Quality Assessment Strategy: Applying Business Process Modelling Understandability Guidelines

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Abstract

The knowledge management in Public Administration is considered a challenging topic. The knowledge, in fact, is often scattered among different devices such as notes, information systems or it is actually based only on personal memories. This challenge the learning activities of civil servants. The project Learn PAd try to solve this issues by providing a holistic e-learning platform to collect knowledge in the graphical form of Business Process models and in the textual form of wiki pages.

However, to guarantee that the knowledge collected in the Learn PAd platform is correct and understandable, a quality assessment strategy is required. In this Technical Report we present our contribution to the Learn PAd platform in terms of: the definition of a Quality Assessment Strategy, the collection and refinement of BP modelling understandability guidelines, the validation of the guidelines and their application on PA scenarios.

Contents

1 Introduction

The knowledge management in collaborative organizations like the Public Administration (PA) is a challenging topic. Civil servants usually deal with heterogeneous information learned from previous field experiences. In some cases, they can access to insights from prior projects, where notes are scattered among manifold "knowledge containers" spanning from the personal memory/notes, to some official information systems. Nevertheless, it is often difficult to use such pieces of "best practices" in a coordinated manner taking into account both the documents content and the document context (i.e., the creation situation, the potential usage situation). In addition, the introduction of new regulations, or their frequent modification, require a PA to be capable of easily adapt. This is one of the major critical issues that PAs have to cope with, transforming their regulation framework in order to improve efficiency and effectiveness. It also reflects on our civil servants, challenging them to always learn to carry out new tasks. Without a strong knowledge management system, the civil servants learning activities may require too much effort impacting badly on the overall PA efficiency. The adoption of the European Interoperability Framework [1] challenges the PAs from the European member states to cope with several and interconnected procedures, that are often documented and modelled in terms of Business Processes (BPs). Then, our research investigates the use of a Model Based Learning platform in order to organize knowledge in the form of BP models, in such a way to support civil servants in learning, managing and mastering the complexity of PA activities.

We carried out our work in the context of the Learn PAd project[1]. Learn PAd is a project that aims to enhance the Public Administrations employees learning experience; it wants to reach this goal through the development of an innovative holistic e-learning platform for Public Administrations that enables process-driven learning and fosters cooperation and knowledge-sharing. The knowledge is collected and shared by means of graphical Business Process models and textual wiki pages with a high participation of the PAs employees that require training. BP models are signed using the BPMN 2.0[2] notation, which has been standardised by OMG [2], and it is currently acquiring a clear predominance, being also supported by a wide spectrum of modelling tools[3].

The knowledge shared in the Learn PAd platform will contribute to train PAs employees. Therefore, a main requirement for the Learn PAd platform, is to have a quality assessment strategy which helps to guarantee that the knowledge shared on the platform is correct and understandable.

BP models cover a main role in the learning process sponsored by the Learn PAd project; they are seen as building blocks for the development of the Learn PAd platform. BP models are taken as input by the Learn PAd platform and processed to generate wiki pages. Those pages will provide a textual and com-

[1] http://www.learnpad.eu/

[2] We use BPMN or BPMN 2.0 interchangeably to refer to version 2.0 of the notation (Release Date: January 2011).

[3] BPMN is already supported by 75 tools (see `http://www.bpmn.org` for a detailed list).

prehensive explanation of the BP represented by the model itself. In this way, a combined BP representation will be available: one, which consists of the graphical BP model and the other, which consists of the textual wiki pages. BP models and wiki pages are then consulted by PA employees that require training on Business Process activities.

Since the use of BP models is meant to facilitate the learning process of civil servants, we agree that BP model understandability plays a main role in the matter. Especially we want to ensure that BP models used in the Learn PAd platform can be considered correct and understandable. To guarantee BP models correctness we rely on some BP verification techniques and on the feedback the PA employees will provide. However to verify that the BP models and the derived wiki pages result to be understandable, we focus on guidelines to be followed by BP modellers. We infer that an understandable model contributes to generate understandable wiki pages (or more understandable wiki pages respect of starting by difficult to understand models). It is in this sense that we provide a Technical Report which focus on the importance of Business Process Modelling Guidelines for the design of understandable BP models. The guidelines have been validated through the results collected from a questionnaire submitted to PA employees and BP model experts.

We contribute to the Learn PAd project by:

- providing a Quality Assessment Strategy which focuses on BP models and the Learn PAd platform contents.
- providing modelling understandability guidelines for BPMN models, with reference to metrics and thresholds.
- validating BP modelling understandability guidelines and providing application examples in the PA domain.

The Quality Assessment Strategy defines the procedure to guarantee that the Learn PAd platform contents, generated from BP models, result in being understandable and, improvable by the feedback from the involved users. Modelling guidelines have been defined to guarantee that the model used for populating the platform are considered understandable, in such a way to generate understandable platform contents. Understandability is critical to acquire new knowledge as an outcome of the civil servant learning process; it is stated in [3] [4] that BP Models with poor results for understandability, also imply poor learnability. The modelling guidelines validation has been carried out to prove that models designed by following those guidelines result in being more understandable than the ones designed without following them.

The report is organized as follow. Section 2 provides a general description of the quality assessment strategy used inside the Learn PAd project. Section 3 introduces an overview of the literature about BP modelling guidelines, BP model metrics and thresholds. Section 4 provides a list of all the guidelines we collected and refined for the design of understandable BP models. Section 5 describes the BP modelling understandability guidelines validation through a questionnaire. Finally, Section 6 concludes the paper with some closing remarks.

2 Quality Assessment Strategy for Business Process Models

This chapter describes the process for the quality assessment of Business Process models – referred in the following as BP models or simply, models. Overall, the process can be partitioned into two complementary quality assessment strategies: an **automated** quality assessment strategy, and a **crowd-based** quality assessment strategy. The former, more software-intensive, employs formal model verification and automated model understandability assessment. The latter, more human-intensive, employs the feedbacks from the learners to improve the quality of BP models, and, in the long term, to provide additional understandability guidelines to plug in the Learn PAd platform.

We first introduce the roles involved within the quality assessment process and their respective tasks.

- **Modeller.** This role is played by an expert in business process modelling. The Modeller designs and updates the models through the modelling platform, he validates the models by means of automated quality assessment and he generates Wiki pages from the models; the Wiki pages will be loaded as learning content in the Learn PAd platform.

- **Learner.** This role is played by a civil servant of the organization for which the model has been developed. The Learner provides feedback to improve the models by means of comments and Like/Dislike buttons.

- **Content Manager.** This role is played by a person who is expert in the specific process described by the BP model. A Content Manager is associated to one or more BP models of an organization. The Content Manager analyses feedback provided by the learners for the model he is in charge of, he suggests model modifications to the Modeller and he can identify and recommend new guidelines to the Guidelines Manager.

- **Guidelines Manager:** this role is covered by a person who is in charge of maintaining the Learn PAd platform. The Guidelines Manager is associated to multiple Content Managers, possibly belonging to different organizations, who will refer to him as the collector of guidelines recommendations. After receiving guidelines recommendations from the Content Managers, he will decide the guidelines to plug in the Learn PAd platform for providing automated quality assessment.

In Fig. 1 we report the overall quality assessment strategy highlighting the interactions between the different involved roles.

The **Automated Quality Assessment Strategy** involves only one role, namely the Modeller. This role designs the model (Design Model Content) and then he performs formal verification and automated understandability evaluation, to automatically validate the produced model (Validate Model Content).

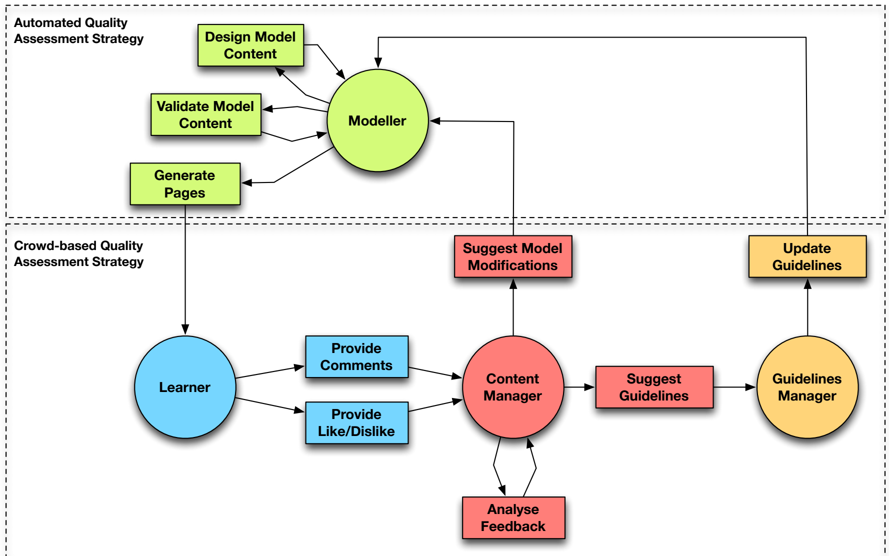


Figure 1: The two quality assessment strategies for BP Models depicted as components of an overall quality assessment process.

In case the model does not result valid, he will update the model according to the result of the validation performed. He will iterate the validation and update the process, until the model is considered valid. When the model results valid (i.e., all the formal verification checks are passed, and all the understandability guidelines are satisfied), the Modeller will generate the Wiki pages (Generate Pages) which afterwards, will be used by the Learners.

The **Crowd-based Quality Assessment Strategy** involves three roles, namely the Learner, the Content Manager, and the Guidelines Manager. The Learner provides feedback on the models, by means of comments (Provide Comments) and like/dislike (Provide Like/Dislike) buttons. The Content Manager will monitor the contributions of the Learners, and will evaluate all these feedback (Analyze Feedback) to understand and prioritize the required modifications on the model. Then, he will recommend such modifications to the Modeller (Suggest Model Modifications), who will modify the models and will repeat the Automated Quality Assessment Strategy. In the long term, the Content Manager will be able to identify typical weaknesses of the models for which he is in charge, according to the feedback of the users. To address these common weaknesses, he will recommend modeling guidelines to plug into the Learn PAd platform (Suggest Guidelines). The Guidelines Manager will collect guidelines recommendations from multiple Content Managers, and will define techniques to automatically assess such guidelines (Update Guidelines). These iterations will enable a refinement of the Automated Quality Assessment Strategy.

3 State of the Art

In this chapter we introduce a state of the art representing the starting point for the definition of quality assessment strategies for BP models. It helps to focus on the works already done in the area and make aware the reader on the different techniques and solutions already available. First of all we focus on BP model understandability and than we consider formal verification approaches.

To make a BP model understandable, reliable, and reusable it is important to ensure its quality. Several approaches that work in this direction are described in the literature. We have classified them based on their main research topic: (1) approaches focused on improving BP design through the suggestion of modeling guidelines (2) approaches which identify process model metrics to evaluate model qualities (3) approaches which establish thresholds for the identified metrics.

3.1 Business Process Modeling Guidelines

Modeling Guidelines are rules that a modeler should follow to design models which result in being correct and understandable. Here we report some of the approaches that are intended to provide advice and guidelines to improve the BP model qualities.

- Becker et. al. [5] propose a set of guidelines to improve six characteristics of a process model such as correctness, clarity, relevance, comparability, economic efficiency, and systematic design. The provided guidelines aim at improving the quality of the model creation process as well as that of the conceptual model itself. The principle of correctness thereby proposes that the real world excerpt has to be depicted correctly with respect to its content. The principle of relevance prescribes that only elements must be depicted which are relevant for the modeling purpose. The principle of economic efficiency demands that the costs for creating models must not exceed the expected utility. The principle of clarity proposes that a model has to be understandable and readable for the respective users. The principle of comparability requires that models have to be created in such a way that their content can be compared with each other. The principle of systematic design finally proposes that multiple views have to be used for the modeling of different aspects which should be adjusted to each other. Since they were first introduced, the GoM have repeatedly been refined and adjusted according to specific modeling purposes, among others for the modeling of BPs. However, they do not contain concrete measures/guideline to achieve the mentioned goals, which makes their practical application during the modeling process difficult.

- Mendling et. al. [6] study, through interviews, the understandability of models; they concluded that in addition to the factor of the basic individual knowledge, the size of the model is the dominant aspect of understandability. In [7], a successive study, they defined a set of seven process modeling guidelines (7PMG) that are supposed to guide the modeler in designing understandable models that are less prone to errors. Therefore, G1 recommends to use as few elements as possible. G2 suggests to minimize the routing paths per element. The higher the degree of elements in the process model the harder it becomes to understand the model. G3 demands to use one start and one end event, since the number of start and end events is positively connected with an increase in error probability. Following G4, the models should be structured as much as possible. Unstructured models tend to have more errors and are understood less well. G5 suggests to avoid OR routing elements, since models that have only AND and XOR connectors are less error-prone. G6 recommends using the verb-object labeling style because it is less ambiguous compared to other styles . Finally, according to G7, models should be decomposed if they have more than 50 elements. In [8] they extended G4 and G5 including references to the use of design patterns (G4.b) and to the minimizing of connector types heterogeneity and of concurrency. In Table 1 we report the extended version of the guidelines.

G1	Do not use more than 31
G2	No more than 3 inputs or outputs per connector
G3	Use no more than 2 start and end events
G4.a	Model as structured as possible
G4.b	Use design patterns to avoid mismatch
G5.a	Avoid OR-joins and OR-splits
G5.b	Minimize the heterogeneity of connector types
G5.c	Minimize the level of concurrency
G6	Use verb-object activity labels
G7	Decompose a model with more than 31 elements

Table 1: Ten process modeling rules (Mendling et. al. [8].

- Bruce Silver wrote a book [9], which highlights the use of a disciplined approach called "method and style" to help the modeler creating BPMN models that are correct, complete, and clear.

Other sources for BP modeling guidelines can be found online. In particular we consider valuable the contribution by Bruce Silver [10], the one by John Doe [11], and the web pages entitled: Modeling Best Practices[4], BPMN Modeling Guidelines[5], BPMN 2.0 Best Practices[6], and Best Practices in modeling[7].

[4]Located on the Business Process Incubator provided by the Trisotech company: `http://www.bpmnquickguide.com`

[5]Hosted by Signavio GmbH and located at: `http://www.bpmnquickguide.com`

[6]Provided by the Camunda company and located at: `http://camunda.org/bpmn/examples/`

[7]Provided by the Bizagi company and located at: `http://help.bizagi.com/processmodeler/en`

3.2 Business Process Model Metrics

Metrics (or Measures) are used to refer to the amount of BPMN elements and the size of a BP model. Here we report some of the approaches that identify BP model metrics.

- Rolón et. al. [12] and Reynoso et. al. [13], define measures that can be applied to BPMN 1.0 models in order to quantify the understandability and modifiability of conceptual models. These measures have been validated through a correlation and regression analysis [14]. We therefore extracted measures from this analysis, which are the most useful to measure understandability (Table 2).

- Cardoso [15] proposes a Control Flow Complexity (CFC) metric and Rolón et. al. [16] present the use and validation of the CFC metric to evaluate the complexity of BP models developed with BPMN 1.0. The complexity is evaluated from a control-flow perspective. The authors conclude that CFC metric is highly correlated with the control-flow complexity of a BP and therefore with its understandability and modifiability.

- Mendling et. al. [17] present a set of metrics related to size and metrics that capture various aspects of the structure and the state space of the process model. For each of the metrics they discussed the possible connection with error probability and formulated hypothesis.

- Overhage et. al. [18] present the 3QM-Framework, an analytical approach to systematically determine the quality of BP models. The 3QM-Framework makes three contributions: it provides quality marks, metrics, and measurement procedures to quantify the quality level as elements of a theoretically justified quality model.

In Appendix A we report a list of metrics, that have been used to monitor BP Model complexity. Similar works that report a collection of metrics can be found in literature such as [19], [20], and [21].

3.3 Threshold for Business Process Model Metrics

According with the defined metrics for Business Process modeling, some authors tried to identify thresholds which may indicate the level of model qualities e.g. high level of understandability (if some metrics values do not exceed the thresholds) or low level of understandability (if the metrics values exceed the thresholds). Following we report the main sources we considered from the literature.

- Sanchez et. al. [22] and [23] investigate structural metrics and their connection with the quality of process models, namely understandability and modifiability. They consider metrics, like the ones reported in Table 2. They analyzed performance measures including time, correct answers and

Measure	Description
	Measures of Rolón [12]
TNSF	Total Number of sequence flows
TNE	Total Number of events
TNG	Total Number of gateways
NSFE	Number of sequence flows from events
NMF	Number of message flows
NSFG	Number of sequence flows from gateways
CLP	Connectivity level between participants
NDOOut	Number of data objects which are outputs of activities
NDOIn	Number of data objects which are inputs of activities
	Measures of Cardoso [15]
CFC	Control flow complexity. Sum over all gateways weighted by their potential combinations of states after the split
	Measures of Mendling [17]
Number of nodes	Number of activities and routing elements in a process model
Gateway mismatch	Sum of gateway pairs that do not match each other, e.g. when an AND-split is followed by an OR-join
Depth	Maximum nesting of structured blocks in a process model
Connectivity coefficient	Ratio of total number of arcs in a process model to its total number of nodes
Sequentiality	Degree to which the model is constructed from pure sequences of tasks

Table 2: Understandability Measures.

efficiency from a family of experiments for correlations with an extensive set of structural process model metrics. Their findings demonstrate the potential of these metrics to serve as validated predictors of process model quality. Based on the results of paper they determined threshold values to distinguish different levels of process model quality; Table 3 reports the identified threshold values for understandability.

Model Metric	**Very Inefficient**	**Rather Inefficient**	**Rather Efficient**	**Very Efficient**
N°nodes	65	50	37	31
Gateway Mismatch	29	16	6	1
Depth	4	2	1	1
Coefficient of connectivity	1,7	1,1	0,6	0,4
Sequentiality	0,1	0,35	0,6	0,7
TNSF	72	49	34	20
TNE	20	12	7	2
TNG	17	10	5	0
NSFE	28	13	4	0
NMF	27	15	7	1
NSFG	40	22	11	0
CLP	7,5	4,23	2,2	0,2
NDOIN	31	14[8]	4	0
NDOOUT	23	11	3	0
CFCxor	30	17	8	1
CFCor	9	4	1	0
CFCand	4	2	0	0

Table 3: Threshold values for conceptual model metrics (Snchez et. al. [22])

- Mendling et. al. [8] derive thresholds for a set of structural measures for predicting errors in conceptual process models. This is helpful for understanding, for example, that size and complexity are general driving forces of error probability. Significant thresholds were identified, based on ROC curves and the Area Under the Curve [24], and adapted to refine existing modeling guidelines (7PMG) in a quantitative way. The resulting threshold are reported in Table 4.

- Sanchez et. al. in [25] focus on identifying thresholds for gateway complexity measures such as: Control-Flow Complexity (CFC), Gateway Mismatch (GM), Gateway Heterogeneity (GH), Average Gateway Degree (AGD), Maximum Gateway Degree (MGD) and Total Number of Gateways, (TNG). The authors specially focus on the relation between those complexity measures and the understandability external quality of a model. The thresholds resulting from their experiments are presented in Table 5.

Some of the presented metrics and threshold will be associated to the guidelines we are going to define. In fact, those metrics and thresholds can be used

[8] In the original paper [22] this value is reported as 44, we believe it to be a typing error, that is why we suggest the value 14 instead.

Metric	**Threshold**
Conn. Heterogeneity	0.4
Conn. Mismatch	4.5
Token Splits	7.5
CFC	4.5
Nodes	31.5
Density	0.033
End-events	2.5
Sequantiality	0.21
Depth	0.5
Max. Conn. Degree	3.5
Coeff. Connectivity	1.021
Structuredness	0.79
Separability	0.49
Or-Sprilts	0.5
Start-Events	2.5
Av.Conn. Degree	3.09
Cyclicity	0.005
Or-Joins	0.5

Table 4: Thresholds identified based on ROC Curves (Mendling et. al. [8])

to evaluate if a model is following a particular guideline or not, based on the model meets the thresholds or not.

Threshold	Linguistic Label
	Control-Flow Complexity
$CFC \leq 13$	Fairly low measure value or fairly easy to understand/modify.
$13 < CFC \leq 22$	Low measure value or easy to understand/modify.
$22 < CFC \leq 37$	Medium measure value or moderately difficult to understand/modify.
$37 < CFC \leq 51$	High measure value or difficult to understand/modify.
$CFC > 51$	Fairly high measure value or fairly difficult to understand/modify.
	Gateway Mismatch (GM)
-	Fairly low measure value or fairly easy to understand/modify.
$GM \leq 6$	Low measure value or easy to understand/modify.
$6 < GM \leq 15$	Medium measure value or moderately difficult to understand/modify.
$15 < GM \leq 20$	High measure value or difficult to understand/modify.
$GM > 20$	Fairly high measure value or fairly difficult to understand/modify.
	Gateway Heterogeneity (GH)
$GH \leq 0.62$	Fairly low measure value or fairly easy to understand/modify.
$0.62 < GH \leq 0.79$	Low measure value or easy to understand/modify.
$0,79 < GH \leq 0.92$	Medium measure value or moderately difficult to understand/modify.
$0.92 < GH \leq 0.94$	High measure value or difficult to understand/modify.
$0.94 < GH$	Fairly high measure value or fairly difficult to understand/modify.
	Average Gateway Degree (AGD)
$AGD \leq 3.67$	Fairly low measure value or fairly easy to understand/modify.
$3.67 < AGD \leq 3.83$	Low measure value or easy to understand/modify.
$3.83 < AGD \leq 4.06$	Medium measure value or moderately difficult to understand/modify.
$4.06 < AGD \leq 4.18$	High measure value or difficult to understand/modify.
$4.18 < AGD$	Fairly high measure value or fairly difficult to understand/modify.
	Max. Gateway Degree (MGD)
$MGD \leq 4$	Fairly low measure value or fairly easy to understand/modify.
$4 < MGD \leq 5$	Low measure value or easy to understand/modify.
$5 < MGD \leq 7$	Medium measure value or moderately difficult to understand/modify.
$7 < MGD \leq 9$	High measure value or difficult to understand/modify.
$9 < MGD$	Fairly high measure value or fairly difficult to understand/modify.
	Total Number of Gateways (TNG)
$TNG \leq 9$	Fairly low measure value or fairly easy to understand/modify.
$9 < TNG \leq 12$	Low measure value or easy to understand/modify.
$12 < TNG \leq 18$	Medium measure value or moderately difficult to understand/modify.
$18 < TNG \leq 22$	High measure value or difficult to understand/modify.
$22 < TNG$	Fairly high measure value or fairly difficult to understand/modify.

Table 5: Threshold values and linguistic labels for gateway complexity measures (Sanchez et. al. [25]).

4 Understandability Guidelines

The Learn PAd project considers BP models, designed using BPMN, as valuable resources for the representation of Public Administrations services. In particular, within Learn PAd project, BP models are considered fundamental in the process of learning about Public Administration activities in a user-centric perspective. BP models contributes to facilitate the process of learning of a Public Administration employee, hence we agree that BP model understandability plays a main role in the matter.

It is to guarantee BP Model understandability that, we collected, refined, and elaborated guidelines that a modeler should follow for modeling BPs. For the modeling guidelines we referred to multiple sources, that we already mentioned in which include: Scientific papers, books, online articles and webpages. In this section we propose the list of guidelines divided in different categories.

4.1 Categories

We divided the guidelines in categories which name reflects the main characteristic of the guideline. However, the categories are not really strict; it may happen that a guideline has characteristics which belong to one or more categories at the same time. In our case we decided to group such guidelines based on their main scope. The categories are reported in the following.

- **General**: it refers to general rules that impact on different aspects of the process model.
- **Notation**: it refers to best practices in the usage of the BPMN Syntax.
- **Labeling**: it refers to the correct use of names/labels, assigned to BPMN elements.
- **Patterns**: it refers to patterns that may be applied during the modeling.
- **Appearence**: It refers to having a clear representation of the BPMN elements and of the model itself.

In Table 6 we present a template of the tables used to describe the guidelines.

- *Guideline name*: it represents the name of the guideline.
- *Guideline id*: it is a number that represents the id of the guideline.
- *Description*: description of the guideline.
- *Convention concerning the name*: if present, it concerns guideline for labelling elements.
- *Symbol*: if the guideline concerns a BPMN element, here the symbol for the BPMN element is reported.

- *Source*: if present, it indicates the origin of the guidelines otherwise it has been added to this context.
- *Associated Metrics and Thresholds*: if present, it indicates the metrics and thresholds associated to the guideline, if the result of metrics is 0 the model is compliant to the guidelines.
- *Bad/Good modeling*: graphical representation of bad and good practice.

Based on the guidelines category, the template may not contain all the fields describes above. In the category *General*, fields like: symbol, bad/good modeling, convention concerning the name, are not reported since considered unnecessary.

<table>
<tr><td>Guideline Name</td><td>Guideline ID</td></tr>
<tr><td>Name</td><td>ID</td></tr>
<tr><td>Description</td><td rowspan="2">Symbol of the element</td></tr>
<tr><td>The diagram describes the entire process</td></tr>
<tr><td colspan="2">Convention concerning the name</td></tr>
<tr><td colspan="2">BPMN diagrams are always marked with a noun + a verb endlessly.</td></tr>
<tr><td colspan="2">Source</td></tr>
<tr><td colspan="2">Origin of the guidelines.</td></tr>
<tr><td colspan="2">Associated Metrics</td></tr>
<tr><td colspan="2">Metrics of guideline.</td></tr>
<tr><td colspan="2">Convention on the modeling</td></tr>
<tr><td>Bad Modeling</td><td>Good Modeling</td></tr>
</table>

Table 6: Template of description guidelines of Business Process Model Notation.

4.2 General Guidelines

In this section we present general guidelines, that do not refer to specific BPMN elements.

Guideline Name	Guideline ID
Validate models	1
Description	
The designer should create models which comply with the BPMN standard. Once the process logic has been defined, the designer should validate a model ensuring that the model is syntactically correct.	
Source	
[9, 26, 27]	
Associated Metrics and Thresholds	
$$modelsValidated(x) = \begin{cases} 0 & if \quad isValid(x) = true \\ 1 & otherwise \end{cases}$$ *where:* $x \in$ BPMN Model $\wedge$ $isValid$ is true if it comply with BPMN 2.0 standard.	

Guideline Name	Guideline ID
Minimize model size	2
Description	
The designer should try to keep models as small as possible. Large models tend to contain more errors. Additionally they are difficult to read and comprehend. Defining the correct scope of tasks and level of detail of models is the key to reduce the overage of information.	
Source	
[7, 8, 28, 29, 30, 31, 32, 33, 34, 26, 35, 36, 37, 38, 23]	
Associated Metrics and Thresholds	
$$minimizeModelSize(x) = \begin{cases} 0 & if \quad SN <= 31 \\ 1 & otherwhise \end{cases}$$ *where:* $x \in$ Nodes of Model $\wedge$ SN is the number of activities and routing elements in a process model.	

Guideline Name	Guideline ID
Apply hierarchical structure with sub-processes	3

Description

The designer should create a hierarchical model structure. BPMN sub-processes are used to split the process into layers. The designer can expand the sub-processes later to expose details of lower levels of hierarchy. A process model will contain multiple layers, but internally the integrity of a single model has to be maintained.

Source

[9, 29, 34, 38, 39, 40, 41]

Associated Metrics and Thresholds

$$hierarchicalStructure(x) = \begin{cases} 0 \quad if \quad SN > 31 \quad \wedge \quad SB < 0 \\ 1 \qquad otherwhise \end{cases}$$

where:
$x \in$ Nodes of BPMN model $\wedge$
SN is the number of activities and routing elements in a process model $\wedge$
SB is the number of sub-process in a process model.

Guideline Name	Guideline ID
Apply symmetric modeling	4

Description

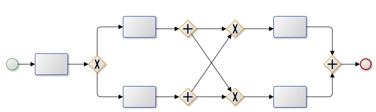
The designer should model as structured as possible. Symmetric structures increase understandability of BPMN process models - for both experienced and inexperienced BPMN users. Well-structuredness, means that for every node with multiple outgoing arcs (a split) there is a corresponding node with multiple incoming arcs (a join), such that the set of nodes between the split and the join form a single-entry-single-exit (SESE) region.

Source

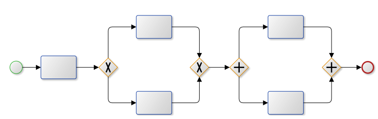
[7, 42, 33, 35, 27, 8, 39, 30]

Convention on the Modeling

Bad Modeling



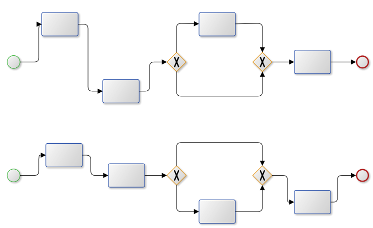
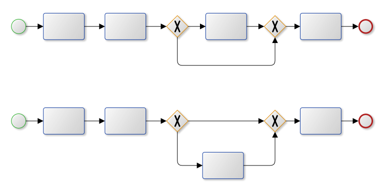
Good Modeling



Guideline Name	Guideline ID
Highlight the “happy path”	5

Description
The designer should make the process logic visible in the model. The “happy path” - a sequence of activities that will be executed if everything goes as expected without exceptions - should be easily identified when reading a model. The designer should model the happy path first and then the alternative flows.

Source
`http://www.bpmnquickguide.com/viewit.html`

Convention on the Modeling	
Bad Modeling 	**Good Modeling** 

Guideline Name	Guideline ID
Minimize concurrency	6

Description
The designer should minimize the level of concurrency which means to reduce the use of parallel gateways and ad-hoc sub-processes. Concurrency, which is represented by parallel gateways, may generate ambiguity, especially if the activities in parallel are “manual tasks” and only one person is responsible for those. In this case there will be no parallelization but it is up to the person to decide the tasks execution order.

Source
[7, 8, 39, 35, 43]

Guideline Name	Guideline ID
Model loops via loop activities	7

Description

The designer should model a loop via activity looping (with the loop marker) instead of using a sequence flow looping; this, where possible, and if this practice actually contributes to simplify the model.

Source

[35, 8]

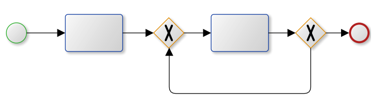
Associated Metrics and Thresholds

$$modelsLoops(x) = \begin{cases} 0 & if \quad \forall \quad z \quad isLoop(z) = false \\ 1 & \quad otherwise \end{cases}$$

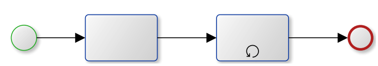
where:
$x \in$ Model $\wedge$ $isLoop(z)$ is true if loop activities are present $\wedge$ $z \in$ Activities.

Convention on the modeling

Bad Modeling



Good Modeling



Guideline Name	Guideline ID
Provide activity descriptions	8

Description

The designer should provide a brief description for each activity in the model.

Source

[11]

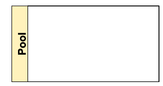
Associated Metrics and Thresholds

$$activityDescritpion(x) = \begin{cases} 0 & if \quad isEmpty(x) = false \\ 1 & \quad otherwhise \end{cases}$$

where:
$x \in$ Activities $\wedge$ $isEmpty$ is true if activities description is empty.

Guideline Name	Guideline ID
Minimize gateway heterogeneity	9
Description	
The designer should minimize the heterogeneity of gateway types. The use of several type of gateway may cause confusion.	
Source	
[7, 8, 35]	
Associated Metrics and Thresholds	
$$minimizeGatewaysHeterogeneity(x) = \begin{cases} 0 & if \quad GH \leq 0.92 \\ 1 & otherwhise \end{cases}$$ *where:* $x \in$ Gateways $\wedge$ GH is the Gateway Heterogeneity.	

4.3 Notation Usage Guidelines

Guideline Name	Guideline ID
Use pools consistently	10
	

Description

The designer should define as many pools as processes and/or participants. Use a black-box pool to represent external participant/processes. The modeled pools need to be in relation with each other and have to be linked to the main process through message exchange.

Source

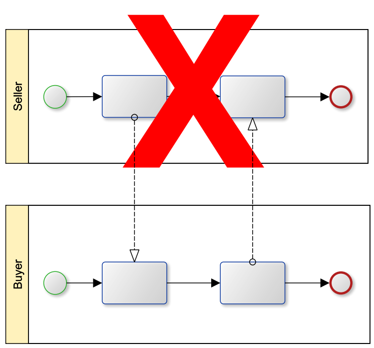
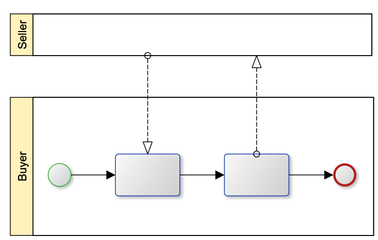
[44, 11]

Associated Metrics and Thresholds

$$usagePools(x) = \begin{cases} 0 \quad if \quad \forall \quad z \quad isExpanded(z) = true \\ 1 \qquad otherwhise \end{cases}$$

where:
$x \in$ Model $\wedge$ $isExpanded(z)$ is an attribute of pools and it is true if the pool is expanded $\wedge$ $z \in Pools$

Convention on the modeling

Bad Modeling	Good Modeling
	

Guideline Name	Guideline ID
Use lanes consistently	11

Description

The designer should model internal organizational units as lanes within a single pool, not as separate pools; separate pools imply independent processes. Create a lane, in a pool, only if at least one activity or intermediate event is performed in it.

Source

[44, 11]

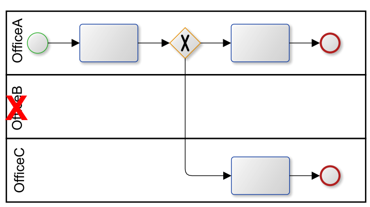
Associated Metrics and Thresholds

$$usageLanes(x) = \begin{cases} 0 & if \quad isEmpty = false \\ 1 & \quad otherwhise \end{cases}$$

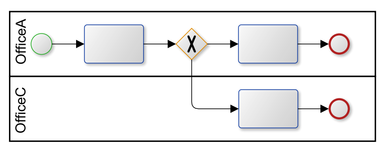
where:
$x \in$ Lanes $\wedge$ $isEmpty$ is true if lane is empty.

Convention on the modeling

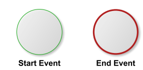
Bad Modeling



Good Modeling



Guideline Name	Guideline ID
Use start and end events explicitly	12



Description

The designer should explicitly make use of start and end events. The use of start and end events is necessary to represent the different states that begin and complete the modeled process. Processes with implicit start and end events are undesirable and could lead to misinterpretations.

Source

[44, 11, 7, 8, 45, 35, 46]

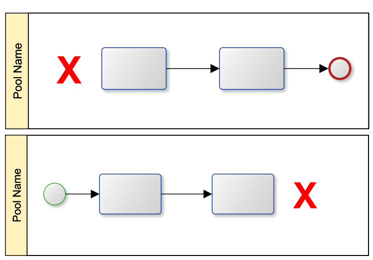
Associated Metrics and

$$explicitStartEndEvents(x) = \begin{cases} 0 & if \quad TNSE > 0 \wedge TNEE > 0 \\ 1 & otherwise \end{cases}$$

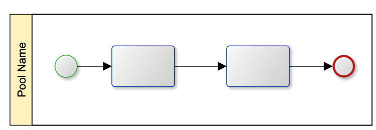
where:
$x \in$ Events $\wedge$ $TNSE$ is the total number of start events $\wedge$ $TNEE$ is the total number of end events.

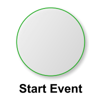
Convention on the modeling

Bad Modeling



Good Modeling



Guideline Name	Guideline ID
Use start events consistently	13
	

Description

The designer should include, in the model, only one start event. Where necessary, alternative instantiations of the process should be depicted with separate start events and using a event-based start gateway.

Source

[44, 11, 7, 8, 34, 35, 39, 46]

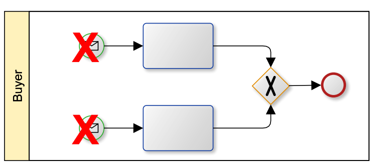
Associated Metrics and Thresholds

$$consStartEvents(x) = \begin{cases} 0 & if \quad TNSE = 1 \\ 1 & otherwhise \end{cases}$$

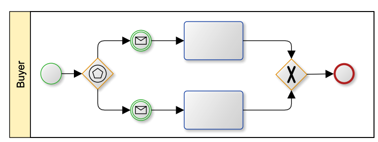
where:
$x \in$ Events $\wedge$ $TNSE$ is the total number of start events.

Convention on the modeling

Bad Modeling



Good Modeling



Guideline Name	Guideline ID
Use end events consistently	14
	

Description

The designer should distinguish success and failure end states in a process or a sub-process with separate end events. Therefore, separate end events that do not represent distinct end states must be merged in a single end event.

Source

[44, 11, 7, 8, 39, 46]

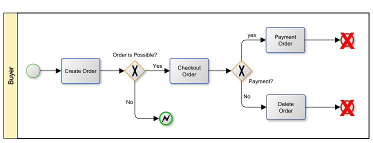
Associated Metrics and Thresholds

$$consStartEvents(x) = \begin{cases} 0 \quad if \quad NENE \leq NEMsE \leq NEEE \leq \\ \qquad\quad NECaE \leq NECoE \leq NELE \leq \\ \qquad\quad NEMuE \leq NETE \leq 1 \\ 1 \qquad otherwhise \end{cases}$$

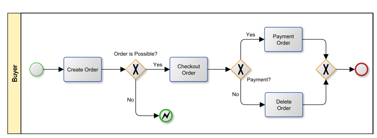
where:
$x \in$ Events $\wedge$
$NENE$ is the number of End None Events $\wedge$
$NEMsE$ is the number of End Message Events $\wedge$
$NEEE$ is the number of End Error Events $\wedge$
$NECaE$ is the number of End Cancel Events $\wedge$
$NECoE$ is the number of End Compensation Events $\wedge$
$NELE$ is the number of End Link Events $\wedge$
$NEMuE$ is the number of End Multiple Events $\wedge$
$NETE$ is the number of End Terminate Events.

Convention on the modeling

Bad Modeling



Good Modeling



Guideline Name	Guideline ID
Restrict usage of terminate end events	15

Description

The designer should use terminate events only when strictly necessary; they are used to model situations where several alternative paths are enabled and the entire process have to be finished when one of them is completed. The designer should use other end events rather than the terminate end event (e.g. a generic end event), to guarantee that the executions of the reaming process paths or activities will not be stopped.

Associated Metrics and Thresholds

$$minimizeTerminateEndEvents(x) = \begin{cases} 0 & if \quad NETE = 0 \\ 1 & \quad otherwhise \end{cases}$$

where:
$x \in$ Events $\wedge$ $NETE$ is the number of End Terminate Events.

Guideline Name	Guideline ID
Use explicit gateways	16

Description

The designer should split or join sequence flows always using gateways. The modeler should not split or join flows using activities or events. This includes that an activity can have only one incoming sequence flow and only one outgoing sequence flow.

Source

[44, 11, 7, 8, 26, 47]

Associated Metrics and Thresholds

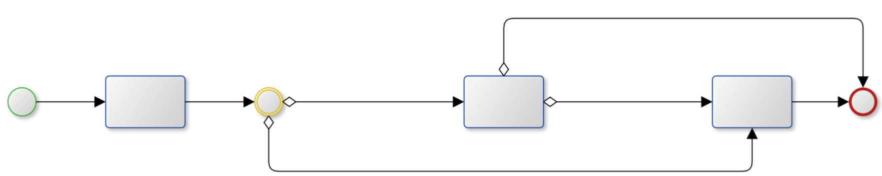
$$explicitGateway(x) = \begin{cases} 0 & if \quad (1) \\ 1 & otherwise \end{cases}$$

(1) $(x \in Activities \cup IntermediateEvents \wedge Edges_{in}(x) = 1 \ \wedge \ Edges_{out}(x) = 1) \ \vee \ (x \in StartEvents \wedge Edges_{in}(x) = 0 \ \wedge \ Edges_{out}(x) = 1) \ \vee \ (x \in EndEvents \wedge Edges_{in}(x) = 1 \ \wedge \ Edges_{out}(x) = 0)$

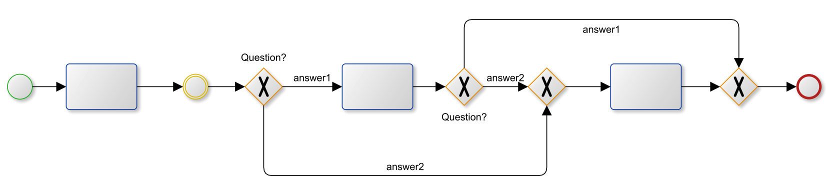
where:
$Edges_{in}(x)$ is the sum of the incoming arcs of element x $Edges_{out}(x)$ is the sum of the outcoming arcs of element x

Convention on the modeling

Bad Modeling



Good Modeling



Guideline Name	Guideline ID
Mark exclusive gateways	17

Description

The designer should use the Exclusive Gateway with the marker “X” instead of using it without marker.

Source

[44, 11]

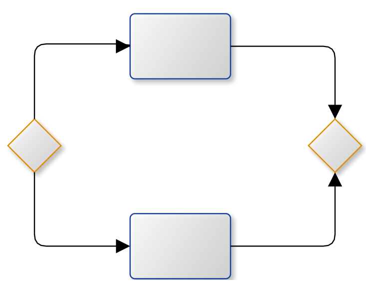
Associated Metrics and Thresholds

$$exclusiveGatewaysMarking(x) = \begin{cases} 0 & if \quad isMarkerVisible(x) = true \\ 1 & \quad otherwhise \end{cases}$$

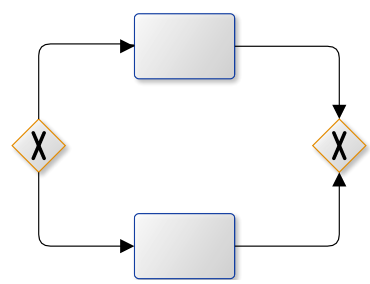
where:
$x \in$ Exclusive Gateways $\wedge$ $isMarkerVisible$ is true if gateway show the marker.

Convention on the modeling

Bad Modeling



Good Modeling



Guideline Name	Guideline ID
Split and join flows consistently	18

Description

The designer should not use gateways to join and split flows at the same time.

Source

[44, 11, 7, 8, 35, 36, 48, 9]

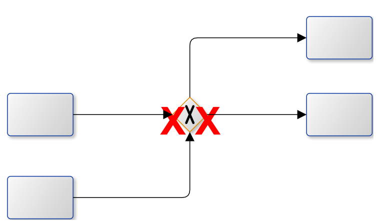
Associated Metrics and Thresholds

$$splitJoinFlows(x) = \begin{cases} 0 \quad if \quad (Edges_{in}(x) = 1 \wedge Edges_{out}(x) > 1) \quad \vee \\ \qquad (Edges_{in}(x) > 1 \wedge Edges_{out}(x) = 1) \\ 1 \qquad otherwhise \end{cases}$$

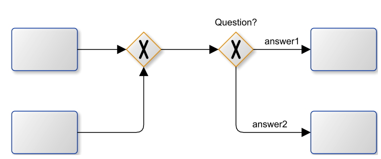
where:
$x \in$ Gateways $\wedge$ $Edges_{in}(x)$ is the sum of incoming arcs of element x $\wedge$ $Edges_{out}(x)$ is the sum of outcoming arcs of element x.

Convention on the modeling

Bad Modeling



Good Modeling



Guideline Name	Guideline ID
Balance gateways	19
	

Description

The designer should always use the same type of gateway used both for splitting and joining the flow. For example, when a flow is divided with a parallel gateway, the resulting parallel flows should be consolidated via another parallel gateway. In particular, the designer should ensure that join parallel gateways have the correct number of incoming sequence flow especially when used in conjunction with other gateways; this is related to ensuring the soundness property. Do not apply this guidelines on Event-based or Complex Gateways.

Source

[7, 8, 45, 33, 27, 39, 30]

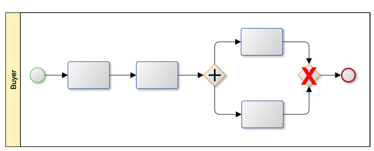
Associated Metrics and Thresholds

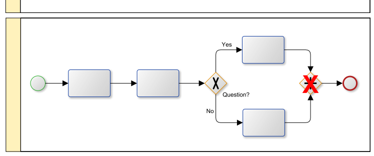
$$BalanceGateways(x) = \begin{cases} 0 & if \quad GM \leq 15 \\ 1 & \quad otherwhise \end{cases}$$

where:
$x \in$ exclusiveGateways $\cup$ parallelGateways $\wedge$ GM is the Gateway Mismatch.

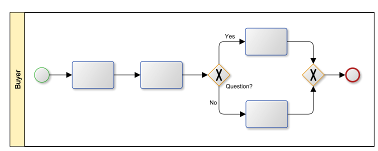
Convention on the modeling

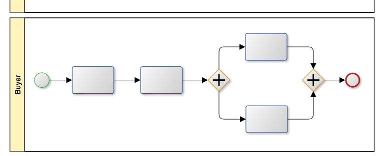
Bad Modeling





Good Modeling





Guideline Name	Guideline ID
Use meaningful gateways	20
	

Description

The designer should not represent gateways that have only one incoming and only one outgoing sequence flow. Gateways with only one incoming and one outgoing sequence flow do not provide any added value.

Source

[44, 11, 7, 8, 29, 42]

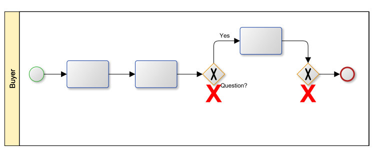
Associated Metrics and Thresholds

$$meaningfulGateways(x) = \begin{cases} 1 & if \quad Edgdes_{in}(x) = 1 \vee Edgdes_{out}(x) = 1 \\ 0 & otherwhise \end{cases}$$

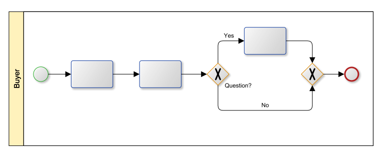
where:
$x \in$ Gateways $\wedge$ $Edges_{in}(x)$ is the sum of incoming arcs of element x $\wedge$ $Edges_{out}(x)$ is the sum of outcoming arcs of element x.

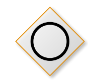
Convention on the modeling

Bad Modeling



Good Modeling



Guideline Name	Guideline ID
Minimize inclusive OR gateways	21
	 Inclusive Gateway

Description

The designer should minimize the use of inclusive gateways (OR-joins and OR-splits). Inclusive OR-splits activate one, several, or all subsequent branches based on conditions. They need to be synchronized with inclusive OR-join elements, which are difficult to understand in the general case.

Source

[7, 45, 39, 34, 43]

Associated Metrics and Thresholds

$$minimizeOrGateway(x) = \begin{cases} 0 & if \quad NID = 0 \\ 1 & otherwhise \end{cases}$$

where:
$x \in$ OR gateways $\wedge$ NID is the number of inclusive decision.

Guideline Name	Guideline ID
Use default flows	22
	

Description

Where possible, after an exclusive and an inclusive gateway, the designer should express the default flow. One way for the modeler to ensure that the process does not get stuck at a gateway is to use a default condition for one of the outgoing sequence flow. This default sequence flow will always evaluate to true if all the other sequence flow conditions turn out to be false.

Source

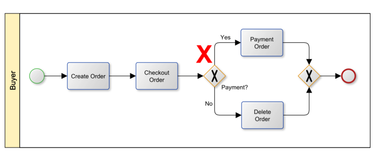
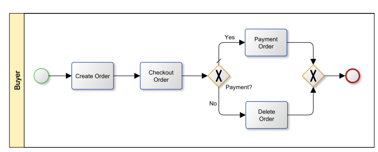
[45]

Associated Metrics and Thresholds

$$usageDefaultFlows(x) = \begin{cases} 0 & if \quad getDefaultSequenceFlow(x) > 0 \\ 1 & \quad otherwhise \end{cases}$$

where:
$x \in$ Exclusive Gateways $\wedge$ $getDefaultSequenceFlow(x)$ is the number of default sequence flows of a gateway.

Convention on the modeling

Bad Modeling	Good Modeling
	

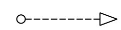
Guideline Name	Guideline ID
Use messages consistently	23

Description

The designer could represent message exchange with different elements. A clearer usage of those elements would be:

- Send Task, can be used to express that the sending of a message requires an effort such as: making a phone call, sending an email, delivering a document, accessing a data store to retrieve data, etc.
- Receive Task, can be used to express that the receiving of a message requires an effort such as: answering a phone call, checking the email, collecting documents, storing data on a data store, etc.
- Intermediate Throwing Event, can be used to express that the sending of a message doesn't require particular effort e.g. the message is automatically processed by a system.
- Intermediate Catching Event, can be used to express that the receiving of a message doesn't require particular effort e.g. the message is received and automatically processed by a system.
- For other cases of message exchange, the modeler should use the remaining Message events such as: Message Start Event (if the process starts after receiving a message); Message Event Sub-Process Interrupting/Non-interrupting (if a received message starts a sub-process); Message Boundary Interrupting/Non-interrupting (if a message is received by a sub-process); Message End Event (if the process or sub-process, ends after sending a message).

Guideline Name	Guideline ID
Use message flows	24



Description

The designer should represent message flows with all message events and send/receive tasks. If in a sub-process are present more message flows to the same pool, the designer should show in the top-level process maximum two message flows: one for all outgoing message flow and one for all incoming message flow with that pool.

Associated Metrics and Thresholds

$$usageMessage(x) = \begin{cases} 0 \quad if \quad \forall \quad z \quad isConnectedIn(z) < 2 \\ \qquad\qquad \vee \quad isConnectedOut(z) < 2 \\ 1 \qquad otherwise \end{cases}$$

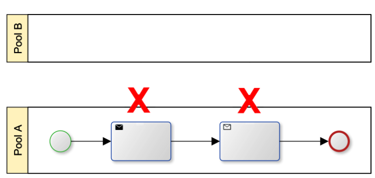
where:
$x \in$ Model $\wedge$ $isConnectedIn(z)$ and $isConnectedOut(z)$ is an attribute of sub-process representing the number of messages incoming respectively and outgoing $\wedge$ $z \in$ Subprocess.

Source

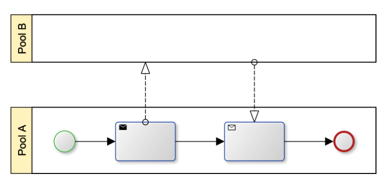
[2]

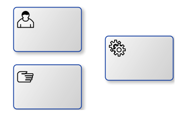
Convention on the modeling

Bad Modeling



Good Modeling



Guideline Name	Guideline ID
Use task types consistently	25
	
Description	
The designer should distinguish task types, e.g. manual task, user tasks and service tasks.	
Source	
[9, 48]	

4.4 Labeling Guidelines

Guideline Name	Guideline ID
Document minor details	26
Convention concerning the name	
The designer should leave details to documentation keeping labels simple and limiting the use of text annotations.	
Source	
[49]	

Guideline Name	Guideline ID
Use a labeling convention	27
Convention concerning the name	
The designer should not use short names or abbreviations. The designer should always use keywords that are meaningful to the business; he should not use the element type in its name. The name should emphasize the goal, and details of activity can be captured in comments or documentation. The designer should not use conjunctions in names raise name abstraction level or split into two subsequent/alternative activities.	
Source	
[18, 29, 26, 47, 35, 37, 50, 51, 52, 53, 54, 55]	

Guideline Name	Guideline ID
Labeling pools	28
	
Convention concerning the name	
The designer should label pools using the participant's name. The main pool can be labeled using the process name. If a pool is present in a sub-process, the name of the pool must be the same of the upper-level process pool which includes the sub-process activity. This means that the pool of the upper-level process and the pool of the sub-process needs to be the same.	
Source	
[11, 37, 51, 50, 52, 53, 54]	
Associated Metrics and Thresholds	

$$labelingPools(x) = \begin{cases} 0 & if \quad getName(x)! = empty \\ 1 & \quad otherwhise \end{cases}$$

where:
$x \in$ Pools $\wedge$ $getName(x)$ returns the name of the Pools.

Guideline Name	Guideline ID
Labeling lanes	29
	

Convention concerning the name
The designer should always assign a label to lanes. The label should identify the responsible entity for the process. Lanes are often used for representing things as internal roles (e.g., manager, associate), systems (e.g., an enterprise application), or internal departments (e.g., shipping, finance).

Source
[11, 37, 51, 50, 52, 53, 54]

Associated Metrics and Thresholds

$$labellingLanes(x) = \begin{cases} 0 & if \quad getName(x)! = empty \\ 1 & otherwhise \end{cases}$$

where:
$x \in$ Lanes $\wedge$ $getName(x)$ returns the name of the Lanes.

Guideline Name	Guideline ID
Labeling activities	30
	

Convention concerning the name

The designer should label activities with one verb, and one object. The verb used should use the present tense and be familiar to the organization. The object has to be qualified and also of meaning to the business. The designer should not label multiple activities with the same name, except for same Call Activities used many time in the process. Send and receive verbs should be present only for sending and receiving activities.

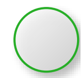
Source

[9, 11, 7, 8, 49, 34, 26, 56, 51, 47, 35, 37, 51, 50, 52, 53, 54]

Associated Metrics and Thresholds

$$labellingActivities(x) = \begin{cases} 0 \quad if \quad getName(x)! = empty \\ 1 \qquad otherwhise \end{cases}$$

where:
$x \in$ Activities $\wedge$ $getName(x)$ returns the name of the Ativities.

Guideline Name	Guideline ID
Labeling events	31
	

Convention concerning the name

The designer should model all events with a label representing the state of the process:

- Events of type message, signal, escalation, and error events should be labeled with a past participle using an active verb;
- Link events should be labeled with a noun;
- Timer events should be labeled with time-date or schedule;
- Conditional events should be labeled with the condition that triggers them.

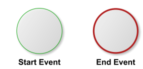
Source

[11, 26, 56, 51, 37, 51, 50, 52, 53, 54]

Associated Metrics and Thresholds

$$labellingEvents(x) = \begin{cases} 0 & if \quad getName(x)! = empty \\ 1 & \quad otherwhise \end{cases}$$

where:
$x \in$ Events $\wedge$ $getName(x)$ returns the name of the Events.

<table>
<tr><th>Guideline Name</th><th>Guideline ID</th></tr>
<tr><td>Labeling start and end events</td><td>32</td></tr>
<tr><td></td><td rowspan="4">
</td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><td></td></tr>
<tr><th colspan="2">Convention concerning the name</th></tr>
<tr><td colspan="2">The designer should not label start none and end none event if there is only one instance of them. The modeler should use labeling when multiple start and end events are used. Label them according to what they represent using a noun. Do not repeat names.</td></tr>
<tr><th colspan="2">Source</th></tr>
<tr><td colspan="2">[11, 56, 51, 37, 51, 50, 52, 53, 54]</td></tr>
<tr><th colspan="2">Associated Metrics and Thresholds</th></tr>
<tr><td colspan="2">

$$labellingEvents(x) = \begin{cases} 0 \quad if \quad getName(x) = empty \quad \wedge \\ \qquad getType(x) = NONE \\ 1 \qquad otherwhise \end{cases}$$

where:
$x \in$ Events $\wedge$ $getName(x)$ returns the name of the Events $\wedge$ $getType(x)$ returns the type of the Events.</td></tr>
</table>

Guideline Name	Guideline ID
Labeling message events	33
	

Convention concerning the name

The designer should draw a message flow whenever he uses a message event, and he should label the event. When a focus on the message itself is required, the designer can represent a message icon and label it with the name of the message.

Source

[11, 56, 51, 37, 51, 50, 52, 53, 54]

Associated Metrics and Thresholds

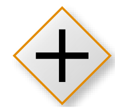
$$labellingMsgEvents(x) = \begin{cases} 0 \quad if \quad isMessageFlow(x) = true \\ 1 \qquad otherwise \end{cases}$$

where:
$x \in$ MsgEventS $\wedge$ $isMessageFlow(x)$ returns true if there is a message flow connected to x. *where:*
$x \in$ Events $\wedge$ $getName(x)$ returns the name of the Events $\wedge$ $getType(x)$ returns the type of the Events.

Guideline Name	Guideline ID
Labeling XOR gateways	34
	
Convention concerning the name	
The designer should label XOR split gateways with an interrogative phrase (do not label XOR join-gateways). Sequence flows coming out of diverging gateways should be labeled using their associated conditions stated as outcomes.	
Source	
[11, 26, 56, 51, 37, 51, 50, 52, 53, 54]	
Associated Metrics and Thresholds	

$$labellingXorGateways(x) = \begin{cases} 0 \quad if \quad getName(x)! = empty \quad \wedge \\ \qquad\qquad Diverging(x) = true \\ 1 \qquad otherwhise \end{cases}$$

where:
$x \in$ Exclusive Gateways $\wedge$ $getName(x)$ returns the name of the Gateways $\wedge$ $Diverging(x)$ return true if gateway is diverging.

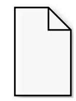
Guideline Name	Guideline ID
Labeling AND gateways	**35**
	
Convention concerning the name	
The designer should omit labels on AND splits and joins (and sequence flows connecting them); they add no new information, so it is best to omit them.	
Source	
[11, 26, 56, 51, 37, 51, 50, 52, 53, 54]	
Associated Metrics and Thresholds	
$labellingAndGateways(x) = \begin{cases} 0 & if \quad getName(x) = empty \\ 1 & otherwhise \end{cases}$ *where:* $x \in$ Parallel Gateways $\wedge$ $getName(x)$ returns the name of the Gateways.	

Guideline Name	Guideline ID
Labeling converging gateways	36

Convention concerning the name
The designer should not label converging gateways. When the convergence logic is not obvious, the designer should associate a text annotation to the gateway.
Source
[11, 45, 26, 37, 51, 50, 52, 53, 54]
Associated Metrics and Thresholds

$$labellingXorGateways(x) = \begin{cases} 0 \quad if \quad getName(x) = empty \quad \wedge \\ \qquad\qquad Diverging(x) = true \\ 1 \qquad otherwhise \end{cases}$$

where:
$x \in$ Xor gateways $\wedge$ $getName(x)$ returns the name of the Gateways $\wedge$ $Converging(x)$ returns true if gateway is converging.

Guideline Name	Guideline ID
Labeling data objects	37
	

Convention concerning the name

The designer should label data objects using a qualified noun that is the name of a business object. The designer should label multiple instances of the same data object (which are really data object references) using a matching label followed by the applicable state in square brackets.

Source

[11, 37, 51, 50, 52, 53, 54]

Associated Metrics and Thresholds

$$labellingDataObjects(x) = \begin{cases} 0 & if \quad getName(x)! = empty \\ 1 & otherwhise \end{cases}$$

where:
$x \in$ Data Objects $\wedge$ $getName(x)$ returns the name of the dataobject.

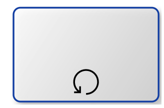
Guideline Name	Guideline ID
Labeling synchronised end/split	38

Convention concerning the name

The designer should use gateways and sub-processes consistently. The designer should match the labels of sub-process end states with the labels of a gateway immediately following the sub-process; this allows to have a clear vision on how sub-process and process are linked together.

Source

[11, 37, 51, 50, 52, 53, 54]

Guideline Name	Guideline ID
Include loop marker annotations	39
	

Convention concerning the name

The designer should associate a text annotation to a loop represented with a loop marker so to express the condition (which alternatively is hidden).

Associated Metrics and Thresholds

$$annotationLoops(x) = \begin{cases} 0 \quad if \quad getAnnotation(x)! = empty \\ 1 \qquad otherwhise \end{cases}$$

where:
$x \in$ Loop Tasks $\wedge$ $getAnnotation(x)$ returns the annotation of a loop task.

4.5 Patterns Guidelines

Guideline Name	Guideline ID
Reduce the number of redundant activities	40

Description

The designer should integrate activities (without boundary events) that can be performed by the same person. The designer can represent these activities as a single activity or he can represent them in a sub-process. A set of consecutive activities in the same lane (or in a pool without lanes) may indicate missing participant details, too much detail, or a misalignment in scope.

Source

[29, 35]

Guideline Name	Guideline ID
Use sub-processes	41

Description
The designer should make use of sub-processes to group activities with the same purpose when: • A set of consecutive activities has an owner different from the main process owner; • A set of consecutive activities has a different goal from the main process one; • A process or a fragment must be re-used in another process (use Call Activities in this case).
Source
[32, 47, 35, 38]

Guideline Name	Guideline ID
Use sub-processes to scope attached events	42

Description
The designer should use a sub-process with attached event to clearly define the scope of an event. If the response to the handling of an exception (in the use of boundary events) is the same for every activity within a contiguous segment of the process, the designer should not attach the same boundary event to all the activities and he should not represent the same exception flows multiple times. The correct way, the designer should model it, is to enclose that segment in a subprocess and attach a single boundary event to the sub-process boundary.
Source
[47]

4.6 Appearance Guidelines

Guideline Name	Guideline ID
Design neat and consistent models	43

Description

The designer should keep the model as neat and consistently organized as possible by following this list of advices:

- Maximize the number of orthogonally drawn connecting objects.
- Make your models long and thin (instead of square): maximize the number of connecting objects respecting workflow direction.
- Minimize the drawing area.
- Adapt the size of objects such that elements have enough space.
- Use a uniform style for flow layout.

Source

[29, 35]

Guideline Name	Guideline ID
Avoid overlapping elements	44

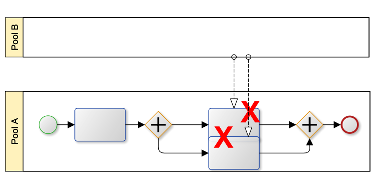
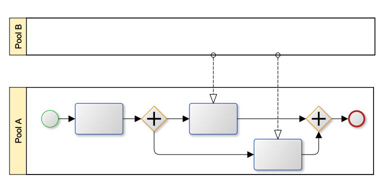
Description

The designer should avoid overlapping, or crossing, BPMN elements.

Source

[44, 11, 26, 35, 36, 57, 58]

Convention on the modeling

Bad Modeling	Good Modeling
	

Guideline Name	Guideline ID
Use linear sequence flows	45

Description

The designer should use linear sequence flows without useless foldings; it helps to maintain the model clean.

Source

[44, 11, 32, 35, 36, 57, 58]

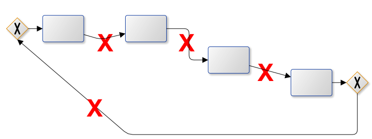
Associated Metrics and Thresholds

$$sequenceFlowsLinearity(x) = \begin{cases} 0 & if \quad isSequenceFlowLinear = false \\ 1 & \quad otherwhise \end{cases}$$

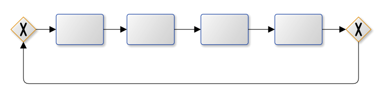
where:
$x \in$ Model $\wedge$ $isSequenceFlowLinear$ returns true if all the sequence flows are linearly drawn.

Convention on the modeling

Bad Modeling



Good Modeling



Guideline Name	Guideline ID
Use linear message flows	46

Description

The designer should use linear message flows without useless foldings; it helps to maintain the model clear.

Source

[44, 11, 35, 57, 58]

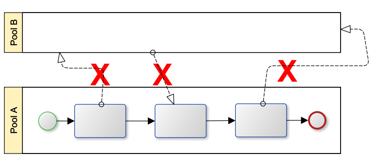
Associated Metrics and Thresholds

$$messagesLinearity(x) = \begin{cases} 0 & if \quad \forall \ z \ \ isMessageFlowLinear(z) = false \\ 1 & \quad otherwhise \end{cases}$$

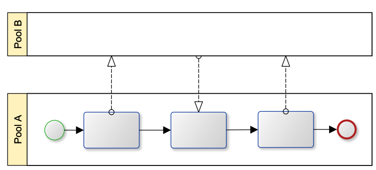
where:
$x \in$ Model $\wedge$ $isMessageFlowLinear$ returns true if all the message flows are linearly drawn $\wedge$ $z \in MessageFlows$.

Convention on the modeling

Bad Modeling



Good Modeling



Guideline Name	Guideline ID
Use a consistent process orientation	47

Description
The designer should draw pools horizontally and use consistent layout with horizontal sequence flows, and vertical message flows and associations.
Source
[44, 11, 59, 26, 35, 57, 58]
Associated Metrics and Thresholds

$$processOrientation(x) = \begin{cases} 0 & if \quad isHorizontal(x) = false \\ 1 & \quad otherwhise \end{cases}$$

where:
$x \in \text{Model} \wedge isHorizontal(x)$ returns true if the model is horizontally drawn.

Guideline Name	Guideline ID
Organize artifacts flows	48

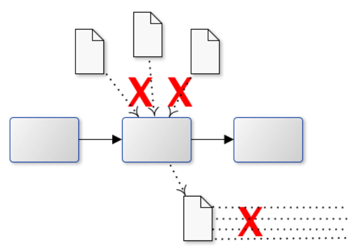
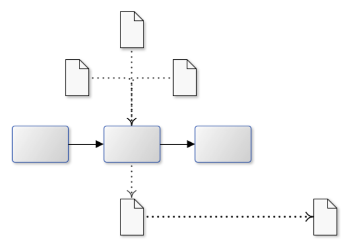
Description

The designer should group artifacts flows, if there are several artifacts. The designer should pick a point on the boundary of an activity and have all the flows connected to that point. If there are multiple flows for the same artifact, the designer should group the flows.

Source

[44, 11, 45, 58]

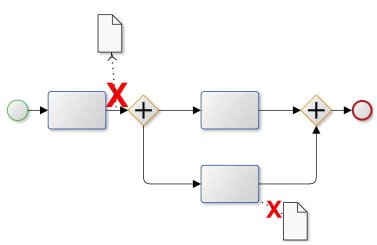
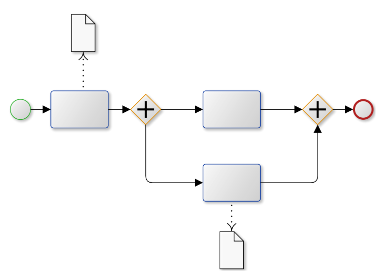
Convention on the modeling

Bad Modeling	Good Modeling
	

Guideline Name	Guideline ID
Associate data objects consistently	49

Description
The designer should associate data objects only to activities. In particular the modeler should not associate a data object with a sequence flow if the sequence flow is connected to a gateway. The associations should always be modeled with a direction.

Source
[45]

Convention on the modeling	
Bad Modeling 	**Good Modeling** 

Guideline Name	Guideline ID
Keep a standard format	50

Description
The designer should keep a unique format along diagrams and focus on a clean and friendly look and feel. Using different font sizes, colors, boxes sizes or overlapping labels might make the diagrams reading a challenge. The designer should not model further properties with different colours, in order to make diagrams recognizable.

Source
[44, 11, 26, 58]

5 Gathering understandable models

The guidelines we presented for the design of understandable BP models have been extracted from the good practices present in literature and they have been improved with our experience to facilitate the process of learning. In order to validate these guidelines we developed a questionnaire presented in the next section. The idea was to use questionnaire answers to improve the guidelines as illustrated in Figure 2.

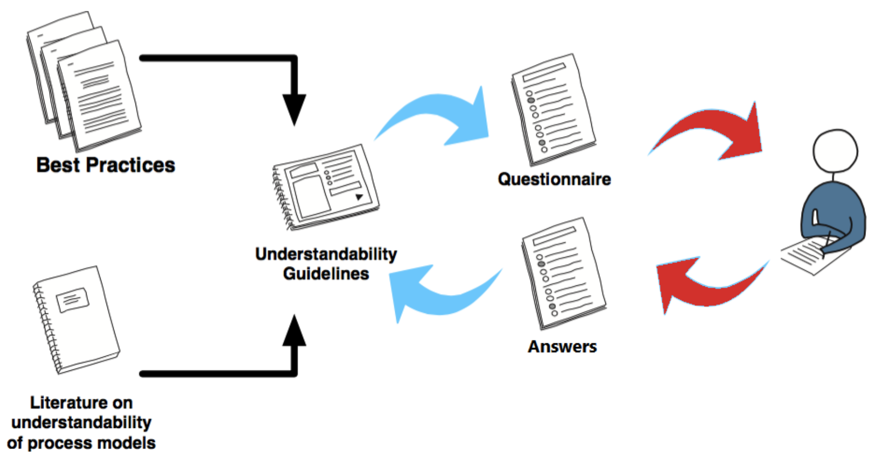


Figure 2: Applied Methodology

The questionnaire has been distributed both to the Public Administrations and the Academic contexts targeting employees, students, researchers, professors and managers. We gave them a month of time to fill the questionnaire. Provided answers were directly saved in a spreadsheet by the google form technology. After 40 days, to account for possible delays, a group of people with members belonging to CNR and Unicam analysed the answers. The total number of filled questionnaire was 75.

In Section 5.1 we present the questionnaire, and in Section 5.2 we present the answers to the questionnaires together with some illustration and discussion.

5.1 The questionnaire

In this section we report the questionnaire that we defined. As we already state, with these questions we want to investigate the importance of the modelling guidelines for the design of understandable BP models.

5.1.1 User Profile

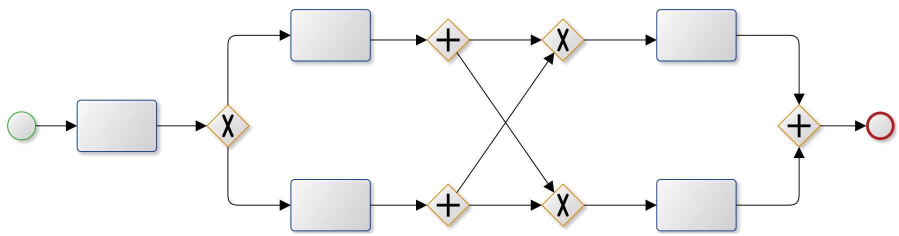
The following questions have been defined in order to identify the profile of the person answering the questionnaire, and then to hijack him to the successive set of questions relevant for the specific profile.

1. **What is your occupation (profession)?**
   - ◯ Employee
   - ◯ Student
   - ◯ Researcher
   - ◯ Professor
   - ◯ Manager
2. **What is your knowledge level of BPMN notation?**
   - ◯ I don't know the BPMN notation
   - ◯ I can intuitively understand the BPMN notation, and I know the basic elements of the notation
   - ◯ I know most of the elements of the BPMN notation, but I never used the notation to create models
   - ◯ I know most of the elements of the BPMN notation, and I can create simple models
   - ◯ I am an expert of the BPMN notation, and I can create complex models with the notation
3. **Have you ever attended a Business Process modelling course?**
   - ◯ Yes, I have.
   - ◯ No, I haven't.

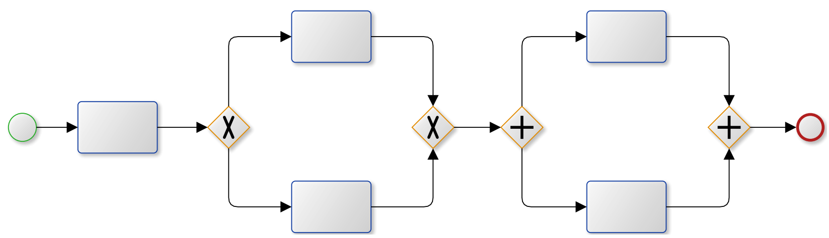
5.1.2 Notation Usage

The following questions concern the use of specific BPMN elements.

4. **Which of the following BP model layouts do you find easier to understand?**
   Please, look at the images before answering the question.
   - ◯ Process A.
   - ◯ Process B.



Process A

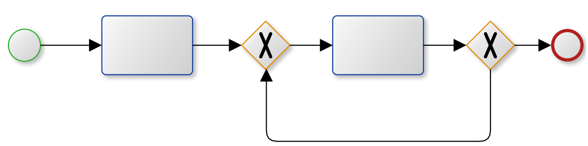


Process B

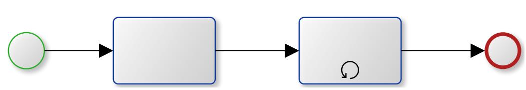
5. **Which of the following BP model layouts do you find easier to understand?**
   Please, look at the images before answering the question.

   ◯ Process A with explicit modeling of the loop.

   ◯ Process B with task with the loop marker.



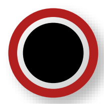
Process A



Process B

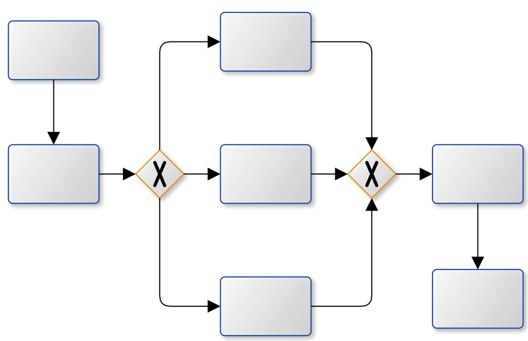
6. **Do you know the meaning of the following BPMN element?**
   Please, look at the images before answering the question.

   - ◯ Yes, it is Terminate End Event. This Event terminates only the branch where it's attached
   - ◯ Yes, it is Terminate End Event. This Event terminates all the branches of the BP model.
   - ◯ No, I don't.

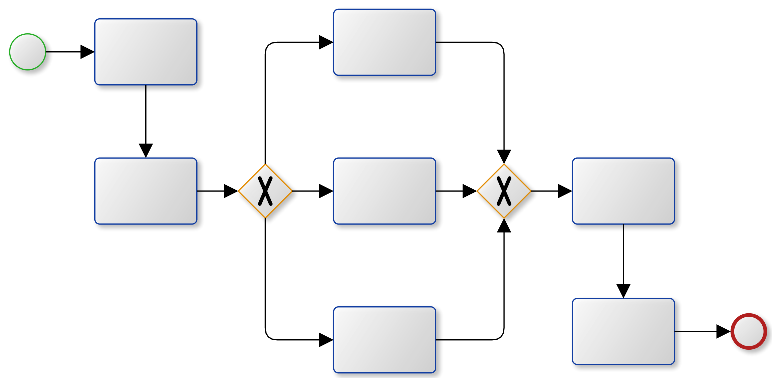


7. **Observing the follow models, do you think that the explicit use of Start and End events improve the understandability of the model?**
   Please, look at the images before answering the question.

   - ◯ No, Process A is more understandable than Process B
   - ◯ Yes, Process B is more understandable than Process A



Process A



Process B

8. **In order to make model easier to understand, if in a subprocess you have more than one message flow in the same direction, how many message flows do you show in the toplevel process?**

   ◯ Only one message flow, which synthesize the multiple message flows that I have at the subprocess level

   ◯ All message flows

9. **After an exclusive or inclusive gateway, do you think that the use the Default Flow improves the understandability of the model?**

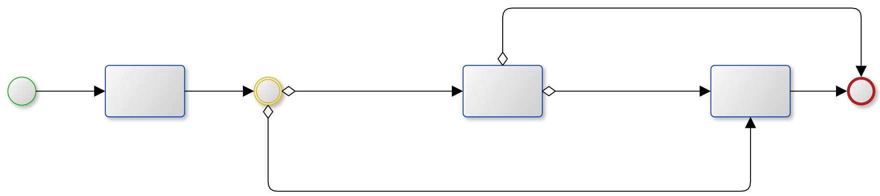
   ◯ Yes, the use of the Default Flow improve the understandability of the model

   ◯ No, the use of the Default Flow doesn't improve the understandability of the model

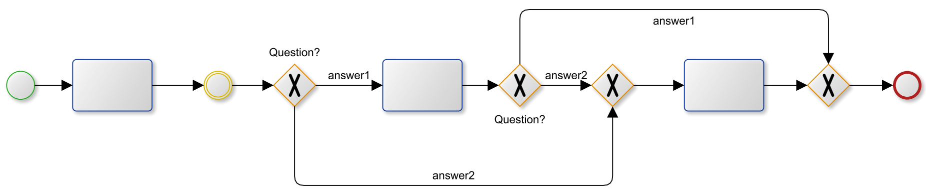
10. **Which of the following BP model layouts do you find easier to understand?**
    Please, look at the images before answering the question.

    ◯ Process A with implicit use of gateways, and no labels

    ◯ Process B with explicit use of the gateways, and explicit labels



Process A

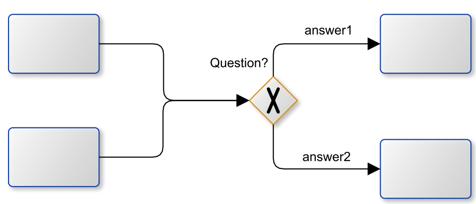


Process B

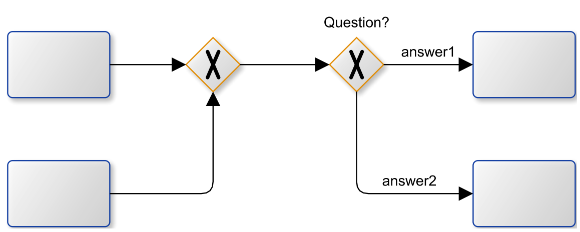
11. **Which of the following BP model layouts do you find easier to understand?**
    Please, look at the images before answering the question.

    ◯ A - a gateway can be used for both splitting AND joining different flows.

    ◯ B - a gateway can be used for splitting OR for joining different flows



A



B

12. **Observing the following Exclusive Gateway, do you think that the marker improves the understandability of the model?**
Please, look at the images before answering the question.

◯ No, A I prefer the Exclusive Gateway without marker

◯ Yes, B I prefer the Exclusive Gateway with marker

A

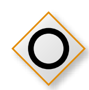
B

13. **Do you know the meaning of the following BPMN element?**
Please, look at the images before answering the question.

◯ Yes, I do. It is Inclusive OR Gateway

◯ Yes, I do. It is Exclusive XOR Gateway

◯ No, I don't.



14. **Which is the execution order of the activities in the model below?**
Please, look at the images before answering the question.

◯ 1) Task A Task B Task C Task D

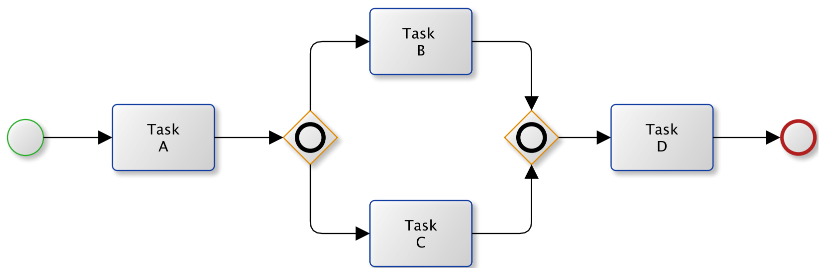
◯ 2) Task A Task B Task D

◯ 3) Task A Task C Task D

◯ 4) Task A Task C Task B Task D

◯ 5) All the previous answers (1,2,3,4) are possible executions

◯ 6) I don't know



5.1.3 Labeling

15. **In order to make models easier to understand, do you think that an Activity Description should be associated with each Activity?** The description is not directly shown in the model but it can be accessed to get more information about the activity itself.

    ◯ Yes, I do agree with it. The Description improve the understandability of the model.

    ◯ No, I don't.

16. **In order to make models easier to understand, matching the label of a subprocess end state with the label of a gateway immediately following the subprocess, do you think that allows to have a clear vision on how subprocess and process are linked together?**

    ◯ Yes , I do agree with it. This improve the understandability of the model.

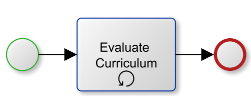
    ◯ No, I don't.

    ◯ I don't know.

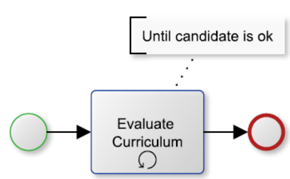
17. **Which of the following BP model layouts do you find easier to understand?** Please, look at the images before answering the question.

    ◯ Process A is easier to understand

    ◯ Process B with Annotation is easier to understand



Process A



Process B

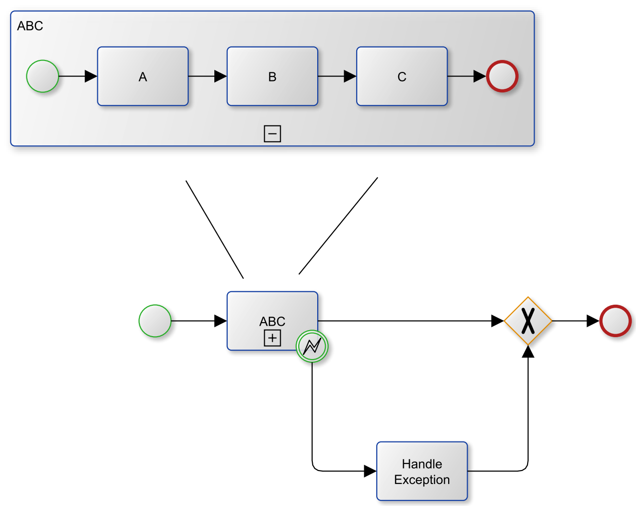
5.1.4 Patterns

The following questions concern the use of patterns in the modelling phase.

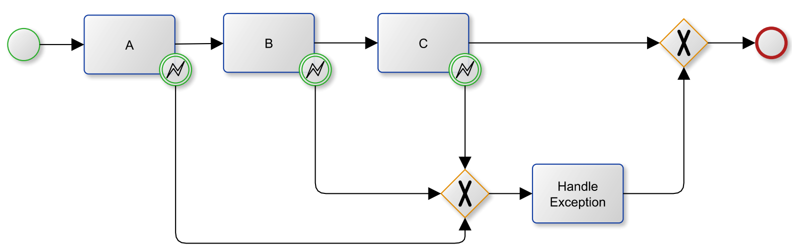
18. **Which of the following BP model layouts do you find easier to understand?**
    Please, look at the images before answering the question.

    ◯ Process A with a subprocesses and a single boundary event is easier to understand

    ◯ Process B, with a boundary event for each activity is easier to understand



Process A



Process B

5.1.5 Appearence

19. **Which of the following BP model layouts do you find easier to understand?**
    Please, look at the images before answering the question.

    ◯ Figure A with edge overlay

    ◯ Figure B without edge overlay

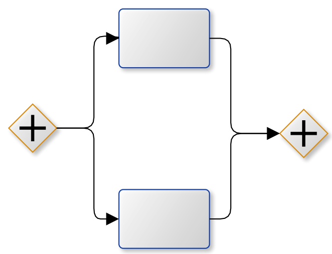


Figure A

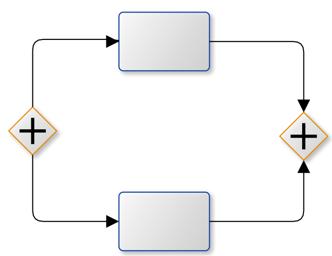


Figure B

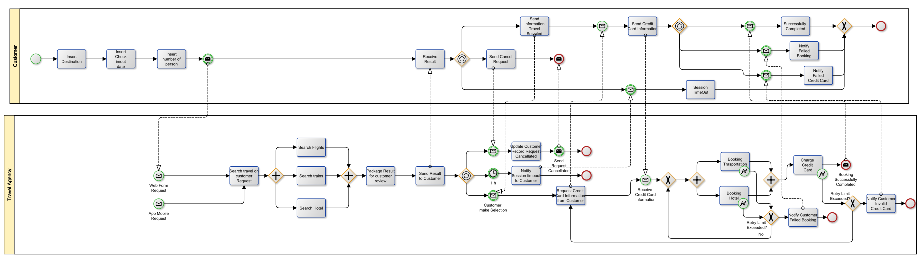
5.1.6 Overall Models

The following are questions on complete Business Process models concerning a Travel Agency.

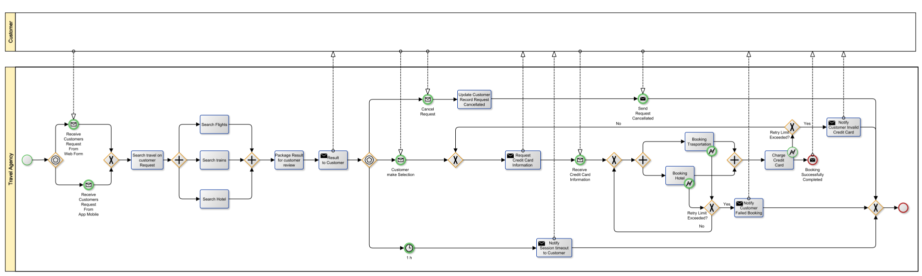
20. **Which of the following BP model layouts do you find easier to understand?**
    The model describes a process of a travel agency. Please, focus only on the travel agency Pool. Both models contain the same tasks. Use the following links to zoom the models.

    ◯ Model A https://goo.gl/eHdpDl

    ◯ Model B https://goo.gl/ywOvLe



Model A

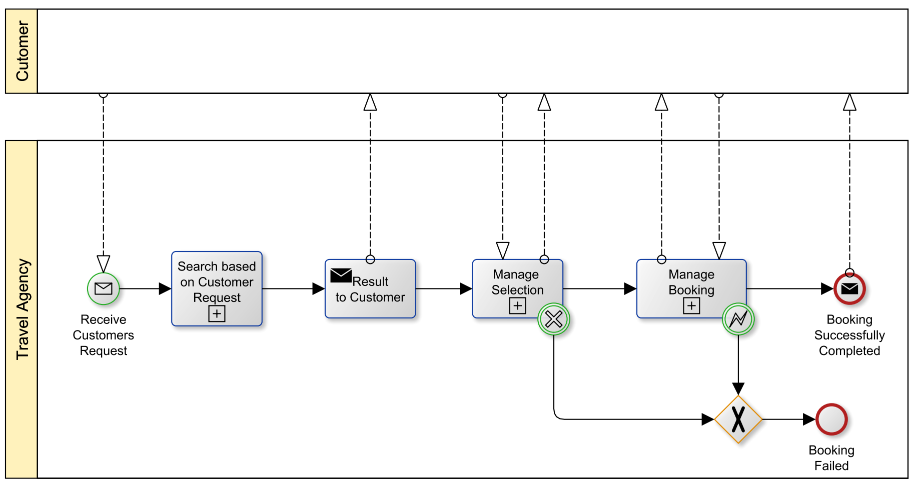


Model B

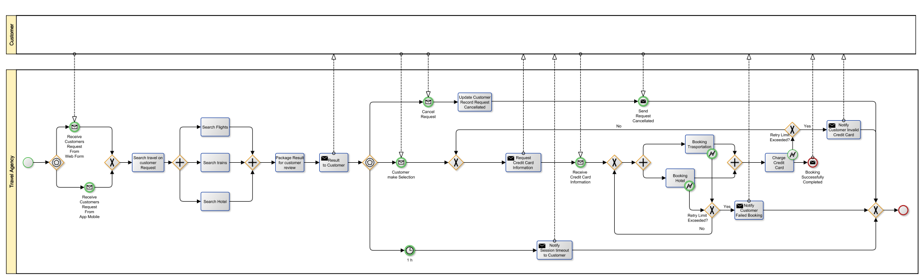
21. **Which of the following BP model layouts do you find easier to understand?**
These models describe a process of a travel agency. Use following links to zoom the models.

◯ Model A, with hierarchical subprocesses is easier to understand https://goo.gl/KXO0po

◯ Model B, without subprocesses is easier to understand https://goo.gl/ywOvLe



Model A



Model B

5.2 Results

In this section we report some illustrations and discussions about the 75 answers to the questionnaires. In particular, we report below the categorization of answers related to the user profile with some overall comment. Answers considering the guidelines are progressively introduced. To access the entire list of answers we refer to `https://docs.google.com/spreadsheets/d/1ckjaq44z2P9s-4hL0wk_AoKigO8N3kDTVoJ14orS9xk/edit#gid=1028432167`.

5.2.1 Users Profile

The 75 interviewees are divided as follows: 25.3% Employee, 48% Students, 16% Researchers, 4% Professors and 6,7% Managers (see Figure 3).

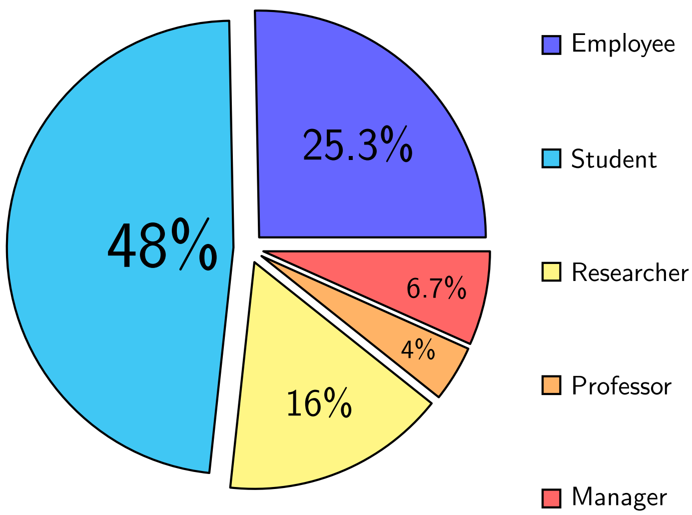


Figure 3: Occupation (profession) of the interviewees

Figure 4 shows the knowledge level of the interviewees on the BPMN notation, in particular the 14,7% of the interviewees is an expert of the notation, the 57,4% of the interviewees has created models, the 36% of the interviewees has a low/intuitively understand of the BPMN notation and only the 6,7% of the interviewees don't know the BPMN notation, this last interviewees cannot go any further in the questionnaire.

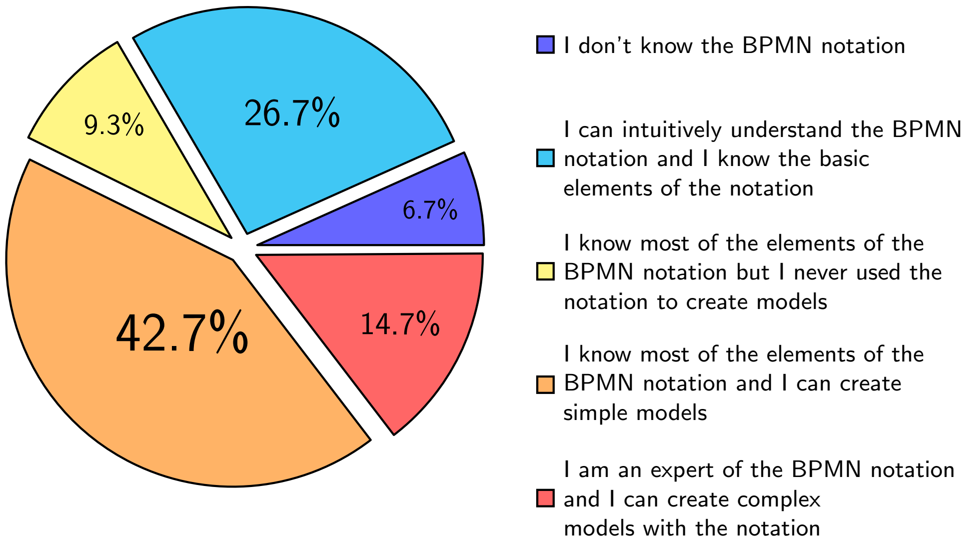


Figure 4: Knowledge level of BPMN notation of the interviewees

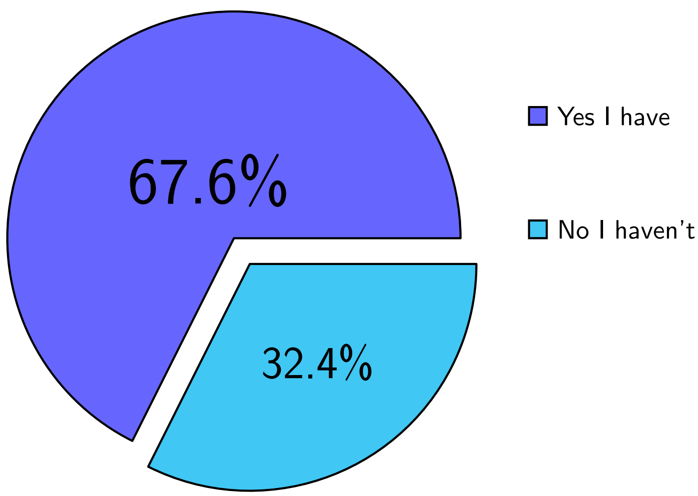


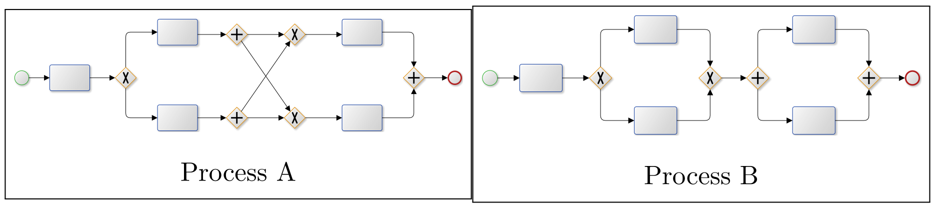
Figure 5: Interviewees that have attended a BP modelling course

Figure 5 shows the interviewees that have attended a Business Process modelling course they are more than 2/3 of the interviewees.

5.2.2 Guidelines

Following we show the answers to the questionnaire considering guidelines in detail, for each question has been associated a pie summarizing the answers.

4. **Which of the following BP model layouts do you find easier to understand?**



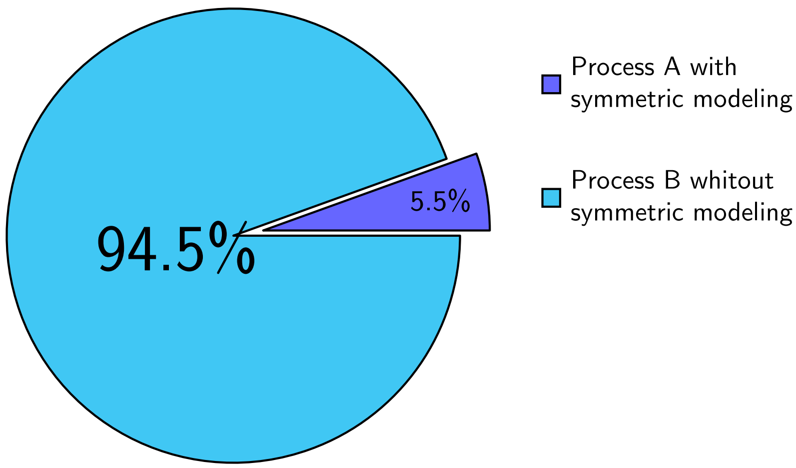


Figure 6: Answers to question 4.

5. **Which of the following BP model layouts do you find easier to understand?**

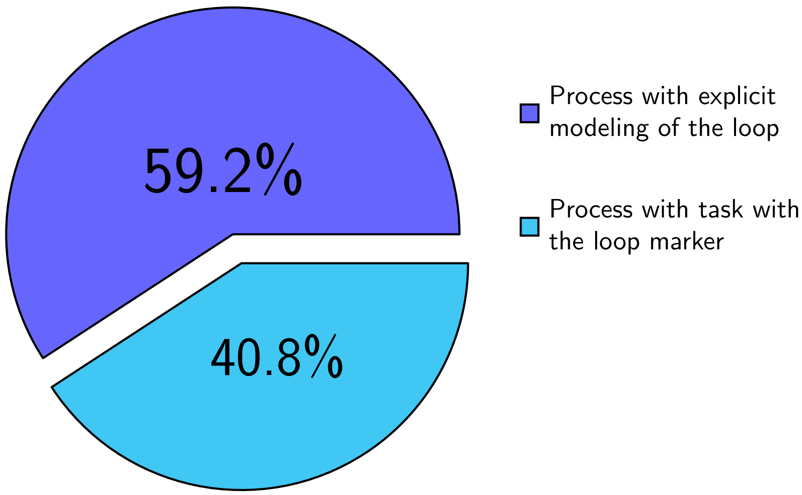


Figure 7: Answers to question 5.

6. **Do you know the meaning of the following BPMN element?**

BPMN Element

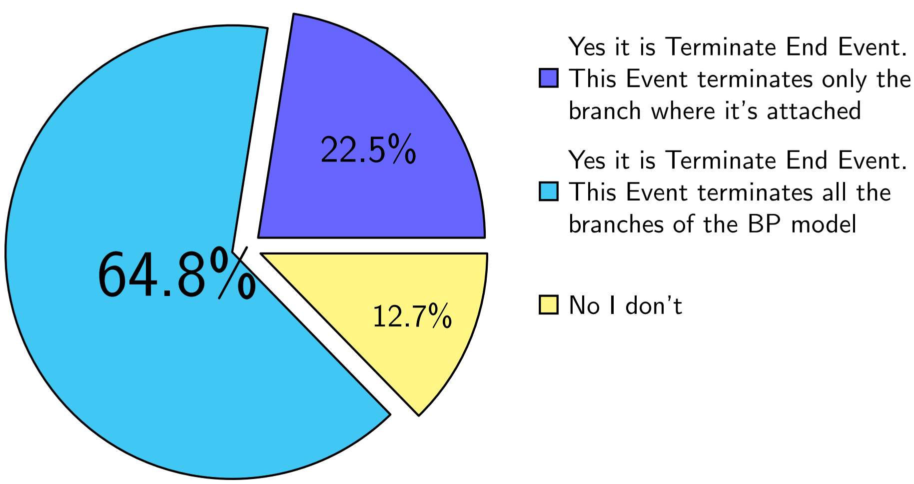
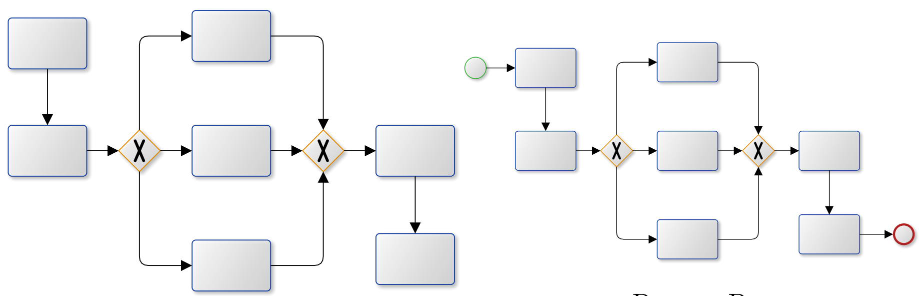


Figure 8: Answers to question 6.

7. **Observing the follow models, do you think that the explicit use of Start and End events improve the understandability of the model?**



Process A

Process B

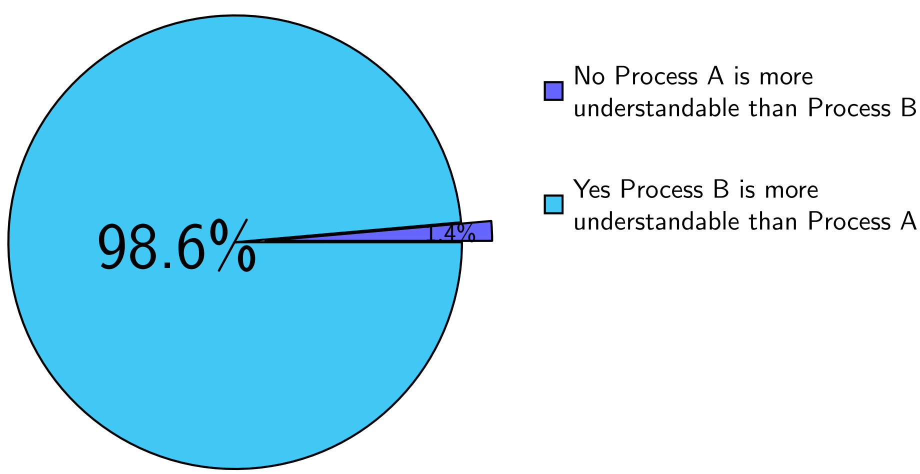


Figure 9: Answers to question 7.

8. **In order to make model easier to understand, if in a subprocess you have more than one message flow in the same direction, how many message flows do you show in the top-level process?**

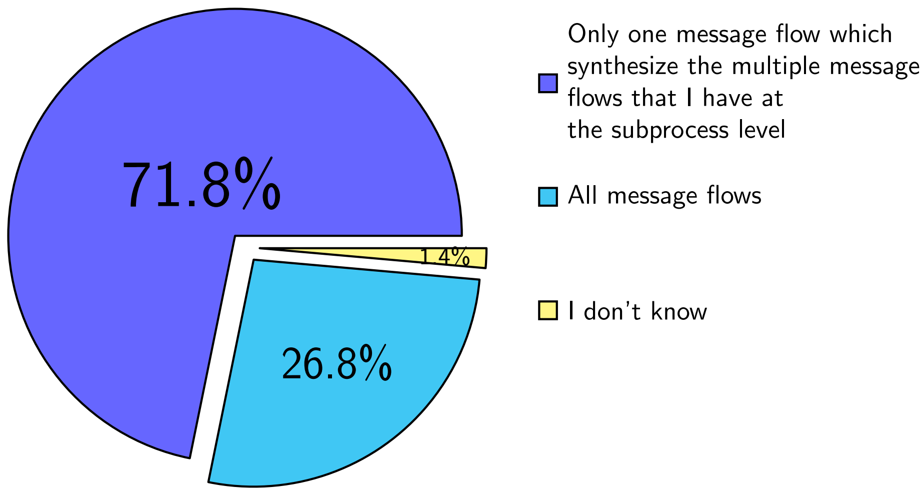


Figure 10: Answers to question 8.

9. **After an exclusive or inclusive gateway, do you think that the use the Default Flow improves the understandability of the model?**

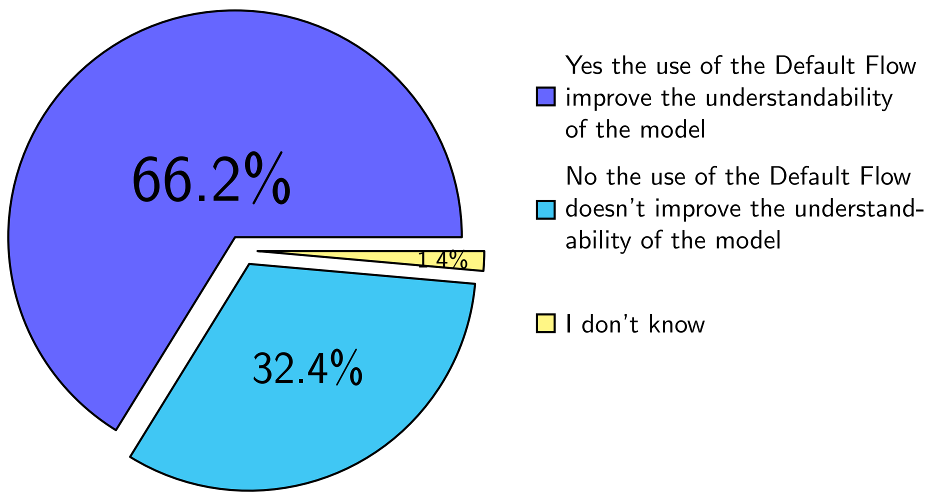
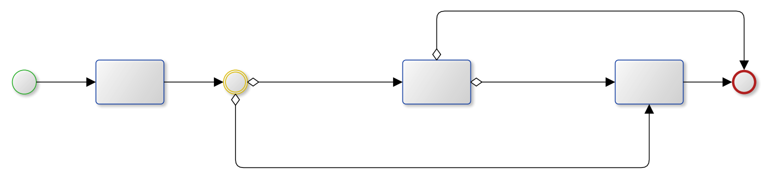
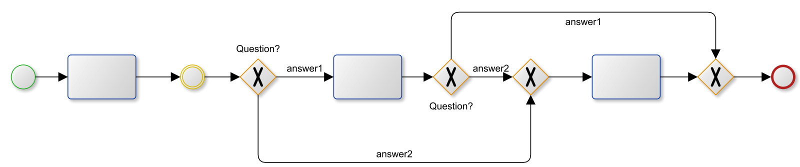


Figure 11: Answers to question 9.

10. **Which of the following BP model layouts do you find easier to understand?**



Process A



Process B

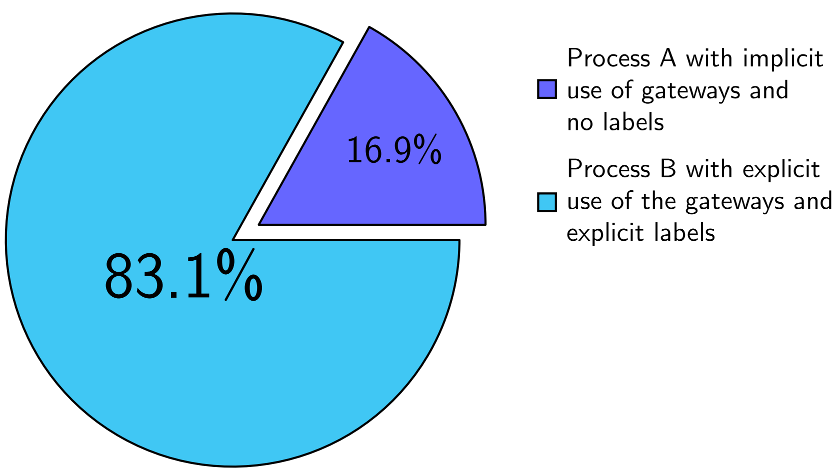
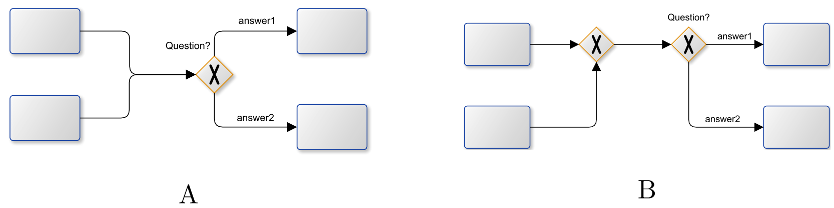


Figure 12: Answers to question 10.

11. **Which of the following BP model layouts do you find easier to understand?**



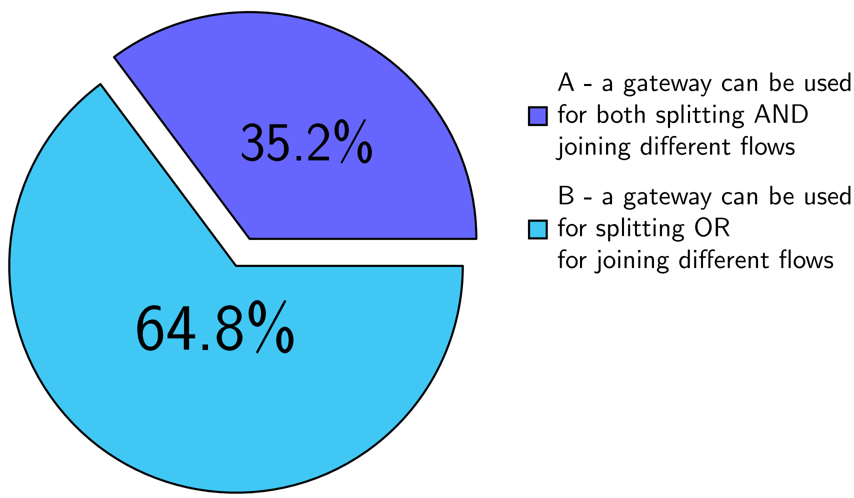


Figure 13: Answers to question 11.

12. **Observing the following Exclusive Gateway, do you think that the marker improves the understandability of the model?**

A

B

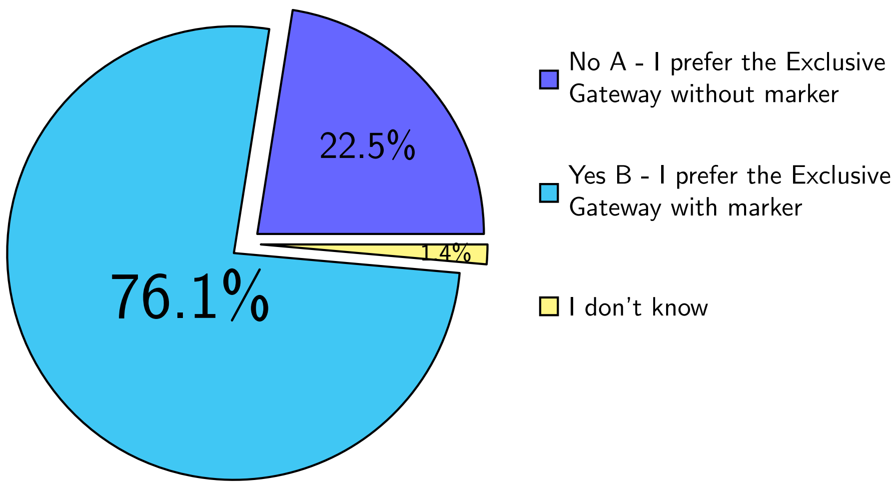


Figure 14: Answers to question 12.

13. **Do you know the meaning of the following BPMN element?**

Gateway

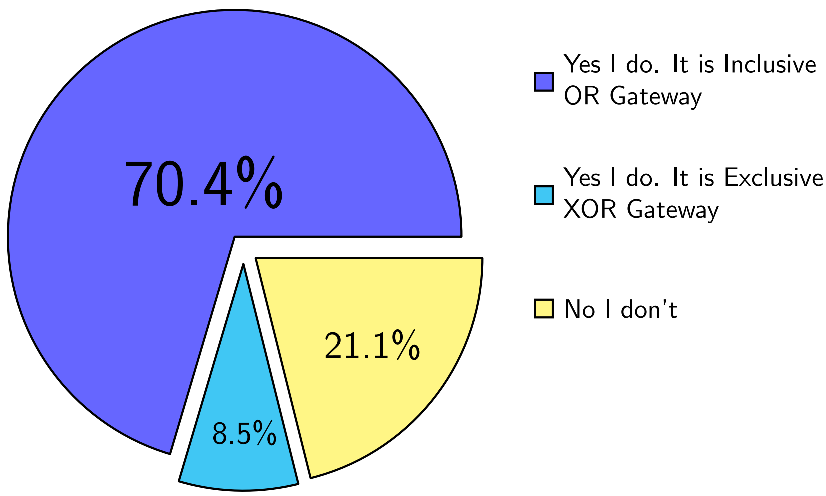
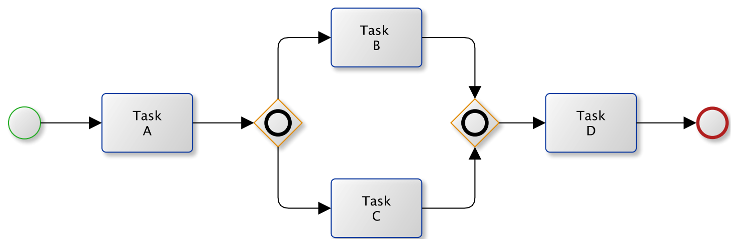


Figure 15: Answers to question 13.

14. **Which is the execution order of the activities in the model below?**



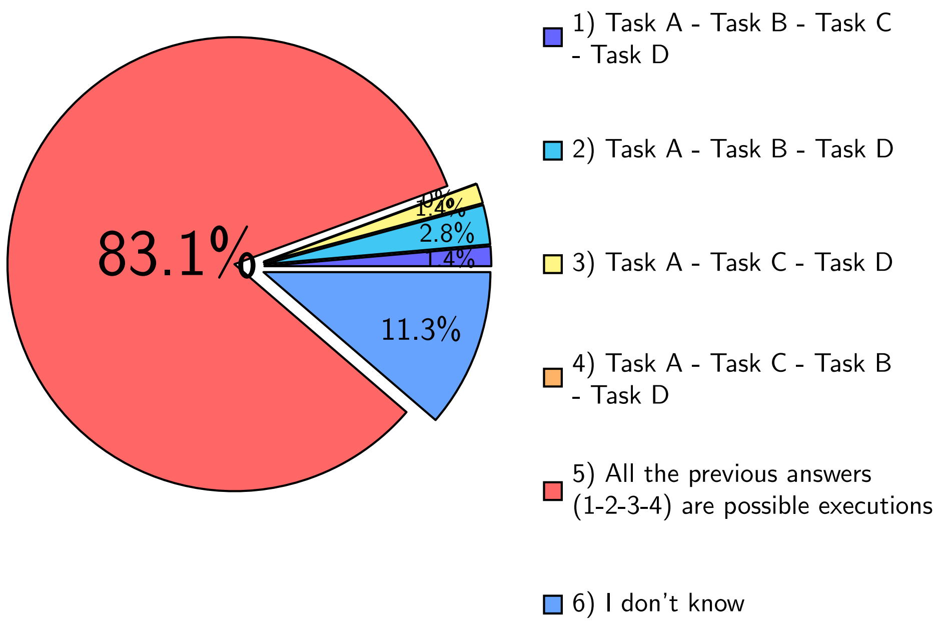


Figure 16: Answers to question 14.

15. **In order to make models easier to understand, do you think that an Activity Description should be associated with each Activity?**

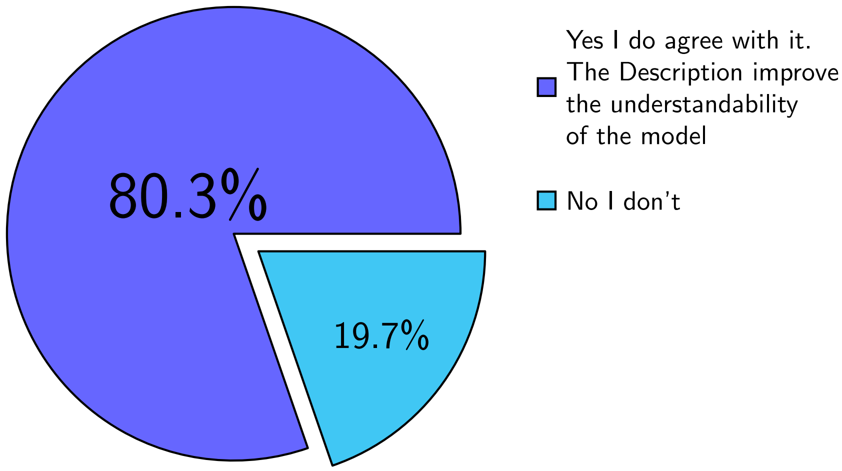


Figure 17: Answers to question 15.

16. **In order to make models easier to understand, matching the label of a subprocess end state with the label of a gateway immediately following the subprocess, do you think that allows to have a clear vision on how subprocess and process are linked together?**

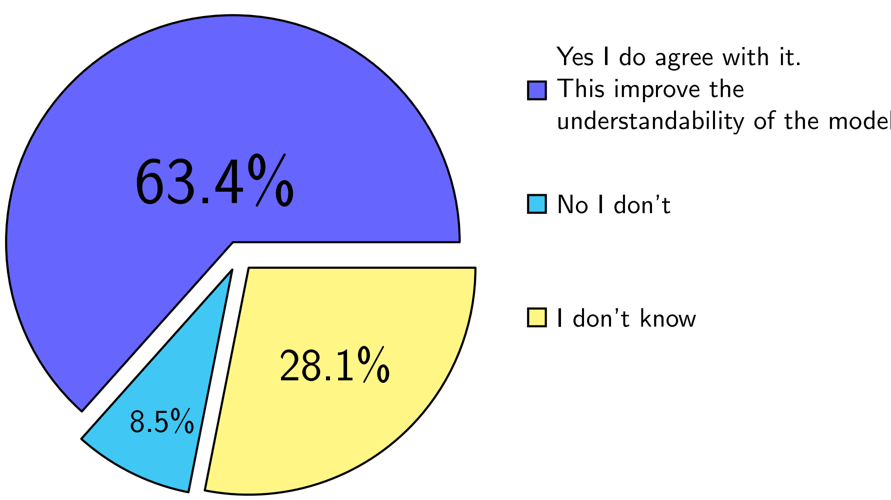
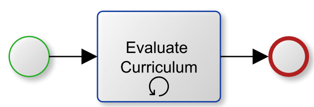
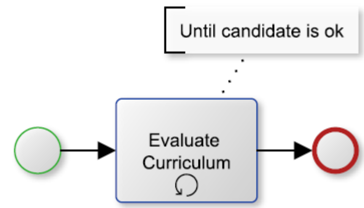


Figure 18: Answers to question 16.

17. **Which of the following BP model layouts do you find easier to understand?**



Process A



Process B

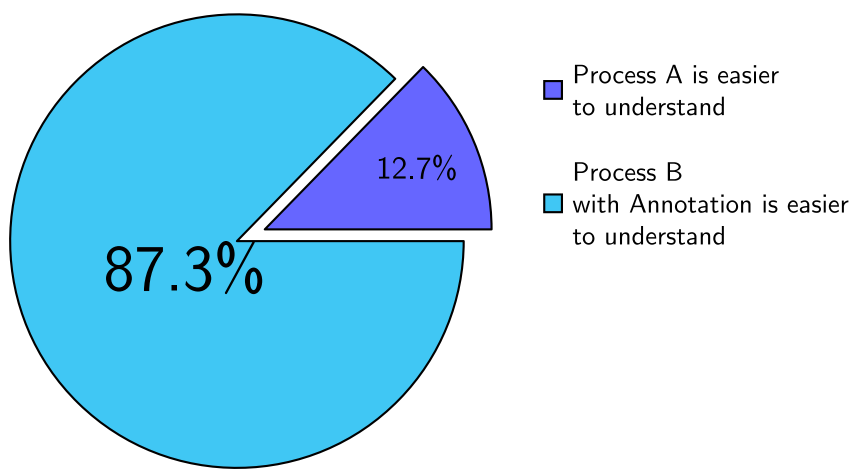
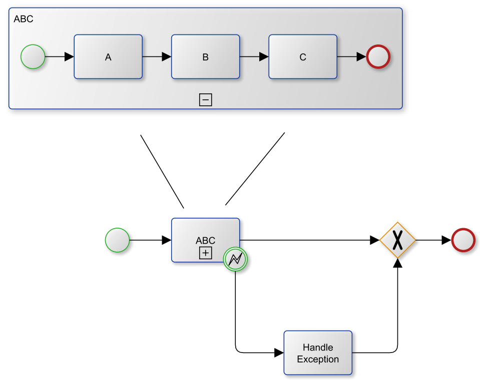
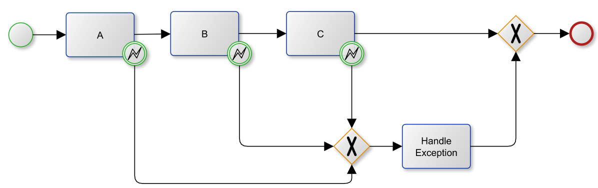


Figure 19: Answers to question 17.

18. **Which of the following BP model layouts do you find easier to understand?**



Process A



Process B

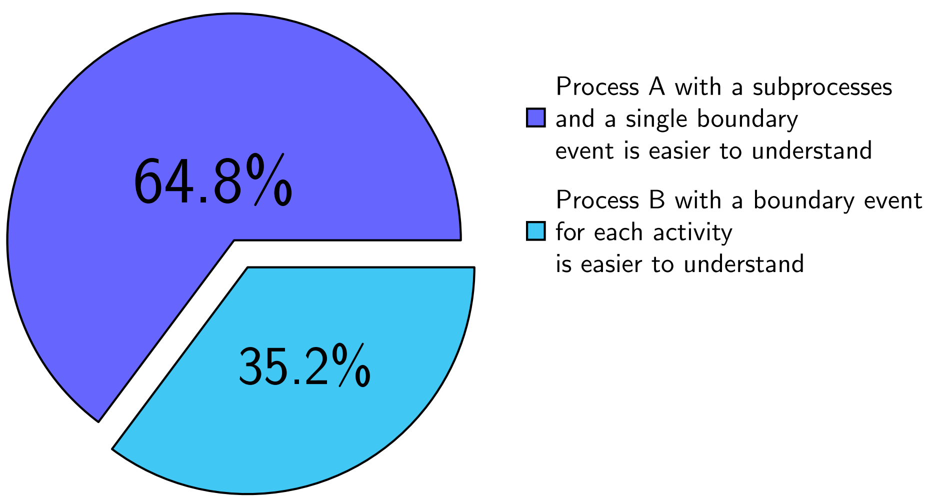


Figure 20: Answers to question 18.

19. **Which of the following BP model layouts do you find easier to understand?**

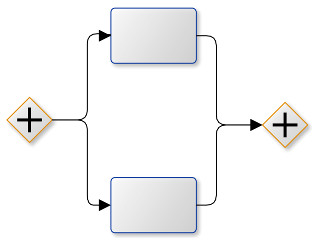


Figure A

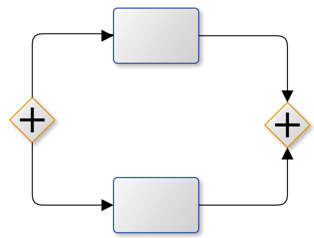


Figure B

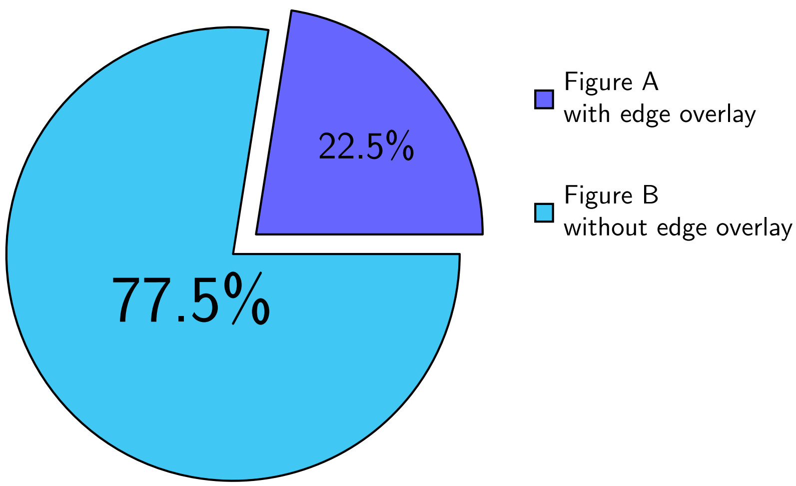
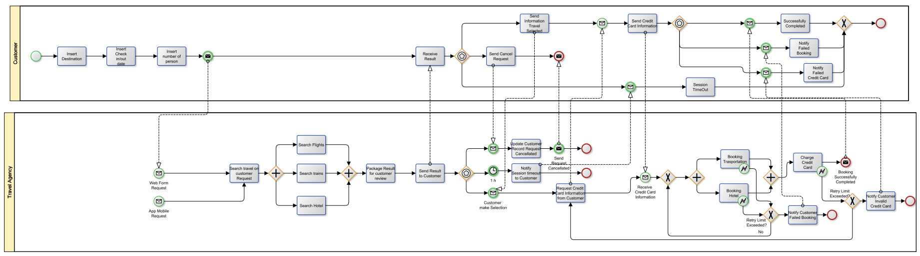
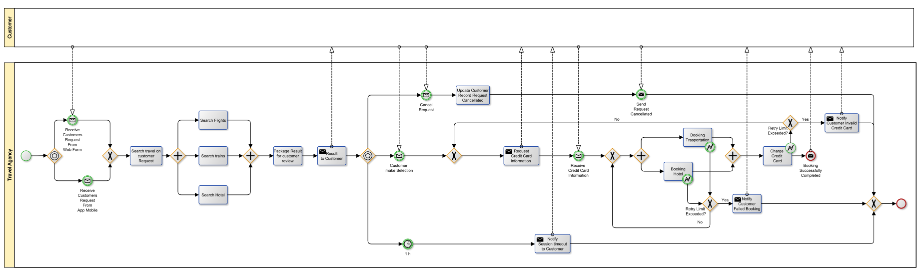


Figure 21: Answers to question 19.

20. **Which of the following BP model layouts do you find easier to understand?**



Model A



Model B

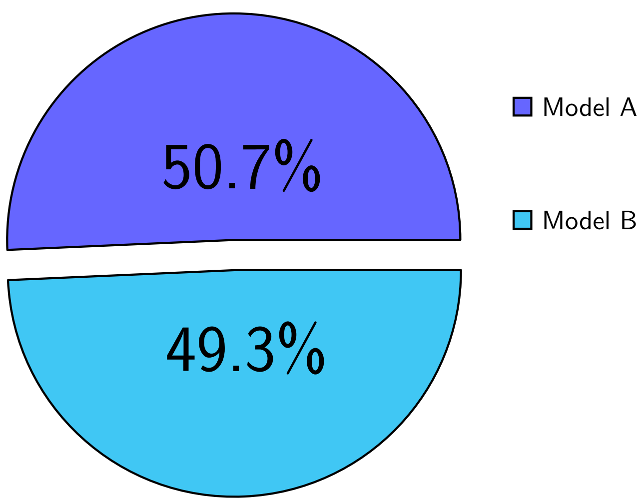
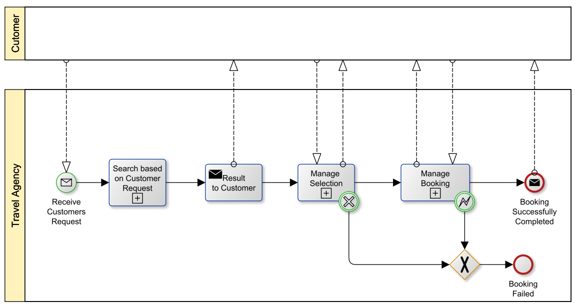
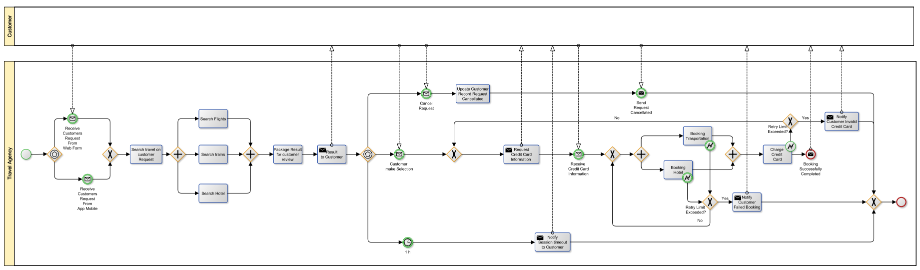


Figure 22: Answers to question 20.

21. **Which of the following BP model layouts do you find easier to understand?**



Model A



Model B

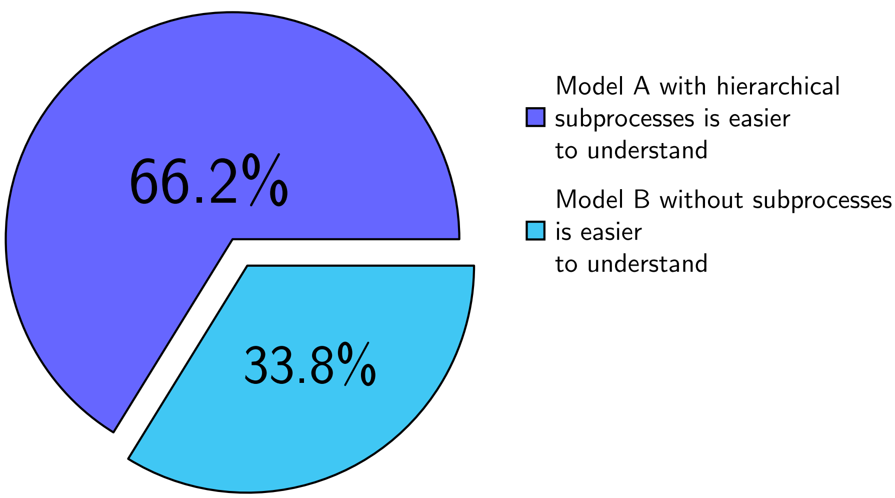


Figure 23: Answers to question 21.

5.2.3 Summary

We analysed the overall answers to the questionnaire and we came to the conclusion that the answers by different profiles are quite similar. Then we can assert that the user profile is not an indicator for the questionnaire answers. Moreover, the answers to the questionnaire comply with the vision that led us to the definition of the BPMN modelling guidelines. We consider this as a positive fact since the platform targets different users with different skills and knowledge. As a result we do not need to revise models depending on the platform target users. This result can be seen in the questions about the "Overall Models" (question 20 and 21).

Referring to the answers of question 20, we were expecting the interviewees to prefer Model B (after the application of some of our defined guidelines) over Model A (the original model) because of its reduced number of elements (Model A hides the process associated to the other pool). However we obtained nearly a fifty-fifty result which probably means that neither one or the other model is considered more understandable. This can be due to the fact that both the models are quite complex. This can be also due to the fact that during learning be aware of what is the internal behavior of all the participant can be useful for some of the target end-users.

A better result can be seen with the answers to question 21. Here in fact the interviewees preferred Model A over Model B (as we expected). Model A is the result of guidelines application and it is probably considered more understandable than Model B because of its reduced size. In particular, Model A highlights the usage of sub-processes to reduce the model size, which improves model understandability.

After this questionnaire we can confirm that the usage of the defined modelling guidelines leads to the design of understandable BPMN models.

6 Guidelines Automatic Verification: a Java based Tool

We carried out our work in the context of the Learn PAd project[9]. The project involves an innovative holistic e-learning platform that aims to enhance, in a PA context, the civil servants learning experience through the use of BP models. This platform enables process-driven learning and fosters cooperation and knowledge-sharing. In Learn PAd, we developed a quality assessment strategy that allows to guarantee that the used BP models result being understandable by the civil servants; for more details please refer to [60]. The knowledge shared in the Learn PAd platform contributes to train civil servants (learners).

The quality assessment strategy includes modelling understandability guidelines which are supported by a Java tool integrated with the platform, especially

[9] `http://www.learnpad.eu/`

with the Learn PAd Modelling Environment[10]. The Java tool helps the Modeller, to establish if a model complies with the guidelines. This component is a freely downloadable[11] plugin written in Java. The Tool reads a *.bpmn* file compliant with the OMG BPMN 2.0 standard and produces a XML file which describes the guidelines that are not met and the BPMN elements violating them. This component exposes also a *RESTful* interface for being used outside to the Learn PAd platform and it is also ready to be packaged as a WAR to be deployed on an Application Server like Tomcat. We also developed, for demostrability and reusability purposes, a basic web user interface to permit the access to the guidelines verification component[12]. The Tool allows to automatically verify 31 of the 50 guidelines; this 31 guidelines are the ones that have an associated threshold or refer to the presence/absence of BPMN elements, their associated labels and their appearance in the model. Each guideline applies to specific model elements. Therefore, the implemented algorithm navigates the model elements that are relevant and checks whether the elements comply to the guideline. For example, guideline (ID 12) "Explicit Start and End Events" applies to BPMN event elements. In this case, the algorithm navigates the whole set of events, to check that Start and End Events are included in the model.

7 Conclusion

In this Technical Report we described our contribution to the Learn PAd project. In particular we illustrated the Quality Assessment Strategy, we defined, for ensuring understandability and correctness of the Learn PAd platform contents. We focused especially on the definition of modelling guidelines for the design of understandable BP models used as input to populate the Learn PAd platform. We described the process that led us to the collection and the refinement of 50 modelling guidelines and the association of metrics and thresholds to some of them. In particular, for the metrics we provide in Appendix a list of the ones that apply to BP modelling. Then, we reported each guideline describing the meaning and providing, where possible, an example of bad and good guideline application. We modelled two scenarios included in the Learn PAd project (the SUAP and the EPBR) describing them ad showing how we applied our guidelines to improve the defined models. This, to provide understandable BP models to use as input for the Learn PAd platform. At the end we provided the procedure we followed to validate the guidelines, which involved a questionnaire submitted to Public Administration and Academic contexts, and the feedback of a group of expert for the EPBR scenario. From the result of the validation, we can conclude that models designed by following BP modelling guidelines result to be more understandable than the ones designed without following such guidelines.

[10] Learn PAd modelling environment, available at: `https://www.adoxx.org/live/web/learnpad-developer-space/learn-pad-modelling-environment`

[11] Guidelines verification component, available at: `https://goo.gl/hK33Ix`

[12] `http://understandability.isti.cnr.it`

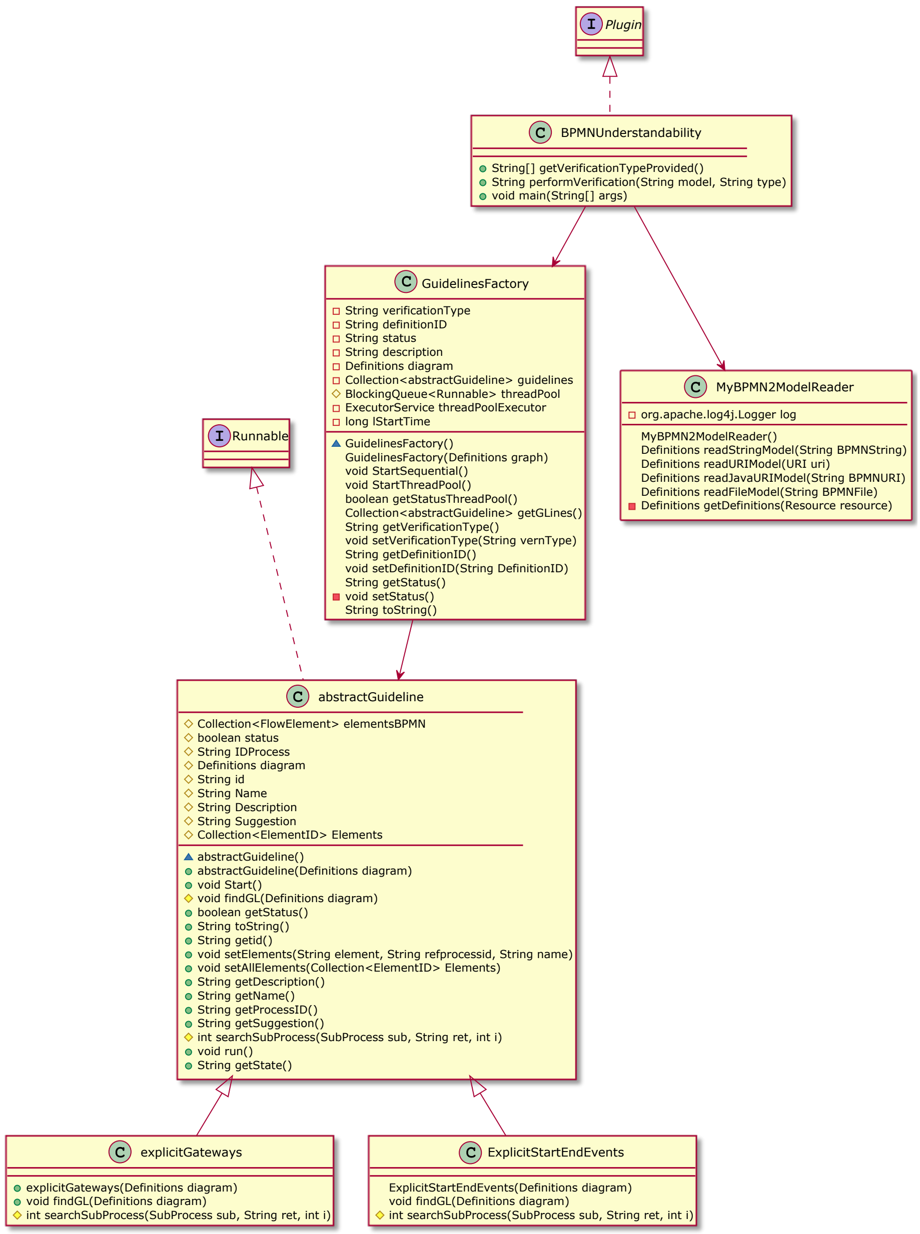


Figure 24: Class Diagram of the Tool

Acknowledgments

This research has been partially founded by EU project LearnPAd GA: 619583.

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Appendix A Business Process Model Metrics

NAME	DESCRIPTION	SOURCE	YEAR
NT	Number of tasks.	[12]	2006
NCD	Number of complex decision.	[12]	2006
NDOin/NDOout	Number of data objects which are input/outputs of activities.	[12]	2006
NID	Number of inclusive decision.	[12]	2006
NEDDB	Number of exclusive data-based decision.	[12]	2006
NEDEB	Number of exclusive event-based decision.	[12]	2006
NL	Number of lanes.	[12]	2006
NMF	Number of message flows.	[12]	2006
NP	Number of pools.	[12]	2006
NPF	Number of parallel forking.	[12]	2006
NSFA	Number of sequence flows between activities.	[12]	2006
NSFE	Number of sequence flows from events.	[12]	2006
NSFG	Number of sequence flows from gateways.	[12]	2006
...	...	[12]	2006
CLA	Connectivity level between activities. Total Number of Activities / Number of Sequence Flows between these Activities. $CLA = TNA/NSFA$	[12]	2006
CLP	Connectivity level between participants. $CLP = NMF/NP$	[12]	2006
PDOPin/PDOPout	Proportion of data objects as incoming/outgoing products and total data objects. $PDOPIn = NDOIn/TNDO$; $PDOPOut = NDOOut/TNDO$	[12]	2006
TNT	Total number of tasks. $TNT = NT + NTL + NTMI + NTC$	[12]	2006
PDOTout	Proportion of data objects as outgoing product of activities of the model. $PDOTOut = NDOOut/TNT$	[12]	2006
PLT	Proportion of pools/lanes and activities $PLT = NL/TNT$	[12]	2006
TNCS	Total number of collapsed subprocesses. $TNCS = NCS + NCSL + NCSMI + NCSC + NCSA$	[12]	2006
TNA	Total number of activities. $TNA = TNT + TNCS$	[12]	2006

Table 7: Business Process Model Complexity Metrics. Part 1.

NAME	DESCRIPTION	SOURCE	YEAR
TNDO	Total number of data objects in the model. $TNDO = NDOIn + NDOOut$	[12]	2006
TNG	Total number of gateways. $TNG = NEDDB + NEDEB + NID + NCD + NPF$	[12]	2006
TNEE	Total number of end events. $TNEE = NENE + NEMsE + NEEE + NECaE + NECoE + NELE + NEMuE + NETE$	[12]	2006
TNIE	Total number of intermediate events. $TNIE = NINE + NITE + NIMsE + NIEE + NICaE + NICoE + NIRE + NILE + NIMuE$	[12]	2006
TNSE	Total number of start events. $TNSE = NSNE + NSTE + NSMsE + NSRE + NSLE + NSMuE$	[12]	2006
TNE	Total number of events. $TNE = TNSE + TNIE + TNEE$	[12]	2006
CFC	Control-flow Complexity metric. It captures a weighted sum of all connectors that are used in a process model.	[61]	2005
NOA	Number of activities in a process.	[62]	2006
NOAC	Number of activities and control-flow elements in a process.	[62]	2006
NOAJS	Number of activities, joins, and splits in a process.	[62]	2006
HPC_D	Halsted-based Process Complexity (process difficulty).	[62]	2006
HPC_N	Halsted-based Process Complexity (process length).	[62]	2006
HPC_V	Halsted-based Process Complexity (process volume).	[62]	2006
NoI or Fan-in	Number of activity inputs. The fan-in of a procedure A is the number of local flows into procedure A plus the number of data structures from which procedure A retrieves information.	[62]	2006
NoO or Fan-out	Number of activity outputs. The fan-out of a procedure A is the number of local flows from procedure A plus the number of data structures which procedure A updates.	[62]	2006
Length	Activity length. The length is 1 if the activity is a black box; if it is a white box, the length can be calculated using traditional software engineering metrics that have been previously presented, namely the LOC (line of code) and MCC (McCabe's cyclomatic complexity).	[62]	2006

Table 8: Business Process Model Complexity Metrics. Part 2.

NAME	DESCRIPTION	SOURCE	YEAR
IC	Interface complexity of an activity metric. $IC = Length * (NoI * NoO)^2$, where the length of the activity can be calculated using traditional Software Engineering metrics such as LOC (1 if the activity source code is unknown) and NoI and NoO are the number of inputs and outputs.	[62]	2006
NOF	Number of control flow connections (number of arcs).	[62]	2006
TNSF	Total number of sequence flows.	[14]	2009
CC	Cross-connectivity metric. It is the ratio of the total number of arcs in a process model to the total number of its nodes.	[63]	2008
ICP	Imported Coupling of a Process metric. It counts, for each (sub-) process, the number of message/sequence flows sent by either the tasks of the (sub-) process or the (sub-) process itself.	[64]	2009
ECP	Exported Coupling of a Process metric. It counts, for each (sub-) process, the number of message/sequence flows received by either the tasks of the (sub-) process or the (sub-) process itself.	[64]	2009
W	Cognitive Weight. It measures the cognitive effort to understand a model; it can indicate that a model should be re-designed	[65]	2006
MaxND	Maximum Nesting Depth, where the nesting depth of an action is the number of decisions in the control flow that are necessary to perform this action.	[65]	2006
(Anti)Patterns for BPM	It counts the usage of anti-patterns. In a BP Model, it can help to detect poor modeling.	[65]	2006
CP	Coupling metric. The metric calculates the degree of coupling. Coupling is related to the number of interconnections among the tasks of a process model. The higher coupling value of the process, the more difficult it is to change the process and the higher probability that there will be errors in the process.	[66]	2004
Cohesion	Cohesion measures the coherence within the parts of the model.	[66]	2004
CNC	Coefficient of Network Complexity or Connectivity coefficient. It is the ratio of total number of arcs in a process model to its total number of nodes. It is calculated as: $CNC = NOF/NOAJS$.	[67]	2001

Table 9: Business Process Model Complexity Metrics. Part 3.

NAME	DESCRIPTION	SOURCE	YEAR
MeanND	Mean Nesting Depth, where the nesting depth of an action is the number of decisions in the control flow that are necessary to perform this action.	[65]	2006
CI	Complexity Index (CI), or reduction complexity. It is defined as the minimal number of node reductions that reduces the graph to a single node.	[67]	2001
RT	Restrictiveness Estimator. It is an estimator for the number of feasible sequences in a graph. RT requires the reachability matrix rij, i.e. the transitive closure of the adjacency matrix, to be calculated. $RT = \frac{2\sum r_{ij} - 6(N-1)}{(N-2)(N-3)}$	[67]	2001
S_N	Number of nodes: number of activities and routing elements in a process model.	[17]	2008
$\Pi(G))$	Separability. It is the ratio of the number of cut-vertices divided by the total number of nodes in the process model.	[17]	2008
$\Xi(G)$	Sequentiality. It is the degree to which the model is constructed out of pure sequences of tasks. The sequentiality ratio is the number of arcs between none- connector nodes divided by the number of arcs.	[17]	2008
diam	Diameter. It is the length of the longest path from a start node to an end node.	[17]	2008
$\wedge$	Depth. It is the maximum nesting of structured blocks in a process model.	[17]	2008
GM or MM	Gateway Mismatch or Connector Mismatch. It is the sum of gateway pairs that do not match with each other, e.g. when an AND-split is followed up by an OR-join.	[17]	2008
GH or CH	Gateway Heterogeneity or Connector Heterogeneity. It defines the extent to which different types of connectors are used in a process model.	[17]	2008
Φ	Structuredness. It relates to how far a process model can be built by nesting blocks of matching join and split connectors. The degree of structuredness can be determined by applying reduction rules and comparing the size of the reduced model to the original size.	[17]	2008
CYC	Cyclicity. It captures the number of nodes in a cycle and relates it to the total number of nodes	[17]	2008

Table 10: Business Process Model Complexity Metrics. Part 4.

NAME	DESCRIPTION	SOURCE	YEAR
TS or Concurrency	Token Splits or Concurrency. It captures the maximum number of paths in a process model that may be concurrently activate due to AND-splits and OR-splits; it sums up the output-degree of AND-joins and OR- joins minus one.	[17]	2008
$\Delta(G)$	Density. It is the ratio of the total number of arcs in a process model to the theoretically maximum number of arcs.	[17]	2008
ACD or AGD	Average Connector Degree or Average Gateway Degree. It is the average of the number of both incoming and outgoing arcs of the gateway nodes in the process model.	[6]	2007
MCD or MGD	Maximum Degree of a Connector or Maximum Gateway Degree. It is the maximum sum of incoming and outgoing arcs of these gateway nodes.	[6]	2007
ECaM	Extended Cardoso Metric. It is a Petri net version of metric that generalizes and improves the original CFC metric proposed by Cardoso. It focuses on the syntax of the model and ignores the complexity of the behavior.	[68]	2009
ECyM	Extended Cyclomatic Metric. It is directly adapted from McCabe Cyclomatic. It focuses on the resulting behavior and ignore the complexity of the model.	[68]	2009
SM	Structuredness Metric. It recognizes different kinds of structures in the process model and scores each structure by giving it some penalty value. The sum of these values is the Structuredness Metric (SM).	[68]	2009
DSM	Durfee Square Metric. It is based on h-index. It equals d if there are d types of elements which occur at least d times in the model (each), and the other types occur no more than d times (each)	[20]	2012
PSM	Perfect Square Metric. It is based on the g-index. Given a set of element types ranked in decreasing order of the number of their instances, the PSM is the (unique) largest number such that the top p types occur (togheter) at least p^2 times.	[20]	2012
Layout complexity	It evaluates the usability of different screen designs based on the Shannon formula.	[69]	1993
Layout appropriatness	It is the efficiency of a screen in terms of cost involved in completing a collection of tasks.	[70]	1996
Layout measure	It is a group of measures that quantify layout of models: number of edge crossing, number of non-rectilinear edges, overlapping area, etc.	[71]	2009

Table 11: Business Process Model Complexity Metrics. Part 5.