Workflow Time Management Revisited

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Abstract Time is an important aspect of business process management. Here we revisit the following contributions of early workflow time management approaches: representation of temporal information and temporal constraints, analysis of temporal constraint satisfiability, and computation of workflow execution plans that satisfy temporal constraints. In particular, we summarize some of the most important research efforts and results in: (a) modeling temporal aspects of workflows, (b) analysis of temporal properties of workflow models, (c) computation of workflow execution schedules, (d) minimization of exceptions due to violation of temporal constraints, (e) monitoring of temporal workflow aspects, and (f) modeling and calculation of temporal properties for distributed workflows and for guaranteeing Quality of Service in Web-service composition.

1 Introduction

Time is an important component of the management and execution of (business) processes. Processes have to be planned in a temporal dimension for several reasons, e.g., users demand information about process duration, and managers need

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temporal information for scheduling and organizing work and workforce. Temporal information is necessary for improving business processes, lower cost, and allow timely reactions to external events. Many business processes have restrictions such as limited duration of subprocesses or activities, terms of delivery, dates of re-submission, or activity deadlines. Typically, violations of temporal constraints increase the cost of business processes, may create unnecessary additional work, or lead to the violation of contracts with clients. In summary, poor consideration of temporal aspects reduces the quality of the services offered by an organization and lowers its competitiveness.

Therefore workflow managements systems should care for the following requirements [13, 15]:

- At build-time, when workflow schemas are defined and developed, workflow modelers need means to represent time-related aspects of business processes (activity durations, time constraints between activities, etc.) and check their feasibility.
- Process managers need support to compute schedules for the execution of processes. They need means to be warned about possible violations of temporal constraints as early as possible such that they can react and take measures to avoid time failures, e.g. by extending internal deadlines if possible, assigning overtime, or invoking "emergency" processes.
- Workflow participants need information about urgencies of the tasks assigned to them to manage their personal work lists in accordance with the overall goals.
- Workflow management systems should recognize violations of temporal constraints and trigger exception handling steps to regain a consistent state of active workflow instances.
- Recording temporal information about business process executions helps improving (re-engineering) business processes and allows better planning of process execution.

At the end of the 1990s, the temporal aspects of workflows were taken up by Information Systems Engineering research. Solutions in related areas could not be easily applied to workflows. Production scheduling was an established discipline, but workflows differ from shop floor processes considerably, especially in the information about the individual activities (process steps), the resources they require, the decisions (choices) made during run-time, etc. Project management tools, on the other hand, are tailored towards supporting individual projects rather than the management of multi-instance workflows. While temporal reasoning was helpful for model analysis, it did not address disjunctive constraints (XOR splits) and did not provide support for the other requirements outlined above.

Around 1997–1999 the first papers (e.g. [4, 16, 31, 35, 37]) raising the issues of time management for workflows were published and set the topic on the agenda.

2 Time Constraints in Workflow Systems

In [16], we made contributions to: the formulation of the requirements for workflow time management, the representation of temporal information in workflow models, the temporal analysis of workflow models, and the computation of schedules for workflow execution.

In addition to the definition of the duration of workflow activities and the specification of deadlines for the execution of workflows, we introduced lower- and upper-bound constraints between start and end execution events associated with workflow activities. Furthermore, we allowed events to be bound to fixed dates.

We presented an algorithm that effectively checks whether the set of temporal constraints is satisfiable for a given workflow at build time. The algorithm is constructive in the sense that it computes a time plan specifying the admissible intervals for the start and end events. At process instantiation time, the time plan is mapped to an actual calendar, and the fixed date constraints are resolved and incorporated in the schedule. At run time, execution progress is monitored and the schedule is refined by taking the actual time points of the events into account.

3 Temporal Aspects in Workflows

During the last decade, the management of temporal aspects for workflows has attracted considerable research efforts across different dimensions. We summarize what we consider the most important strands of research in this space and exemplarily reference some relevant papers below.

- *Modeling of temporal aspects and analysis of workflows:* The types of temporal information represented in workflows has been extended by including more complex forms of constraints, such as transport times, and supporting more complex workflow models by considering more complex control structures. The algorithms for computing time plans have been modified accordingly to address these extensions [3, 10, 11, 14, 27, 28].
- *Probabilistic time calculations:* Uncertainty is an integral characteristic of many workflows that can be introduced by many factors, including branching at split points, iterations, and varying activity durations. To better deal with uncertainty, probabilistic temporal workflow models have been developed which allow the computation of probabilistic execution plans [12, 29].
- *Patterns:* The different approaches for representing temporal information and temporal constraints for workflows have been consolidated and documented as temporal workflow patterns [25].
- *Resource constraints:* While temporal constraints are very important, workflow management must also address resource constraints in many scenarios [2, 26].
- *Scheduling:* The information available in timed workflow graphs has been used to support scheduling of workflow activities, computation of individual schedules

for workflow participants to organize their work, and for various attempts to improve the performance of workflow execution [17, 23, 38].

- *Exception handling:* The violation of temporal constraints leads to exceptions in the execution of a workflow. To capture and manage these exceptions in an automatic or an semi-automatic way, various techniques combined approaches from temporal workflow management and exception handling [33, 36, 39].
- *Prediction:* Another approach comes from the confluence of temporal workflow management with workflow mining. While workflow time calculation always relied on empirical data coming from workflow logs, the analysis of these logs with workflow mining techniques provides additional valuable data for scheduling [1].
- *Adaptability, change, flexibility*: In many situations, workflows cannot be executed in their entirety as planned. Rather, they have to be modified at runtime to accommodate unforeseen situations. Adaptable workflows and flexible workflows provide the means for dealing with these situations in an adequate an reliable way. Temporal information is quite important there as changed workflows have to satisfy temporal obligations [9, 24, 32].
- *Grid workflows:* Applications in e-science require the execution of workflows over the grid. The scheduling of these workflows requires temporal information, as well as an efficient way for monitoring execution progress in order to react to different load distributions [6, 7].
- *Distributed workflows:* Business processes do not stop at the perimeter of organizations, but typically transcend organization boundaries. Different approaches for inter-organizational workflows representation and exchange of temporal information between the organizations participating in an inter-organizational workflow have been developed. In addition, various algorithms have been developed to allow time management by exchanging only the permitted temporal information required for balancing the need for temporal workflow management with restrictions associated with passing information between participants [19, 20, 30].
- *QoS for web service composition:* Temporal information is associated with the quality of Web service executions. The techniques of workflow time management have been taken up and adopted for the calculation of Quality-of-Service aspects for the composition of web services [5, 18, 22, 36, 40, 41].
- *Application:* Workflow time management methods have been applied to solve problems in specific application areas like supply chains [21], health care and hospital information systems [8, 34], or scientific workflows [29].

4 Conclusions

Workflow time management was a very productive field of research during the last decade. Enormous progress was made towards providing workflow management systems and workflow applications with sophisticated models and techniques

for representing temporal information and temporal constraints and to greatly improve the quality of execution of business processes from a temporal perspective. Developed techniques reduce the number of violations of temporal constraints, and provide better temporal information for workflow managers, workflow participants and the consumers of process executions.

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