Workflow-based Process Monitoring and Controlling - Technical and Organizational Issues

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Abstract

Workflow management systems enable the exact and timely analysis of automated business processes through the analysis of the logged audit trail data. Within the research project CONGO[1] we develop a process analysis tool (PISA) that can be employed to analyze the audit trail data of different workflow management systems in conjunction with target data from business process modeling tools. A working prototype has been completed that integrates data of the ARIS Toolset and IBM MQSeries Workflow. The analysis focuses on three different perspectives – processes and functions, involved resources, and process objects.

We outline the economic aspects of workflow-based process monitoring and controlling and the current state of the art in monitoring facilities provided by current workflow management systems and existing standards. After a discussion of the three evaluation perspectives, sample evaluation methods for each perspective are discussed. The concept and architecture of PISA are described and implementation issues are outlined before an outlook on further research is given.

1. Distributed process information systems

1.1. Workflow monitoring and controlling

The need to serve customers in global markets and the tendency towards smaller, more flexible, less hierarchical organizations leads to an increasing spatial distribution of companies. This distribution of formerly centralized enterprises on the one side and the (temporary) integration of different companies (virtual enterprises) leads to the necessity of an organizational and functional connection of the distributed workplaces. Distributed information systems and Internet-based workflows are the enablers for these kinds of ventures.

During the enactment of workflow-supported business processes the automation of coordination increases the efficiency of process execution through the elimination of transport times, the automation of routing decisions and the monitoring of deadlines. However, the actual benefits of workflow management are usually described in vague terms. While the costs for the selection and introduction of the system can be described rather precisely, the benefits of workflow automation are more difficult to determine. Besides quantitative benefits such as decreasing cycle times, reduced personnel cost and (if workflow and document management are combined) document storage space and paper cost, qualitative aspects have to be taken into account as well. These figures include shorter time to market due to process improvement, higher process quality due to decreased error rates and faster response to customer inquiries. Moreover, while most costs from the introduction of a workflow management system are generated during the system introduction phase, the benefits are generated over a much longer period of time. In order to enable a cost-benefit analysis during the requirements analysis phase of a workflow project, time-adjusted methods of investment analysis are necessary.

The historical data of workflow instance execution provides a valuable source for the analysis of the economic impact of workflow management systems. This historical data can be evaluated either in real-time or during an ex-post analysis.

Operative process controlling, also called *workflow monitoring*, deals with the analysis of workflow instances at run-time. Active monitoring of the current state of

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workflow instances can serve numerous purposes, such as the generation of exception reports for overdue work items or early warning reports for potentially overdue work items (Management-by-Exception, cf. e. g. [1]). Passive monitoring upon request can deliver status information about running workflow instances, e. g. for answering a customer inquiry about the status of an order (cf. e. g. [2], [3]). Workflow monitoring can also be divided into technical and organizational monitoring. While technical monitoring is used for performance measurement (e. g. system response time, system load etc.), organizational monitoring measures the organizational efficiency (e. g. idle times, workload analysis etc.).

Strategic process controlling, i. e. *workflow controlling*, aims at the ex-post analysis of the logged audit trail data of process enactment (sometimes called strategic process controlling). Here the single workflow instances are aggregated according to different dimension schemes which are described in section 3. Workflow controlling is useful for the detection of long-term developments in workflow enactment and the review of already existing workflow implementations. In order to identify deviations in process execution, the audit trail data is often compared to target data derived from corresponding business process models.

With the distribution of information processing facilities in enterprises as described above, the stakes for management information systems increase, since the executives now have to be provided with relevant information from distributed processing sources, independent of the source or the destination of the information requested. This development leads to new problems in the design of process information systems. For example, the enactment of a process by parties around the globe may lead to the situation, that one activity is executed by a performer in Munich, while the next activity is executed in New York. If the audit trail data (i. e. the logged history information about the activity enactment) reflects the local time of enactment without specifying the time zone, an analysis of the process might show that the second activity was executed before the first.

1.2. Related work

Workflow-based process controlling has received relatively little coverage in the related literature. Most publications in this area describe the technical facilities necessary for the logging of the audit trail data (cf. e. g. [4]). The Workflow Management Coalition Interface 5 specifies the elementary information a workflow management system should record about the execution of workflow instances [5], but gives no advice on how to evaluate this information.

WEIKUM compares a temporal database approach for the storage of workflow runtime data with a text-file based approach in order to store the log entries [6].

The management of history data in distributed applications is discussed by KOKSAL et al. in the context of the distributed workflow management system Mariflow [3]. Technical issues for the storage of the data and economic queries on distributed data sources are presented, but no further discussion of the economic exploitation of the history data is given.

An approach for the tracking of history information in a distributed workflow management system is presented by MUTH et al. [7]. Within the prototype Mentor-lite, data about current and past workflow instances are kept in a temporal database that can be queried either at runtime or for ex-post analyses.

A methodology for the analysis of sequential design processes has been proposed by JOHNSON and BROCKMAN [8]. Their approach focuses mainly on the execution time of single process activities and is limited to sequential processes. However, one of the main optimization effects of workflow management systems is the concurrent execution of independent subtasks within one workflow. Therefore, this approach is only applicable to a small subset of all workflow processes. A wider scope on the analysis of historical process data can be found in [1], where the author discusses the evaluation of workflow history data as workflow “metrics”. The controlling applications described are statistical evaluations as well as the run-time detection of late cases and overdue tasks.

All in all, the current work does not deal with process monitoring and controlling from a business and a technical viewpoint at the same time.

2. Continuous process engineering

Process monitoring and controlling is primarily not a technical issue, but an organizational one and, as such, it is of high importance for all process management initiatives. An approach to position process monitoring and controlling in a procedure model for process management can be found in figure 1.

The initial activity in this procedure model is always the selection of the processes to be redesigned. The most relevant processes are characterized by the facts that they require reorganization and that they produce important net benefits. These processes must be modeled in order to have a common understanding of the processes. The results of this activity are as-is process models, which are to be discussed by the project team. To-be process models describe the new process design and document the result of all process optimization efforts. The implementation of the new processes requires organizational and technical activities like the configuration of associated ERP modules, the introduction of workflow-based applications or the training of new staff members. Typically, process implementation is the stage in which most projects finish. The process realization itself is usually out of the scope of business process reengineering projects. However, it is the critical stage, when project activities are converting into a running business. Process monitoring and controlling can be seen as an activity which lies on top of the business processes.

- Priorization of relevant processes
- Process modeling (current)
- Process analysis
- Process optimization
- Process implementation
- Process realization
- ***Process monitoring/contolling***

Figure 1. Process Change Management

The main objective of process monitoring and controlling as an embedded task within such a holistic process management is to provide the necessary data basis for continuous process change management. By this, the reorganization efforts are extended beyond the first initial implementation of new processes.

The data gained through the monitoring and controlling of data can be used for two purposes. On the one hand, the performance of business processes can be evaluated. On the other hand – and in addition to this main objective – process monitoring and controlling is useful to measure the value of the IT investment necessary to improve the processes. The main IT infrastructure of process monitoring and controlling is a workflow management system. The effects related to a workflow management system can be distinguished in monetary and non-monetary effects.

Selected monetary effects of the use of a workflow management system are:

- reduced processing times (personnel cost)
- reduced transport times (personnel and resource cost)
- reduced storage costs (for paper archives)

As a consequence, an IT system for process monitoring and controlling needs interfaces to applications like HR systems, financial accounting, cost and revenue accounting, and asset management.

More often, it will not be possible to measure the effects on a monetary level. Examples of these kinds of non-monetary effects are:

- digitalization of routine work
- more time available for valuable work
- reduction of error frequency and error types
- higher process transparency
- better quality of process documentation and status information

3. Views of process monitoring and controlling

In order to reduce the complexity, which is related to process monitoring and controlling, it is useful to differentiate three views. Every view has its own purpose, but various interrelations exist between the three views.

3.1. Process View

Potential dimensions for an analysis in the process view are workflow models and activity models, both at the type and instance level. The process view is the core view of process monitoring and controlling. In this view all key performance indicators related to the business processes are evaluated. The evaluations in this view can be differentiated whether they concern time, cost or quality. Possible evaluations are:

- the average, maximum and minimum process time,
- the average, maximum and minimum costs of the execution of one process,
- the quality of the process expressed in the number of failures or loops as an indicator for necessary rework.

Corresponding reports can range from one specific process instance to different process aggregations. Among others, learning curves can be used to show whether the process performance increases over time.

One particular problem in the process view results out of the 1:n-relation between the process models on the type level and the process instances. In order to have a fair basis for the comparison it is indispensable to break the process model down in all possible process variants. All relevant workflow instances which are to be compared have to have the same execution path. That is, the same activities were executed in all processes and in case of exclusive-or splits the same branch was followed in all cases. Consequently, during the execution of a process the corresponding process variant has to be identified. This leads to difficult problems for the forecast of the processing time in those cases, in which in an early stage of the process execution the process variant can not be identified yet.

The data gained within the process view can be used for a continuous update of the corresponding attributes in the process models. Consequently, a bi-directional interface between the process monitoring and controlling application and the business modeling application is required.

3.2. Resource View

Though the design of efficient processes seems to dominate the current discussion regarding the state of the art design of companies' organizational structure, the isolated optimization of the process criteria is not the only objective. This easily could lead to a situation, in which a high process efficiency is accompanied by a poor usage of the available resources. In other words: The customer might appreciate a short processing time, but the costs for this are not acceptable. In order to avoid such an isolated analysis a framework for process monitoring and controlling has to include also a view that expresses the resource performance. As in the process view, the reports in this view analyze the costs, the time and the quality of the resources. The costs of the involved resources can be derived from applications like asset management accounting. As process monitoring and controlling is usually dealing with a subset of all processes, and the resources are in the most cases not for 100 % allocated to one process, only an appropriate part of the resource costs has to be taken into account.

The time dimension in the resource view reports on the availability of the resources. Comparable to the costs, only the part of the resource capacity has to be analyzed that is required for the execution of the process.

The quality of a resource can be measured in terms of good parts per 100s or 1000s (efficiency) or the total output (effectiveness).

If resources with redundant functionality are available, the cost, time and quality indicator can be used within the role-based staff resolution. This is another example for the intensive interrelation between process monitoring and controlling as a primarily reactive (descriptive) application and the staff resolution as the mainly active (prescriptive) application.

3.3. Object View

Processes can be defined as the logical sequence of functions necessary to process a business relevant object. Examples of these objects are inquiries, orders or invoices. Within a separated object view it is - in addition to the process and resource view - possible to define the processes' cost and value drivers. Very often cause-effect-relationships between the objects and the processes can be identified. Again, cost, time and quality criteria can be differentiated. Typical cost criteria would be the costs for the handling of an object. Elaborate approaches like activity-based costing can be used for the exact calculation of the costs and revenues belonging to an object. Similar time data related to objects inform about the typical processing time for these objects. These data can be used, e. g. in sales for a more realistic estimation of the processing time within negotiations with a potential customer. Finally, quality indicators can inform about potential problems related to an object.

As in the process and resource views, the object view has a type and an instance level. On the instance level, a customer can be informed about the progress of a specific order. In this way, the object view acts as a kind of access to the process view. Currently, logistics service providers are offering object-related information on the instance level within their web-based tracking systems. On the object type level discussions about the outsourcing of objects can be made.

Various projects with retail companies demonstrated that the object view is of significant importance for this sector. In one case e.g., the object analysis was used to identify the complexity drivers in the invoice verification process. On the basis of an individual workflow management system, those invoices had to be identified, that caused the most problems. As the relevant department received more than 10,000 invoices monthly and had more than 140 employees working on the verification of invoices, this was a critical challenge. The processes dealing with invoices including mistakes were analyzed and related to the involved objects. These objects have been clustered into different groups after testing the significance of variables like the vendor, the goods received, or the involved staff member. It turned out, that the vendor was the best explanatory variable. Consequently, the costs related to these processes were used within the next negotiation with the suppliers concerning the required conditions.

4. Measuring the impact of workflow technology

4.1. Available information

The information available for process analysis varies with the workflow management system used. While some systems mainly record system events with their timestamps, others also record the object processed within the activity (cf. e. g. [9]). The availability of information determines the quality and depth of the analyses possible. However, in some cases it is possible to enhance the vendor-specific audit trail with additional information. In order to enable an object-view based analysis of workflow instances during the development of our process information system PISA (which is described in detail in section 5 of this paper) an activity was inserted into the workflow model that created a log-entry which contained the relationship between the workflow instance ID and the process object ID, which was not available in the audit trail data of the workflow management system. Using this additional information, a drill-down analysis from the process information to the process object could be implemented.

The majority of workflow management systems record three types of data: State-changes regarding processes and activities, resource information about the generators of the state-changes and timestamps of the state-changes. This information from the workflow audit trail files can be used for a number of analyses in a process information system:

- Time of events: Using the timestamp of the activation, execution and completion or abortion of workflow activities, a process information system can compute process cycle times, lay- and idle-times as well as activity processing times and their deviations. A forecast of potentially overdue activities as well as a preliminary turnover time can be determined.
- Involved resources: The information about the organizational entities and information systems involved in the execution of activities can be used to compute the average and peak workload of resources. The change in processing time of activity instances over time that were executed by the same resource indicates potential learning curve effects. The number of different resources involved in the execution of a single workflow as well as in a set of workflow instances can provide information about the input-output relationship of a process.
- State-changes: The kind and number of state-changes in a process provides information about the number and type of exceptions that occurred during the execution of the process (for example, if a workflow changes frequently from “running” to “suspended”). The analysis of active workflow activities within single workflow instances can be used to determine the probabilities of execution paths in case the workflow model contains parallel branches. This information can in turn be used for simulation purposes.

Besides those elementary information objects, advanced analyses such as effects of workflow on the time to market, changes in process quality or competitive advantage are useful in order to assess the economic effect of a workflow management system. However, the strategic importance of the information is directly inverse to the measurability of this type of information (cf. figure 2). While operative, i. e. substitutive, effects of workflow technology can be measured rather easily (e. g. the reduction of personnel during process enactment), complementary effects such as job enlargement and enrichment for workflow participants are more difficult to measure. Substitutive effects are also regarded as being calculable, while complementary effects involve some estimation. Strategic effects of workflow technology, such as the ability to deliver new types of products to customers or a shorter time to market can no longer be determined in monetary figures.

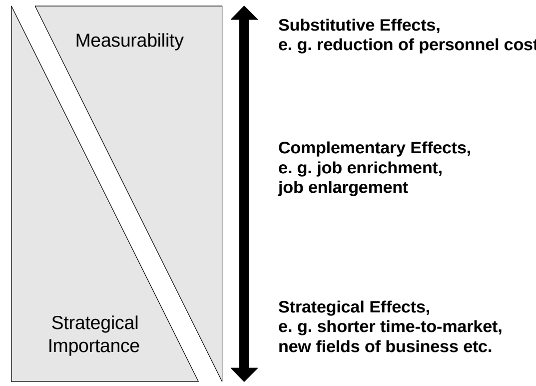

Figure 2. Impact and measurability of workflow

4.2. Measuring techniques

Various statistical techniques can be used within process monitoring and controlling. As an example, the cluster analysis within the object view was already mentioned. Another relevant evaluation technique is the *statistical process control (SPC)*, that has been applied in production management systems for four decades. SPC requires the definition of an upper and a lower level of tolerance referring e.g. to the expected processing time. Following the management-by-exception idea, the monitoring and controlling system informs the process owner, if one value is above the upper or under the lower level. Another rule is that the process owner gets an early warning message, if n (with n usually >5) values are continuously increasing or decreasing.

A further interesting approach in the context of workflow-based process monitoring and controlling is the use of the *hedonic wage model* [10]. Originally designed to evaluate the improvement in the office area caused by new IT systems, the hedonic wage model can be easily adapted for process-related analysis. This approach requires that it is known what class of employees (defined by their salary) is doing what type of work (defined by the degree of difficulty). Each class of employees is related to one class of activities. The assumption is that an employee should only work on activities with which s/he is qualified. For a given situation the hedonic value can be derived through a system of equations, in which the amount of work the different classes of employees are actually spending on different activities is summed up to the salary of this class of employees. This leads to the hedonic value for each class of activity. These as-is-values can be compared with the desired to-be-models or the situation after a reorganization.

To date, a major disadvantage of the hedonic wage model is the time-consuming process of identifying who is actually doing what type of work.

Workflow management systems are an ideal support for the hedonic wage model. In order to implement this

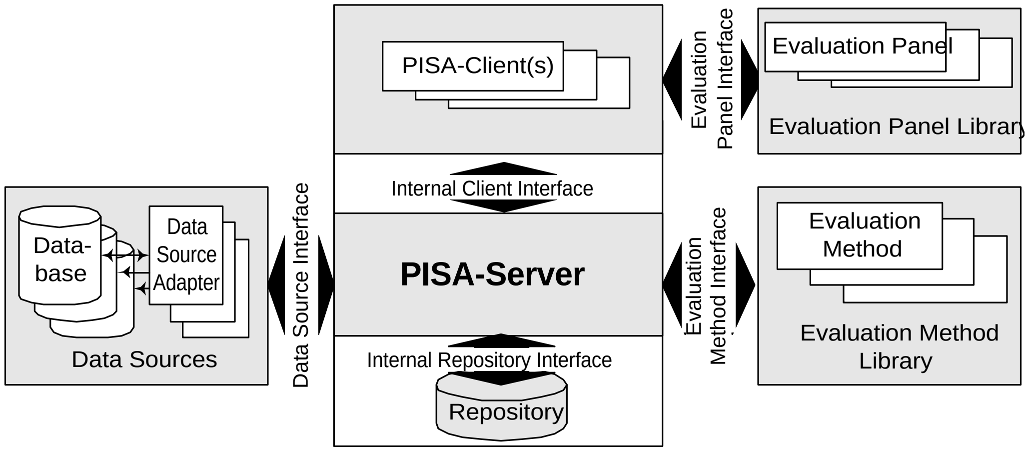

Figure 3. PISA Architecture

concept, every activity as well as every involved organizational unit has to be classified. Furthermore, both classifications can not only be used for the hedonic wage model, but also for role-based staff resolution. With these classifications, it is quite simple to get the required reports.

5. A prototype for workflow monitoring and controlling: PISA

5.1. History and intention

The development of PISA started in the fall of 1995 as a working prototype based on Microsoft Access. The systems used at that time were IDS Corp. ARIS Toolset Version 3.0 for the conceptual process model data, and IBM FlowMark Version 2.2 for the run-time workflow audit trail data. The FlowMark audit trail data was imported into the prototype repository, whereas the ARIS database was accessed using ODBC. This first version served as a feasibility study and implemented elementary evaluation methods based on the three dimensions process/activity, type/instance and organizational unit/ role/user.

Whereas the first prototype employed only a few evaluation methods, the second version (also based on Microsoft Access) was designed using more sophisticated evaluation methods, such as the hedonic wage model, and allowed additional evaluations on process objects, such as a cluster analysis.

The current (third) version of PISA has been rewritten from scratch in order to realize a fully distributed system architecture as well as database and client independence. Despite the original intention to design a workflow monitoring and controlling system, the open architecture of PISA also enables the use of PISA as a generic Management Information System, relying on different data sources.

As a basic service for PISA, the World Wide Web was chosen for a number of reasons.

- Due to the increasing number of www-users, most of the potential PISA users are familiar with the handling of current web bowsers, which reduces training effort for the handling of the system.
- Since data evaluation and program execution are handled by the web browser, potential problems of hard- and software heterogeneity are resolved in advance. The local installation of client software is no longer necessary. This provides for a high degree of autonomy and mobility of the users.
- The www-browser can contain active (e. g. an event-driven worklist of a workflow management system) as well as passive user interfaces (ef. e.g. [11]). The latter enable the user to instantiate workflows or to receive monitoring information.
- The majority of distributed workflow management systems rely on Internet services for at least a part of their distribution mechanism [12]. If a process information system is to integrate seamlessly with existing workflow clients, it has to use the same mechanisms.

5.2. System architecture

The PISA system architecture is depicted in figure 3. It consists of the main server and client components and three additional modules that are connected via three interfaces. PISA is realized in a multi-layer architecture using the VisiBroker for Java Object Request Broker [13],[14]. The five core components of the PISA system are:

- the *PISA Server*, which is responsible for the evaluation of data and the coordination of all application components,
- the *PISA Client*, which provides the user interface and presents the evaluation results to the user,
- the *Data Source Adapter*, which is responsible for the realization of access to operative data sources and therefore provides the PISA server with data,
- the *Evaluation Method Library*, which contains Java classes with evaluation procedures that can be applied to the raw audit trail data and,
- the *Evaluation Panel Library*, which consists of various graphical representations for the methods of the evaluation method library.

5.2.1. PISA Server and Client

The PISA Server is a stand-alone application that coordinates the PISA clients and delivers evaluation methods, the according graphical representation panels as well as the results of internal evaluations on the audit data. The PISA client is a Java Applet that can be executed with every Java-capable web-browser. After loading a startup HTML page with the embedded client applet, the JAR-archives with the Java classes are transferred to the client and the applet is executed. In case the ORB-classes are not present in the web browser, these classes have to be transferred as well. Since the VisiBroker consists of less than 100 KB bytecode, this download requires only little bandwith.

5.2.2. Data Source Adapter

The data source interface connects the system kernel with the data source adapter. The data source adapter is a mapping module specifically designed to connect the contents of a workflow audit trail database with the audit trail repository of the PISA system. It performs conversions between data formats and provides a transparent access to the data source. While some workflow systems allow direct queries on audit trails stored in relational databases, others like e. g. IBM MQSeries Workflow [IBM 98] provide the user with an ASCII file of the audit trail data. In the first case, access can be realized using JDBC, while in the latter case, we rely on Java-Beans that provide a database-like handling of ASCII files. Currently a different data source adapter has to be developed for every workflow management system. In the course of the standardization of Common Workflow Audit Data by the Workflow Management Coalition [5] a generic adaptor will be developed, that enables access to all WfMC Interface 5 compliant workflow management systems. If the Workflow Management Coalition decides to standardize a set of audit trail API functions similar to those API functions specified for the Interfaces 2 and 3 [15], the generic data source adapter could be enhanced with this set of functions.

Furthermore, different data source adapters integrate various data sources. Relevant information for process monitoring and controlling purposes do not solely originate in workflow management systems, but also in business process modeling tools and operative application systems such as HR modules of ERP systems. The consistent and transparent handling of this data from the point of view of the PISA server is realized through specific adjustment of the data source adapter's access mechanisms.

Figure 4 shows the Data Navigator Frame, where a PISA user selects the workflow or activity to be evaluated. Depending on the selection, the other selection fields are dynamically updated, i. e. if a user selects a specific workflow instance, only those activity instances become accessible, that were executed within this specific workflow instance.

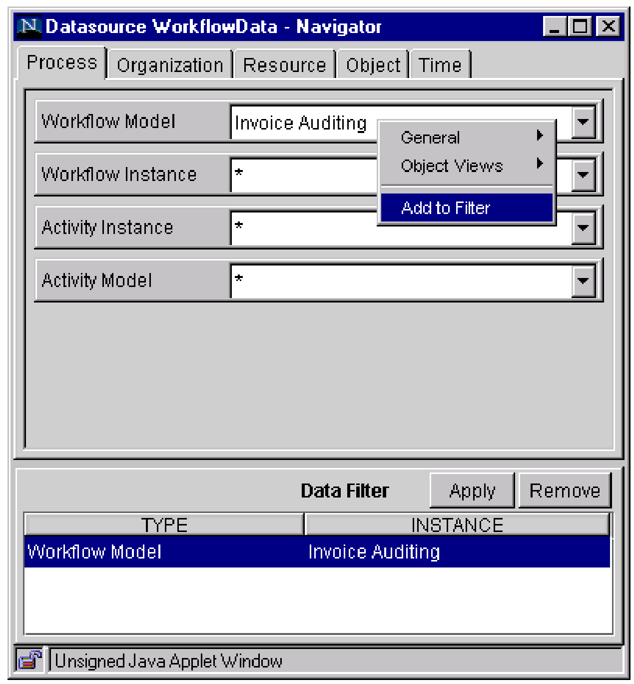

Figure 4. Data Navigator Frame

5.2.3. Evaluation Method Library

Evaluation methods are algorithms for the analysis of information objects that can be applied to one or more different object types. Every evaluation method queries the data source for evaluation data, therefore the data structure of the data source has to be known to the evaluation method designer. Some methods, however, can be designed independent of the data analyzed, leading to a system-independent reference library of evaluation methods. The audit trail data specification of the

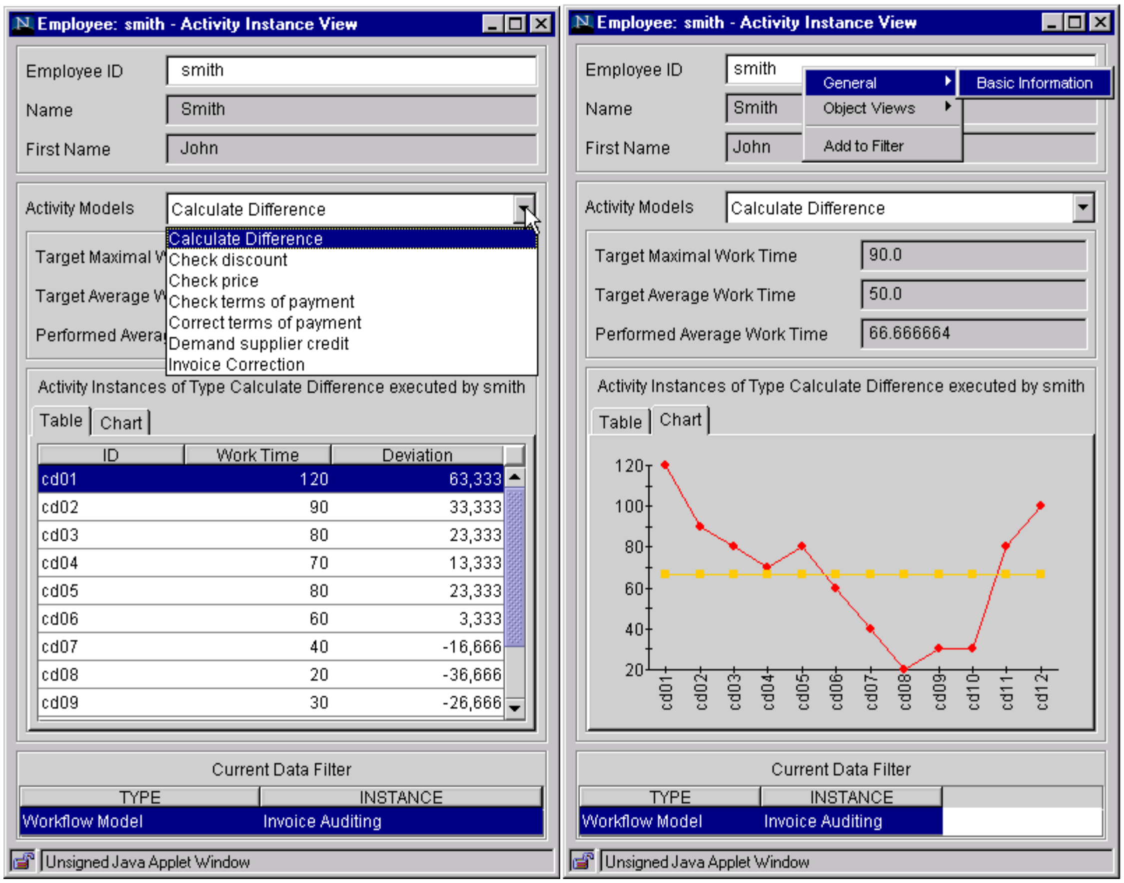

Figure 5. Evaluation of workflow participant data on the activity level

Workflow Management Coalition [5] can serve as a foundation for the design of these reference methods.

The evaluation methods are stored in separate Java classes, that can be loaded dynamically at runtime. This way, the evaluation method library can be enhanced without restarting or recompiling the PISA server. New evaluation methods are available to clients that have been started after the extension of the method base.

Among other methods of evaluation, PISA supports the hedonic wage model. The hedonic values are presented graphically for every class of work and over time. By this, the process owner can analyze, whether the resources involved in the process are adequately used.

5.2.4. Evaluation Panel Library

The Evaluation Panel Library contains a collection of user interfaces for the representation of different evaluation methods. Every class of the library defines a rectangular frame with appropriate GUI-elements. For example, the Enumeration Panel consists of two columns of text for the display of objects and their attributes, the Grid Panel consists of a table and the appropriate graphical representation of its values.

For every evaluation started on the server, a window on the client is opened that contains one or more of these evaluation panels. Since an evaluation panel can be used by more than one evaluation method, the amount of byte-code that has to be transferred to the client is reduced considerably.

Figure 5 shows the application of a processing time evaluation on activity instance level. On the left hand side the elementary data is displayed in a table, by choosing the associated chart panel the user can view the changes in the processing time for a specific activity as a graph, tracing e. g. learning curve effects.

5.3. Security aspects

In order to restrict access to the monitoring database, e. g. because of legal restrictions or company specific regulations, PISA can restrict access to methods, data and objects. For each of these aspects, different profiles can be generated by the PISA administrator.

- The Method Access Profile determines, which evaluation methods may be executed on which information objects. During the assignment of methods it has to be ensured, that the evaluation method can in fact be executed using the given object type. The information object types within the repository are referenced using their IDs. The exact description is retrieved from the current data source. In this way, potential homonym and synonym conflicts, which are frequent among workflow management systems (cf. e.g. [16]), can be avoided. The Method Access Profile also determines the associations between evaluation methods and menu entries. This way different users can access the same evaluation method in different context menus (e. g. inductive vs. deductive evaluations as opposed to a classification using time, cost and quality).

- The Data Access Profile defines the subset of the data source data that may be accessed by the user. The access to data sources may be limited due to time or organizational constraints. An example is the head of department, who may only access workflows that were executed within this specific organizational unit.
- The Object Access Profile limits the types of information objects that may be seen and evaluated by the user. For example, access to the object type “workflow user” may be limited due to privacy reasons. The Object Access Profile is closely related to the Method Access Profile, since it is not advisable to exclude objects from user access whose attributes can be seen in a different evaluation.

Figure 6 shows the login screen of PISA. Depending on the user information Method Access, Data Access and Object Access Profile are evaluated and only accessible repository databases are presented for selection. This way, a flexible multi-user-management can be implemented and privacy concerns can be addressed in an easy and flexible way.

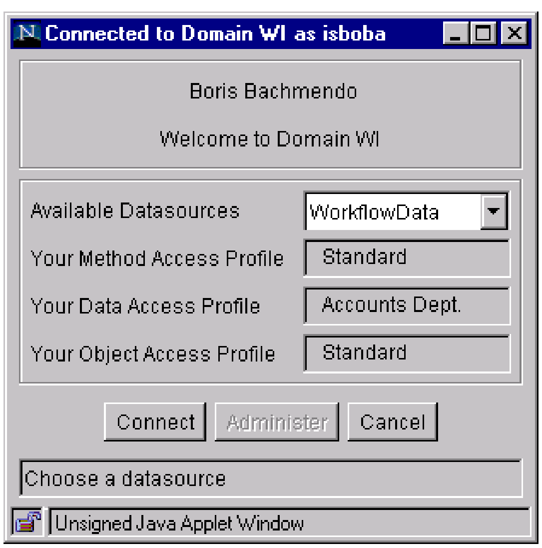

Figure 6. Login Screen of PISA

6. Conclusions

Today’s enterprises focus on the identification and first-time optimization of processes, while the continuous process engineering cycle has been implemented only in a small number of cases. This is caused in part by the lack of specialized process monitoring and controlling support tools. We have presented a lightweight, distributed prototype of a process information system that allows the evaluation of workflow history data using the three perspectives process, resource and object. In order to maintain a flexible level of privacy, the prototype implements a security concept based on access profiles for evaluation methods, data sources and information objects.

Our future work concentrates on the active feedback of the evaluation data on the modeling of workflow processes, closing the workflow-life-cycle and enabling an active real-time-controlling, e. g. through the re-assignment of workflow activities based on a workflow analysis or through a knowledge-based redirection of workflow exceptions, that delivers exceptions to more experienced resources first, before a member of the next level of hierarchy is notified.

Workflow-based process monitoring and controlling enables the evaluation of business processes with a higher quality of data than before and poses a promising field of development for management information system designers. It allows process analyses whose application had been impossible due to a lack of quality data, such as the hedonic wage model. Nevertheless, although there are tempting technical opportunities, cultural and legal restrictions have to be taken into account, as well.

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