Juliane Neumann, Max Rockstroh, Sascha Vinz, Thomas Neumuth

TECHNICAL REPORT

SURGICAL WORKFLOW AND PROCESS MODELING

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Innovation Center Computer Assisted Surgery (ICCAS)
Leipzig University / Faculty of Medicine
Semmelweisstraße 14
04103 Leipzig
Germany

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ABSTRACT

In the context of the modern OR, medical and technical innovations for surgical assistance systems and process automation are going to be established in the near future. For this purpose workflow management systems (WfMS) can be implemented in the operating room environment. Clinical and surgical processes as well as medical devices can be managed and monitored by this kind of process-driven software system. An essential aspect for workflow management support is the description and visualization of the underlying surgical processes and activities, actors, resources and information. The processes must be provided in a machine readable form as surgical process models (SPM). For this purpose business process- and workflow modeling languages in combination with appropriate computer-aided modeling tools can be used.

The objective of this technical report is to identify specific requirements for business process and workflow modeling languages as well as their corresponding software tools for surgical application. In the business domain the most frequently used modeling languages are BPMN 2.0, event-driven process chain diagrams (EPC) and YAWL. These languages and 9 adequate process modeling tools have been analyzed and evaluated in the context of the surgical domain.

In conclusion EPCs are the most suitable modeling language for surgical business processes, since they allow different views on the process and also actors, data and information flows as well as resources to be modeled. For process automation business process models must be transformed in workflow models. Due to its presentation possibilities and the widespread distribution, BPMN 2.0 can be recommended as workflow modeling language of choice.

1 INTRODUCTION

For quite some time now business process modeling is being successfully used by several enterprises to represent internal processes for the purpose of continuous optimization. Since it is common practice for process control and optimization in other domains already, workflow management systems (WfMS) are used increasingly often in the clinical and surgical domain as well. WfMS can be used to standardize, automate and optimize processes to conserve time and resources [1].

In the context of the modern operating room, intraoperative WfMS could manage and monitor surgical processes and medical devices [2]. Status information from medical devices, for example, could be used in combination with process information to predict the current process phase [3], next activities and work steps or the remaining time for an intervention [4]. Based on this prediction, devices like the OR lights could be manipulated or parameterized in a context-sensitive manner. Furthermore workflow management and the analysis of surgical processes can improve process quality and patient security [5].

An essential aspect of workflow management support is the abstraction, description and visualization of the underlying surgical processes and activities, actors, resources and information in machine readable form. To that end surgical interventions and processes can be represented in a surgical process model (SPM) [6], [7]. For (semi-) formal process representation, business process and workflow modeling languages in combination with suitable computer-aided modeling tools can be used.

Objective

The objective of this technical report is to identify functional and technical requirements for business process and workflow modeling languages as well as their corresponding software tools for surgical application. Therefor the most widespread business process modeling languages BPMN 2.0, event-driven process chain diagrams (EPC) and YAWL will be analyzed. Based on the determined criteria, the advantages and disadvantages of these modeling languages were analyzed and evaluated to provide a foundation for selecting the most suitable language for describing clinical and surgical processes.

In addition to inspecting the process modeling languages the respective modeling tools will be included in the analysis and evaluation as well. Due to the large number of modeling tools, unifying criteria for namely availability, number and type of supported modeling languages, range of functions as well as applicability to the surgical domain, were specified.

Methods

In this technical report a review of literature and an analysis of perioperative parameters is used for requirements analysis. The identified functional and technical requirements for business process and workflow modeling languages as well as their corresponding modeling tools are described in this report. The most widespread business process modeling languages, identified as BPMN 2.0, EPC and YAWL were analyzed and evaluated in respect to the developed requirements. Afterwards the business process modeling languages were compared against each other and the results of this requirements analysis is presented in form of a feature table.

This technical report does not include a complete representation of the specifications of the modeling languages in question, but rather focuses on evaluating them against the specific requirements of the surgical domain. Furthermore emphasis is put on modeling the processes and not on the feasibility of having them executed by a WfMS.

In addition to the languages themselves nine suitable business process- and workflow modeling tools were identified. They were chosen for testing based on availability (free to use or free of charge for academic purposes), subjective renown, availability of documentation and further information, the existence of a user and/or developer community and finally their design and overall usability. The features and characteristics of the modeling tools were compared via fixed criteria.

2 UNDERLYING CONCEPTS

2.1 BUSINESS PROCESSES AND WORKFLOWS

From the perspective of business administration every process in a company is a *business process*. A business process in the surgical domain or a *surgical process* (SP) is defined "as a set of one or more linked procedures or activities that collectively realize a surgical objective within the context of an organizational structure defining functional roles and relationships" [6].

In contrast to this rather economical loaded term, a workflow is a computer assisted process or operational sequence [8], [9]. Activities are the atomic logical entities of a business process. They can be divided into manual activities and automatable activities (workflows). Manual activities are performed exclusively by participating persons whereas automatable activities can be supported or outright performed by a software system. [9]

A *surgical workflow* is defined as "the automation of a business process in the surgical management of patients, in whole or part, during which documents, information, images or tasks are passed from one participant to another for action, according to a set of procedural rules"[10].

2.2 MODELING BUSINESS PROCESSES AND WORKFLOWS

Modeling business processes or workflows is used to describe and visualize business processes, existing procedures, resources, tasks, persons and other relevant elements. The express goal is to create a clear portrayal and illustration of the actual current processes and desired target processes inside a company. First off the fundamental information regarding the process, like inherent activities and tasks, their sequence of completion and possible alternate paths and branches the process could take are modeled. Depending on which point of view is adopted when creating the process model, different elements and information can be integrated in the model, like involved persons, organizational structures, temporal aspects, monetary costs, events, states, resources, relevant data and documents as well as probabilities and priorities for the completion of certain activities [11].

Modeling workflows is a special form of business process modeling and is first and foremost meant to enable control and monitoring of the processes by a workflow management system [12]. Workflow models are created through refinement of the underlying business process models. The workflow models are then used to generate code for the workflow engine, so that the model can be executed by the workflow management system.

In the specific domain of surgery a *Surgical Process Model (SPM)* is defined "as a simplified pattern of a Surgical Process that reflects a predefined subset of interest of the SP in a formal or semi-formal representation" [6], [13]. In addition Jannin et al. defined a surgical model as „generic or patient-specific surgical procedures that workflows aim to automate" [10]. When modeling surgical workflows, different aspects of a surgical intervention such as surgical activities and behavior, actors, medical devices, materials and instruments as well as anatomical/pathological structures have to be taken into account [6], [10]. A surgical workflow management system operates based on SPMs and the corresponding machine readable surgical workflows (workflow scheme).

2.3 WORKFLOW MANAGEMENT SYSTEMS

Workflow management systems are software systems which actively coordinate and control applications, activities and data flows in order to support the process execution and the participating persons [8]. The system must be able to interpret process definitions (workflow schemes), interact with the involved actors and, where appropriate and necessary, offer IT support tools [9].

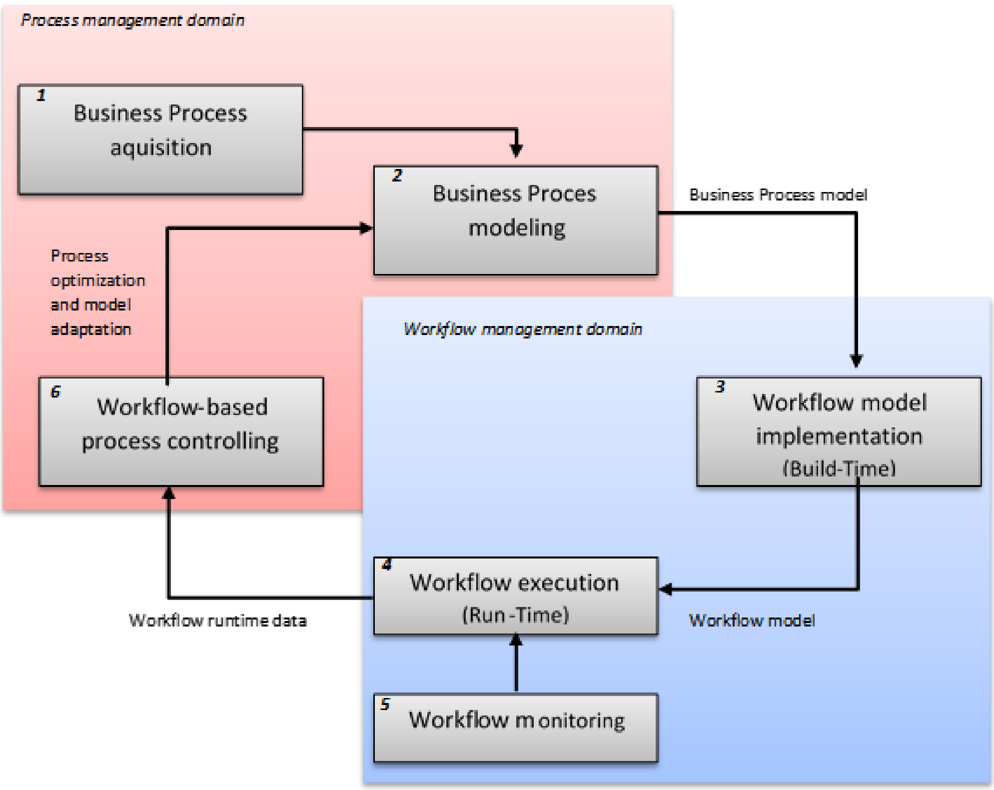

Figure 1 - Workflow Life cycle, referred to [14], [15]

The workflow life cycle (Figure 1) pictures the implementation of a WfMS inside a company [14]. First off, the business processes of the company or hospital must be gathered and described in an appropriate modeling language with the help of modeling tools. Next the models are converted into a machine-readable workflow model by adding workflow-specific information, such as technical conditions or information about the structural organization. Then the workflow model can be transferred to the workflow management system's development environment (build time) and executed therein (run time). This is done by calling a separate instance for every single workflow from the workflow management system and processing it using the needed resources. During run time the WfMS monitors the execution and retains relevant information, such as time stamps, conducting staff members or used resources. Afterwards the gathered information is used for workflow-based controlling and process optimization [15].

3 MODELING LANGUAGES

There is a plenty of different languages for modeling business processes and workflows in existence. Most often these languages are based on Petri nets, the extensible markup language (XML) or event-driven process chains (EPC). Hereafter three of the most widespread modeling languages will undergo detailed consideration: BPMN 2.0, EPC and YAWL.

3.1 BUSINESS PROCESS MODEL AND NOTATION 2.0 (BPMN 2.0)

Business Process Model and Notation (BPMN) is a language for modeling business processes and workflows which uses standardized symbols for tasks and processes. The language is supported by a multitude of modeling tools from different vendors and was declared to be the ISO/IEC standard (19510:2013) for modeling and executing business processes in 2013 [16].

The BPMN standard encompasses several types of models suitable for depicting business processes from different points of view or under differing aspects. These include choreographic diagrams, conversation diagrams and process diagrams, with the latter being the most used display format for business processes [17]. Process diagrams can depict individual people, activities, tasks and resources and will be looked on in detail in the following paragraph.

Activities

The most vital element for depicting processes are activities, which are executed by participating people or an IT system. In BPMN these activities are partitioned into tasks, subprocesses and call activities, which can trigger global tasks or processes. A task describes a single job or an atomic process step. Between tasks there is a sequence flow, which denominates the chronological order in which they are executed. Tasks can take various forms in BPMN, such as manual tasks (tasks without IT support), user tasks (tasks with IT support) or service tasks (calls to web services or applications), which serves as a more detailed description of the task. Furthermore a task can have a specialization, which is represented by an additional icon inside the task element. Among others BPMN supports specializations like loops, multiple instances, sub processes and ad hoc processes [17].

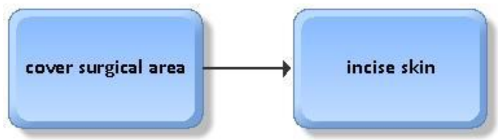

Figure 2 - BPMN 2.0 symbols: Task and Sequence flow

Pools and Lanes

Figure 3 - BPMN 2.0 symbols: Pool and Lane

In BPMN operational sequences are commonly shown in a horizontal view to ease matching activities and work steps to people and organizational entities visually. Organizational entities are depicted as pools, which can be sectioned further into smaller organizational units (pools) or actors, roles and IT systems (lanes). A sequence flow can only be modeled for one pool. Activities and processes spanning across multiple pools are modeled as messages and message flows. [17]

Events

Every process diagram in BPMN has at least one start event and one end event. Events which occur during the process are called intermediate events. Events can be specified further to be for instance message, timer, signal or boundary events, though not every specialization is applicable to every event type (start, end, intermediate). Boundary events are a noteworthy case as they disrupt the complete process and initiate a new parallel one. [17]

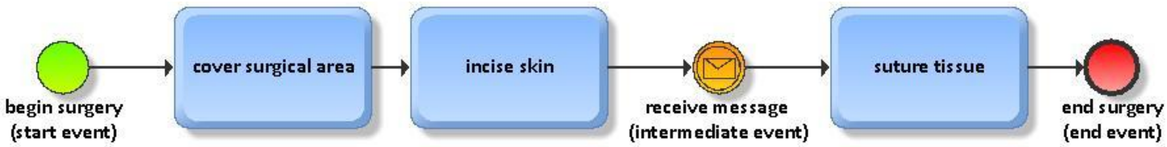

Figure 4 - BPMN 2.0 symbols: Start-, Intermediate- and End-event

Gateways

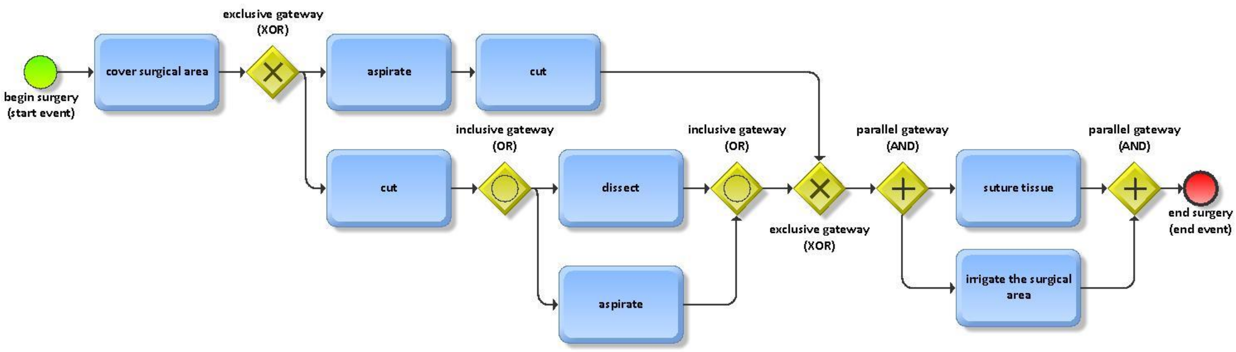

Figure 5 - BPMN 2.0 symbols: Gateways

Since clinical processes are usually rather complex by nature and are not unlikely to run parallel to each other, decision elements (gateways) are a necessity for modeling them. Most modeling languages offer XOR (exclusive gateway), OR (inclusive gateway) and AND gateways (parallel gateway) for splitting and joining control flows. In addition to those, BPMN offers some more complex gateways for controlling the process flow. [17]

Data objects and data flow

For modeling input data and output data, which is generated during process execution data objects are used. Data objects describe the path data or documents take during the process. Data stores have a separate pictogram. Data flows between tasks, data objects and stores are modeled as a dotted line. [17]

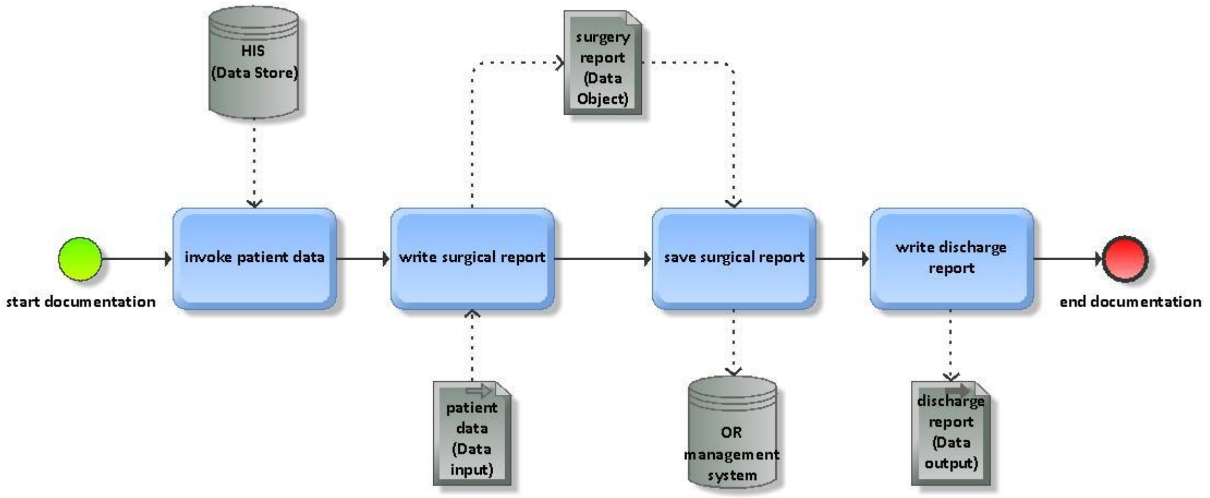

Figure 6 - BPMN 2.0 symbols: Data Object and Data Flow

Messages und Message Flow

Communication between involved organizations, departments and persons is modeled as messages and message flows in BPMN. Message flows can be connected to pools, activities and certain events.

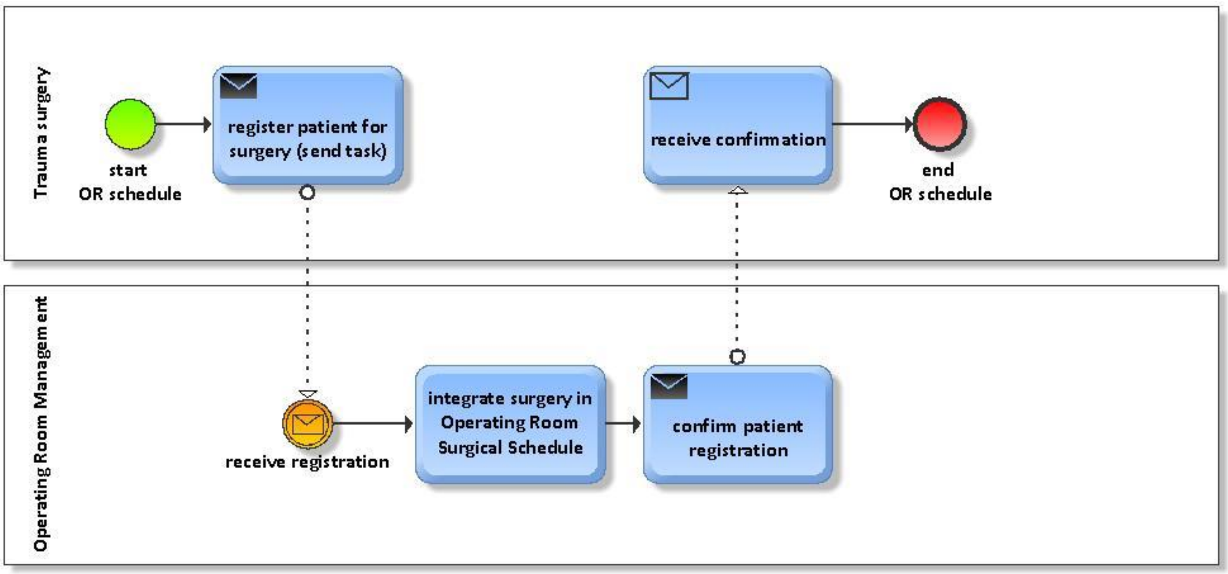

Figure 7 - BPMN 2.0: Messages and Message Flow

3.2 EVENT-DRIVEN PROCESS CHAIN (EPC)

Event-driven process chains (EPC) are a language for modeling business processes and organizational structures. They are essentially based on the concept of Petri nets [18] and were developed as part of the ARIS concept (Architecture of Integrated Information System). To portray a corporation as fully as possible, ARIS features 5 different views, each one being focused on a certain aspect of business process modeling [19]:

- Product/Service view (depiction of products and business services)
- Data view (depiction of data and data flow)
- Functional view (depiction of business processes and their relations)
- Organizational view (depiction of resources and their relations, e. g. human resources and organizational structure)
- Control view (depiction of connected views (EPC)). [19]

EPCs describe business processes in a semiformal way. For visualization they use directed graphs with the addition of logical connections between process elements. Personnel, technical and material resources as well as data and information flows can all be depicted in the process diagrams.

EPCs are not an open standard and cannot be executed by a workflow engine. For this purpose they have to be translated into an executable language, e.g. BPMN 2.0 or BPEL.

Functions and events

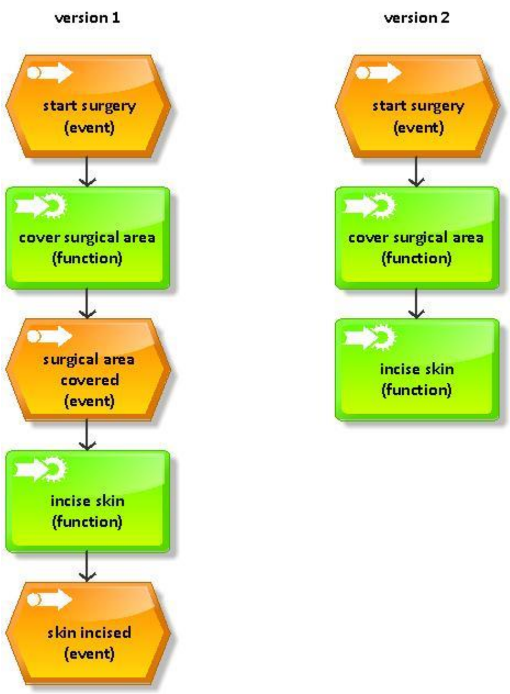

Figure 8 - EPC symbols: Functions and Events

There are two kinds of nodes in an EPC: Events and functions. Events and functions are modeled in alternation with directed sequence flow connection in a 1:1 relationship [18]. Events are the triggers for and the results of functions and describe the appearance of an object or the alteration of one of its attributes [18]. Each EPC has exactly one start event and exactly one end event.

Functions are tasks or activities that are triggered by an event [20]. Therefore each node in an EPC, with the exception of the end event, has a directed connection pointing at a node of the respective other type to depict the control flow.

Organizational Units, Roles and Persons

Modeling the organizational structure in ARIS is done with organigrams. The respective models and symbols can also be used in EPC diagrams however. Organizational entities, roles, positions and persons as well as their respective locations can be modeled and connected to function nodes. [15]

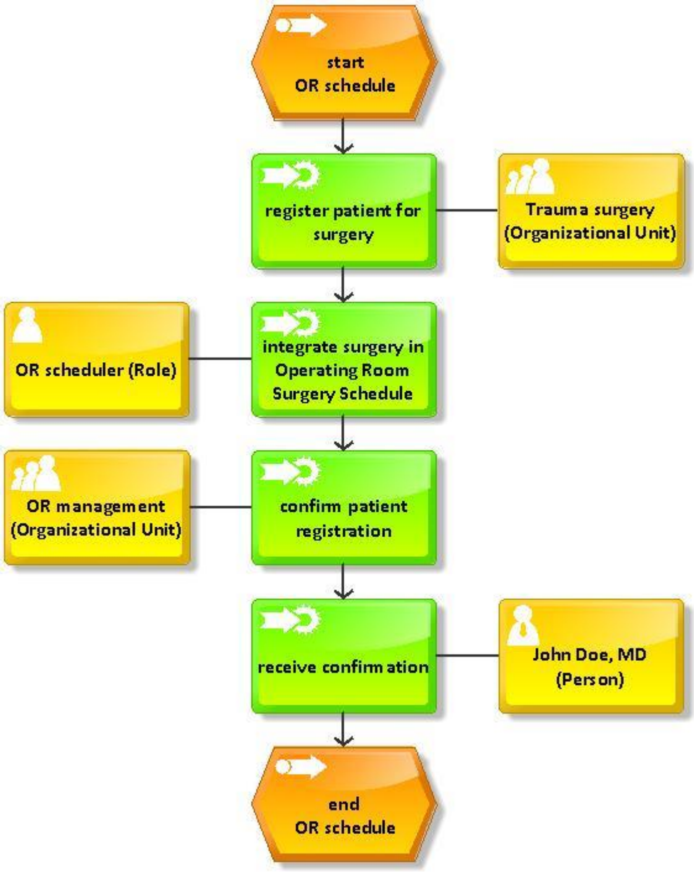

Figure 9 - EPC symbols: organizational symbols

Gateways

There are three logical operators available for splitting or joining the control flow in EPCs: AND, OR (inclusive or) and XOR (exclusive or). These gateways can be the endpoint of directed connections from multiple nodes and can also point at multiple nodes themselves. All incoming connections must come from nodes of the same type and all outgoing connections must point at nodes of the other type. Instead of nodes operators can also be connected to other operators, yet the rule above then applies to the set of interconnected operators. [15]

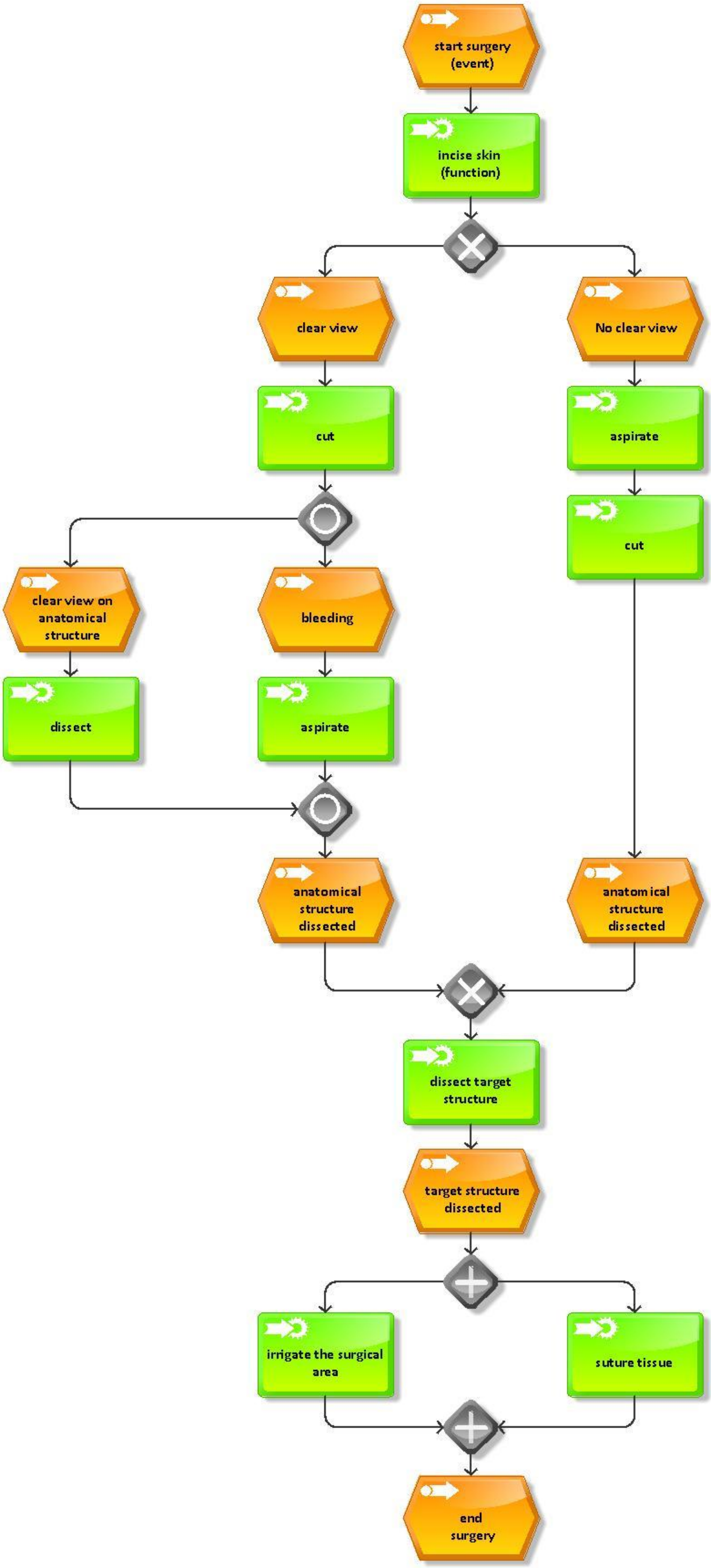

Figure 10 - EPC symbols: Gateways

Process Interface

Process interfaces can be inserted anywhere in the diagram in place of a function. They symbolize transitions to other process models.

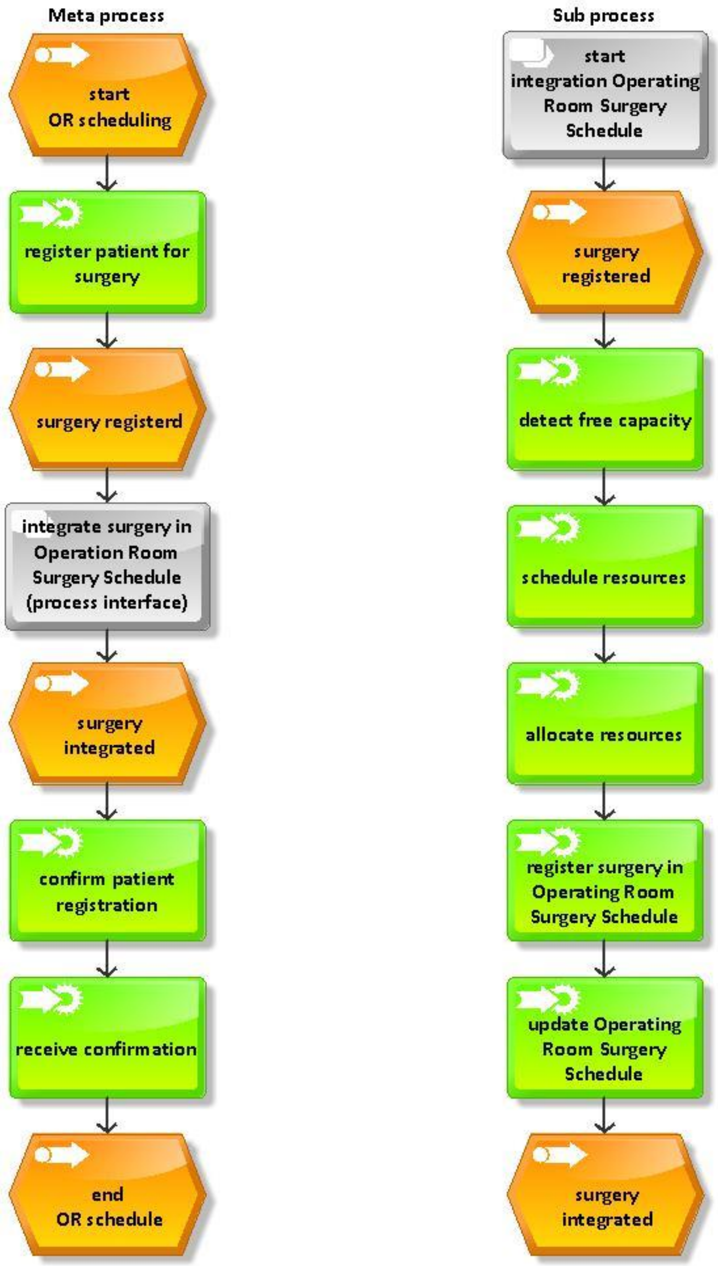

Figure 11 - EPC symbols: Process Interface

Data and Data Flow

A corporation's data stock is represented by information objects, which come in the form of documents, files and data storages. Data objects can have one incoming and one outgoing directed connection to functions. The connection's direction hints on whether the data or document is generated or required by the given process step.

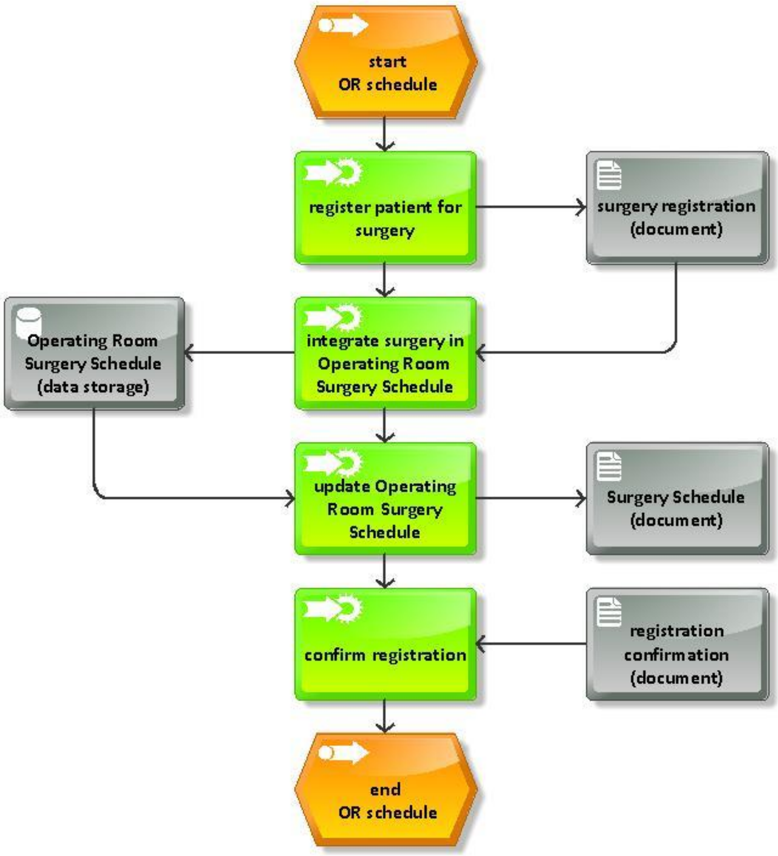

Figure 12 - EPC symbols: Data storage and Documents

IT infrastructures and system landscapes

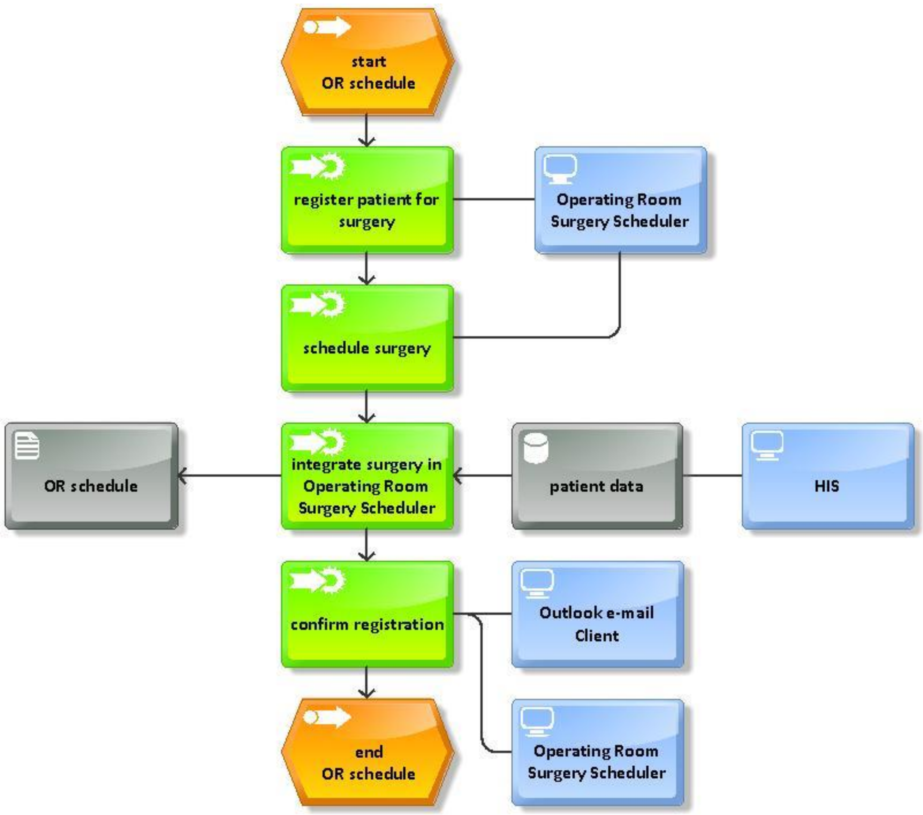

Figure 13 - EPC symbols: IT-system

The IT infrastructure of a corporation can be included in business process modeling with EPCs. In separate IT infrastructure and system landscape diagrams networks, network components and hardware components can be depicted.

3.3 YET ANOTHER WORKFLOW LANGUAGE (YAWL)

YAWL is a workflow modeling and execution language and also the name of the associated workflow management system. After analyzing business processes and already existent workflow languages the Workflow Patterns Initiative (WPI [21]) developed workflow patterns [22], [23]. YAWL was created as a language that implements all of the defined patterns [23]. The theoretical foundation of YAWL for the most part consists of workflow nets, which in turn are Petri nets[23], enriched with specific workflow functionalities.

In contrast to BPMN and BPEL YAWL is a formal modeling and execution language, since its syntax and semantics are formal [24]. This eases semantic examination and analysis of process models which are written in YAWL.

YAWL allows for viewing a business process from three different perspectives. One can model the control flow, the data flow (task and execution variables) or the organizational perspective (organizational structures, resources and liabilities) of a business process [25], [26].

Conditions und Tasks

A process definition in YAWL consists of tasks and conditions, with conditions being the equivalent to places in Petri nets or events in EPCs. Conditions represent the conjunction between two tasks. Every model or sub process starts with exactly one input condition and has to be able to reach an output condition. [23]

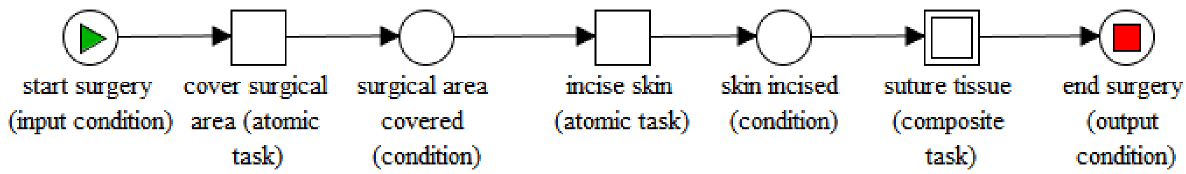

Figure 14 - YAWL symbols: Tasks and Conditions

Tasks are the equivalent to transitions in Petri nets or activities in EPCs, they are executed by people or IT systems. Individual process steps are modeled as atomic tasks. A task that can be executed multiple times parallel is a multiple instance task. A composite task is a sub process composed of multiple subtasks and is described in detail in another workflow model. The control flow is visualized through arrows between the tasks and conditions and symbolizes the order of task execution. [23]

Gateways

XOR, OR and AND gateways are part of the standard set of symbols in YAWL. The difference to e.g. EPCs however, is that these gateways are separated into split and join operators, which can be added to a task. Note that they cannot be added to conditions. [23]

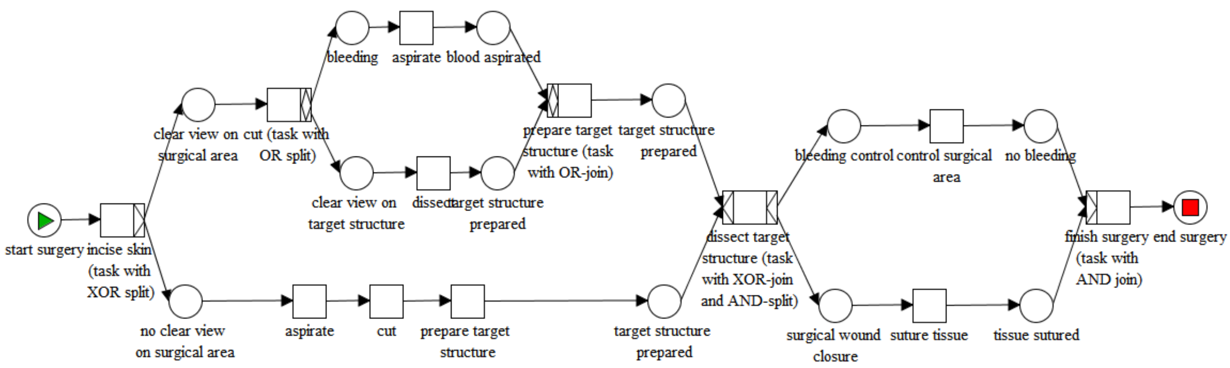

Figure 15 - YAWL symbols: Gateways

Data Flow

The data flow and the exchange of variables between tasks, instances or processes are modeled as decompositions in YAWL. A distinction is made between global net variables, which retain their validity for the whole process, and local task variables, which are only valid for a single work step. Variables cannot be passed from one task to another directly. Local and global variables can be converted from one to the other using XQuery expressions though [27]. As an example, task decomposition can be used to specify whether an atomic task has to be done manually, and will therefore be displayed on the schedule of the responsible person, or if it will be executed automatically by an IT system or a WfMS.

Organizational structure and resources (organizational view)

Modeling the organizational perspective is done by creating users, roles, organizational structures and physical resources as decomposition variables and assigning them to the appropriate process steps. Additionally it can be specified whether a decomposition variable is offered or allocated to the organizational element. [26]

3.4 COMPARISON OF MODELING LANGUAGES

The presented modeling languages were analyzed and compared to each other, focusing on functionalities that are relevant for modeling clinical pathways and intraoperative processes. This means for instance being able to display the process from a sequence-centered and from an organizational perspective and to be able to portray the resources used in the process. A tabular overview of the languages' traits and functionalities is given in chapter 3.5.

Process structure and modeling techniques

The process structure describes a hierarchical representation of all activities occurring during process execution. Therefore each process view is described by its own specific level of detail [28]. With an adequate surgical process model the following questions should be answered:

- What is being done? (modeling activities, events, process steps)
- Who is responsible? (modeling persons, roles or IT-system)
- What information is needed? (modeling data and information flow)
- What is needed? (modeling resources). [28]

A modeling language should support business processes visualization from different perspectives [29], [30]. All of the analyzed modeling languages in question support graphical display of the functional perspective, meaning visualizing processes, work steps and their chronological order. The graphical depiction of the organizational view is supported by BPMN (pools and lanes) and EPC (symbols for roles, persons and organizational units). In YAWL this can be done by binding the organizational components to variables, a graphical accentuation is missing though. The situation is alike when it comes to the operational perspective. Modeling and graphical visualization of medical devices, hardware components, IT systems, interfaces, networks, application software and the like is sufficiently implemented only in EPC diagrams. YAWL does not offer any symbolic representation of these and in BPMN there are only uniform pools and lanes. For modeling surgical processes including the needed medical and technical resources however this perspective is especially relevant. The information-centered perspective can be illustrated well by using BPMN diagrams or EPCs. In YAWL yet again information can be presented as variables, but don’t have their own graphical symbols.

For the sake of lucidity the modeling languages should offer mechanisms for displaying meta models, meaning superordinate process models [31]. Then one should be able to refine these at will, so that process models of arbitrary granularity can be generated. The granularity of a workflow is described as the abstraction level and the degree of subdivision of workflows and sub workflows. Incidental modeling aspects can be abstracted in the meta process and refer to the detailed visualization in sub process models. Therefore the level of detail of the process models have to be defined at the beginning of modeling. MacKenzie et. al [32] defined the granularity of surgical process models as the procedure, the step, the substep, the task, the subtask and the motion. The highest granularity level is the meta process or in case of surgical process modeling the procedure itself. The procedure can be divided into phases, like intraoperative phase, anesthetic induction or suture phase. Each phase can be described for example as process steps, substeps or tasks with detailed granularity. All of the examined languages offer modeling meta and sub processes as well as process interfaces and logical conjunctions between process models.

For modeling clinical pathways and surgical processes it is necessary to depict the steps in the treatment process [33] as well as all of the elements of clinical diagnostics and therapy and also the results of different therapeutic measures [34]. Clinical and surgical processes are often highly complex and variable. Therefore foreseeable exceptions, treatment variations and medically induced ad hoc decisions have to be integrated in the process model [35]. Basically all of the three modeling languages can be used to describe mutable clinical and surgical processes. Another essential aspect is the examination of a patient’s condition and ways to deal with possible changes of it [36]. All languages offer depicting states or state altering events respectively. State alterations can then be used to call sub processes, e.g. emergency treatment.

Especially for the portrayal of surgical processes the general information about the surgery, like positioning of the patient, type of anesthesia, average duration, material and technical resources used by default as well as costs should be considered. The examined languages offer denotation of these parameters via attribute specification, annotations or graphical symbols.

Modeling of organizational structures

Modeling surgical and clinical processes usually involves the representation of a considerable amount of participating persons, organizational units and liabilities [31]. In BPMN a hospital’s organizational structure can be depicted as pools and lanes. YAWL allows assigning the liable persons to tasks via variables. EPCs offer the most extensive amount of possibilities for portraying an organizational structure. In contrast to BPMN and YAWL, EPCs include specialized organigrams, which can display the complete organizational hierarchy and also provision of deputies. Furthermore EPCs include a library of symbols for persons, roles, organizational units and locations. When modeling surgical processes one should include various persons and organizational units, such as surgeons, assistants, anesthetists, nursing personnel and also the specialty departments in the model.

Modeling of functional structures

Clinical and surgical processes are often complex and nonparallel, so decision elements (gateways) are required for process modeling. For modeling a sequence the basic control flow patterns (XOR, OR and AND gateways) are a vital functionality [37], [38]. Those are implemented in all the examined languages. Additionally BPMN offers a loop element, which simplifies depicting recurring activities.

Another essential component of clinical and surgical process modeling are human workflows [39], [40], so work steps that have to be carried out manually by a person or organizational unit and which could eventually be supported by a WfMS via task lists. In BPMN human workflows are modeled as user tasks explicitly. In YAWL persons can be modeled as variables, adding them to a task then defines it as a user task. When modeling EPCs, user tasks emerge from assigning persons, roles or organizational units to activities. In contrast to BPMN it is possible to assign multiple people to a task, this is important for modeling e.g. the passing of instruments to the surgeon during a surgery.

In the course of clinical and surgical processes predictable or unforeseeable events, like the activation of an endoscope or the failure of a medical device, can happen. This usually means that additional process steps have to be executed or the process has to be left and an alternative route has to be taken. Because of this, all of the modeling languages support events [41]. BPMN and YAWL offer a great variety of different event types, such as interrupting events, timer events, deadline events and exceptional events. EPCs only offer unspecified events.

These unexpected events, ad hoc decisions, unforeseen external influences, long durations and perpetually shifting parameters make clinical and perioperative processes very complex and highly erratic [35]. Thus, in addition to modeling events, mechanisms for exception handling and flexibilization are a necessity for a modeling language that is to be used in this domain [42]. Furthermore one has to be able to portray the clinical procedures as flexible and adaptable to an individual patient. Therefore expected exceptions should already be considered in the process model and depicted by alternate process flows and decisions [43], [44].

Workflow patterns are well suited for modeling exception handling [45]. As yet YAWL is the only modeling language that supports all of the workflow patterns concerning exception handling. Basic mechanisms for flexibility and exception handling exist in all of the languages though, albeit EPC, not being a workflow modeling language, exhibits deficits when it comes to modeling placeholder or resource-dependent process execution.

If a process offers multiple options for continuing its execution, the participating people often have to take a decision. These decisions are modeled as gateways. Here it can be beneficial to know at run time which choices were made most often in the past, so a standard path or transition probabilities can be displayed. Especially during surgeries it can benefit the surgeon to know which alternate processes are available and which paths were commonly chosen. BPMN and EPC offer explicit declaration of transition probabilities and standard paths as gateway attributes. In YAWL this can be achieved by using external simulation tools.

For the comprehensive portrayal of a processes organization additional attributes must be integrate in the modeling process. These include priorities for human workflows [39]. Priorities are supported by BPMN and EPC and by YAWL as well. Beyond that temporal aspects and restrictions for an activity, or a process respectively, have to be representable in order to depict e.g. maximal and minimal durations, deadlines or dates [46]. In case of a missed deadline or date escalation marks (deputies, reminders and alternate processes) should be lodged within the model to prevent process stagnation. Temporal aspects can be depicted as timer events in BPMN or variables in EPCs and YAWL respectively. Another desirable attribute of a process or work step is its monetary cost or gain. This enables determination of optimal paths and process costs or gains during a process simulation prior to execution.

Modeling of Data and document organization

Process modeling should include representation all of the documents, data and applications that are needed for a specific process step, so the WfMS can manage the data and information flow inside the operating room during process execution. Required data and documents can then additionally be offered directly to involved persons via task lists. This implies that a multitude of different media types, like emails, forms, documents and data records have to be representable by the used modeling language. The WPI defined several workflow patterns for document and data organization [47], which specify the exchange and calling of data between employees and also between IT systems. All of the examined languages support the WPI's basic workflow data patterns and are equipped with a substantial amount of mechanisms for data exchange, document organization and communication beyond that. In BPMN, EPCs and YAWL calls for data and documents and to applications can be linked to process steps, so that required resources can be made available automatically to the processing person during run time. YAWL doesn't offer a graphical depiction though.

Modeling of resource organization

Apart from data, the organization of other resources, like medical devices, operation room appliances (e.g. lighting), hardware and software components, medical instruments and if necessary locations has to be visualized for modeling surgical processes as well. Resource organization should therefore incorporate and manage all of the resources that are needed for the execution of the process, so that the needed resources for completing a task can be allocated to the right person at the right time [11]. In part resource organization can already be determined during build time. To do this, the WPI defined resource patterns, which govern the allocation of resources to activities or persons [48]. BPMN, EPCs and YAWL all support the basic resource patterns. Because BPMN doesn't offer specific symbols for resources, like personnel, devices, materials or IT systems, one has to rely completely on the notation for pools and lanes to visualize them. In YAWL the human and non-human resources can be depicted as attributes or allocated dynamically during the workflow's run time. EPCs have specific symbols for resources, such as persons, IT systems, materials, devices, medical instruments and locations. Solely the dynamic allocation of resources to process steps and people during run time is limited in BPMN and EPCs as opposed to YAWL. Depending on the modeling tool used, resource data objects can be equipped with several attributes, such as resource data (e.g. price, capacity), resource states (e.g. in use, defective) or restrictive covenant.

Workflow execution

Once the process models are generated, a WfMS can take over process execution. The WfMS creates a workflow as an instance of a workflow model, e.g. one specific patient's surgery. The workflow can be separated into steps that are executed by the WfMS (technical workflows) and steps that are carried out by involved people (human workflows). When managing the workflow, the WfMS has to allocate all relevant information, data, documents and resources at the proper time.

BPMN and YAWL are execution languages, this means that their models can be passed directly to a WfMS for execution. The basic business process models have to be enriched with additional technical information to enable process automation though. EPCs can't be executed directly, yet most EPC tools can translate them into BPMN or another execution language, such as BPEL or XPDL.

3.5 OVERVIEW ON MODELING LANGUAGE FUNCTIONALITY

	BPMN 2.0	EPC	YAWL
1. Process structure and modeling techniques[1]			
1. Modeling different perspectives on business processes [29], [30], [49]			
Functional perspective (processes)	X	X	X
Behavioral perspective (sequence and logical relation between processes)	X	X	X
Organizational perspective (responsible persons)	X	X	X (parameter)
Informational perspective (data, documents and information)	X	X	X (parameter)
Operational perspective (IT systems, applications, interfaces, hardware and software components)	X (parameter, additional symbol available in Signavio)	X	X (parameter)
2. Generation of meta models [31]	X	X	X
Creation of process models with different granularity	X	X	X
Subprocess modeling	X (subprocess)	X (process interface)	X (composite task)
Connection of different process models	X	X	X
3. Modeling clinical pathways[34]			
Modeling of OR parameters (duration, time, anesthesia, position, …)	X	X	X
Modeling of diagnostic and therapeutic process elements	X	X	X
Modeling of treatment elements	X	X	X
Modeling of alternative pathways	X	X	X
Modeling of treatment results	X	X	X
Decision modeling	X	X	X
Modeling costs of treatment	X	X	X
Modeling patient state[36]	X (state change event)	X (event)	X (process state pattern)
Resource modeling (materials, devices, instruments, OR, …)	X (pool)	X (entities, …)	X (parameter)
Modeling of anatomical and pathological structures	X (pool)	X (entities, …)	X (parameter)
2. Modeling of organizational structures			
1. Organizational and functional units	X	X	X (parameter)
2. Roles (patient, surgeon, staff nurse, …)	X	X	X (parameter)
3. Persons	X	X	X (parameter)
4. Organizational and hierarchical structure [31]	-	X (organizational chart)	X/- (parameter)
5. Absence management[50]	-	X	X

[1] X- function/property available; - function/property unavailable

	BPMN 2.0	EPC	YAWL
6. Location[31]	X (pool)	X	-
3. Modeling of functional structures			
1. Control patterns[38]			
Sequence	X	X	X
AND split, AND join	X	X	X
XOR split, XOR join	X	X	X
OR split, OR join	X	X	X
Loops	X (additional symbols available)	X (workaround)	X (work-around)
2. Modeling of human workflows[39], [40]	X	X	X
Assignment of roles and activities	X	X	X (Variable)
Assignment of multiple roles and activities	-/X (workaround, additional function in Signavio)	X	X
3. Event modeling [41]	X	X	X
Trigger events	X	X	X (transition)
Cancel events	X	X	X (Cancel transition)
Intermediate events	X	X	X (transition)
User decisions	X	X	X
Timer events (deadline, dates, …)	X	X	X (timer transition)
Message events	X	X	X (message transition)
Exception events (errors, …)	X	X	X (exception transition)
4. Modeling of priorities (flow- and schedule tasks)[39]	X	X (annotation)	X
5. Modeling temporal aspects[46]	X (time event)	X (parameter)	X
Dates (with assignment to tasks)	X	X	X
Deadlines	X	X	X
Minimal and maximal time periods between activities	X	X	X
Escalation points	X	X (event)	X (escalation transition)
6. Transition probability			
Modeling of transition probabilities in order to determine the further process execution (e. g. for simulation purposes)	X	X	X (simulation)
Modeling of transition probabilities with respect to already executed process steps (e. g. for simulation)	X/- (explicit definition)	X/- (explicit definition)	X/- (explicit definition
7. Costs and income	X	X	X

	BPMN 2.0	EPC	YAWL
8. Modeling of exception handling[45]			
Work item failure	X	X	X
Deadline expiry	X	X	X
Resource Unavailability	X/- (workaround, (event subprocess))	-	X
External trigger	X	X	X
Constraint violation	X	X (parameter: interruptible)	X
9. Modeling of flexibility	X	X	X
Predictable exceptions[51], [43], [44]	X	X	X
Alternative pathways [51], [43]	X	X	X
Resource dependency (influences pathway)	X (workaround)	-	X
Placeholder for processes and activities (late binding, late modeling)[52]	X/- (ad-hoc subprocess)	-	X
4. Modeling of Data and document organization			
1. Modeling data patterns[47]			
Task Data	X	X	X
Block Data	X	X	X
Case Data	X	X	X
Push messages	X	X	X
Pull messages	X	X	X
2. Modeling data objects			
Documents (Data, forms, lists, media)	X	X	X (parameter)
Information (input data, output data)	X	X	X (parameter)
Messages	X (event)	X	X (parameter)
3. Message flow modeling	X (choreography)	X (annotation)	X/- (annotation)
4. Data and application modeling	X	X	X (parameter)
5. Modeling of resource organization			
1. Modeling resource patterns[48]			
Direct Assignment of resources to one person	X (pool)	X	X (parameter)
Assignment of resources to a role	X (pool)	X	X (parameter)
Assignment of resources at runtime	X/- (partly)	X/- (partly)	X (parameter)
Automatic execution	X	X	X
2. Resource Modeling[53]		X (entities, system symbols)	
Person	X	X	X (parameter)
Materials	X (pool)	X	X (parameter)
Devices	X (pool)	X	X (parameter)
Instruments	X	X	X

	BPMN 2.0	EPC	YAWL
	(pool)		(parameter)
(Operating) Rooms, Locations	X (pool)	X	X (parameter)
Time contingent	X	X	X
IT systems, applications	X (pool and additional symbols in Signavio available)	X	X (parameter)
3. ERP and resource management integration[50]	X (SAP Netweaver BPM, …)	X (SAP Business Suite, Solution Manager, Business Object Repository (Application Core Processes), Oracle OEM)	-
6. Workflow execution			
1. Execution of workflow models [31]	X	-/X (execution by automatic conversion in a workflow language (e. g. BPMN, BPEL, …))	X

Table 1 – Summary of functions and features of analyzed modeling languages

4 BUSINESS PROCESS AND WORKFLOW MODELING TOOLS

Modeling tools are software products that provide functions and methods for analyzing, documenting, modeling and eventually simulating business processes. The choice of modeling tool usually dictates which modeling language is used. Some tools support multiple different languages and perspectives though. Some modeling tools only support modeling business processes and workflows and others offer additional functionality, such as simulation, analysis and execution of workflows. Many companies don't use complete BPMN suites, which would cover all functionalities within the workflow's life cycle, but rather downright tool chains with different (open source) programs each for analysis and evaluation, modeling, simulation and execution.

Nine different business process and workflow modeling tools were chosen for evaluation against specific requirements concerning surgical process and workflow modeling. In the following a detailed analysis is done. The choice of modeling tools for further testing was done based on availability (free to use or free of charge for academic purposes), subjective renown, availability of documentation and further information, the existence of a user and/or developer community and finally their design and overall usability.

4.1 ACTIVITI

Activiti is a complete open source workflow management system which is currently being maintained and updated by Alfresco Inc. and the Activiti community. The project is furthermore supported by different manufacturers, such as Signavio, Springforce and Camunda.

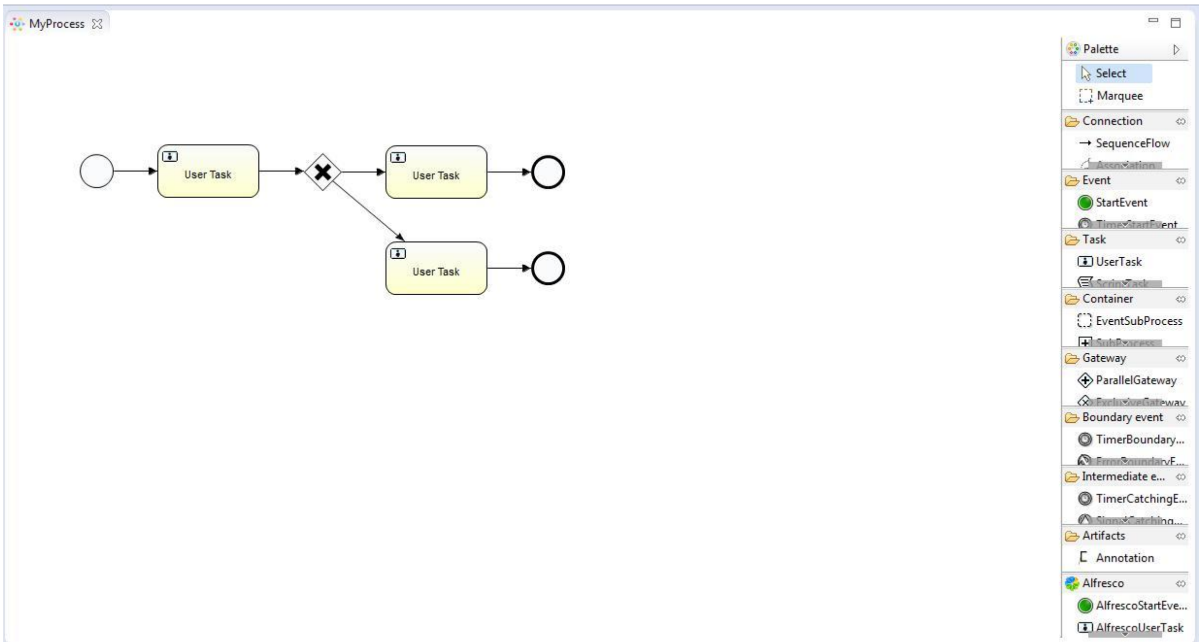

Figure 16 - Activiti Designer for Eclipse

Activiti was written in Java and is made of several components: a browser-based modeling tool, an Eclipse (Java development environment) plugin for modeling and implementation of workflows, the Activiti engine (workflow management system), the Activiti repository and a web-based user and administration interface for the Activiti engine. Both the browser-based modeling tool and the Eclipse plugin support virtually all aspects of BPMN 2.0 notation. The browser-based tool Activiti Modeler builds upon the Signavio Process Editor, which will be described in chapter 4.8. The Activiti

Designer and the Eclipse plugin, which can be used for modeling and testing workflows as well as deploying them to the Activiti engine were tested. In order to configure the respective parameters for automation and thereby modeling an executable workflow, basic Java knowledge is necessary though.

4.2 ADONIS: CE BUSINESS PROCESS MANAGEMENT TOOLKIT

Since 1995 the BOC AG is developing ADONIS, which covers recording, modeling, analysis and evaluation of business processes, it does not however include a workflow engine (run time environment). The process modeling tool exists as a fee-based version (ADONIS GPM Suite) and since 2008 as a freeware community edition (ADONIS:CE). For this report ADONIS:CE was analyzed. The freeware tool has a limited range of functions, several functions for simulation, analysis and evaluation are only available in the fee-based version. ADONIS GPM is also a client server application, whereas ADONIS:CE is a single user desktop application. Both versions do support the full BPMN 2.0 standard for business process modeling.

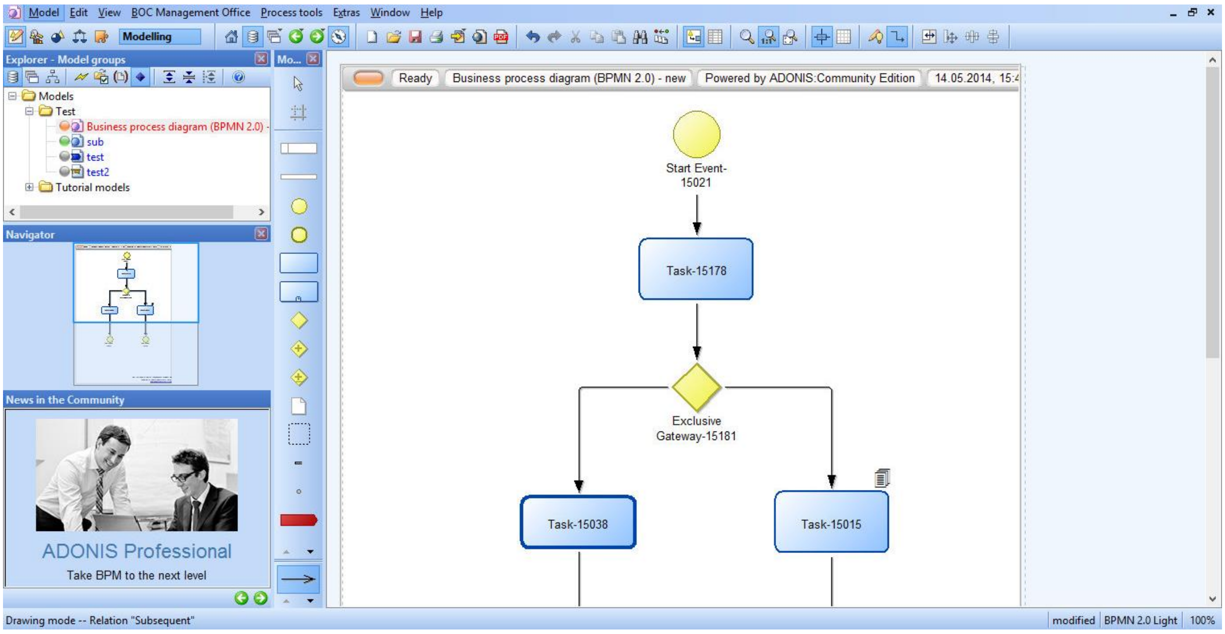

Figure 17 - ADONIS:CE Business Process Management Toolkit

4.3 ARIS PLATFORM

The ARIS platform is made of several tools for business process modeling, analysis, simulation, publishing, controlling, reporting, optimization and administration. It was released in 1992 by IDS Scheer [18] and is currently being distributed, maintained and updated by the Software AG. Due to its tight coupling and integration with various SAP products ARIS has been one of the most popular tools for business process modeling and evaluation in enterprises since the 90s [54].

The part of the platform responsible for modeling of business processes is the ARIS Business Architect. The ARIS platform is usually distributed as a fee based Pro-version, yet for universities and students parts of it were made available free of charge as an academic version. Additionally the Software AG and the ARIS community are continuously developing the freeware modeling tool ARIS Express [55], which covers the greater part of the ARIS concept, yet doesn't extend its functionality beyond business process modeling (Figure 19). For the present technical report we examined the academic version of the ARIS Software Architect, version 9.6. An evaluative comparison of ARIS with other tools was not possible to do due to licensing restrictions.

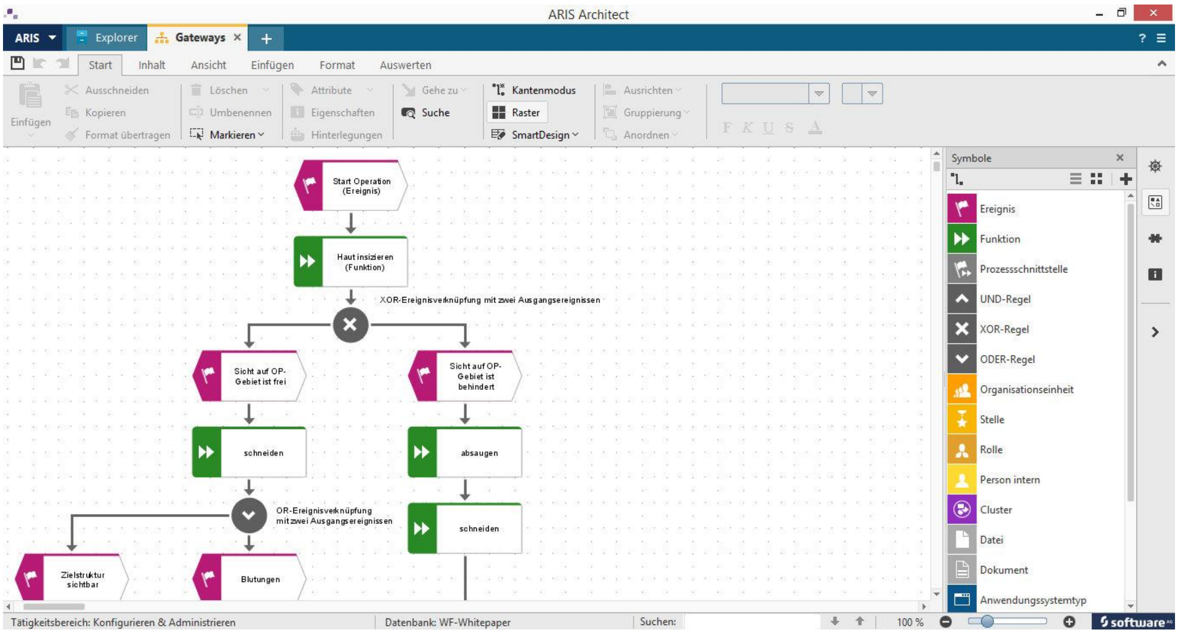

Figure 18 - ARIS Business Architect

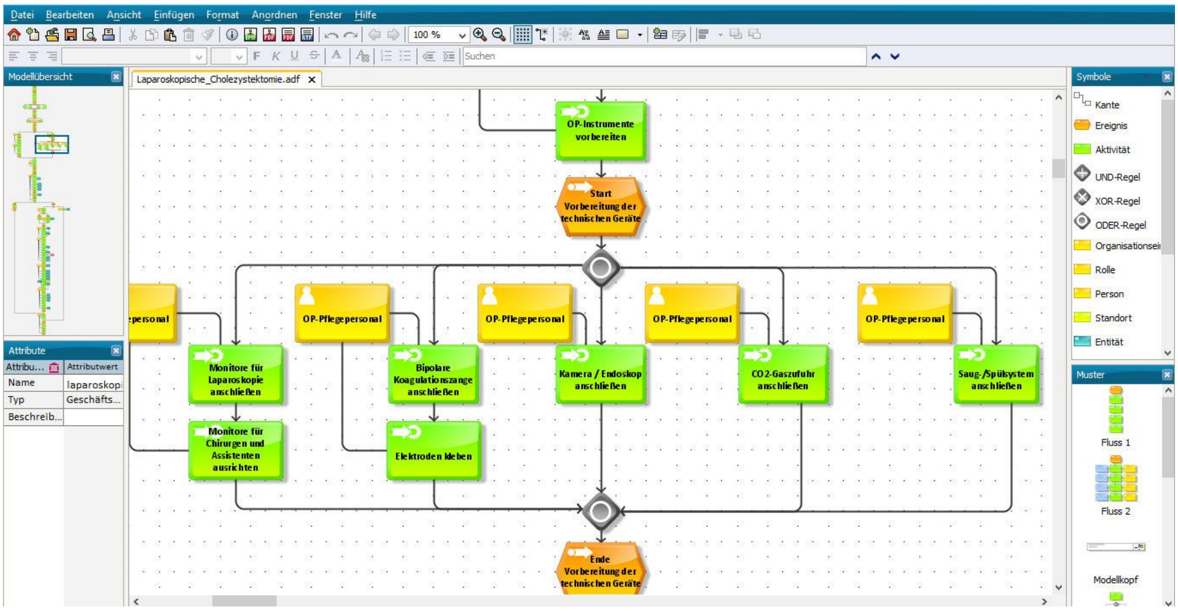

Figure 19 - ARIS Express (Freeware)

Both ARIS modeling tools support EPC modeling and the complete BPMN 2.0 notation. With EPC diagrams not being executable, the ARIS Business Architect offers automated translation to BPMN, BPEL or XPDL. A runtime environment is not part of the toolset though.

4.4 BIZAGI PROCESS MODELER

The Bizagi Process Modeler is a freeware modeling tool which is being maintained and updated by Bizagi Ltd. According to a Gartner study from 2010 [56], Bizagi is among the top 25 multinational producer of business process modeling tools. The fee based full version, the Bizagi Suite, is a complete WfMS including a runtime environment. It was written in .NET and is therefore platform dependent (Microsoft Windows) though. The Bizagi Process Modeler, which was tested for this report, is a neat modeling tool which covers the full BPMN 2.0 standard. Beyond that the tool offers extensive functionality for the evaluation and simulation of the created process models. Due to licensing restrictions there will be no comparative evaluation in this report.

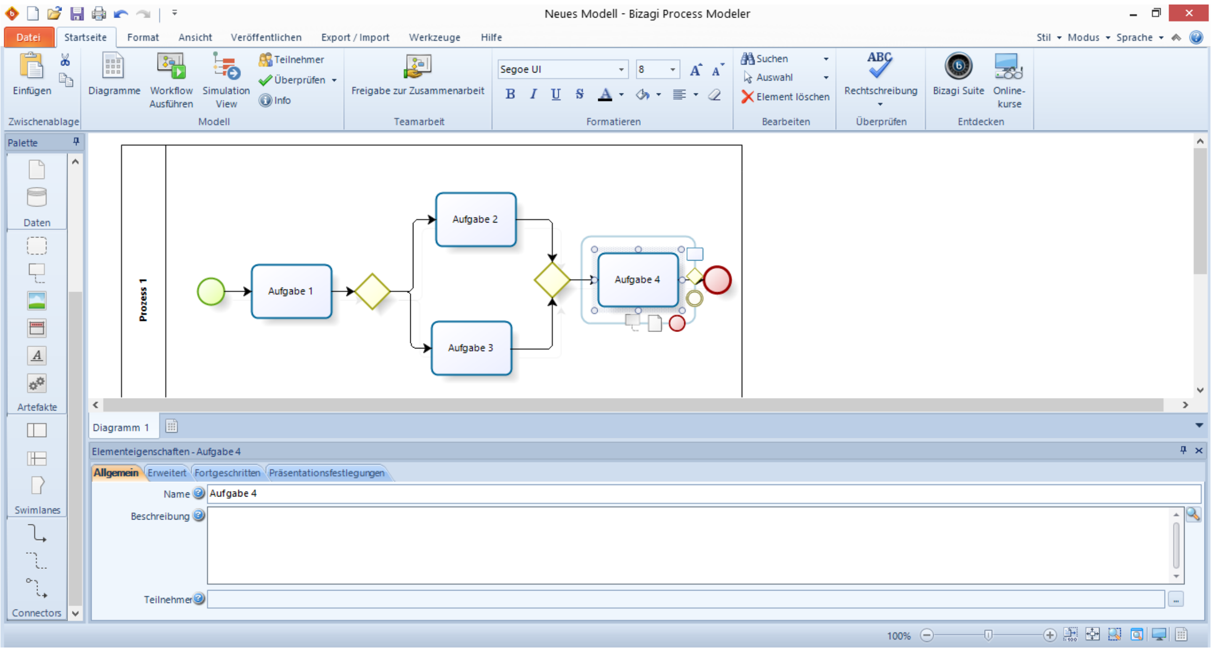

Figure 20 - Bizagi Process Modeler

4.5 BONITA BPM COMMUNITY

The Bonita BPM Suite was released in 2001 and is currently being distributed by BonitaSoft. Bonita is a complete WfMS including a neat modeling tool, a java based runtime component and a web based process portal as well as an extensive task list component. The tool is available in the form of a fee based version, but also as a freeware open source edition (Bonita BPM Community).

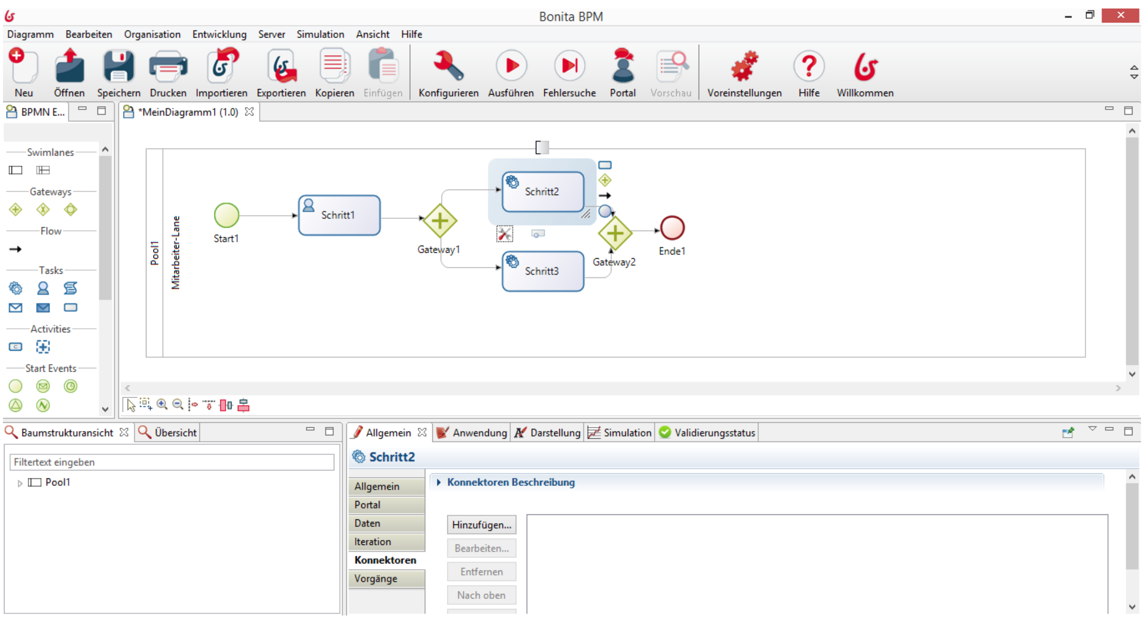

Figure 21 - Bonita BPM Community

In contrast to the various Pro-editions, the in this report analyzed, community edition mainly lacks functionality in the fields of teamwork and collaboration (e.g. repositories) as well as document administration. The modeling tool supports almost all aspects of the BPMN 2.0 standard and offers a form creation component for the design of tasks lists.

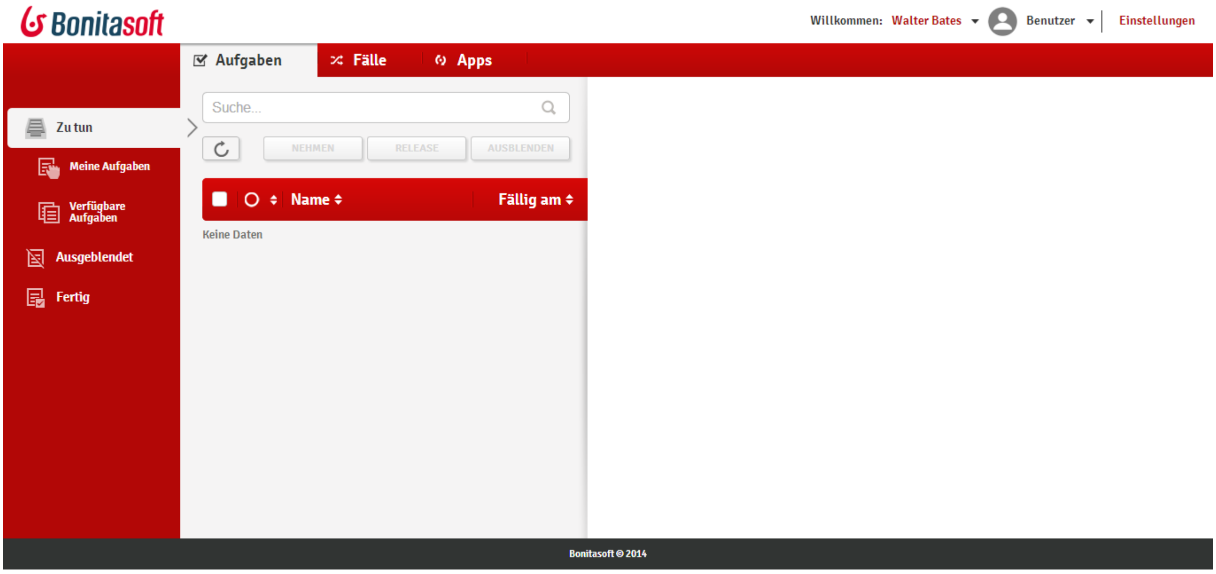

Figure 22 - Bonita BPM Community: web-based process portal with task list component

4.6 CAMUNDA

Camunda BPMN is a complete open source WfMS based on Activiti that is being maintained and updated by the Camunda GmbH. Camunda features a java based workflow engine and offers its modeling tool as a standalone desktop application or as an Eclipse plugin. Both versions support nearly every aspect of the BPMN 2.0 standard. Camunda also features additional components, such as a process cockpit for the administration and monitoring of processes, a repository for handling the process models and an extensive task list component. Additionally other commercial or freeware modeling tools can be integrated with the Camunda runtime environment by doing a roundtrip.

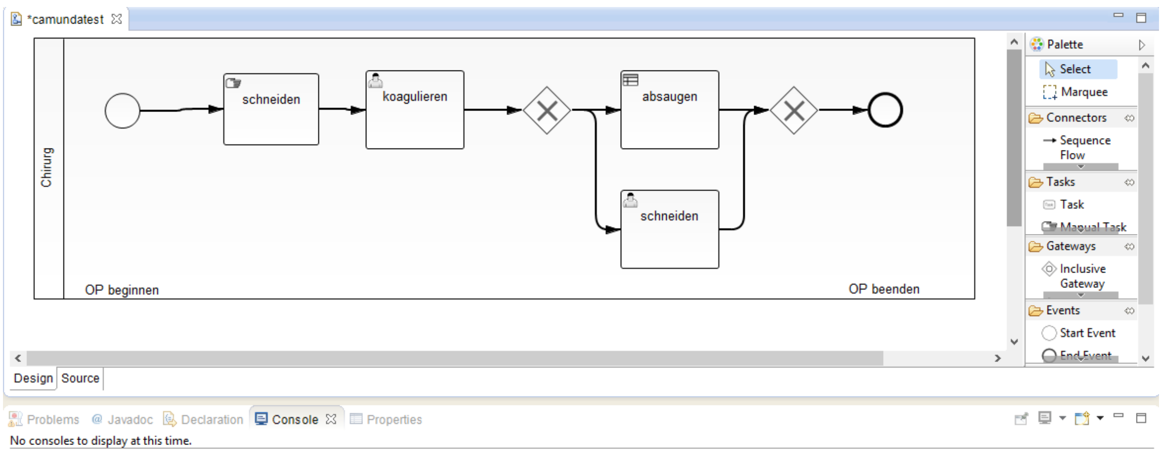

Figure 23 - Camunda Modeler for Eclipse

4.7 JBPM

jBPM is an open source workflow management system which is maintained and updated by JBoss and the jBPM community. It features a java based runtime environment, BPMN 2.0 conform modeling tools in the form of an Eclipse plugin and the web based WebModeler and a web portal for administrating task lists and processes. Via the jBPM Modelers Eclipse environment various methods for analysis and evaluation can be created. Both versions of the modeling tool support the complete BPMN 2.0 standard as well as the greater part of the WPI workflow patterns [21].

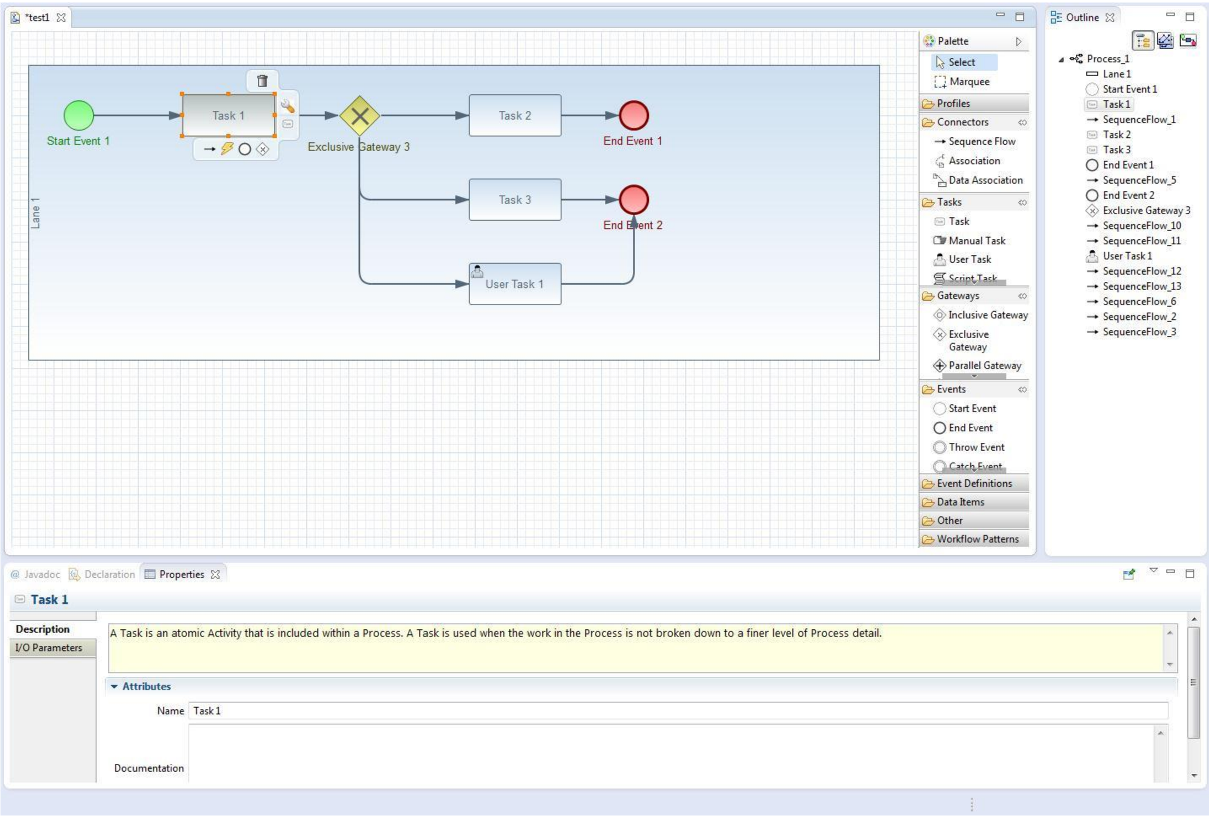

Figure 24 - jBPM Modeler for Eclipse

4.8 SIGNAVIO PROCESS EDITOR

The Signavio Process Editor is a visually appealing modeling tool without a runtime environment which is distributed by the Signavio GmbH. Since the editor is implemented as a cloud service and is accessed via the web browser, there is no need for any software to be installed on one's local machine. Signavio is available as a fee based commercial version and as a free to use academic version for students and universities. Every model made with the academic version has to be released to the community though.

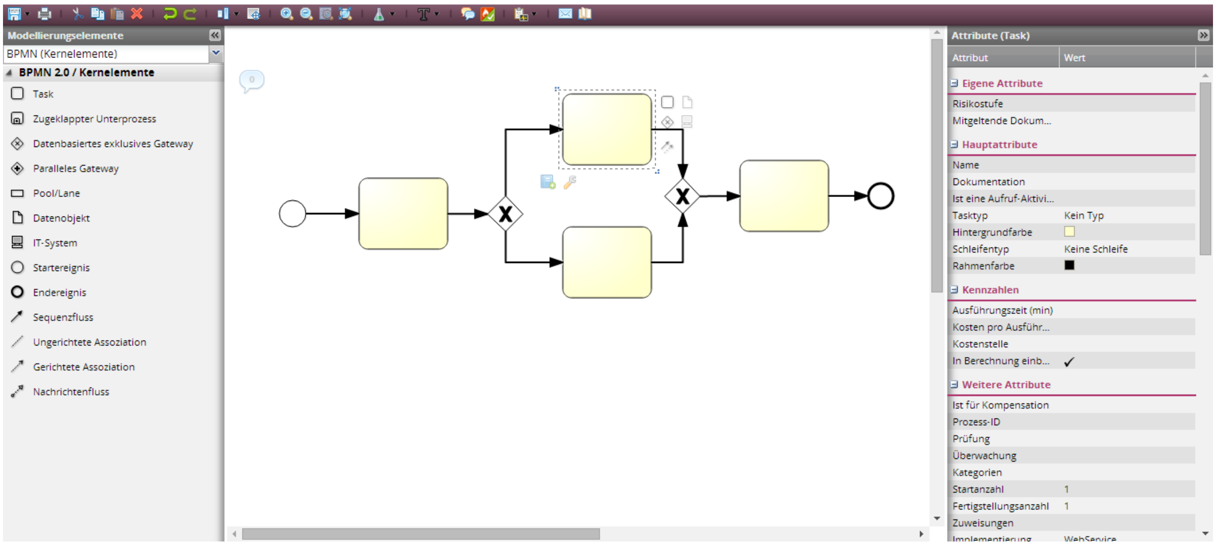

Figure 25 - Signavio Process Editor: BPMN 2.0 modeling

Signavio enables the creation of diagrams in BPMN 2.0, YAWL, jBPM, UML or EPC as well as Petri nets. It supports the full BPMN 2.0 standard and features components for evaluation and simulation, a model repository and various collaboration functions, such as sharing, commenting and multi-user editing of process models as well as extensive functionality for reporting and publication.

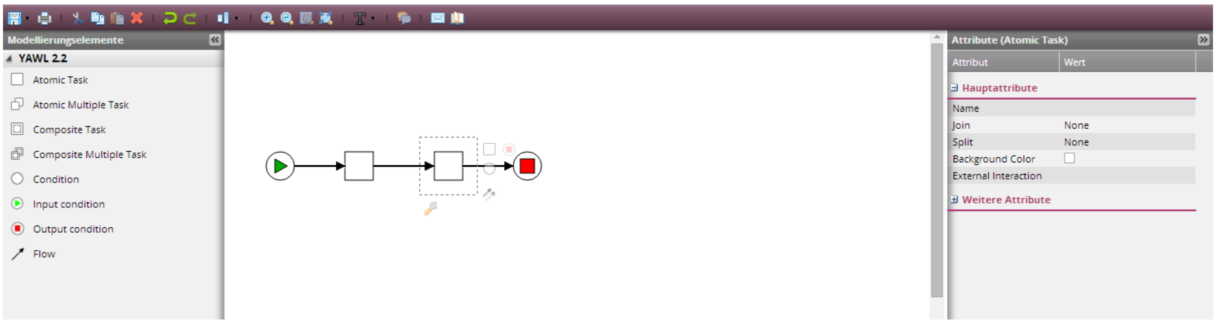

Figure 26 - Signavio Process Editor: YAWL modeling

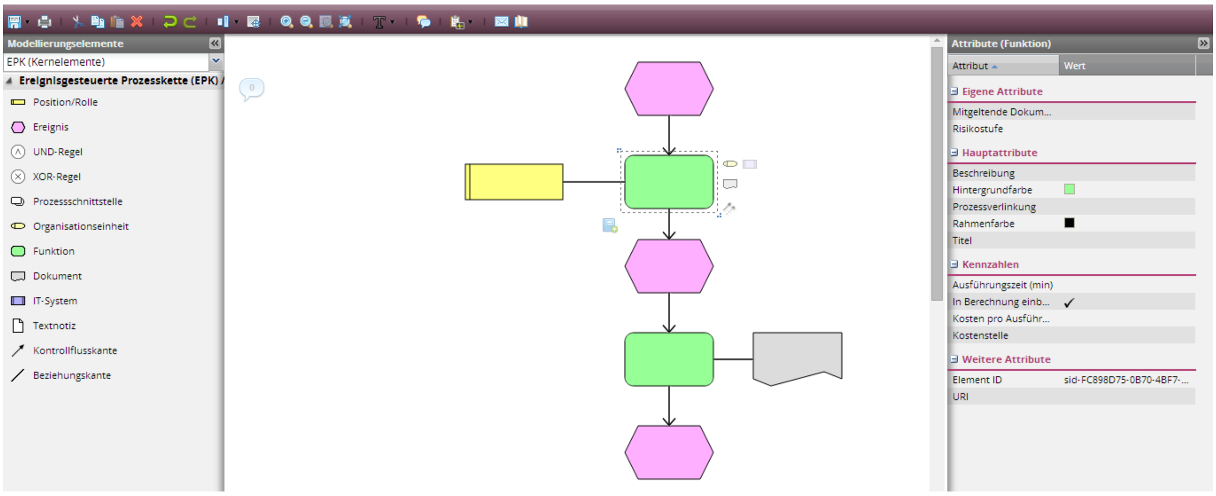

Figure 27 - Signavio Process Editor: EPC modeling

4.9 YAWL

Besides denominating the modeling language YAWL is also the name of a software framework which was developed at the Center of IT of the Queensland University of Technology in Brisbane. YAWL is an open source WfMS that supports all of the workflow patterns defined by the WPI [57]. Within the scope of this technical reports the tool YAWL4Study was tested. The YAWL framework offers a modeling tool, a runtime environment, a web based task list component and a form creation component, but also an extensive set of functions for analysis and evaluation based on the formal semantics of the underlying Petri nets.

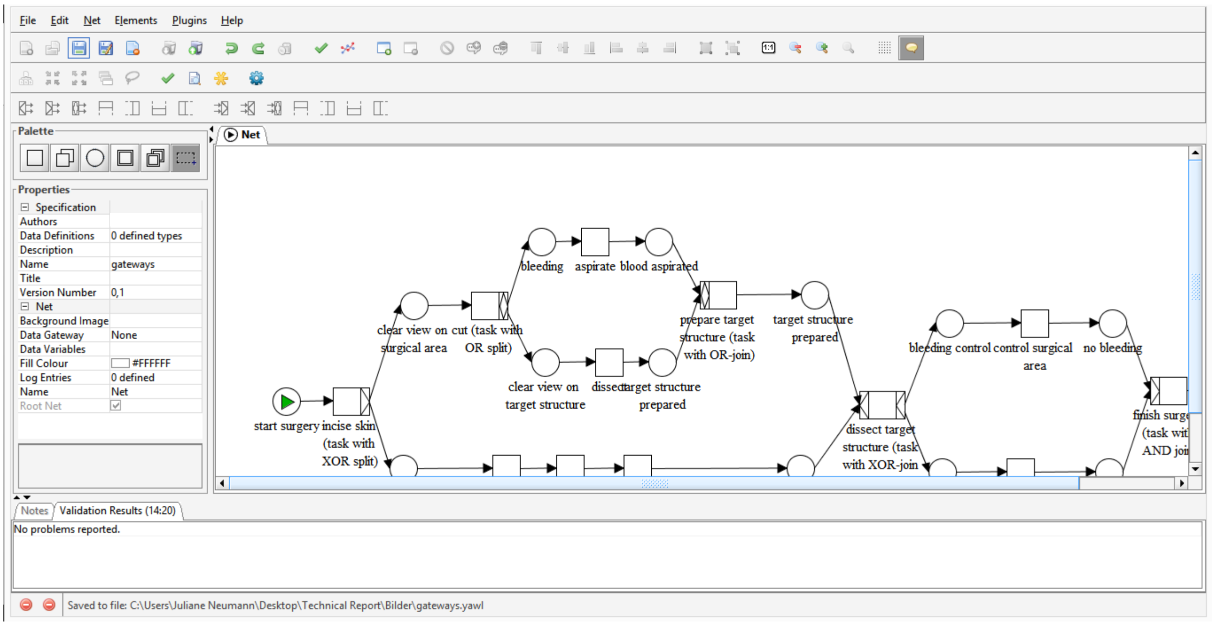

Figure 28 - YAWL4Study

4.10 COMPARISON OF MODELING TOOLS

Hereafter the selected modeling tools will be evaluated on the basis of various requirements and compared to one another. The focus will lie on their ability to give a comprehensive representation of surgical and clinical processes or workflows. Furthermore those traits and features of a modeling language that are needed for the depiction of processes in the surgical domain should be supported by the modeling tool as well. An overview of this is given in tabular form in chapter 4.11.

Both the ARIS Platform and the Bizagi Process Modeler were analyzed in the scope of this study. An evaluative comparison cannot be done here due to license restrictions though.

Modeling Tool

There are several modeling tools (or BPM-tools/suites respectively) in existence that support every step in the workflow life cycle [14], from modeling of the business processes to executing the workflow to analyzing and simulation to controlling and process optimization. Other tools confine themselves to the core functionalities needed for modeling without integrating a runtime environment (workflow engine). Among the analyzed tools Activiti, Bonita BPM, Camunda, jBPM and YAWL featured a runtime environment besides the modeling tool, enabling execution, management and monitoring of the modeled workflows by a WfMS. ADONIS and the Signavio Process Editor are pure modeling tools. However, ADONIS offers interfaces and standard format exports, so that workflows can be executed by common WfMS. Signavio offers export and import functionalities for executing the modeled workflows with Camunda via roundtrip.

For the purpose of process automation the modeled business processes have to be enriched with various parameters and additional information, data, applications, resources, etc. [8]. There are two different approaches the manufactures took to achieve this. The "zero code" approach, as e.g. used by Bonita BPM, allows the creation of technical workflows by end users without any knowledge about programming. If functionalities are needed for modeling workflows in complex scenarios that are not natively supported by the tool, the "zero code" tools often has to be individualized by the manufacturer. Because of this in recent years the concept of "less code" has become established [58]. This concept envisages parameterization to be done by a model developer with an appropriate level of knowledge about the underlying programming language. Activiti, Camunda, jBPM and YAWL are premised by the concept of "less code" and therefore require the modeler to be familiar with Java. The runtime environments of these tools are bound to the respective development environment, e.g. Eclipse or NetBeans.

Beyond the pure process modeling all of the analyzed modeling tools offer basic or very extensive functions for the analysis of business processes and workflows. Which functions are implemented in which modeling tool will be shown in detail in the paragraph captioned "Analysis".

Before executing workflows or testing them in the productive environment it makes sense to first simulate them in a virtual environment. Except for Activiti, Camunda and YAWL all of the analyzed tools offer a simulation feature. YAWL does offer an interface between its workflow engine and the Process Modeling Framework (ProM) though, which allows converting YAWL process models to simulation models. The exact functions that are needed for simulations will be explained in the paragraph "Simulation".

To complete the workflow life cycle, a BPM tool should additionally offer functions for controlling, for example a monitoring component for the management and control of running workflows or statistical functions for the evaluation of a processes key performance indicators (KPI) [59]. These in turn can be used for optimizing the underlying process models. All tools offer at least basic functions for statistical analysis and the evaluation of process KPI, as well as monitoring and reporting of processes and workflows.

Business Process and Workflow Modeling

For the purpose of modeling intraoperative and surgical processes the modeling tools should be capable of depicting the processes from different points of view [49]. All of the analyzed tools can display the processes from a functional and behavioral perspective, which is the processes order of task and events with the respective work steps and their logical relation to one another.

Modeling the organizational structure is of particular importance for surgical processes, since people collaborate in different roles and organizational units and have differing competence levels as well. The differing accountabilities for processes and individual work steps should therefore be portrayable by the used modeling tool. BPMN doesn't explicitly envisage the portrayal of the organizational structure in a separate diagram, yet all of the analyzed modeling tools can depict personnel resources as pools and lanes. Beyond that Signavio provides the user with an extensive library of organizational symbols for EPC modeling and, like ADONIS, offers the ability to model additional organigrams. YAWL has no options for the graphical portrayal of the organizational structure, since it is represented by the assignment of variables.

The technical perspective, focused on the resources used in a process and responsible for the depiction of medical devices, interfaces, hardware and software components as well as consumable supplies, etc., is also very important for the accurate portrayal of surgical business processes and workflows. A modeling tool used in this domain should therefore have at least basic capabilities for representing technical systems and other resources. BPMN does not have any specific symbols for hardware or software components, interfaces or consumable supplies by default. Instead these have to de depicted as pools and lanes or the assignment of additional variables, just like other human and nonhuman resources. Solely EPC modeling with Signavio enables access to extensive symbol libraries for the accurate portrayal of IT environments and nonhuman resources.

With the help of modeling tools it should be possible to model data, files and documents with their corresponding input and output variables to represent data and information flows inside the operation room. Among the analyzed tools only Activiti, Bonita BPM and YAWL have no means of displaying data, files and documents as symbols. Modeling the data organization is done via variable assignment in these tools. Especially Bonita BPM offers predefined connectors to other applications, systems and services, such as ERP, CMS, Microsoft Exchange or Google Calendar though. Any other analyzed tool does, besides using variable assignment for this purpose, offer distinct symbols for data. Explicitly modeling the organizational structure, the IT environment, data and resource flows, partially in distinct diagrams and perspectives, is supported sufficiently only by Signavio and ADONIS.

For the purpose of increasing clarity and reducing the complexity of individual process models, modeling them should not only be possible from different perspectives, but also with scalable granularity [31]. It should also be possible to connect models of differing granularity. The modeling tool should therefore be able to connect main and sub processes and to integrate different views on the process as sub processes into the meta-process. All of the analyzed tools allow connecting semantically related process models.

All of the analyzed tools provide a free repository for administration, versioning and organization to ease the handling of large amounts of semantically related process models, except for YAWL and Bonita BPM, which offers a repository as fee based extra. In YAWL it's only possible to store and reuse particular process elements from the repository. Activiti, ADONIS, Camunda, jBPM and Signavio allow categorization of process models and to safe them in arbitrary subfolders. Except for Activiti and Bonita all of the tools also offer functions for the easy reuse of previously made models from the repository. If multiple people are supposed to be working on the same process models the need for access and collaboration management arises. Activiti, ADONIS, Bonita BPM and Signavio provide extensive functionality for multi user modeling and team collaboration.

With the exception of YAWL, which is only able to read and write YAWL models, all tools support various formats for import and export. Concrete information about which file formats are supported by which tool can be found in Table 2. All of the BPMN tools are able to import and export models in the standardized format of BPMN-XML. Thus all of the BPMN tools are able to export models that can be executed as BPMN, BPEL or XPDL by a workflow engine. The exchange of BPMN and XPDL files between different tools is not always possible due to the yet inconsistent or incomplete implementation of the BPMN standard in many tools though.

Analysis

Many modeling tools provide functionalities for evaluating and analyzing the created process models, besides their core modeling functions. Various tests are meant to help with the creation of executable workflows that are as flawless as possible. So all modeling tools except for ADONIS and YAWL support the user already during modeling by context sensitive display of suitable symbols when choosing the next process element.

Checks of the syntactical and semantic correctness of a model as well as predefined testing methods for the modeled business processes are, to a greater or lesser extent, available in all of the modeling tools. These should ensure the executability and flawlessness of the models. During checking the correctness of a model constellations inside the model which could cause runtime errors, such as deadlocks, missing connectors or erroneously set gateways, should ideally also be found. Most modeling tools don't find all of these logical errors. Deadlocks, for instance, are reliably detected only by Bonita BPM, jBPM, Signavio and YAWL. Missing connectors are found by all of the tested tools. Additional JUnit tests can be created with Activiti, Camunda and jBPM, due to the Eclipse user interface.

When working with different versions of the same model it can be useful to compare the current version with older ones. Some of the analyzed modeling tools, namely Activiti, Camunda, jBPM and Signavio, therefore offer a function for contrasting models with each other and highlighting the differences.

Further methods of business process analysis are significantly simplified by the automatic generation of statistical key performance indicators, evaluations and reports from the created models. Especially Signavio offers a wide range of methods for creating documents from previously made models.

Simulation

Many modeling tools are capable of interpreting the definition of a process based on a defined set of initial conditions and simulating its execution for the purpose of verifying its correctness. This enables formulating quantitative statements about a process execution, such as statements about cycle times, occupancy rates or workloads, prior to actual execution. Moreover simulations can help (re-)organizing the process definition, since alternate versions can be tested and evaluated this way. Except for Activiti, Camunda and YAWL all of the tools offer an integrated simulation environment, albeit sometimes as a fee based extra feature. YAWL does however offer an interface to the Process Mining Framework (ProM) which allows converting YAWL process models to simulation models. All of the modeling tools that have an integrated simulation environment are capable of integrating durations, costs, probabilities and capacities with the process model and to use them for simulating process execution. Beyond that the more copious tools, like Bizagi, partly jBPM and Signavio can also depict and simulate occupancy rates and resource needs and statuses. These tools also allow scanning the model for bottlenecks, so that extra resources and personnel can be dispatched for the live process execution to avoid shortages.

4.11 OVERVIEW ON FUNCTIONS AND FEATURES OF BUSINESS PROCESS AND WORKFLOW MODELING TOOLS

* purchase version	**Activiti (BPMN)**	**ADONIS (BPMN)**	**ARIS [2] Platform (EPC/ BPMN)**	**Bizagi[2] (BPMN)**	**Bonita BPM (BPMN)**	**Camunda (BPMN)**	**jBPM (BPMN)**	**Signavio (BPMN/ EPC/ YAWL)**	**YAWL**
1. General information									
Version	Activiti Designer, Activiti 5.14.1	ADONIS CE, v.3.05.02	ARIS 9.6 for research and education	Bizagi Process Modeler 2.7.0.2	Bonita BPM Commu-nity 6.3.0	BPMN 2.0 Modeler 2.5.0	jBPM Modeler (Drools - Eclipse) 6.0.1	Signavio Process Editor 8.0.2	YAWL-4Study 3.0
Developer	Alfresco+ Activiti Community	BOC AG	Software AG	Bizagi Ltd.	Bonita-soft	Camunda services GmbH	JBoss Inc.	Signavio GmbH	YAWL initiative
Open Source/Freeware	X	X/-*	X/-*	X/-*	X/-*	X	X	X/-*	X
License	Apache License 2.0	ADONIS CE License	ARIS University License	Bizagi Acade-mic License	GNU General Public License V2/ LGPL V2	Apache License 2.0	Apache License 2.0 (LGPL) und Eclipse Public License	Signavio Academic Initiative License	Apache License LGPL V3
Platform	Java	Java/ C++	Java	.NET	Java	Java	Java	Java	Java
Operational environment: Server (S), Client Application (C), Web/ Software as a Service/ Cloud/ Browser (W)	S (C/W – Modeler)	C/S	C/S	C/S	C/S	C/S	S (C/W – Modeler)	C/W	C/S
2. Modeling tool									
1. Workflow life cycle support [14]									

[2]Unavailable evaluation because of licensing restrictions

* purchase version	Activiti (BPMN)	ADONIS (BPMN)	ARIS [2] Platform (EPC/ BPMN)	Bizagi[2] (BPMN)	Bonita BPM (BPMN)	Camunda (BPMN)	jBPM (BPMN)	Signavio (BPMN/ EPC/ YAWL)	YAWL
Business process modeling	X	X			X	X	X	X	X
Workflow modeling (Build time)	X	-			X	X	X	-	X
Workflow execution (Run time)	X	-* (Inter-face to usual wfms)			X	X	X	- (Round-trip with Activiti, Camunda, jBPM, ...)	X
Analysis	X	X (*)			X	X	X	X	X
Simulation	-	X (*)			X(*)	-	X	X/- (Bimp Online Simulator)	X/- (via ProM)
Controlling (monitoring, statistics, reporting)	X	X (*)			X*	X	X (Eclipse BIRT)	X	X (process portal)
2. Complete BPMN 2.0 support	-	X			-	-	X + WFP	X	
3. Zero/Less-Code[58]	Less-Code	-			Zero-Code	Less-Code	Less-Code	-	Less-Code
3. Modeling									
1. Process view and perspectives [49] (Process modeling in different views and perspectives)									
Functional view (Process- and sequence diagrams, Business process diagrams, Business rules or process maps, …)	X	X			X	X	X	X	X
Organizational view (organizational charts)	-	X			-	-	-	X	-
Operational view (system landscape (server,	-	X			-	-	-	X	-

* purchase version	Activiti (BPMN)	ADONIS (BPMN)	ARIS [2] Platform (EPC/ BPMN)	Bizagi[2] (BPMN)	Bonita BPM (BPMN)	Camunda (BPMN)	jBPM (BPMN)	Signavio (BPMN/ EPC/ YAWL)	YAWL
hardware, applications, interfaces), SOA-Maps, …)									
Business Object Diagrams, Data Models	-	X			-	-	-	X/- (Xforms)	-
Individual and special diagrams and data objects	-	X			-	-	-	X	-
2. Resource Modeling [53]									
Human resources	X	X			X	X	X	X (additional symbols)	X (parameter)
Data and information	X (parameter)	X			X (para-meter)	X	X	X	X (parameter)
Applications/Services	X (pool or parameter)	X (pool)			X (pool or para-meter)	X (pool or para-meter)	X (pool or para-meter)	X (BPMN: pool, additional symbols, EPC: symbols)	X (parameter)
Resources (devices, instruments, …)	X (pool)	X (pool)			X (pool)	X (pool)	X (pool)	X (pool)	X (parameter)
3. Connection of meta- and subprocesses and other process models[31]	X	X			X	X	X	X	X (link)
4. Repository	X	X			X*	X	X	X	X (only for process elements)
Classification of process models	X	X			-	X	X	X	-
Reuse of process models (stored in	X	X			-	X	X	X	-

* purchase version	Activiti (BPMN)	ADONIS (BPMN)	ARIS [2] Platform (EPC/ BPMN)	Bizagi[2] (BPMN)	Bonita BPM (BPMN)	Camunda (BPMN)	jBPM (BPMN)	Signavio (BPMN/ EPC/ YAWL)	YAWL
repository) [31]									(only for process elements)
Model version management [31]	X	X			X	X	X	X	X
5. Team collaboration support (multiple user modeling with rights management)	X	X			X	-	-	X	-
6. Process model exchange									
Process model import	X (XML, BPMN)	X (ADONIS. ADL, BPMN, XPDL, Visio)			X (Bonita .bos, BPMN, XPDL, jBPM)	X (BPMN)	X (BPMN, XML, BPMN2)	X (BPMN, XPDL, jPDL)	- (.yawl)
Process model export	X (BPMN)	X (ADONIS .ADL, BPMN, XPDL)			X (Bonita .bos, BPMN)	X (BPMN	X (BPMN, BPMN2)	X (Signavio .sgx, BPMN, XPDL, XML,jPDL)	- (.yawl)
4. Analysis									
1. Plausibility and validation checks[42]									
Context sensitive suggestions (show or hide process elements)	X	X/- (alerts)			X	X	X	X	-
Debugging functions (Deadlocks, Loops, missing connectors)	X/- (partly)	-*			X	X/- (partly)	X	X	X
Syntactic and semantic checks	X	X			X	X	X	X	X
Predefined test methods	X	X			X	X	X	X	X
2. Visualization of differences in process models	X	-			-	X	X	X	-
3. Report generation	-	X			-	-	-	X	-

* purchase version	Activiti (BPMN)	ADONIS (BPMN)	ARIS [2] Platform (EPC/ BPMN)	Bizagi[2] (BPMN)	Bonita BPM (BPMN)	Camunda (BPMN)	jBPM (BPMN)	Signavio (BPMN/ EPC/ YAWL)	YAWL
5. Simulation									
1. Simulation of process models[31]	-	X			X	-	X (Drools WD)	X	-
Duration	-	X			X	-	X	X	-
Costs	-	X			X	-	X	X	-
Probabilities	-	X			X	-	X	X	-
Capacities	-	X			X	-	-	X	-
Workload	-	X*			X	-	-	X	-
Indicators (trigger events for processes and instances)	-	X*			X	-	-	X	-
Resource requirements	-	-			X	-	X/-	X	-
Detection of bottlenecks in process execution	-	-			X*	-	-	X	-
Human resources requirements	-	-			X	-	X	X	-
2. Comparison of process models under different views and parameters	-	-			-	-	-	-	-

Table 2 - Summary of functions and features of analyzed modeling tools

5 EVALUATION

The evaluation of the functional comparison of the analyzed modeling languages from chapter3 revealed that BPMN 2.0, EPC and also YAWL possess the essential features and functionalities needed for the portrayal of clinical and surgical processes. No fundamental differences in the range of functions offered by these languages could be found. The differences between the modeling languages lies in detail, weighing the specific advantages and disadvantages of each language against the other. In the next step a weighed functional comparison concerning the intended purpose was performed. For this purpose the following core criteria for choosing a modeling language for clinical and surgical processes were defined:

Depiction of intraoperative processes (functional structure)

Intraoperative surgical as well as clinical processes have to be thoroughly and comprehensively described with the modeling language. Therefore it should cover the requirements from the category "functional structure" to the fullest. The basic functional elements, such as process steps and decisions, can be portrayed in all three languages. When taking a closer look, the following differences between them emerge:

- A disadvantage of EPC modeling becomes apparent when implementing the control flow workflow patterns. The basic patterns are supported by all the languages, but the more complex patterns are supported party only by BPMN and to the full extent by YAWL. Both languages are therefore more expressive than EPC when modeling the functional structure [23], [60], [61].
- On the other hand BPMN does not support assigning multiple people, or roles respectively, to one activity. This is detrimental for representing processes during a surgery, since this often involves the collaboration of multiple actors during a single process step. This kind of process depiction is handled by modeling message exchange between multiple pools and lanes in BPMN. In EPC and YAWL this is done by assigning multiple organizational symbols or personnel variables to an activity.

For modeling the functional structure, YAWL offers the most extensive range of functionalities. In practice EPC and BPMN can be used for modeling as well.

Depiction of organizational structure

The depiction of personnel responsibilities is another relevant aspect of modeling intraoperative workflows, since these processes involve a multitude of different actors which should be represented in the model. All of the analyzed languages can associate personnel responsibilities to particular process steps, yet the following differences between the languages were observed:

- BPMN can depict process responsibilities only in a limited fashion, since the only graphical concept available for the depiction of persons, roles and organizational units is the pools/lanes concept. In case many people are involved with the process, its graphical representation becomes highly fragmented, making it seem very complex and confusing.
- YAWL lacks of a graphical representation of personnel responsibilities completely and relies on variable assignment for this purpose.

- In contrast to the other two EPCs offer an extensive library of organizational symbols and allows the creation of separate organigrams that can be linked to the process model. Furthermore absence management and locations (of people and resources) can be defined in EPCs.

In conclusion the organizational structure is best modeled in the form of EPC diagrams.

Depiction of resources

When modeling clinical and surgical processes, the involved resources, such as medical devices, operation room appliances (e.g. lighting), surgical instruments, consumable supplies or anatomic structures should also be represented by the model. The following differences exist between the three languages when modeling resource view:

- Since BPMN doesn't provide specific symbols for representation of resources or IT systems, these have to be represented using solely the pools/lanes concept. Some modeling tools do allow defining special symbols for certain resources (IT systems). Other resources, such as services, software applications, etc. can be modeled via variable assignment.
- YAWL has the capability to set various human and nonhuman resources as attributes in a process step's definition for the purpose of process execution. A graphical representation of these resources is not part of the language though.
- In EPCs resources, such as people, IT systems, consumable supplies, devices, medical instruments or locations can be depicted as distinctive symbols or entities.

The fact that resources are not being represented by uniform constructs or variables in EPCs, is a significant advantage for the modeler. Modeling EPCs means having access to diverse easy to use symbol libraries and not having to depict resources via the programming of variables. This leads to EPCs being more suitable for depicting resources than BPMN or YAWL.

Process execution

If clinical and surgical processes are meant to be supported technically by a WfMS, they have to be formalized and visualized in the form of a business process model beforehand. For this the observational focus lies on the practical modeling. Thereafter the process models have to be translated to an execution language and the process has to be implemented technically.

Among the analyzed languages only EPCs are a pure business process modeling language, meaning they have to be translated to an executable language such as BPMN, XPDL or BPEL. For this purpose some of the introduced modeling tools offer automatic converting functions. BPMN 2.0 and YAWL on the other hand can be used to build business processes as well as immediately executable workflows.

Usability

When looking for a modeling language that is suitable for modeling surgical processes the aspects of usability and user friendliness should also be considered. Creating models with the modeling language should be effectively and efficiently. This implies that the language should be easy to understand, simple to learn and intuitive to be used.

- YAWL is not well suited for usage by users without a BPM background since, due to its limited symbol libraries, a considerable programming and parameterization effort is required. Modeling workflows with YAWL, especially depicting and assigning resources, such as people, applications and data, is a complex and barely intuitive endeavor. Furthermore modeling a process from various perspectives is supported only to a limited degree, making the creation of an extensive representation of intraoperative business processes a highly time consuming matter.
- When compared to YAWL, BPMN proves itself to be far more intuitive to use. Nonetheless the user may become overwhelmed by the large variety of specific activities and events or the missing symbols for resources. When compared to EPCs, the familiarization with BPMN is therefore considered to be less easy [62].
- Due to extensive symbol libraries and the almost complete nonexistent need for parameterization EPC modeling is easy to learn and intuitively useable [63]. Moreover the expressive symbols and annotations enable the creation of comprehensible process representations. When confronted with the task of modeling a process from different points of view, the ARIS layer architecture, which is related to EPCs, exhibits significant advantages.

A non-representative study explored the acceptance for BPMN and EPC modeling [63]. The EPC models were classified as more logical, better to understand and easier to model with a lucid layout when compared to BPMN. Conversely the average quality of the BPMN models was determined to be higher and the time needed for making them was shorter. With respect to usability both languages seem to be better suited than YAWL.

Interoperability

A modeling language should preferably not be tied to the usage of one specific tool. It should rather be convertible to an interchange format, enabling the interoperable exchange of models between multiple tools, run time environments and organizations.

- Most tools are able to safe BPMN models as ".bpmn" files. These are usually also readable by other BPMN modeling tools.
- EPCs cannot be interoperable exchanged between the analyzed modeling tools. Some tools were able to convert them to BPMN 2.0 models though, which in turn worked flawlessly with almost all of the other tools.
- YAWL does not offer any file formats for storing the created models other than its own ".yawl" format. Models cannot be converted to any other modeling or execution language and the ".yawl" files can only be read by particular YAWL modeling tools.

With respect to interoperability and the exchange of process models, both EPC and BPMN modeling show clear advantages over YAWL.

Modeling tools

The selection of a modeling language often determines the appropriate business process and workflow modeling tool. Therefor the modeling tool should comply with the defined requirements for modeling languages. In addition, the functionalities and features of a modeling language envisaged for the specific use in a surgical and clinical environment have to be supported by an adequate modeling tool. Furthermore the modeling tool should be available for free, it should be ergonomic and intuitive, easy to learn, dependably and widely spread with an active user community.

Basically, every analyzed tool could be used for surgical workflow and business process modeling. There is no essential difference in functionality and operation between the evaluated products. Every modeling tool has specific advantages and disadvantages, so that the selection of a modeling tool depends on the specific needs and the intended usage:

- As the first step in workflow life cycle the business process should be formalized as a business process model. With the focus being put on creating business process models in detail and within the inclusion of different views on the surgical process, a modeling tool with EPC support, like ARIS, or Signavio, can be recommended. Even with ADONIS business process models for surgical procedures could be easily generated.
- Based on business process models, executable workflow models can be generated in the second step of the workflow life cycle (build time). When focusing on workflow modeling, modeling tools with BPMN 2.0 support can be recommended. For non-technical or medical modelers zero code modeling tools, like Bizagi or Bonita, can be a compromise between medical and technical workflow modeling. For technical modelers less code modeling tools, like Activiti, Camunda or jBPM, are the method of choice.
- For a specific use case the features and functionalities listed in Table 2 can be analyzed. Based on required functionalities it should be possible to select an adequate modeling tool.

6 CONCLUSION

In the following a recommendation for a modeling language and tool suitable for modeling surgical workflows should be made, based on the evaluation from chapter 3 and 4. Analysis and evaluation of the introduced languages and tools lead to the attribution of a principal applicability to all of them. From the special requirements the envisaged surgical use case inherits core criteria were defined and the modeling languages were tested against them in detail. Functions and features of the modeling languages and tools were weighed according to these core criteria, leading to the appearance of specific advantages and disadvantages, summarized again for reasons of clarity in the following table:

	BPMN 2.0	EPC	YAWL
Advantages	• established standard, with continuous development • wide spread • wide ranging vendor support • good depiction and modeling of surgical processes • workflow language (executable models) • easily comprehensible process models	• wide spread and long lasting market success • supported by large vendors • depiction of process in different views (ARIS concept) • Good depiction of data structure, organizational structure and resource management (medical devices, software, hardware, IT systems, ...) • Comprehensive range of symbols • Parameterization and programming effort is hardly necessary • Intuitive, easily comprehensible and learnable • Transformation in BPMN and other workflow languages is possible	• Formal language based on theoretical principles of petri-nets • Good depiction of surgical processes • Dynamically resource management is supported • Full workflow pattern support • Workflow language (executable models)

Table 3 - Advantages of modeling languages

	BPMN 2.0	EPC	YAWL
Disadvantages	• Only a few perspectives on surgical process can be modeled • Only a few possibilities of graphical modeling actors and resources • No depiction of activities performed by different actors and resources at the same time • Many different concepts of activities and events (complex constructs and symbols) • Programming skills are required	• No official standard • Business process modeling language (executable workflows can't be modeled) • Only a few modeling tools are available which support EPC modeling • Deficits in modeling functional structure of surgical processes (space holder modeling)	• Uncommon language • Only a few modeling tools which support YAWL are available • Only functional view on process can be modeled • Only a few symbols are available • Many parameterizations necessary • High programming effort • Less intuitive • No interoperability

Table 4 - Disadvantages of modeling languages

Because of their advantages under the aspects of modeling different perspectives on a process, depicting a processes organizational structure and portraying its data and resource organization event-driven process chains (EPC) are recommended for the initial representation of clinical and surgical processes. They are especially suitable for displaying the subject-specific perspective and for modeling by non-technical personnel. The models are intuitively creatable, easy to understand and the language is simple to learn. As tools for modeling the surgical business processes we can recommend the ARIS platform and Signavio.

For technical process modeling and supporting the processes by a WfMS the business process models have to be converted to workflow models, or in other words models written in an executable language, in the second phase of the workflow life cycle (build time). Because of its profound methods of illustration and its wide distribution BPMN is recommended as workflow modeling and execution language. For non-technical or medical modelers zero code modeling tools, like Bizagi or Bonita, can be a compromise between medical and technical workflow modeling. For technical modelers less code modeling tools, like Activiti, Camunda or jBPM, are the method of choice.

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