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Research Report

Risk Extensions to the BPMN 1.1 Business Process Metamodel

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Introduction

Business process models have become a ubiquitous tool for documenting, designing, and managing the core functions of an enterprise. The range of information that can be represented in process modeling software toolkits has steadily expanded beyond simple workflow representations to include information regarding process objectives and measures of process performance, oversight and control policies, and supporting resources. By representing these concepts in a standardized framework, business process models provide managers with insight and a common language to describe how their businesses operate and how they provide value to their customers and stakeholders.

Business process models are also seen as an integral tool for corporate governance and risk management. For many companies, process modeling has also become a legal requirement after the passage of regulatory legislation such as the Sarbanes-Oxley (SOX) Act. Such laws were passed in the wake of the accounting scandals and financial industry crises of the early 2000's, with a primary aim of ensuring that companies would enact the proper controls to reduce their operational risks. Other regulations, such as the Basel II accords, additionally require firms to measure and hold reserves against their operational risk exposures.

Currently, however, most risk management and quantification techniques are only loosely coupled with process modeling. Risk management techniques such as Failure Mode and Effect Analysis (FMEA) use business process models as a starting point for identifying and locating possible risk exposures, but do not document the risks themselves in the process models, or use the process model relations explicitly in quantifying risks. To date, there have been few efforts made to formally integrate risk management concepts into a standard business process metamodel. For example, no standardized notation has emerged to express such notions as failure modes of resources, root cause events, and sources of execution failure and low job output quality directly in the context of process models.

This paper attempts to remedy this situation by defining a set of metamodel extensions to standard process modeling languages that incorporate risk information directly in the process model. In particular, we shall define a set of extensions to the BPMN 1.1 process modeling specification standard (OMG, 2008). This report contains only the technical specification of the BPMN metamodel extensions. A fuller description of the definitions and use of these extensions, including graphical notation, connections to the existing literature, and a method for constructing risk-extended process models, can be found in Cope et. al. (2009), to which this report serves as an appendix.

Risk Extensions to the BPMN 1.1 Specification

This section formally adds attribute extensions and modifications to the execution semantics of BPMN version 1.1. The tables listing the attribute extensions to the BPMN classes reference in their header captions the table numbers (of the form B.xx) of the attribute tables that they extend, as they appear in Appendix B of OMG (2008). We only include the extensions to the existing BPMN model elements, and refer the reader to OMG (2008) for the full statement of the BPMN model.

1 Business Process Diagram Attributes

We remove the attribute "Pools" and add the following attributes:

Table 1: Business Process Diagram Attribute Extensions (B.1)

Attributes	**Description**
Jobs (1-n): Job	A BPD SHALL allow one or more types of jobs to be processed. See Table 14 for details on the class Job.
MitigationActions (0-n): MitigationActions	A BPD MAY allow mitigations actions to be specified which determine variants of the process and supporting artifacts. See Table 12 for details on the class MitigationAction.
BPDElementSets (1-n): BPDElementSet	The element sets define, for each job, a set of pools, artifacts, and connecting object elements. These elements define the processes, resources, environmental factors, mitigation actions, performance measures, risk events that make up the business process diagram for a particular job type, as well as the connectors that link these objects. See Table 29 for more details on the class BPDElementSet.
AssignmentRules (1-n): Expression	The assignment rules attribute is an expression that specifies for each job and mitigation action a corresponding BPD Element Set.

2 Process Attributes

We remove the attribute "GraphicalElements" and add the following attributes:

3 State Diagram Attributes

State Diagrams are extensions to BPMN and are classed as "supporting elements."

Table 2: Process Attribute Extensions (B.3)

Attributes	**Description**
GraphicalElementSets (1-n): GraphicalElementSet	A graphical element set identifies a group of graphical elements that define a process or process variant. Each set is correlated with one or more procedural errors. See Table 27 below for more details on GraphicalElementSets.
AssignmentRules (1-n): Expression	The assignment rules attribute is an expression that specifies for each procedural error a corresponding GraphicalElementSet.

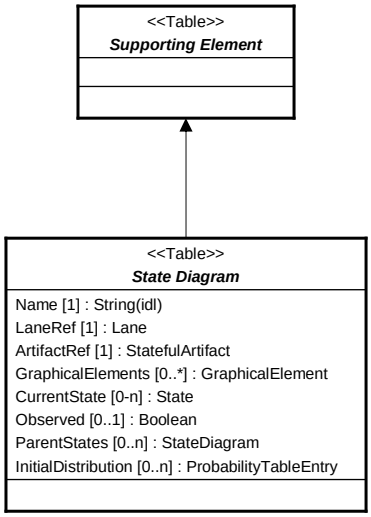

Figure 1: State Diagram Attributes.

Table 3: State Diagram Attributes (New)

Attributes	**Description**
Name : String	Name is an attribute that is a text description of a resource.
LaneRef : Lane	LaneRef provides a reference for the lane in which the state diagram is to be represented.
ArtifactRef : StatefulArtifact	ArtifactRef refers to the artifact to which the state diagram belongs.
GraphicalElements (0-n): GraphicalElement	The GraphicalElements attribute identifies all of the objects (e.g., States, State Transitions) that are contained within the State Diagram.
CurrentState (0-n): State	The CurrentState attribute references the current state of the state diagram.
Observed (0-1): Boolean	The Observed attribute is set to TRUE if the current state of the artifact has been observed, and FALSE if the current state is not known.
ParentStates (0-n): StateDiagram	The ParentStates attribute references any state diagrams (state variables) of stateful artifacts that may influence the initial probability distribution of the initial state assignment to be made in the preprocessing phase. The relationship graph of stateful artifacts and their parents MUST form a directed acyclic graph.
InitialDistribution (0-n): ProbabilityTableEntry	The InitialDistribution is a table that specifies, for each configuration of parent states, what the probability distribution from which to draw the initial state of the state diagram is to be during the preprocessing phase. For each configuration of parent states, the sum of the probabilities over states of the artifact MUST sum to one.

4 States

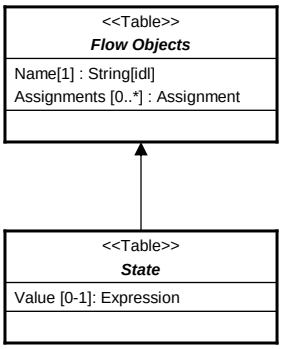

Figure 2: State Attributes.

Table 4: State Attributes (New)

Attributes	**Description**
Value (0-1) : Expression	The Value attribute MAY be used to record the state value, in the case of quantitative state levels. Qualitative state levels on the other hand are simply distinguished by the state name, and a separate state object is assigned for each qualitative level.

5 Events

We extend the class of events by defining three new subclasses: "Risk Event," "State Change Event," and "Inspection Event." Figure 3 depicts how these new elements fit within the existing BPMN class diagram:

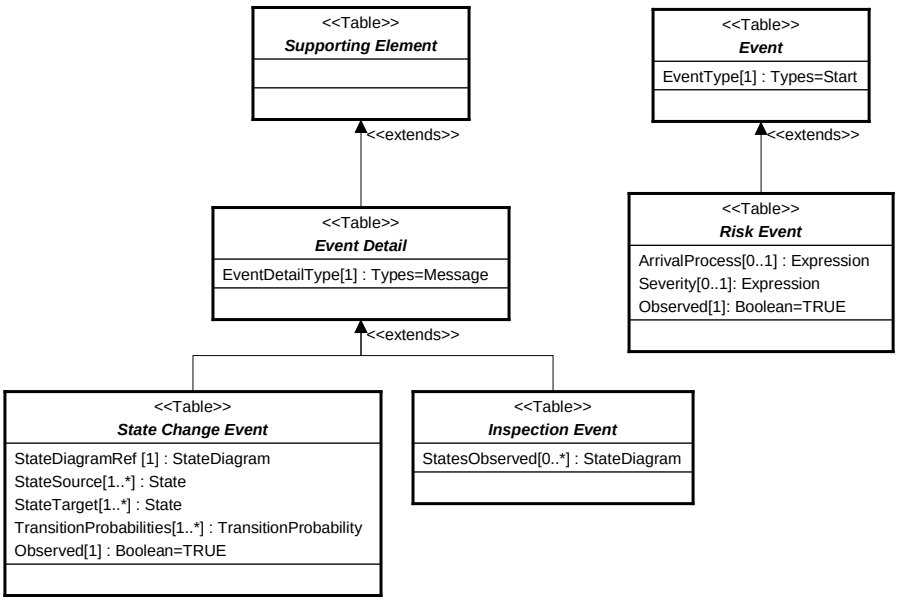

Figure 3: Extensions of the BPMN Event Elements and Attributes.

5.1 Common Event Attributes

We remove the attribute "EventType" and replace it with the following attribute:

Table 5: Common Event Attribute Extensions (B.5)

Attributes	**Description**
EventType (Start|End|Intermediate|Risk) Start: String	The event type MUST be of type Start, End, Intermediate, or Risk.

5.2 Risk Event

Table 6: Risk Event Attributes (New)

Attributes	**Description**
ArrivalProcess (0-1): Expression	The arrival process attribute expression indicates the frequency of occurrence of the risk event.
Severity : Expression	The severity attribute expression provides an indication, where appropriate, of the severity of a given risk occurrence.
Observed True: Boolean	The Observed attribute indicates whether the occurrence of a risk event is known.

5.3 State Change Event

Table 7: State Change Event Attributes (New)

Attributes	Description
StateDiagramRef : StateDiagram	The StateDiagramRef attribute refers to the state diagram whose states are to undergo transition in the event.
StateSource (1-n): State	The StateSource attribute indicates which state(s) of the target artifact that will change under the state change event. At least one StateSource MUST be defined.
StateTarget (1-n): State	The StateTarget attribute indicates the states to which the target artifact may change as a result of the state change event. At least one StateTarget MUST be defined.
TransitionProbabilities (1-n): TransitionProbability	A TransitionProbability MUST be defined for each State-Source and StateTarget pair. The probabilities for all State-Targets for a given StateSource must sum to one.
StatesObserved (0-n) True: Boolean	The Observed attribute indicates which of the resulting states of the target artifact will be observed.

5.4 Inspection Event

Table 8: Inspection Event Attributes (New)

Attributes	Description
StatesObserved (0-n):	The StatesObserved attribute indicates the state diagram whose current state is observed in the inspection event.

6 Activities

6.1 Common Activity Attributes

We modify the specification of the attribute "IORules" to allow the rules to map each input set and a set of execution errors to an output set. That is, if the activity is instantiated with a specified input and a set of execution errors, the activity shall complete with the specified output. Note that the output sets include artifacts whose states may be random, where the probability distribution governing the state of the output artifact can be dependent on the set of occurring execution errors.

Table 9: Common Activity Attribute Extensions (B.9)

Attributes	Description
FlowObjectErrorRef (0-n): FlowObjectError	A set of Flow Object Errors MAY be specified for each activity to document procedural, precondition, or execution errors. See Table 19 for more details on the FlowObjectError class.

7 Gateways

7.1 Common Gateway Attributes

We remove the Gates attribute of this class and replace it with the following attribute:

Table 10: Common Gateway Attribute Extensions (B.23)

Attributes	Description
GateSets (1-n): GateSet	A GateSet is a set of gates that may be associated with a gateway. Each GateSet represents a gateway variant that may arise as a result of procedural errors. (See also Table 28 for more on GateSets.)

8 Artifacts

We extend the class of artifacts by defining two new subclasses,"mitigation actions" and "stateful artifacts." The latter subclass has four further subclasses: "Resource," "Environmental Factor," "Job," and "Performance Measure." Figure 4 depicts how these new elements fit within the existing BPMN class diagram:

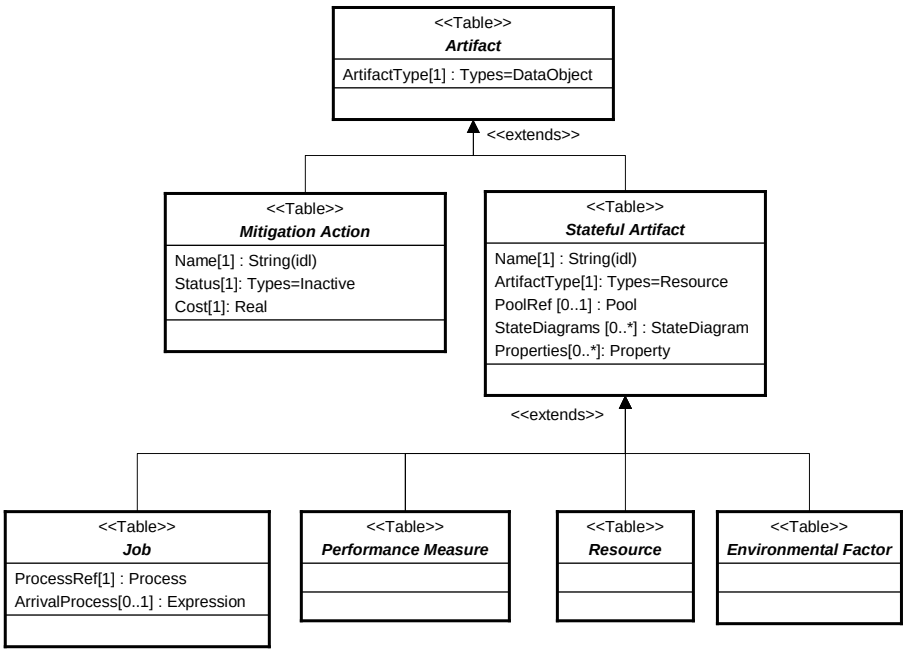

Figure 4: Extensions of the BPMN Artifact Elements and Attributes.

8.1 Common Artifact Attributes

We remove the entry for ArtifactType and replace it with the following attribute:

Table 11: Common Artifact Attribute Extensions (B.31)

Attributes	Description
ArtifactType (DataObject |Group |Annotation |Stateful |Mitigation) DataObject: String	The ArtifactType MAY be set to DataObject, Group, Annotation, Stateful, or Mitigation. The ArtifactType list MAY be extended to include new types.

8.2 Mitigation Action Attributes

Table 12: Mitigation Action Attributes (New)

Attributes	Description
Name : String	Name is an attribute that is a text description of a mitigation action.
Status (Active |Inactive)	The status of a mitigation action MUST be set to either Active or Inactive.
Cost : Real	The attribute Cost refers to the implementation cost of a mitigation action.

8.3 Stateful Artifact Attributes

Table 13: Stateful Artifact Attributes (New)

Attributes	Description
Name : String	Name is an attribute that is a text description of a resource.
ArtifactType (Resource |Job |Environmental Factor |Performance Measure) Resource: String	The ArtifactType MAY be set to Resource, Job, Environmental Factor, or Performance Measure. The ArtifactType list MAY be extended to include new types.
PoolRef (0-1): Pool	The attribute PoolRef MAY refer to a pool containing the state diagram for the states of the resource.
StateDiagrams (0-n): StateDiagram	The StateDiagrams attribute lists the state diagrams associated with the artifact.
Properties (0-n): Property	Properties of an artifact indicate details of the artifact type, which allow it to be associated with other artifacts and with risk events.

8.4 Job

Table 14: Job Attributes (New)

Attributes	Description
ProcessRef : Process	The ProcessRef attribute refers to the process which is required to service the job.
ArrivalProcess (0-1) : Expression	The ArrivalProcess attribute MAY be used to indicate a stochastic process or other mechanism that determines when job arrivals occur.

8.5 Performance Measure, Resource, Environmental Factor

No new attributes are added for these three subclasses of Stateful Artifacts, beyond what has already been described above in Table 13.

9 Graphical Connecting Objects

We extend the class of graphical connecting objects by defining a new subclass, "State Transition," as well as four new types of associations: "Can Affect, " "Can Cause," "Inspects," and "Modifies." Figure 5 depicts how these new elements fit within the existing BPMN class diagram:

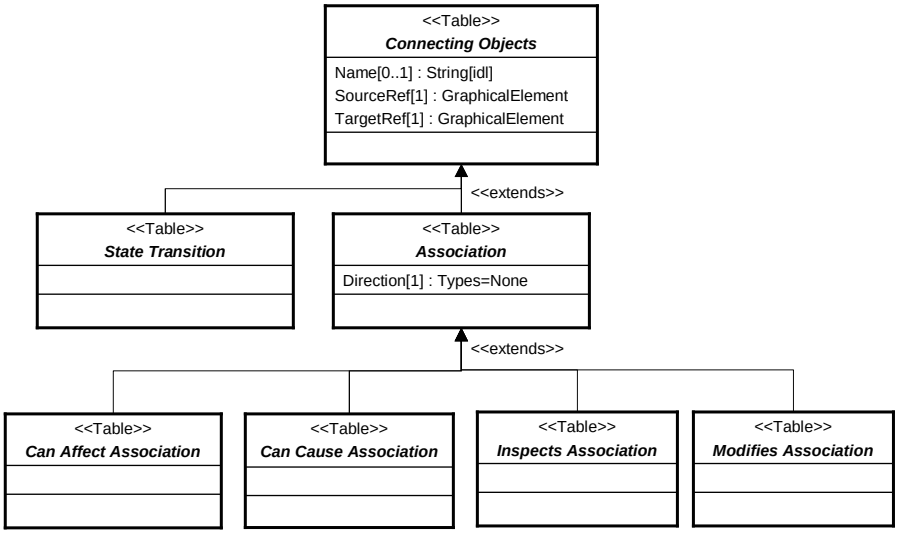

Figure 5: Extensions of the BPMN Connecting Object Elements and Attributes.

9.1 State Transition Relation

No new attributes are required for the StateTransition relation. The SourceRef and TargetRef attribute may include only States.

9.2 Can Affect Relation

No new attributes are required for the Can Affect relation. We note that the Direction attribute MUST be set to One. The SourceRef attribute may include only the following element types: Risk Event, Resource, Environmental Factor, Activity, and Job. The TargetRef may include only

the following element types: Resource, Environmental Factor, Activity, Job, and Performance Measure.

9.3 Can Cause Relation

No new attributes are required for the Can Cause relation. We note that the Direction attribute MUST be set to One. The SourceRef and TargetRef attribute may include any Event; additionally, an Activity may be a SourceRef.

9.4 Inspects Relation

No new attributes are required for the Can Cause relation. We note that the Direction attribute MUST be set to One. The SourceRef may include only Activities, Gateways, and Inspection Events. The TargetRef may include only swimlanes containing state diagrams of stateful artifacts.

9.5 Modifies Relation

No new attributes are required for the Modifies relation. We note that the Direction attribute MUST be set to One. The SourceRef may include only Mitigation Actions. The TargetRef may include only the following element types: Risk Event, Resource, Environmental Factor, Activity, Job, and Performance Measure.

10 Supporting Elements

We extend the class of supporting elements by defining nine new subclasses: Figure 6 depicts how these new elements fit within the existing BPMN class diagram:

10.1 Artifact Input

Table 15: Artifact Input Attribute Extensions (B.39)

Attributes	Description
RequiredStates (0-n): String	The RequiredStates attribute specifies the set of acceptable states of the artifact to be in in order for activity execution to begin. Absence of any RequiredStates indicates that all states are acceptable.

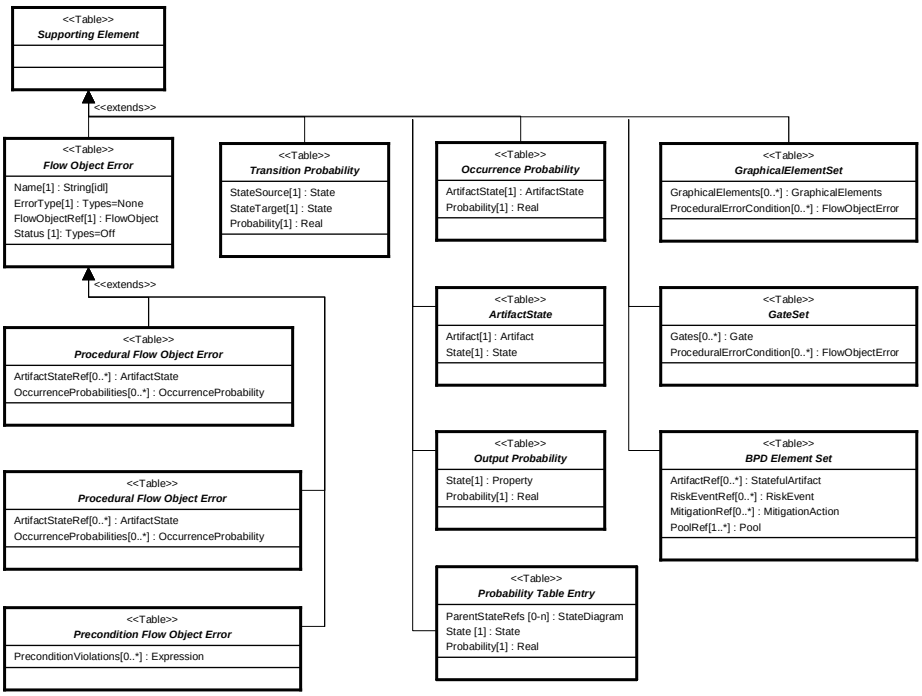

Figure 6: Extensions of the BPMN Supporting Elements and Attributes.

10.2 Artifact Output

Table 16: Artifact Output Attribute Extensions (B.40)

Attributes	**Description**
OutputStates (0-n): String	The OutputState attribute indicates the state of the artifact upon completion of the activity.
OutputProbabilities (0-n): OutputProbability	Output probabilities SHALL be specified for each of the OutputStates attributes. These probablities must sum to one. See Table 25 for more details on the OutputProbability class.

10.3 Event Details

We only extend the subclass of Error Event Details.

Table 17: Error Event Details Attribute Extensions (B.48)

Attributes	**Description**
FlowObjectErrorRef (0-n): FlowObjectError	The FlowObjectErrorRef attribute MAY reference one or more Flow Object Errors that give rise to the error event. See Table 19 for more details on the FlowObjectError class.

Table 18: Artifact Input Attribute Extensions (B.55)

Attributes	**Description**
ErrorCondition (0-n): FlowObjectError	The ErrorCondition attribute MAY reference one or more FlowObjectErrors which condition the input set on the occurrence of a procedural error. The FlowObjectError MUST be of the type "Procedural." See Table 19 for more details on the FlowObjectError class.

Table 19: Flow Object Error Attributes (New)

Attributes	**Description**
Name 1: String	Name is an attribute that is a text description of the object.
ErrorType (Procedural|Execution|Precondition): String	The error type is an attribute that provides information about whether it represents a procedural error, an execution error, or a precondition error.
FlowObjectRef 1: FlowObject	The Flow Object Reference attribute indicates the Flow Object that is affected by this error. These MUST be of the type Activity or Gateway.
Status (On|Off) Off: String	The error status is an indicator, set during the preprocessing phase of the activity, of whether the error occurs or not (corresponding to "On" and "Off," respectively). The default value is Off.

10.4 Input Set

10.5 Flow Object Errors

Procedural or Execution Flow Object Errors

The following are additional attributes of a Procedural or an Execution Flow Object Error (where the ErrorType is set to "Procedural" or "Execution.")

Precondition Flow Object Errors

The following are additional attributes of a Precondition Flow Object Error (where the ErrorType is set to "Precondition.")

Table 20: Procedural or Execution Flow Object Error Attributes (New)

Attributes	**Description**
ArtifactStateRef (0-n): ArtifactState	The ArtifactStateRef attribute represents a pairing of an artifact and the value of a state of the artifact. See Table 24 for more details on the ArtifactState class.
OccurrenceProbabilities (0-n): OccurrenceProbability	The OccurrenceProbability attribute determines the likelihood that a given procedural or Execution Flow Object Error occurs during the execution of an activity, given the state values of the artifacts referenced in ArtifactStateRef. See Table 23 for more details on the OccurrenceProbability class.

Table 21: Precondition Flow Object Error Attributes (New)

Attributes	**Description**
PreconditionViolations (0-n): Expression	The PreconditionViolations attribute MAY contain one or more expressions that describe the nature of a precondition violation, namely which states of which artifacts are not in compliance with the requirements.

10.6 Transition Probabilities

Table 22: Transition Probability Attributes (New)

Attributes	**Description**
StateSource : State	This attribute specifies the current state of the artifact (which is to be changed in a state change event.)
StateTarget : State	This attribute specifies the transitional state of the artifact (to which the state will change in a state change event.)
Probability : Real	Probabilities represent the likelihood of changing to the state target given the state source. set, given an input set and a set of flow object errors. They are real numbers between 0 and 1.

10.7 Occurrence Probabilities

Table 23: Occurrence Probability Attributes (New)

Attributes	**Description**
ArtifactState : ArtifactState	The ArtifactState attribute MUST reference an Artifact-State Pair. See Table 24 for more details on the Artifact-State class.
Probability : Real	The Probability attribute determines the likelihood that a given procedural or Execution Flow Object Error occurs during the execution of an activity. It is a real number between 0 and 1.

10.8 Artifact-State Pairs

Table 24: ArtifactState Attributes (New)

Attributes	**Description**
Artifact : Artifact	The Artifact attribute MUST reference an Artifact.
State : State	The State attribute MUST reference a state that is an element of the state diagram of the artifact.

10.9 Output Probabilities

Table 25: Output Probability Attributes (New)

Attributes	**Description**
State : Property	The output set references the state of an attribute that is output at the end of an activity. There MUST be a State specified for each state of the artifact.
Probability : Real	Probabilities represent the likelihood of returning the artifact output in a given state. They are real numbers between 0 and 1.

10.10 Probability Table Entry

Table 26: Probability Table Entry Attributes (New)

Attributes	**Description**
ParentStateRefs (0-n): StateDiagram	The ParentStateRefs attribute refers to all the state diagrams of the "parent" artifacts, whose current state values influence the probability that the child artifact is initialized in a given state.
State : State	The State attribute refers to a state or state value of the artifact which may be an initial state of the artifact.
Probability : Real	Probabilities represent the likelihood of the artifact being initialized in a given state. They are real numbers between 0 and 1.

10.11 Graphical Element Sets

Table 27: Graphical Element Set Attributes (New)

Attributes	Description
GraphicalElements (0-n): GraphicalElements	The GraphicalElements attribute identifies all of the objects (Events, Activities, Gateways, Artifacts, etc.) that are contained within a Process.
ProceduralErrorCondition (0-n): FlowObjectError	The ProceduralErrorCondition lists all of the procedural errors that are associated with the process variant represented by the set of graphical elements. These MUST be uniquely specified across all GraphicalElementSets. The referenced FlowObjectErrors MUST be of the type "Procedural." See Table 19 for more details on the FlowObjecterror class.

10.12 Gate Sets

Table 28: Gate Set Attributes (New)

Attributes	Description
Gates (0-n): Gate	The Gates attribute identifies all the gates that are contained within a Gateway object,
ProceduralErrorCondition (0-n): FlowObjectError	The ProceduralErrorCondition lists all of the procedural errors that are associated with the gateway variant represented by the set of gates. These MUST be uniquely specified across all GateSets. The referenced FlowObjectErrors MUST be of the type "Procedural."

10.13 BPD Element Sets

Table 29: BPD Element Set Attributes (New)

Attributes	**Description**
ArtifactRef (0-n): StatefulArtifact	The ArtifactRef attribute lists all the resources, performance measures, and environmental factors to be represented in the business process diagram. The listed artifacts MUST of the type Resource, Performance Measure, or Environmental Factor.
RiskEventRef (0-n): RiskEvent	The RiskEventRef attribute lists all the risk events to be represented in the business process diagram.
MitigationRef (0-n): MitigationAction	The MitigationRef attribute lists all the mitigation actions to be represented in the business process diagram.
PoolRef (1-n): Pool	A business process diagram SHALL contain one or more pools.

References

Cope, E.W., J. Küster, D. Etzweiler, L. Deleris, and B. Ray. "Incorporating Risk into Business Process Models." Submitted to *IBM Journal of Research & Development*, Special Issue on Business Integrity Through Integrated Risk Management, 2009.

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