## Modeling the Radiology Workflow: A hands-on Comparison of established Process Modeling Languages

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**Introduction and Problem statement** Workflow modeling and workflow optimization are gaining importance due to limited financial resources, increasing commercial pressure, changing hospital reimbursement e.g. in DRG based systems and an increasing need for quality management in medicine [1-4]. This paper is part of a larger effort performed at two German university hospitals to improve and optimize the workflow for inpatient radiology examinations using data mining techniques. Modeling workflows are the starting basis for process improvement efforts. A great variety of modeling languages exists and is currently applied in the clinical domain [1, 2, 4-10]. Requirements differ, however, depending on the purpose of process modeling and the modeled domain. In order to find the most suitable modeling language for this project, a comparison between four commonly used modeling languages was performed, by systematically evaluating a predefined set of criteria based on [3, 4, 6]. Those criteria were expressiveness, simplicity and clearness of visualization, suitability, degree of formalization, analytical and validation capabilities, execution and simulation capabilities and the vendor independence.

**Methods** Graphical modeling languages may be divided into data flow oriented, control flow oriented and object oriented modeling languages [9]. For this project from the control flow oriented modeling languages the Petri nets, the event-driven process chains (EPC) and the business process modeling notation (BPMN) and from the object oriented languages, the UML 2.0 activity diagrams (UML AD) were chosen. To examine Petri nets a variant called workflow nets (Wf-net) was used [5]. A representative of data flow oriented languages was not selected since those were not suitable for our purposes. Domain specific approaches were not considered due to heterogeneous visualizations and insufficient tool support [7]. The analyzing and modeling of five levels of a radiology workflow with all four modeling languages was the basis for this comparison. The modeled hierarchy was: The "Patient process" on top-level, the "Diagnostic process" on level 2, the "Non invasive imaging" on level 3, "Perform Procedure" on level 4 followed by the 5th level process "Perform CT using oral and iv contrast". The complete model comprised 19 compound activities on the 4th and more than 70 atomic activities on the 5th level. An example of a modeled subsection is given in figure 1.

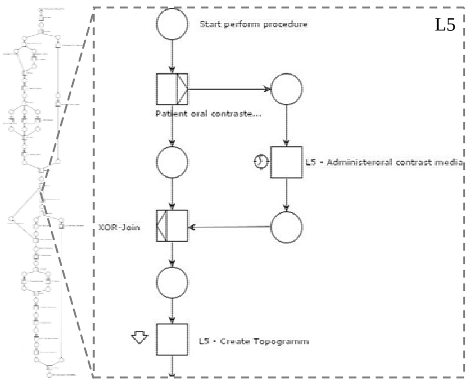


Fig. 1: Radiology workflow as a level 4 and level 5 Wf-net

The expressiveness of the languages was rated by assessing their capabilities to describe the control flow, the dataflow, involved data objects, hardware and software and the ability to model actors and roles inside the organizational structure. Furthermore the ability to model temporal aspects like waiting times and task duration was considered [3, 4, 6, 11]. Simplicity and clearness of visualization as well as suitability cannot be directly quantified. Therefore those criteria were rated by six experts, two from the clinical, two from the industrial and two from the scientific domain using a questionnaire. The degree of formalization of a modeling language and the ability to analyze or validate its process models were assessed, too. As parameters, the analysis for qualitative aspects (like logical correctness) and for quantitative aspects (primarily concerning performance issues) were examined [5]. The execution and simulation capabilities of a modeling language were assessed by checking whether the corresponding models could be interpreted e.g. using a simulation or workflow engine. The vendor independence criterion was assessed by checking whether the modeling language is an official standard, a de facto standard, freely available but not commonly used or proprietary.

| | Wf Net | eEPC | BPMN | UML AD |
|---|---|---|---|---|
| expressiveness | ○/● | ● | ○/● | ● |
| simplicity and clearness | ● | ● | ● | ● |
| suitability | ● | ●● | ○/● | ○/● |
| formalization and precision | ●● | ● | ●● | ●● |
| analytical and validation capabilities | ●● | ● | ○/● | ○/● |
| execution and simulation capabilities | ●● | ●● | ● | ○ |
| vendor independence | ○/● | ○/● | ●● | ●● |

Table 1: Summary of results

**Results** An overview of our results is given in Table 1. It shows that none of the languages fulfills all criteria. But our investigation showed that it is possible to model radiology workflows – to a certain degree - in all four modeling languages. All elementary control flow constructs like sequences, parallel splits, synchronizations, exclusive choices and simple merges are supported. Nevertheless, closer examination revealed that significant differences arise e.g. regarding the expressiveness (e.g. modeling cancellation of activities, role assignments or temporal aspects). For simplicity and clearness of the visualization all 4 languages scored equally positive (our expert rating based on the modeled workflow hierarchy). In addition, the experts stated a good suitability of Wf-nets and even better suitability of eEPCs for the radiology domain. Formalization and precision were assessed on the basics of current modeling theories. Wf-nets, UML ADs, and BPMN showed a high degree of formalization and precision, as they own a precise and formal semantic [4-6, 12, 13]. In contrast, eEPCs are less formalized [6], but there have been various efforts to improve formalization [14] which results in a mediocre rating. Wf-nets boast best analytical and validation capabilities. Structural aspects as well as behavioral and dynamic aspects (e.g. liveness, reachability of activities or performance) can be analyzed [6]. In this regard eEPCs score second best, using the ARIS toolset. BPMN and UML ADs have weaker analytical and validation capabilities. Wf-nets (based on the Petri nets) and eEPCs both demonstrated excellent execution and simulation qualities. For both many supportive tools like the Staffware Process Suite from TIBCO (www.tibco.com) for Petri nets and the Bonapart tool from Pikos GmbH (www.pikos.net) for EPCs exist. BPMN is based on the BPML process execution meta-model which directly defines executable processes [8]. However, simulation capabilities are limited compared to Wf-nets and EPCs. UML does not define any execution meta-model. In this case additional efforts are required, using e.g. Model Driven Architecture (MDA) [8, 13]. Regarding vendor independence, UML and BPMN perform best, being officially standardized under the umbrella of the Object Management Group (www.omg.org). Wf-nets and EPCs are not standardized but well-known in the process management community. EPCs are owned by IDS Scheer (www.ids-scheer.com) but are widely-used.

**Discussion** In the present paper four modeling languages were compared by examining their appropriateness for modeling clinical radiology processes. Among the chosen criteria, expressiveness is the most important one for precise modeling [3, 6]. Confronted with insufficient expressiveness the process modeler is forced to oversimplify his models [3]. Although we could demonstrate that modeling radiology workflows down to the level 5 process "Perform CT using oral and iv contrast" is possible in all four languages, we found significant differences e.g. regarding modeling of cancellation, assignment of multiple roles or time-based aspects, which is well aligned with [4-6, 11]. Simplicity and clearness of BPMN diagrams (our expert opinion) match well with its development objectives [13]. As a final result of this study we would either select eEPCs or Wf-nets as a first choice, due to their expressiveness and analytical and simulation capabilities. For a uniform view on all (even administrative) processes of a hospital - especially from a cost-effective point of view – eEPCs probably offer the most comprehensive solution. Third choice would be BPMN. For a software development close modeling we would prefer UML ADs. But as depicted in Table 1, this order may be altered depending on the modeling objective.

### Literature

[1] Noumeir, R. Radiology interpretation process modeling. J Biomed Inform. 2005 Sep 12

[2] Sloane E, Wagner W. Clinical Engineering Use of Event-Driven Process Chain (EPC) to Develop Enterprise Models of Collaborative Information and Workflow for Re-Engineering the Operating Room. Americas Conference on Information Systems; 2004; New York, USA

[3] van der Maas A, ter Hofstede A, ten Hoopen A. Requirements for medical modeling languages. J Am Med Inform Assoc. 2001 Mar-Apr;8(2):146-62.

[4] Sarshar K; Dominitzki P, Loos P. Einsatz von Ereignisgesteuerten Prozessketten zur Modellierung von Prozessen in der Krankenhausdomäne - Eine empirische Methodenevaluation. In: Nüttgens M, Rump F (Eds.), 4th GI-Workshop Geschäftsprozess-management mit EPK, 2005 Dec 08-09; Hamburg, Germany

[5] van der Aals W, van Hees K. Worklow Management - Models, Methods, and Systems. 1st ed. Cambridge, USA: MIT Press; 2004

[6] von Hagen C, Stucky W. Business-Process- und Workflow-Management. 1st ed. Wiesbaden, Germany: Teubner Verlag; 2004

[7] Sarshar K, Loos P. Modellierung überbetrieblicher Behandlungsprozesse durch Objekt-Petrinetze. Wirtschaftsinformatik, 2005; 47(3):203-210

[8] Havey M. Essential business process modeling. 1st ed. Sabastopol (CA),USA: O'Reilly; 2005

[9] Gadatsch A. Grundkurs Geschäftsprozess-Management. 4th ed. Wiesbaden, Germany: Vieweg; 2005

[10] Keller G, Nüttgens M, Scheer A: Semantische Prozeßmodellierung auf der Grundlage Ereignisgesteuerter Prozeßketten (EPK). In: Scheer AW (Ed.): Veröffentlichungen des Instituts für Wirtschaftsinformatik. Heft 89, Saarbrücken, Germany, 1992.

[11] van der Aalst W, ter Hofstede A, Kiepuszewski B, Barros A. Workflow Patterns. Distributed and Parallel Databases. 2003;14:5-51

[12] Object Management Group. Unified Modeling Language: Superstructure, v2.0. 2005 August. www.omg.org/cgi-bin/doc?formal/05-07-04 last visited 2006 March 03

[13] BPMN.org. Business Process Management Initiative (BPMI); 2005 www.bpmn.org last visited 2006 March 03

[14] Cuntz N, Kindler E. On the semantics of EPCs: Efficient calculation and simulation. In: van der Aalst W, Benatallah B, Curbera F, editors, 3rd Intl Conf BPM, 2005:LNCS 3649:398-403; Nancy, France. New York; Springer 2005