



How to Model and Transform Executable BPMN Process Models

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Declaration of Authorship

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I hereby declare that I have written this Doctoral Thesis independently, that I have completely specified the utilized sources and resources and that I have definitely marked all parts of the work - including tables, maps and figures - which belong to other works or to the internet, literally or extracted, by referencing the source as borrowed.

Vienna, 1st January, 2022

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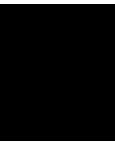
Abstract

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Introduction

Business Process Model and Notation (BPMN) is an widely used and established diagramming language with the purpose of documenting and visualizing business processes in organizations. Process models are usually created by process analysts together with domain experts. BPMN-models created that way contain incomplete and implicit information for the specific business domain and are therefore called conceptual BPMN model. By involving IT-experts these conceptual BPMN models can be made executable and automated using a Business Process Workflow Management System. [4]

Today Business Process Workflow Management Systems like Camunda BPM and Alfresco Process Services (BPM) are widely used by big organizations [2] [?]. Real-life Processes being executed in BPMN Workflow Management Systems are inherently complex and have to be changed and reevaluated together with the Software embedded in these processes as requirements and guidelines for the specific domain change.

One advantage of directly automating processes described as BPMN is its readability for IT-experts and domain-experts. As a consequence both parties have a common understanding of the process that is executed and have basis for discussion when changes have to be made. In order for the cooperation between IT and Business to work smoothly, executable BPMN model should be as simple to understand as possible and be in line with known standards and best practices.

Applying guidelines for good executable BPMN model does not only increase readability but can also have direct impact on process costs. Due to the pricing scheme of some enterprise Business Process Workflow Management Systems, which take into account the total number of nodes passed by process instances, eliminating non necessary handovers and therefore reducing the number of nodes in the BPMN model can have an impact on the license needed.

1.1 Goal of This Thesis

The Goal of this Thesis is to give practical guidance on how to apply best practices and methodologies to create good executable BPMN model and to improve existing models.

This will be achieved by stating the current research on creating executable BPMN models. After that this work will take a look at methods for transforming and improving existing executable BPMN models and how to use them to create models in line with the stated best practices. Finally this thesis will provide detailed information about how to use these methods in practice.

1.2 Structure of This Thesis

This Thesis will start with an state-of-the-art section consisting of two chapters. The first one will be about the nature of executable BPMN models and how to make an existing conceptual BPMN model executable by an BPMN Workflow Management System. The second chapter will provide methods for analyzing and improving processes focusing on Six Sigma approaches.

Along with this thesis a software was developed which suggest changes to an executable BPMN model given as an Extensible Markup Language XML (XML)-file based on the best practices found in the first two chapters. The documentation and implementation details on this software can be found in chapter 3.

Not every aspect of transformation given in the first two chapters will be suitable to be fully automated and requires knowledge on the specific domain of the process. Therefore, the last chapter will provide a case-study to an existing process model applying the principles from the first two chapters and giving a guide on how to use those principles in practice.

Automating Business Processes

The following chapter will provide an overview of the current research on executable BPMN models. First it will discuss the motivation behind process automation and using BPMN Workflow Management Systems and the benefit it might bring to an organization. Then it will state the differences between an conceptual BPMN model, that cannot be deployed on an Business Process Workflow Management System, and an executable BPMN model. Finally this chapter will list the steps necessary to turn an conceptual BPMN model executable.

2.1 Why automate Processes?

While process automation seems to be in itself a pursued goal, there are some quantifiable advantages of using a Business Process Management System Business Process Management System (BPMS) besides the possibility to automate certain process steps.

- **Shorten process lifetimes:** Managing processes manually requires handling tasks such as starting sub processes or handling handovers from one entity to another manually and can lead to unnecessary waiting periods between two operation tasks in the process. By implementing an Workflow Management System resource allocation and parallelization can be automated where possible to assure optimal use of process resources. [6]
- **Reduction in process cost:** By reducing process lifetimes and increase productivity due to better handling resources can reduce process costs [6] but due to the high price for Business Process Workflow Management Systems the overall cost does not have to decrease necessarily [7].
- **Workload reduction:** As stated earlier, managing processes needs to be done either by an Business Process Workflow Management System or manually which

creates additional workload for an organization. Workloads for employees executing the processes are also kept steady due to dynamic resource assignment. [4][6]

- **Enforce rules:** Defining the processes that is then directly executed and controlled by an Business Process Workflow Management System enables the organization to enforce the execution of the process at it is designed. Following Rules and Protocols can partially be automated and enforcing guidelines and laws in an organization becomes easier. [4]
- **Create Transparency:** Using an Business Process Workflow Management System provides insights to the actually processes that are executed in the organization. It makes it easier to determine the performance of the processes by providing historical information of completed process instances and provides insight of the current status of processes that are still in progress. [6]

2.2 Executable vs Conceptual Process Models

Process Models are inherently Business-oriented as their purpose is initially to define and visualize the processes happening in an organization. Business-oriented or conceptual BPMN model are meant to be read by domain experts and contain usually implicit information known to these domain experts [4]. They are usually incomplete, meaning that not every possible outcome of a process is modeled. In fact, usually only the best-case scenario, also known as the 'happy-path', of a process is modeled in an conceptual BPMN model [5].

Because of this, business-oriented models cannot be executed in an Business Process Workflow Management System as they are but have to be turned into an executable BPMN model. executable BPMN model are meant for IT-experts and should be a technical representation of the business process while still begin understandable by domain experts. They should leave no room for interpretation as they have to contain all the information necessary for the process to be executed using an Business Process Workflow Management System. Besides the visual information, executable BPMN model also need to contain execution properties like interface definitions and Variables that are used by the Process called Process Variables.[4]

An algorithm on how to efficiently turn an conceptual BPMN model executable as stated in the book *Fundamentals of Business Process Management* [4] is described in the next section.

2.3 Making Process Models executable

As stated earlier, BPMN models can not directly be executed by a BPMS but have to be converted from an conceptual BPMN model into an executable BPMN model.

There are different approaches how an executable BPMN model can be derived from a business-oriented conceptual BPMN model. In [4] performing such a transformation is broken down into 5 steps:

1. Identify the automation boundaries
2. Review manual tasks
3. Complete the process model
4. Bring the process model to an adequate granularity level
5. Specify execution properties

2.3.1 Identify the automation boundaries

The first step in turning an conceptual BPMN model in an executable BPMN model is to identify which steps can be automated using a Business Process Workflow Management System.

Tasks which can inherently be automated are called Automated tasks [4, p. 317]. Taking a look at the BPMN 2.0 standard an Automated task can be one of the following Task types:

- **Service Task:** A Task that invokes a service. Can be a Webservice or a application code.
- **Send Task:** Used to send a message to an external participant (A participant that is not part of the process)
- **Receive Task:** Used to receive a message from an external participant
- **Script Task:** Executes a Script that can be interpreted by the BPMN Workflow Management System
- **Business Rule Task:** Executes a rule. (e.g. provides input for a business rule engine and gets the output of that calculation)



(a) Service Task (b) Send Task (c) Receive Task (d) Script Task (e) Business Rule Task

Figure 2.1: Automated Tasks according to the BPMN 2.0 standard [9]

Usually not every step of a Process can be fully automated. Processes can also have **Manual Tasks** and **User Tasks**. A **User Task** is a Task performed by a User with the aid of an Business Process Workflow Management System while a **Manual Task** does not use any help from a business process execution engine.

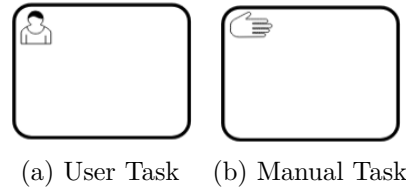


Figure 2.2: Manual and User Tasks according to the BPMN 2.0 standard [9]

2.3.2 Review manual tasks

As mentioned earlier Manual Tasks are not automated and do also happen without the aid of a Business Process Workflow Management System. In this step we need to analyse if the identified manual tasks in our BPMN-model can be incorporated into the Business Process Workflow Management System. This can be done in two ways:

- **Automate the task:** Depending on the nature of the task that is currently performed manually, it might be possible to fully automate the task or to model the task as a Receive Task where the modelled task waits for a message that indicates the physical manual tasks completion.
- **Turn it into a User task:** If the task cannot be automated or the organization lacks the resources to automate the task yet, it might be possible to turn the Manual Task into a User Task. One possibility could be to dedicate a person in charge of the manual task to notify the BPMN Workflow Management System on the completion of the task via a worklist handler. [12]

In the case that neither an Automated task nor an User Task is suitable for modelling the Manual Task one might also consider isolating the task and modelling the rest of the process. If this is also not possible due to the manual task being crucial for the expressiveness of the model it might be reconsidered if this process can or should be executed using a Business Process Workflow Management System[5, p. 228]

2.3.3 Complete the process model

Usually conceptual BPMN models are not complete and leave out certain informations that are seen as implicit knowledge or as not important by the person modelling the process but might be crucial if a complete picture of the process is needed for automation.

A common flaw in many conceptual models is ignoring errors and only implementing the 'happy path'. The 'happy-path' is the best-case scenario that can happen in the execution

of a process. While it might be sufficient for a conceptual BPMN model, showing the process for a customer order, to not show what happens in case the product is out of stock or what happens if the payment does not work, a executable BPMN model has to take into account what happens in case an error occurs.

It is also necessary to model the input and output data of our tasks in this step using Data Stores and Data Objects.

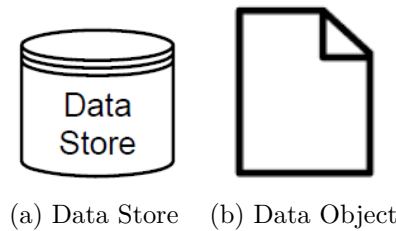


Figure 2.3: Data store and Data Objects according to the BPMN 2.0 standard [9]

2.3.4 Bring the process model to an adequate granularity level

The granularity of tasks modelled in an conceptual BPMN model does differ from the granularity needed in an executable BPMN model. The goal of process automation is not to automate as much as possible but to have a centralized BPMN Workflow Management System that does not only decide what task has to be done when but also who needs to be doing this task. [5]

Therefore consecutive tasks that are done by the same participant should be clustered together as one task to minimize handovers that have to be unnecessarily processed by the BPMN Workflow Management System. [4] However there are some exception to this rule:

- **Tracking progress:** In order to know how much the process has advanced it can be useful to split certain parts even if they are done by the same person.
- **Handling exceptions:** If for a set of tasks that it performed by the same participant different erros and exceptions can occur, it might be useful to keep these tasks separated.
- **Managing Resources:** Sometimes consecutive tasks are performed by participants that have the same role, but could to be done by two different participants in order to use resources better. In this case it is also to dis-aggregate the task accordingly.

2.3.5 Specify execution properties

The final step in turning an conceptual BPMN model executable is to specify the details of the implementation details of our BPMN model. While the changes performed up to

this step had an impact of the graphical representation, the execution properties are not graphically embedded into BPMN but are encoded into the XML representation of the BPMN-model. [4] A schematic representation of the structure if BPMN is provided in 2.4. For the full specification of the BPMN-XML the XML-schema can be found on the OMG-Website[1].

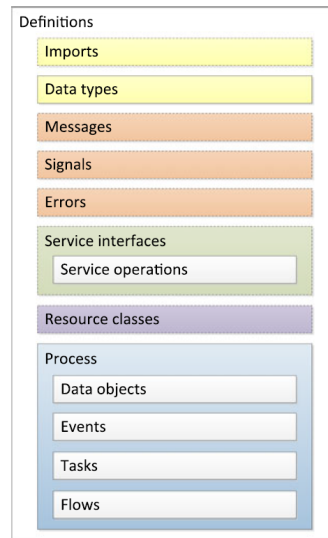


Figure 2.4: Structure of the BPMN format [4]

Process Variables

In order to use data in different elements of our process, we need process variables that can be read, created and modified during the processes execution. Every Process variable has a **data type** that can either be simple (strings, integers, doubles, booleans, dates, times, ...) or complex (composed of other types). A complex Type needs to be described as an XML Schema Definition XSD (XSD)-Schema File.

```

<xs:element name="person">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="name" type="xs:string"/>
      <xs:element name="address" type="xs:string"/>
      <xs:element name="city" type="xs:string"/>
      <xs:element name="country" type="xs:string"/>
    </xs:sequence>
  </xs:complexType>
</xs:element>
  
```

Listing 2.1: The XML-Schema Definiton for a complex type 'person'

```
<person>
  <name>Dragana Sunaric</name>
  <address>Wiedner-Hauptstrasse 5</address>
  <city>1040 Wien</city>
  <country>Austria</country>
</person>
```

Listing 2.2: An instance of the complex type 'person'

The definition of common Errors, Messages and Escalations that are thrown or listened to by Events and Tasks are also part of the execution properties. Every Element has at least an **id** that identifies the given Element and a descriptive **name** of the element. [9]

Messages

```
<message id="Message_ID" name="Message_NAME"/>
```

Errors

Errors additionally have an **errorCode** that specifies the given Error. Events can listen for this specific error code and trigger when it is thrown.

```
<error id="Error_ID" name="Error_NAME" errorCode="Error_CODE"/>
```

Escalations

Similar to errors, escalations additionally have an **escalationCode** that specifies the given Error and can be listened to by events.

```
<escalation id="Esc_ID" name="Esc_NAME" escalationCode="Esc_CODE"/>
```

Input and Output Variables

As mentioned earlier, Process Variables are active during the whole Process life-cycle. Apart from this data that can be accessed globally, it is also possible to define input and output values for each Task or Event in our process-model. These values are only visible within the Task or Event and have to be defined as an XSD-Schema File (similarly to complex process variables). [4]

Service Tasks

In order for service tasks to call external application or web-services, the interaction with the given service has to be defined in the process model. Connected services need to provide a service interface that describes the available service-operations and their

parameters as well as return values. Service-operations can be synchronous, meaning the process instance waits for the operation to finish and to return a value or error code, or asynchronous, meaning the process does not wait for a response and carries on with the process after calling the service. Based on the service interface definition, input and output variables have to be defined for the service-call. The Business Process Workflow Management System does this by copying the above mentioned Input values of the Task into the service call and if necessary, copy the output values of the service call into the output values of the Service task. [4]

Evaluating and Optimizing Executable Process Models

3.1 Six Sigma Approaches

The first set of analysis and optimization techniques discussed in this chapter originate from the Six Sigma initiative. The name Six Sigma originates from the interval of 6σ in the normal distribution that indicates the aimed success rate of 99.99966% [11][15]. A representation of the statistical meaning can be seen in figure 3.1. Apart from the goal to decrease the error rate, 6σ is also a methodology for systematically improving process quality [13].

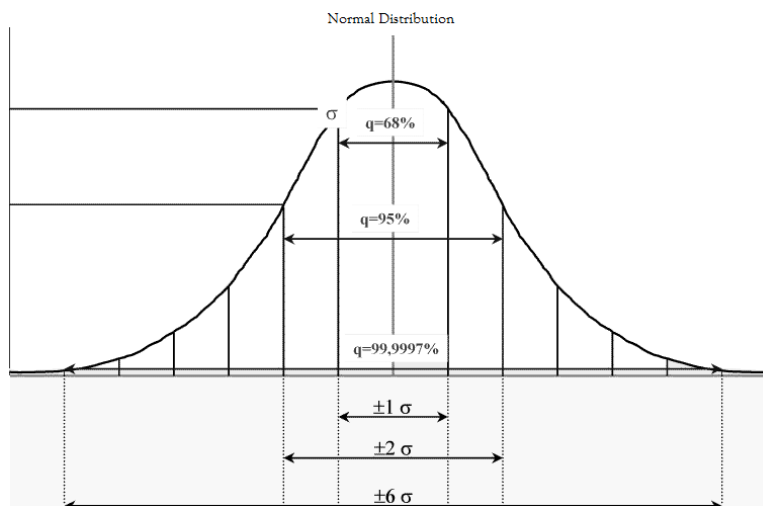


Figure 3.1: The standard normal distribution showing the 6σ interval (graphic from [15])

3. EVALUATING AND OPTIMIZING EXECUTABLE PROCESS MODELS

Applied in the context of (executable) business processes, Six Sigma provides a set of methods to identify and eliminate inefficient or needless steps in a process [16]. While countless tools are available as part of Six Sigma, the two main methodologies applied in these tools are **Define, Measure, Analyze, Improve, Control** [10] (DMAIC), used for improving existing processes, and **Define, Measure, Analyze, Design, Verify** [10] (DMADV), used when creating new processes [10] .

In the following, a few selected Six Sigma methods are described that apply the **DMAIC** and **DMADV** approach, these being:

- SIPOC Analysis
- Check Sheets
- Cause and Effect Diagram
- Root Cause Analysis
- Quality Function Deployment (QFD)

To demonstrate a few of the following methodologies, the exemplary *Missing Part Process* will be used. The fictional process demonstrates what happens when a customer of a furniture shop reports a missing part in his/her order and requests a new part to be shipped. The corresponding BPMN-model is shown in Figure 3.2

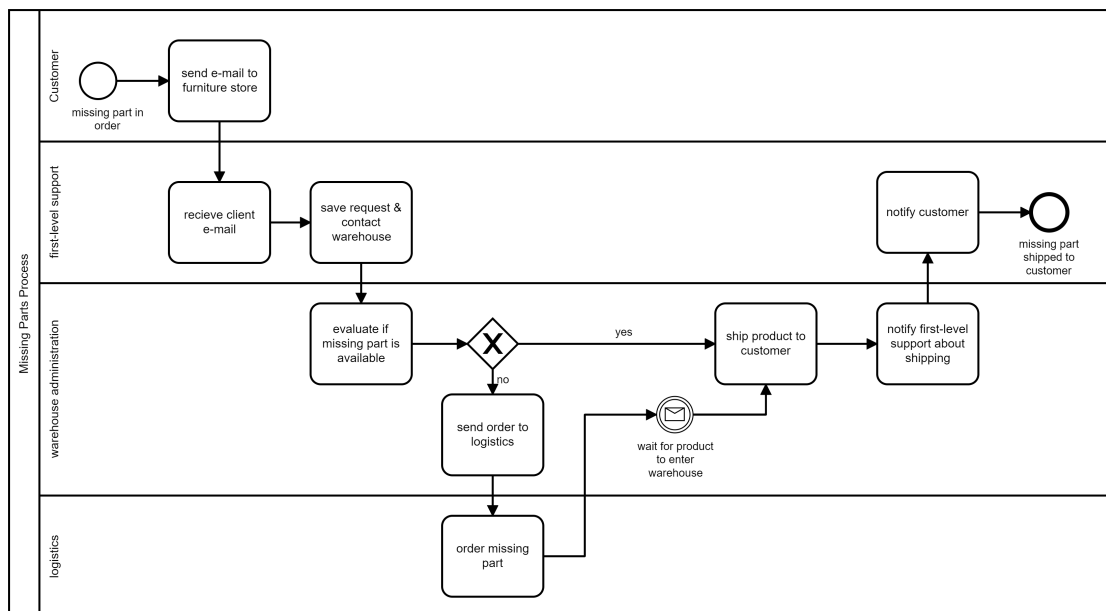


Figure 3.2: The BPMN model for the *Missing Part Process*

3.1.1 SIPOC Analysis

The SIPOC analysis is a tool used in the **Define** phase of DMAIC and DMADV and should provide more detailed information about each process step than the BPMN model [16].

The outcome of a SIPOC analysis is a table, containing the following information for each task in the process [14]:

- **Supplier:** provides the input for this task and influence the output the supplier can be internal or external.
- **Input:** Resources, data or material needed for this task provided by the suppliers.
- **Process:** the series of actions taken in this task. This can also be a subprocess.
- **Output:** represent the result of this process task and provide value for the customer
- **Customer:** the customer that benefits from the output of this task (can be external or internal of the organization)

When this method is applied to the **Missing Part Process** the resulting SIPOC table looks like this:

3.1.2 Check Sheets

3.1.3 Pareto Analysis

3.1.4 Cause and Effect Diagram

3.1.5 Root Cause Analysis

3.1.6 Quality Function Deployment (QFD)

3.2 Other Qualitative Measures

3.2.1 Value Added Analysis (VAA)

3.3 Quantitative Analysis

The issue with qualitative methods for process improvement is the inability to quantify the impact of their application. In order to measure and justify changes in the status quo process we need quantitative methods for analyzing processes. In the context of Business Process Management (BPM), assessable measures about three different dimensions of a process can be investigated : The process as a whole, resources involved in the process and individual Tasks in a process. [4]

Before discussing methods for measuring process performance, it is necessary to define what is measured. The four key performance measures examined in this chapter are: cost, time, quality and flexibility. [4]

The following chapter will present methods for qualitative analysis of processes. Starting with the definition of the four dimensions of process performance: cost, time, quality and flexibility. Afterwards the following methods for measuring performance will be described:

- Flow Analysis
- Queues
- Simulation

3.3.1 Performance Measures

As mentioned above, the performance of a process can be measured using the four dimensions: cost, time, quality and flexibility.

Cost

Time

Cycle time or *throughput time* is the time it takes for a process from start to finish [3]. In the case of the *Missing Part Process* shown in 3.2, the cycle time would be the time that elapses from the moment the customer notices that a part is missing to the time the missing Part is shipped. While the *Cycle time* of the whole process as a metric is highly relevant for client satisfaction, it is on its own usually not tangible when it comes to improvement of the process. The *cycle time* usually consists of two constituents [4]:

- *Processing time*: The time where the request is actively processed, meaning the process participants (e.g. people or software) actually spend this time handling the process.
- *Waiting time*: The time a process spends waiting. Waiting time includes the time the process is waiting in a queue for resources to finish the processing of previous processes and other waiting times, like waiting for the product to enter the warehouse in the *Missing Part Process*

Quality

Flexibility

3.3.2 Flow Analysis

The Idea behind (work)flow analysis is to estimate the overall performance of a process given the performance of individual tasks.

Flow analysis is especially useful in order to analyze alternative process designs. By considering the performance of each step in the process, the benefit of process redesigns can be quantified and the impact of automating individual tasks becomes visible.

In the following the analyzed performance measure that is looked at will be execution time.

Sequential Tasks

The first calculation starts with sequential tasks or blocks. The execution time of consecutive tasks in a process can be added together to calculate the total time of those two tasks. Considering the tasks in 3.3 where the runtime of each task is brackets below the task name, this would result in a process time of 30s for this block. [8] [4]

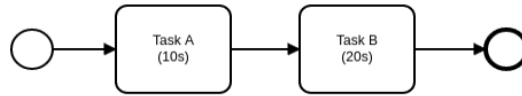


Figure 3.3: a process with two sequential executed tasks

Considering a more general process model P with sequential blocks $B_1, B_2 \dots B_n$ the runtime R_P of process P can be calculated using the formula 3.1.

$$R_P = \sum_{i=1}^n B_i \quad (3.1)$$

Parallel Tasks

The cycle time of parallel tasks or blocks can be calculated using the maximum time of the two parallel blocks. Given the parallel block in 3.4, this would result in a process time of 20s for this block.[4]

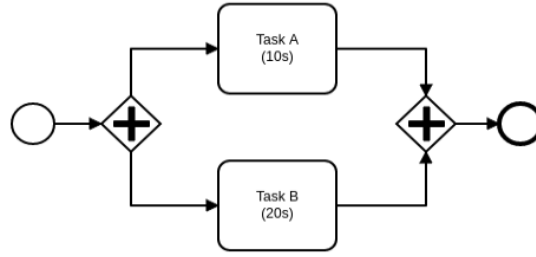


Figure 3.4: a process with two parallel executed tasks

Considering a more general process model P with parallel blocks $B_1, B_2 \dots B_n$ the runtime R_P of process P can be calculated using the formula 3.2.

$$R_P = \arg \max_i B_i \quad (3.2)$$

Alternative Sequence Flows

When having two or more alternative sequence flows with different execution times, additional knowledge about the likelihood of those alternatives is needed [4]. When looked at the alternative executed tasks in 3.5, the average cycle time can be estimated by multiplying the probability of the two alternatives with the execution time of the tasks and summing up the results. This results in $10 * 70\% + 20 * 30\% = 13s$ estimated execution time.

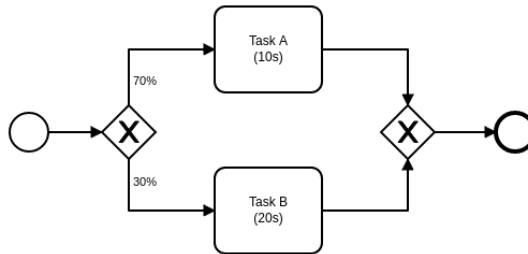


Figure 3.5: a process with two alternative sequence flows

Generally, the cycle time R_P of a process P with one or more alternative blocks, that have the runtimes $B_1, B_2 \dots B_n$ and a likelihood of $p_1, p_2 \dots p_n$ respectively, is estimated with the formula 3.3. [4]

$$R_P = \sum_{i=1}^n B_i * p_i \quad (3.3)$$

Repeating Tasks

According to the BPMN-Standard[9] defined by OMG, there are multiple ways to indicate that a task or sequence is executed more than once:

- **Multiple Instances:** Three lines in the bottom of the task indicate that a task is executed multiple times - once for every instance or element. There are two kinds of multi-instance tasks, sequential, meaning the instances are processes one after another and parallel, meaning the instances are processed at the same time.



Figure 3.6: Multiple Instance Tasks

The execution time of these tasks can be estimated using the same calculations as described above with parallel and sequential tasks.

Having a Process P consisting of only one multi-instance task with the runtimes $B_1, B_2 \dots B_n$ for each instance, the total runtime R_P of process P can be calculated using the formula 3.2 when the instances are executed parallel and 3.1 when the instances are executed sequential.

- **Activity Looping:** A loop in the bottom center of the activity indicates, that this task is performed more than once. The definition on when this task repeats is specified in the *loopCharacteristics*-XML Element.



Figure 3.7: A Task with Activity Looping

- **Sequence Flow Looping:** Whenever a whole sequence flow instead of a task needs to be repeated, a *Sequence Flow Looping*-pattern can be used where the looping condition is defined within an exclusive gateway. The default flow points back to the start of the repeating sequence flow.

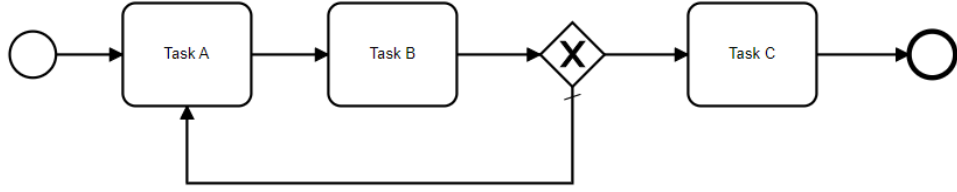


Figure 3.8: The Sequence Flow Looping Pattern

The execution time of both **Sequence Flow Looping** sequences and **Activity Looping** tasks are dependent on the probability that these sequences are repeated. Looking at the two equivalent processes in ?? the probability of Task A repeating is 20% for each loop taken. Task A is always executed at least once. The probability for Task A being executed twice is $20\% = 0.2$. The probability of Task A being executed three times is $0.2 * 0.2 = 0.04$. Following this pattern, the execution time

can be estimated with the infinite sum $\sum_{i=1}^{\infty} 0.2^i * 10s$

(3.4)

Figure 3.9: a process with sequence flow looping (left) and the equivalent using activity looping (right)

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3.3.3 Queues

As mentioned before, the cycle time of a process consists of the time the process is actively executed (*processing time*) and the time the process spends waiting (*waiting time*). In the previous section basic flow analysis was introduced to approximate and analyze these measures. While the processing time can be approximated using basic flow analysis, getting an idea about the total expected waiting time of a process is more complex, since flow analysis as it is has no tool to estimate queuing time.

In order to bridge this gap, the flow analysis can be extended using an queuing approximation algorithm as it is described in this paper[8].

3.3.4 Simulation

3.3.5 Cycle Time Efficiency

3.3.6 Littles Law

3.4 Benchmarking Processes



Concept and Implementation

- 4.1 Architecture
- 4.2 Technologies
- 4.3 Interface
- 4.4 Selected Algorithms
- 4.5 BPMN Processing

CHAPTER 5

Case Study

5.1 rename tasks

5.2 bring the model to an adequate granularity level

CHAPTER 6

Conclusion

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Glossary

'happy-path' The best-case scenario in a process. 4, 6

Automated task A task that can be automated in a BPMN Workflow Management System. 5, 6

BPMN Workflow Management System A software for executing workflows specified as BPMN models. 3, 5–7, 23

Business Process Management System see BPMN Workflow Management System. 3, 25

Business Process Workflow Management System see BPMN Workflow Management System. 3–6, 10, 23

Business Rule Task “provides a mechanism for the Process to provide input to a Business Rules Engine and to get the output of calculations that the Business Rules Engine might provide”[p. 163][9] . 5

conceptual BPMN model A BPMN model describing a business process that cannot be directly executed on a Business Process Workflow Management System. 3–7

Data Object “Data Objects representing a Collection of Data”[p. 206][9] . 7

Data Store “A DataStore provides a mechanism for Activities to retrieve or update stored information that will persist beyond the scope of the Process”[p. 208][9] . 7

executable BPMN model A software for executing workflows specified as BPMN models. 3–5, 7

Manual Task “A Task that is expected to be performed without the aid of any business process execution engine”[p. 163][9] . 6

Process Variables Process variables are managed by the BPMS engine to allow data exchange between process elements. 4

Receive Task “designed to wait for a Message to arrive from an external Participant”[p. 161][9] . 5, 6

Script Task “executed by a business process engine. The modeler or implementer defines a script in a language that the engine can interpret”[p. 164][9] . 5

Send Task “designed to send a Message to an external Participant”[p. 159][9] . 5

Service Task “Task that uses some sort of service, which could be a Web service or an automated application”[9, p. 158] . 5

User Task “A typical “workflow” Task where a human performer performs the Task with the assistance of a software application”[p. 163][9] . 6

XML Extensible Markup Language - Defined by W3C[?] . 8, 21

XSD XML Schema Definition - Definition of the structure of a XML File[?] . 8, 9

Acronyms

BPMN Business Process Model and Notation. 3–8, 23

BPMS Business Process Management System Business Process Management System.
3, 4

XML Extensible Markup Language XML. 8

XSD XML Schema Definition XSD. 8

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