Z files. Such an architecture does not scale well because of the large number (X*Y*Z) of connections in the system and also the large number (X*Y) of server process running on the server machine.

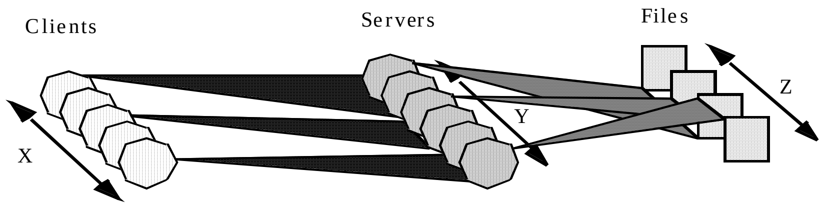

Figure 10. Server-Process-per-Client (X*Y*Z connections)

Figure 11 shows a process per server architecture in which the functionality of the Y applications is provided by one multi-threaded server process. In this case the server process becomes a bottleneck and in the absence of Operating System provided threads, it cannot use multiprocessors effectively. Furthermore, the server program packed with several applications becomes hard to maintain as faults cannot be easily isolated.

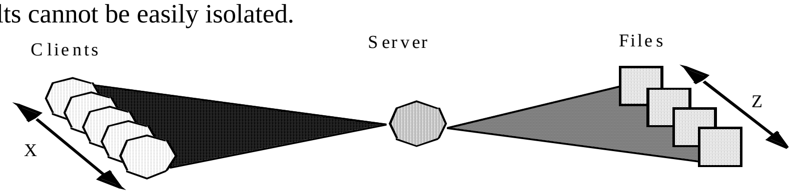

Figure 11. Process-per-Server (X+Z connections)

Figure 12 shows an architecture in which the server functionality and data are partitioned and there is a server process for each partition. As long as the partitioning of the functionality balances the load on the server processes, this architecture addresses the scalability problem to a large extent. However, each client has to be aware of the application partition and any change in the partitioning requires considerable reorganization. Moreover, it is difficult to achieve a proper partitioning of functionality or data.

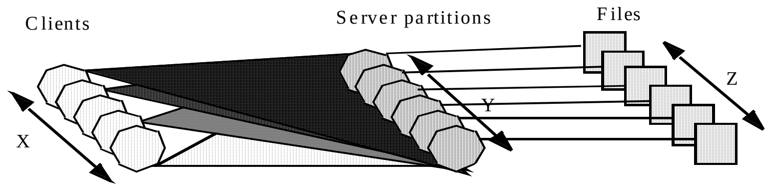

Figure 12. Process-per-Application-per-Server Partition (X+1 connections per server)

Figure 13 shows a "three-ball" architecture where a router between the client and server processes is used to manage a pool of servers. The router automatically balances the load among the servers for each application, spawns new server processes to handle heavy load, and restarts failed server processes. This system can be scaled up further by replicating the router process. In many modern systems, the router is provided by a TP monitor.

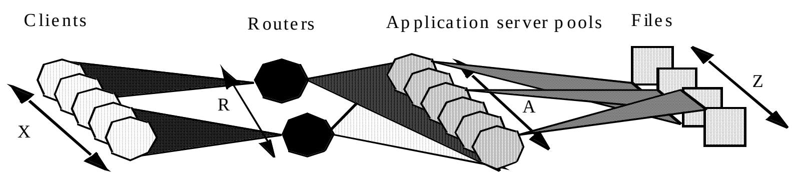

Figure 13. Three-Ball (X+A connections per router).

Out of the box, workflow products can be categorized into one of the "two-ball" architectures Figure 9 through Figure 12. Therefore, they have limited scalability. Consequently, a workflow application's scalability needs should be carefully matched with the scalability provided by the product. To this end, assistance from vendor, preferably in the form of a capacity planning tools, should be sought. In some cases workarounds for the scalability problem will need to be devised.

In many cases a simple partitioning of the instances on geographical basis may be sufficient to scale up. For example, a process for handling visits to customer premises in a particular state can be implemented using several workflow servers – one for each state.

In other cases, e.g., a process for handling service calls from customers all over the country, such a partitioning of instances among workflow servers may not be possible. In such situations WFMS users will have to develop additional complementary software components, e.g., the third ball of the "three-ball" architecture of Figure 13. This software would have to implement the functionality attributed to the router of Figure 13.

In still other situations, the scalability of a deployment can be improved by replacing certain heavy-weight components of the product. For example, a general purpose, but inefficient, worklist handler provided by a product can be replaced with a custom light-weight worklist handler built using the API provided by the vendor.

Interoperability Among WFMSs and Heterogeneous Applications

For workflow processes that access heterogeneous information systems, interoperability among heterogeneous systems and WFMSs is important for the following reasons:

- generic code allows access to heterogeneous information systems without recording when these systems change,
- the absence of code for routing and other types of coordination enables fast development of applications with fewer errors, as opposed to applications that are developed using more conventional methods such as 4GL programming, and
- changes in participating information systems require minimal workflow re-implementation, since coping with this requires no code changes in workflow implementations except re-specification of heterogeneous system interfaces.

Currently, interoperability means that various interface standards on different levels are available, such as protocol standards (e.g., e-mail, TCP/IP), platform standards (e.g., MS-Windows, UNIX, Windows NT), and object interface standards (e.g., OLE, CORBA). However, interoperability at the workflow level requires additional technology and standards that exploit and extend current technology industry solutions for interoperability, such as those developed by the Object Management Group and the World Wide Web Consortium. Because many types of errors could arise in a distributed heterogeneous computing environment in which the workflow is executed or enacted, error handling is generally considered to be a difficult problem. The difficulty is enhanced by the inherent complexity of business processes. Error prevention and handling is one problem area where new breakthroughs are needed in order to deliver genuinely robust workflow processes.

Concurrency Control, Recovery, and Advanced Transactions

Issues of concurrency control are well-understood issues in database and transaction processing products. State-of-the-art WFMSs take different approaches to concurrency control as compared to database and transaction processing products, depending on perceived workflow process requirements.

Current approaches (e.g., check-in/check-out, pass-by-reference/pass-by-value, etc.) are primitive when compared to how DBMS support concurrency. Some WFMSs allow multiple users/applications to retrieve the same data object concurrently. However, if each user decides to update that data object, new versions of the data item are created to be reconciled (merged) by human intervention. The rationale for this approach is the assumption that data object updates are rare. Thus, consistency can be handled by humans who review the data object versions and decide which version to keep.

To support limited forward recovery, contemporary WFMSs utilize transaction mechanisms that are provided by the DBMSs that maintain the process relevant data. In particular, such WFMSs issue database transactions to record workflow process state changes in these DBMSs. In the event of a failure and restart, the WFMS accesses the DBMS(s) to determine the state of each interrupted workflow instance, and attempts to continue executing workflow processes from the point they have been interrupted by a failure. However, such forward recovery is limited to the internal components of the WFMS.

State-of-the-art WFMSs currently offer virtually no support for automatic undoing of incomplete workflow instances. Workflow designers may specify the withdrawal of a specific instance from the system while it is running, possibly at various locations, for which an undo operation is needed at the process level (as opposed to the transaction level). When some business processes fail they can be compensated rather than rolled back. For example consider a workflow for purchasing a house. If the sale of a house is canceled halfway, compensation payments must be made. Recovering from such failures requires that much of the recovery is designed specifically for this workflow application. Also, erroneous execution typically requires some form of human intervention. These issues illustrate that error detection, handling, and recovery are more complicated in the context of business process than they are the database transaction context.

The workflow vendors and the research community are debating whether it is possible to use database management system technology and transaction processing monitor technology, or the extended/relaxed transaction models [GHM96] that have been developed to deal with the limitations of database transactions.

Evaluation of Current BPMTs and WFMSs Integration

In Section 0, we discussed that major BPMT objectives include: (i) to function as universal process definition and monitoring tools for WFMSs, and (ii) to provide for implementation and automation of business processes through integration with WFMS. To achieve these objectives, BPMTs must export (and possibly translate) their process definitions to WFMSs, or share process models and definitions with WFMSs. In the following sections we describe approaches current BPMTs use to provide these, and discuss related requirements and technology.

Loose Integration

The category of loosely integrated BPMTs and WFMSs includes several BPMTs providing Level 1 interoperability (as defined in Section 0). That is, typical BPMTs in this category provide direct and unmediated input of process definitions into WFMS engines from different vendors. Such BPMTs must export their business process definitions using the workflow process model and representation expected by the WFMS(s). Therefore, BPMTs in this category translate their business process definitions into the workflow process model definitions supported by one or more target WFMSs.

Integration with each workflow vendor involves filtering business process model data for appropriate components, translating it into WFMS engine terminology, validating it, and placing it in readable format. Once this is accomplished, systems can be interfaced to save time, minimize redundancy, and insure proper process validation.

Products in this category include Holosofx's WorkflowBPR and Meta's Workflow Analyzer. WorkflowBPR provides direct support for three specific export environments, FileNet's Visual WorkFlo, IBM's FlowMark and the standard WPDL format defined by WfMC. Workflow Analyzer provides specific support for FileNet. Such products offer solutions designed specifically for each target WFMS. The WPDL interface offered by Workflow BPR and some other BPR tools deserves additional discussion.

As we discussed in Section 0, WPDL is currently under development by the WfMC, the only workflow standards body. The WfMC is developing interface specifications that will enable interoperability between WFMSs, as well as between WFMS and BPMTs (since from the perspective of WFMS, a BPMT may be thought as an external process definition tool).

The WfMC has developed a standard Workflow Reference model (Figure 5) and identified a set of interfaces to enable products to interoperate at a variety of levels. The diagram of Figure 14 provides a pictorial description of the WfMC workflow reference model interfaces. Details concerning the definitions and specification of the components and interfaces of the reference model as well as other documents relating to the standards can be found in [WfM97].

WPDL is part of the WfMC interface 1, designed for process definition import and export. Translation (perhaps only partially automated) from a business process definition to the workflow process definition may be possible through this representation. Unfortunately, Interface 1 is defined in draft format and is incompletely specified. In addition to BPMTs, some WFMSs also have import/export capabilities that are versions of this interface.

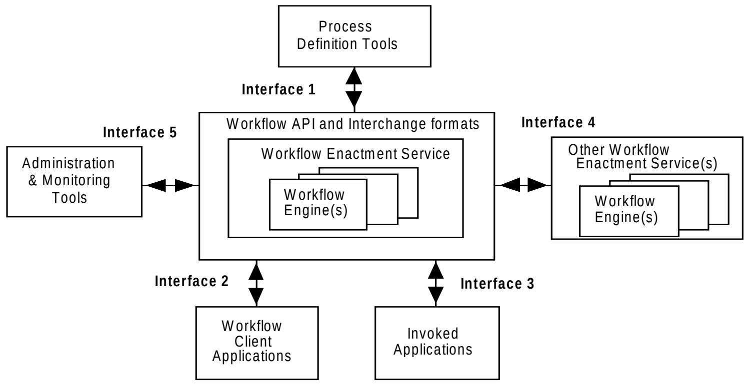

Figure 14. Workflow Reference Model - Interfaces

Tight integration

This category typically includes toolkits that provide tightly integrated BPMTs and WFMSs having Level 2 interoperability (as defined in Section 0). That is, BPMTs and WFMSs in this category use the same process model and share process definitions. The latter is typically accomplished if the BPMT and the WFMS share a common process definition repository, or the BPMT provides direct and unmediated input of process definitions into the WFMS engine. Currently commercial products in this category include toolkits, such as the ARIS and ProcessWise. Such toolkits are typically offered by BPMT vendors attempting to enter the WFMS market.

Reverse integration

In this case, a WFMS is used to define the process. The objective of reverse integration is to be able to import the process in a BPMT. This allows the BPMT to provide the following:

- real time monitoring of workflow processes
- evaluation and improvement of legacy processes designed using a WFMS
- definition of *legacy application-aware* business process, i.e., processes that take into account the existing functionality of legacy systems as basic activity elements in the process design.

Although no BPMT currently provides reverse integration, some vendors (e.g., Holosofx) are currently extending their products to provide reverse integration facilities with WFMSs. Clearly, this will allow BPMTs to define, monitor, and evaluate existing processes designed and implemented using a WFMS. In the following sections we focus on the issue of legacy application-aware processes which we consider as one of the most important limitations in current BPMT and WFMS technology.

Process modeling methodologies and technology provided by BPMTs and WFMSs, have not addressed the problem of workflow implementation involving legacy information systems. For organizations that rely on legacy information systems, business and workflow process specification for performing workflow implementation requires mapping workflow process specifications to legacy system functionality and data. If this is not done, BPR and CPI may produce process specifications that cannot be supported by the legacy information systems.

Today, many processes are embedded within legacy systems to manage the initiation, sequencing, scheduling and monitoring of associated system functions, such as displaying a screen to a user, or initiate transactions to validate a service address or assign a telephone number. The embedded processes may control the sequence of such functions. However, in these legacy systems, functions and process are not separated within the modules of the system. As shown at the top of Figure 15, the functions and processes are intimately intertwined.

Legacy systems provide a limited number of API's through which their functions can be invoked, we refer to such functions as API-provided functions. The API-provided functions are often at a very high level of granularity including a substantial amount of process-relevant code. For example, a legacy system might provide an API for establishing new telephone service and for canceling telephone service, but no APIs for finer grained services such as assigning a new telephone number or adding a new customer into the customer database. The goal of BPMT and WFMS technology is to *accommodate* this legacy situation, and ultimately *rework* legacy systems to:

1. separate functions from process (to some useful degree),
2. express the process explicitly, and
3. invoke the functions from the process.

This is illustrated in the lower part of Figure 15.

Accommodating Legacy Systems: WFMSs and reverse integration of BPMTs and WFMSs can accommodate legacy systems in two ways. First, a BPMT and a WFMS can used to design and implement the activities or subprocesses corresponding to existing API-provided functions. The existing legacy system API's can be used as the implementation of an activity or subprocess. In the example in Figure 1, wherever the business process calls for establishing telephone service for a new customer, the existing legacy system API would be called. Second, the workflow process can be adapted to exploit the existing functions of the legacy system. So, in the case where a business process needs to assign a telephone number, the business process could include steps for creating a dummy new customer telephone service order, and later canceling that telephone service order, in order to get at the legacy system function that assigns a telephone number. In both these cases of accommodation, the legacy system does not have to be modified.

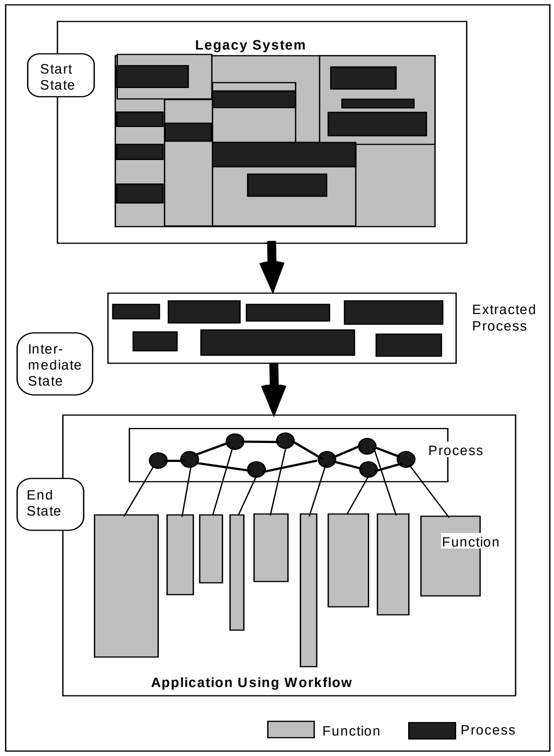

Figure 15. Process Extraction from a Legacy System

Reworking Legacy Systems: In the longer term, there is the option to "break up" (in whole or in part) certain existing legacy systems to make its processes and functions reusable in one or more business processes. Certain systems function can be separated out of the existing API-provided functions, each independently invoked. Once these finer grain functions become available, they can be reused from one business process to another. In the example in Figure 1, this would allow telephone number assignment and service address validation, both subfunctions in the original API-provided function for establishing a new customer, to become new separate functions.

In addition, there is the option that certain embedded processes may be separated out of the legacy applications and into a workflow process definition.

In those cases where the process is unlikely to change in the future, the cost is probably not justified. But, if the process is likely to change, there can be a definite benefit. In this case, the (re)use of these functions by other processes will require exportation of related workflow subprocesses and activities from the WFMS to a BPMT.

In cases where any legacy system modification is contemplated, analysis is needed to identify embedded processes and functions that have potential for reuse and that can be extracted with reasonable effort. Tradeoffs will have to be made between the cost and risk of legacy system modification and both the short term cost/benefit of workflow implementation and the long term cost/benefit as processes change.

Critical Success Factors and Conclusion

In the paper we described BPMT and WFMS technologies and tools. In addition, we proposed that the combination of these can provide support for comprehensive process lifecycle management.

However, even given the ideal BPMT and WFMS technology there are other critical factors that are necessary to ensure the success of BPMTs and WFMSs in supporting BPR, CPI, and process implementation. We believe that the most important among these critical success factors are:

- the organization must be process-centered and the executive commitment to process management must be strong
- the division of responsibilities between process and participating applications must be at the appropriate level

Since both BPMT and WFMS technologies focus on the explicit support of business processes, its deployment requires that the organization be process-centered. That is, there must be a commitment to all aspects of managing the business by process, including explicit process definition, process reengineering, process measurement and evaluation, continuous process improvement, and efficient and rapid process implementation. Executive commitment to process management is also crucial to the successful use of BPMTs and WFMSs. Time and resources must be allocated to define processes correctly and at a working level of detail that includes exception handling and process recovery from failures. Since the primary functions of BPMTs and WFMSs are to evaluate, implement, and enact a process as defined, a substantial risk is poorly defined processes being evaluated and implemented through BPMTs and WFMSs.

Another critical issue is selecting the granularity of workflow activities to be implemented by (new or legacy) applications. Since this divides the process management responsibility between the WFMS-supported process and participating applications (i.e., between the WFMS and the applications supporting the workflow implementation), this determines how well the process can be managed by the WFMS and how easily the process can be adapted as business requirements change. If the level of granularity of activities is too high, the process will be hard to change because the right building blocks are not there. In addition, the management of the process may not contain enough detail to provide insights into current process performance or future performance improvements. If the level of granularity of activities is too low, the process will take longer to develop, the extra effort will not provide any benefit, and the BPMTs and WFMSs will manage unnecessary process detail. In general, frequently changing (sub)processes are best handled by the WFMS, while stable processes can remain in code.

If these critical success factors are met, we envision that the business process management lifecycle will be managed as follows. The business staff responsible for defining the business vision, deciding related business goals, and determining how to meet them, uses BPMT technology to define and evaluate business processes. With the help of IT, they decide which processes are candidates for WFMS implementation and define those processes at a working level of detail, i.e., the level of detail at which processes can be managed WFMS technology. These are accomplished by using a combination of integrated BPMTs and WFMSs, as discussed in this paper. IT staff completes the workflow implementation and assist with its operation using WFMS technology. The business staff monitors the process execution, using tools provided by WFMSs (or BPMTs when there are products supporting reverse integration). These tools provide complete visibility into the state of the process. This visibility gives the business staff great power to manage the process while it is being executed. For example, if a part of the process becomes ‘stuck’ because an unanticipated situation arises such that the process cannot continue, this will become visible and steps can be taken by the business staff to remedy the problem and continue the process.

We believe that such a unified approach to the utilization of integrated BPMT and WFMS technology provides the most benefits throughout any process-centered organization.

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