A BPMN Model of the Charite Stroke Treatment Process

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1 Introduction

In the healthcare domain, business process management (BPM) has become a valuable asset [8]. Thereby, BPM heavily relies on *process models* to identify, review, validate, verify, represent, and communicate process knowledge [11]. In this paper, we describe the model of a *treatment process* for stroke patients at the Charité Berlin, one of the largest university hospitals in Europe. We observe the stroke treatment process at the Charité Berlin for three days and simultaneously model it using the Business Process Model and Notation (BPMN) [7]. BPMN is the de-facto standard language for modeling processes. The resulting BPMN diagram of the stroke treatment process may serve as a real-life input for our ongoing research on validating and verifying processes.

The remainder of this paper is organized as follows: In Sect. 2, we informally describe the stroke treatment process and give a brief overview over the core concepts of BPMN. We present the stroke treatment process as a series of BPMN diagrams in Sect. 3. In Sect. 4, we conclude this paper with a discussion and directions for future work.

2 Preliminaries

In this section, we describe the preliminaries for our work. We give some background information on treating strokes in 2.1, and introduce the core concepts of BPMN in 2.2.

2.1 Stroke and Stroke Unit

The *ischemic stroke* is the most frequently occurring kind of stroke. It is characterized by a reduced blood flow in the affected parts of the brain. The cause is a clot blocking or narrowing one of the blood vessels that supply blood to the brain. The reduced blood flow lowers oxygen transfer to the affected parts of the brain—this can cause necrosis of neurons. A complete stroke can lead to severe neurological deficits (e.g. paralysis, dysphagia, language impairments, impaired vision, imbalance, impaired consciousness as well as symptoms of clinical depression). Because the first neurons start to die four to five minutes after the oxygen transfer was stopped, it is important to start therapy as soon as possible, e.g., *thrombolysis therapy*. The aim of thrombolysis therapy is to break down the clot and to thereby normalize the blood flow to the brain. Apart from the fact that thrombolysis therapy is only permitted within the first three hours after the symptoms started [3], the faster the therapy is started, the lower one expects the damage caused to the brain to be ("time is brain"). Whether thrombolysis therapy can be applied depends on various factors. Most importantly, cerebral hemorrhage must be excluded, which can be done by CT scan. Further, additional risks exist if the patient is on blood thinning medication; this can be excluded by testing the patient's blood in a laboratory.

To assure a time-efficient care of stroke patients, there exists a *stroke unit* in many hospitals. A stroke unit is a special ward for stroke patients where nursing staff and doctors from different specializations cooperate to stabilize and normalize the physiological functions and to initiate therapy. Thereby, an internist and a neurologist jointly decide whether thrombolysis therapy can be applied or not. In order to reduce the time between the arrival of the patient at the hospital and the CT scan (the *door-to-imaging time*), the Charité Berlin launched a stroke alarm. The stroke alarm is triggered manually once a potential stroke patient arrives at the emergency ward, and it immediately notifies all incorporated actors. It has been shown that the stroke alarm reduces the door-to-imaging time at the Charité Berlin to 35 minutes [6].

In this paper, we model the underlying treatment process for stroke patients at the Charité Berlin as a series of BPMN diagrams. Therefore, we introduce the core concepts of BPMN briefly in the following section.

2.2 BPMN

The Business Process Model and Notation (BPMN) [7] is an OMG standard and the de-facto standard for business process modeling [1]. The primary goal of BPMN is to provide a graphical notation of business processes that is easily understood by all business users. BPMN is an open and free standard, which enjoys broad tool support; as of writing, the official BPMN webpage[1] lists 76 implementations. In the following, we briefly introduce the core elements of the latest major revision of BPMN.

In BPMN, a business process is graphically modeled by a *business process diagram*. There exist four categories of modeling elements to build a business process diagram: Flow objects, connecting objects, pools, and artifacts. A *flow object* represents an action which may happen inside a business process. They are categorized into *events* (i.e., something is happening inside the business process), *activities* (i.e., something is done inside the business process), or *gateways*

[1] `http://www.bpmn.org`

(forking or merging connecting objects). A *connecting object* relates several modeling elements, and is categorized into *sequence flows* (indicating in which order flow objects are performed), *message flows* (modeling communication between modeling elements), or *associations* (relating artifacts to other elements). *Pools* allow grouping the modeling elements. An *artifact* is a data object, a group, or a comment. Artifacts provide additional information about the business process without affecting the control flow.

The model described in Sect. 3 consists of the following BPMN elements:

- **Pool.** A *pool* is a well-defined unit that takes part in the process. We model each location as a single pool (e.g., the emergency ward). A pool may communicate with other pools by sending and receiving messages.
- **Task.** A *task* is "an atomic activity within a process flow" [7] (e.g. trigger the stroke alarm).
- **Collapsed Subprocess.** A *collapsed subprocess* is a subprocess whose details are not depicted in the diagram. To describe its details, the collapsed subprocess can be linked to another process diagram (e.g. neurological checkup).
- **Start Event.** A *start event* starts a process.
- **End Event.** An *end event* denotes where a process ends. A process ends if all of its branches reach their end event.
- **Terminate End Event.** A *terminate end event* immediately ends a process. All parallel branches that are currently executed are immediately terminated when this event occurs.
- **Start Message Event.** A *start message event* starts a process by receiving a message.
- **Intermediate Message Event.** An *intermediate message event* continues a branch when it receives (*catching* intermediate message event) or sends (*throwing* intermediate message event) a message.
- **End Message Event.** An *end message event* is an end event that additionally sends a message.
- **Parallel Gateway.** Branches created by a *parallel gateway* are activated simultaneously. All branches merged by a parallel gateway must be completed before the outgoing flow continues.
- **Exclusive Gateway.** From the branches created by an *exclusive gateway*, exactly one branch is activated based on conditions. One of the branches merged by a data-based exclusive decision gateway must be completed before the outgoing flow continues.
- **Event-based Gateway.** Each outgoing branch of an *event-based gateway* is connected with an event. From the outgoing branches of an event-based gateways, the branch whose connected event occurs first is activated.
- **Message.** A *message* is an optional element that can be placed on a message flow. It can denote anything that is passed between different pools. In our process, messages are actors that change locations.

Figure 1 illustrates the modeling elements of BPMN used in the model described in Sect. 3

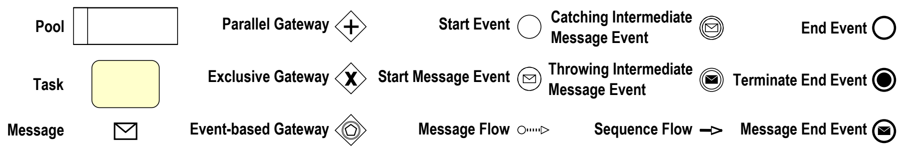

Figure 1: The modeling elements of BPMN used in our process model.

3 Stroke process model

In this section, we present a series of BPMN diagrams that model the stroke treatment process at the Charité Berlin. We created these diagrams after we observed several stroke patients and interviewed the involved doctors.

Five hospital units are involved in the stroke alarm process at Charité Berlin: The emergency ward, the radiology unit, the neurology unit, transport services, and the hospital lab. We have separated the stroke process into pools according to these hospital units. Because the entire process is too large for one diagram, we have split it into several diagrams (figures 2, 3, and 4). The message flows between these diagrams are numbered and message flow arrows with the same number in separate diagrams represent one message flow between these diagrams. For example, one of the message flow arrows originating at the *Trigger stroke alarm* task in Fig. 2 has the number 1. This message flow is continued in Fig. 4 and ends in the start message event of the neurology unit diagram.

Stroke patients are delivered directly to the emergency ward. Sometimes, the emergency ward is notified that a potential stroke patient is en route prior to the patient's arrival at the door, but this does not affect the stroke alarm process. Once the patient arrives, she is immediately examined by the nursing staff who determine whether the patient is *apoplectiform*, i.e., exhibits possible stroke symptoms. If that is the case, the stroke alarm is triggered immediately (see Fig. 2) using the DECT[2] phone system. The stroke alarm will trigger three new processes at the radiology and neurology units as well as the transport service (message flows 5, 1, and 2, respectively). At the neurology unit, a neurologist is immediately dispatched to the emergency ward (message flow 4). The transport services also immediately dispatches an orderly to the emergency ward (message flow 3). At the radiology unit, the stroke alarm triggers the process depicted in Fig. 3.

After the stroke alarm is triggered, the emergency ward process splits into four parallel branches. While three of these threads wait for the arrival of the transport service, the neurologist and a phone call from the radiology unit (message flows 3, 4, and 6), the internist and staff at the emergency unit proceed immediately with an examination of the patient. The staff routinely takes a blood sample, places a peripheral venous catheter, measures vital signs (such as blood pressure, pulse, respiration), and performs an EKG and blood gas analysis.

[2] *Digital Enhanced Cordless Telecommunications* (DECT) is a standard for cordless digital phone systems.

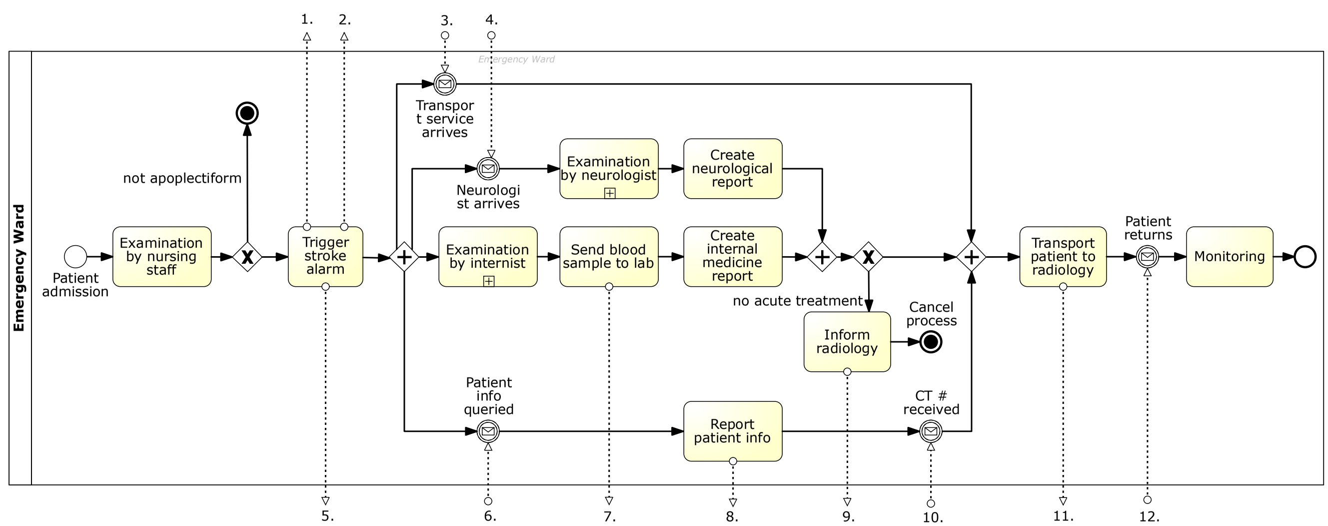

Figure 2: The emergency ward in the Charité stroke unit.

Additionally, the staff inquires into the patient's history and, most importantly, what medication, if any, the patient is currently taking. The blood sample is sent to the hospital laboratory by pneumatic delivery at once (message flow 7). Once the examination is finished, the results are compiled into the internal medicine report.

Usually, a neurologist arrives at the emergency ward within three to five minutes. She performs a neurological examination to confirm the diagnosis and to determine the nature of the stroke. She compiles the results into a neurological report. Meanwhile, the radiology unit's first task is a phone call to the emergency ward to inquire about the patient (message flow 6). After the information was obtained (message flow 8), the radiology process splits into two branches. On the upper branch, the process waits for either a cancellation message (message flow 9) from the emergency ward or for the patient and neurologist to arrive (message flow 11). On the lower branch, one of the radiology unit's CT machines is chosen depending on availability and distance to the emergency ward. The number of the chosen machine is immediately reported back to the emergency ward (message flow 10) so that the patient can be dispatched as soon as possible. Meanwhile, the CT machine is prepared by the radiologist. After that, the radiologist waits for either the patient's arrival or a cancellation message from the emergency ward at the parallel merge gateway right before the *Perform CT scan* task (message flows 9 and 11).

At the emergency ward, once both the internist and the neurologist have finished their examinations, they decide whether the patient can receive acute treatment or not. If not, the radiology unit is notified and the process is cancelled (message flow 9). Otherwise, the process proceeds as soon as the orderly from the transport service has arrived and the number of the CT machine has been reported by the radiologist. Both usually arrive before the internist and the neurologist have made their decision, so the four parallel branches can join again and the process can proceed. The transport orderly takes the patient to the CT machine along with the neurologist, the thrombolytic drugs and all relevant medical files (message flow 11).

At the radiology unit, a CT scan of the patient's brain is performed as soon as the designated CT machine is free and ready. Using the images, the radiologist determines whether there is cerebral hemorrhage. Now the neurologist must decide whether to start thrombolysis therapy or not. This decision depends on several pieces of information that have been obtained previously. If there is a possibility that the patient is taking blood thinning medication, the neurologist can only make the decision once the blood report is back from the hospital lab (message flow 13). If all prerequisites are met, she will begin thrombolysis therapy immediately while still at the radiology unit. The patient will then be transported back to the emergency ward along with the neurologist (message flow 12). There, the patient will be monitored closely until she can be moved to another unit. At this point, the stroke alarm process terminates.

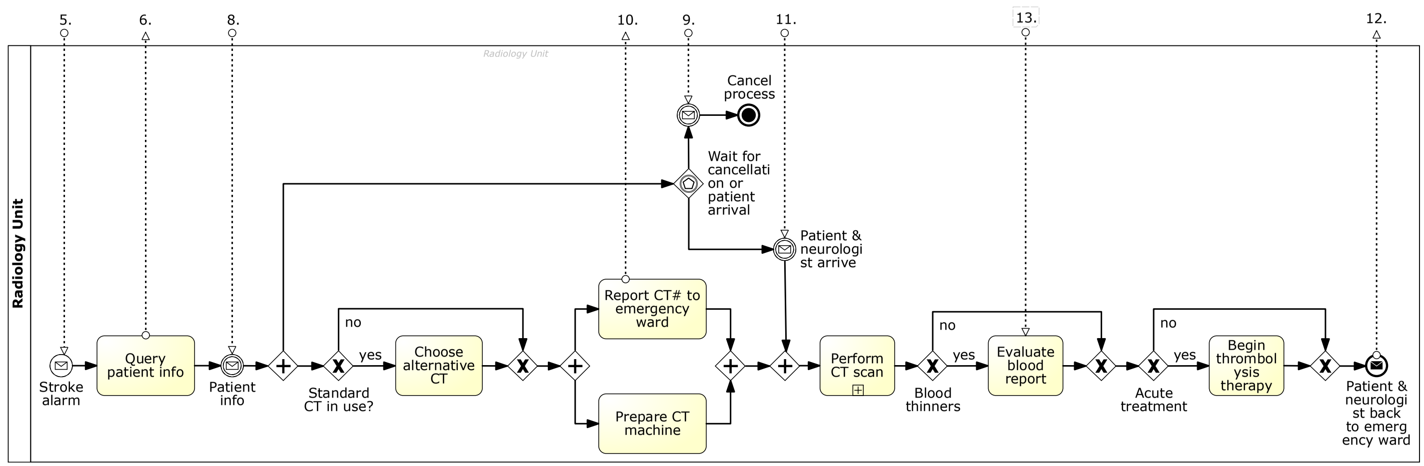

Figure 3: The radiology unit in the Charité stroke unit.

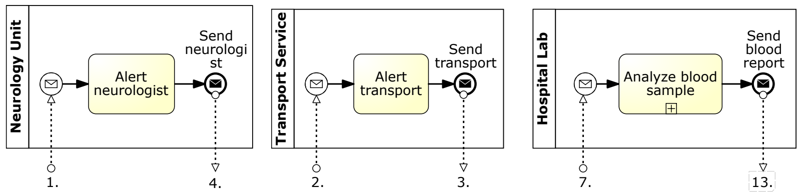

Figure 4: The neurology unit, the transport service, and the hospital lab in the Charité stroke unit.

4 Conclusions

In this paper, we presented a series of BPMN diagrams that model the stroke treatment process at the Charité Berlin. These diagrams may serve as real-life inputs for our ongoing research on validating and verifying processes.

With our case study, we have evaluated an approach that automatically generates orchestrator models coordinating service compositions in time-critical environments [10,9]. For this purpose, we have used our BPMN model to derive timed automata models that represent the different actors participating in the treatment process and to derive formal composition requirements that describe medical and organizational necessities. On the model level, the generated orchestrator coordinates the actors such that all requirements concerning time are fulfilled. We plan to model the process again using *scenario-based modeling* techniques as in [2]. In particular, we want to inspect whether scenario-based modeling yields a model that is easier to understand, yet behaviorally equivalent to the BPMN model presented in this paper. Another aim is to generate one model for each actor participating in this process that represents the behavior of this actor.

For future work, we plan to model the process again using *scenario-based modeling* techniques as in [2]. In particular, we want to inspect whether scenario-based modeling yields a model that is easier to understand, yet behaviorally equivalent to the BPMN model presented in this paper. Another aim is to generate one model for each actor participating in this process that represents the behavior of this actor. For verifying the stroke process, we plan to test the presented model against observed behavior in the form of event logs [4]. In addition, we want to use artificially created event logs from the stroke treatment process to evaluate our open system discovery approach [5]. Furthermore, we plan to enrich the process model with timing information (activity durations and deadlines). This enriched model should then be analyzed and verified with regards to its timing properties, in particular deadlock freedom. Additionally, we plan to create a more detailed model for the hospital lab in the near future.

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