

# Complementing the BPMN to Enable Data-Driven Simulations of Business Processes

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**Abstract.** Business Process Simulation is a useful and widely adopted technique that fits process analysts with the ability to estimate the performance impact of important business decisions before the actions are actually deployed. In order for the simulation to provide accurate and reliable results, process models need to consider not just the workflow dynamics, but also many important factors that may impact on the overall process performance, which constitute what we refer to as the *Process Context*. In this paper we formalize a new Business Process Simulation Model which strictly integrates to the BPMN 2.0 standard and encompasses all the features of a business process in terms of Process Workflow and Process Context respectively. It allows designers to build a resource-based perspective of a business process that enables the simulation of complex data-driven behaviors. To prove the viability of the proposed approach, a case study is finally discussed. The results obtained from the case simulation are also reported.

**Keywords:** BPMN · Business process management · Activity based costing · Data-driven simulation

## 1 Introduction

Business Process Simulation (BPS) is one of the most powerful techniques adopted to enforce re-design of processes. Through simulation, the impact that design choices are likely to have on the overall process performance may be quantitatively estimated. BPS involves steps such as the identification of sub-processes and activities and the definition of the process control flow. But one of the most interesting aspects that simulation should not neglect is the *process context*, i.e., all factors that during the process execution may consistently impact on the process dynamics, and thus, on the process KPIs. The accuracy of the final estimate produced by the simulation depends, among others, on how accurate the process context model is.

The purpose of the work presented in this paper is to define a novel *Business Process Simulation Model*, capable of representing all the main aspects of business processes under a *cost-sensitive* perspective. In order to build that view,

our approach leverages and integrates the BPMN specification and the Activity Based Costing methodology. The work specifically focuses on the need of considering the process' context data as a crucial element capable of influencing the process dynamics and, as a consequence, the process KPIs.

Further, we developed a business process simulator to simulate business processes defined according to the proposed model. A well structured business process model was also designed and used to test the simulator. Process' incurred costs and execution times are gathered from the simulation run and presented to the process analyst.

The paper is structured in the following way. In Sect. 2 the work motivation is explained and the related literature is reviewed along. In Sect. 3 the proposal of a Business Process Simulation Model is detailed. A case study is presented in Sect. 4, while Sect. 5 concludes the work.

## 2 Motivation and Related Works

By the term *Process Context* we refer to the collection of factors that may potentially affect the dynamics of a business process at execution time. These factors include, among others, the timing of the process activities, the availability and the quality of the *resources* consumed by the process and the way the resources themselves are consumed by the process. The majority of commercial Business Process Simulators [1–3] offer simulation models which cover factors like the statistical behavior of the tasks duration and the consumption of both human and non human resources. From a thorough review of such tools we realized that there is low or no support for the representation and modeling of the **Process Data**, i.e., the information that is consumed, updated and dynamically generated by the process tasks. Put in a simple way, Business Processes (BPs) interact to each other's and involve multiple activities, which have to be fed with many data in order to complete successfully. Those data have the power to influence the process dynamics as well as the resources do.

In the literature many have stressed the need of looking beyond the process workflows, and propose to define business process models capable of representing all the crucial aspects of the process dynamics. In the study conducted in [4] authors point out that the classic BP modeling tools are not able to elicit all the functional requirements required to integrate the process workflow with the enterprise's information system. According to that study, a single BP is characterized, among others, by some pre/post conditions (conditions which must be fulfilled before/after the process is executed), the *data object* consumed/produced by the process flows, the business rules to be enforced in strategic points of the process branches, and the set of actions that both human beings and the system carry out during the normal execution of the process. In [5] authors discuss the limitations of traditional simulation approaches and identify three specific perspectives that need to be defined in order to simulate BPs in a structured and effective manner: the control flow, the data/rules and the resource/organization. Focus is put on modeling at the right abstraction level the business data influencing the process dynamics and the resources to be allocated to process activities.

Similarly, authors in [6] argue that a BP simulator can not disregard the *environment* where processes are executed and the *resources* required to carry on the process activities. They also propose to use an ad-hoc workflow language (YAWL [7]) to model resources involved in the process dynamics. In [8] authors propose the definition of a conceptual resource model which covers all the types of resource classes and categories that may be involved in the process execution. The resulting model is expressed in the Object Relation model (ORM) notation as they believe it fits the need to define resources and their mutual relationships in an way that can be easily understood by a non-technical audience. In that paper, a concrete example of resource modeling through ORM is provided and integrated to a workflow model which, in turn, is expressed in the YAWL.

The Business Process Modeling and Notation (BPMN 2.0) [9] is the most famous and widely adopted standard notation to model BPs. The BPMN was conceived to support process designers to model the process' *workflow* and *data flow*. It provides little support for the *resource* representation and no support at all to model the timing of activities. The Business Process Simulation BPSim [10] is a standardization effort to augment BP models (defined in either BPMN or XPD L) with information useful for the simulation and analysis of the structure and the capacity of BPs. Though many fundamental context features may be specified through the BPSim notation (resources, statistical distributions of activities' duration), data specification is left out of the scope.

The objective of our work is to overcome the limitations shown by both the commercial BP simulation tools and the most prominent standardization efforts. The gap we aim to fill specifically concerns the lack of support for the representation of BP data as a factor capable of actively influencing the dynamics of the BP execution. The remainder of the paper will discuss the design of a meta-model to define the *context* of a BP; emphasis is put on the novel approach to the *BP data representation*.

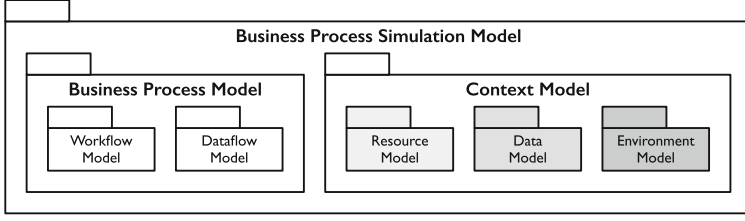
### 3 Business Process Simulation Model

In this section we propose the definition of a novel Business Process Simulation (BPS) Model. The model will have to cover both the structural features of BPs and all external entities and factors that may potentially affect the dynamics of BPs at execution time.

For what concerns the structure of a BP, the model will have to support:

- the representation of process' activities and tasks and their control flow, i.e., the representation of the *process workflow*;
- the representation of the high-level information that is consumed/produced by the process tasks and that evolves along the process itself, or briefly, the *data flow*.

We will refer to the *Context* of a BP as the collection of factors, external to the process logic, yet capable of influencing the process behavior and performance at execution time. This set includes, for instance, human resources responsible



**Fig. 1.** Package view of the business process simulation model

for carrying out process tasks, non-human resources consumed by process tasks, business rules enforced on decisor elements, any impromptu event occurring at process execution time, and the concrete data set that the process tasks interact with. In the Fig. 1 we depicted a package view of the proposed BPS model. The *Business Process Model* encloses the Workflow and the Dataflow sub-models. The former is intended to model the dynamic flow of (sub)activities carried out within the process to attain a specific goal; the latter represents the flow of data (artifacts, documents, database records, etc.) accompanying the process activities. The *Context Model*, in its turn, is broken down into the Resource, Environment and Data sub-models respectively, whose details are going to be thoroughly discussed throughout the paper.

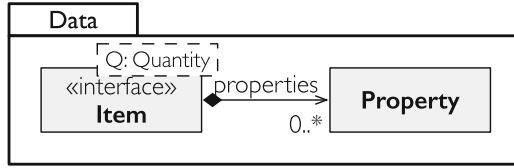
The business process model specified in the BPMN 2.0 standard perfectly fit into the *Business Process Model* depicted in the Fig. 1. In fact, the process workflow is fully supported by elements such as Tasks, Sequence Flows, Gateways, Message Flows, and so on. The data flow representation is realized by means of the Data Object element, which is a generic data container with a well defined lifecycle, that follows the process flow and that may undergo changes whenever is “worked” by the process tasks it traverses. That said, in the remainder of the paper we will replace the Business Process part of our BPS Model with the BPMN.

The focus of this work, then, shifts to the design of the Context Model, which instead is the novelty of our proposal. In our design, the overall *Context Model* is defined to be the union of a *Resource Model*, a *Data Model* and an *Environment Model*. In the following we will discuss in details each of the those models.

### 3.1 Data Model

One of the aim of this work is to define a model to represent all the process data that affect the execution of the process and thus the performance of the process’ KPIs. Such a model will have to help process designers to define a “container” of process information to which process elements (tasks, activities) may access in order to (a) consume existing information, (b) make updates of existing information or (c) create new information.

In the Fig. 2 a class diagram representation of the proposed *Data Model* is shown. To keep the approach to the data as much generic as possible, the single



**Fig. 2.** Data model class diagram representation

datum is represented by the *Item* concept to which zero ore more *properties* may be associated. If on the one hand this simple representation may look too basic, on the other it ensures maximum flexibility for the characterization of complex data structures. The *Data Model* has of course a strong relationship with the *Dataflow Model* of the Business Process package depicted in the Fig. 1: the former specifies how data are structured, while the latter defines how data flow from activity to activity. Further, as better described in the Sect. 3.3, the *Data Model* is strongly coupled with the *Environment Model* as well.

### 3.2 Resource Model

In this section we propose the definition of a cost-oriented *Resource Model* capable of capturing the resource categories that BPs may need. The *Resource Model* aims at capturing and representing costs and other process related information regarding any kind of resource that need to be “consumed” by a process task, be it a *human* or a *non-human* resource, and more specifically puts the basis for an Activity Based Costing (ABC) [11] analysis of processes.

ABC is a costing methodology that assigns the cost of each activity that consumes resources to all products/services according to the actual consumption of resources made by each activity. The basic assumption of ABC is that any enterprise cost is generated whenever an activity consumes a resource. The strength of ABC is that all costs generated in the system from the consumption of resources by activities may be directly allocated to these activities by means of appropriate *resource drivers*; in other words, all costs – including overhead costs produced by enterprise’s support activities [12] – are treated as *direct costs* when allocated to activities that are indeed precise *costs carriers*.

Given the full activity cost configuration, it is afterward possible to allocate these costs to the *final cost-objects* through their *activity drivers* that define how each activity is “consumed” by the final cost-object. By “final cost-object” we refer to every business entity whose cost has to be computed for the analysis, such as products, customers or channels.

The ABC model depicted in Fig. 3 defines the *CostObject* as the base entity for all subsequent cost-oriented concepts. Each *CostObject* has an unit of measure and can be “driven” by a set of *Drivers* that defines its requirements as the amounts of different cost-objects demanded for one unit of it. In addition, every *CostObject* can target in the run a set of other cost-objects through *Allocations* of its quantities to them over different dimensions such as cost, units and time.

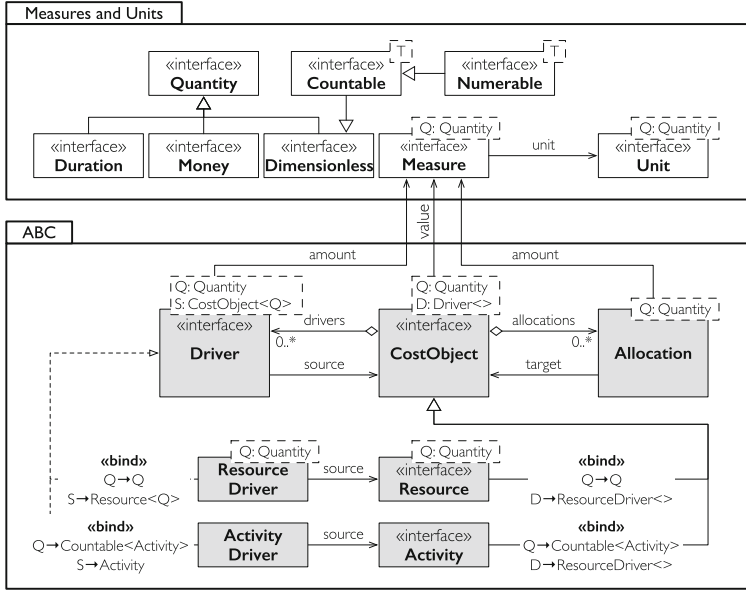


Fig. 3. Cost model. Class diagram representation

An implementation of the Java Units of Measurement API<sup>1</sup>, namely the JSR-363, was used as measures and units framework (package *Measures and Units* in Fig. 3).

The *Resource Model* defines the resource concept as a cost-object extension itself. Figure 4 presents its relevant classes and their relationships in the UML notation [13]. A Resource, no matter the kind, produces a cost whenever it is allocated and actually consumed by some business operation. The CostObject concept depicted in the diagram represents the element that, in our proposed

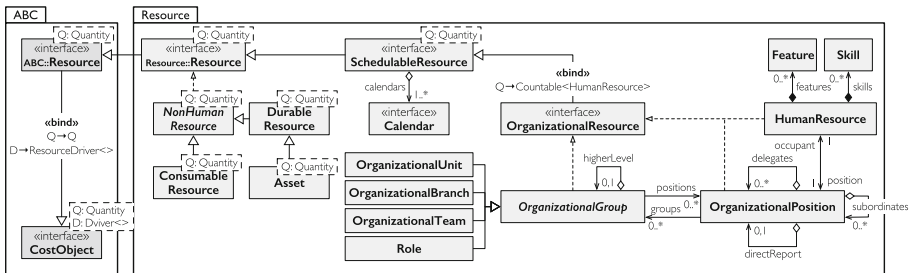


Fig. 4. Resource model. Class diagram representation

<sup>1</sup> <http://www.unitsofmeasurement.org>.

view, bridges the domain of resources and the domain of all the business operations that actually make use of resources.

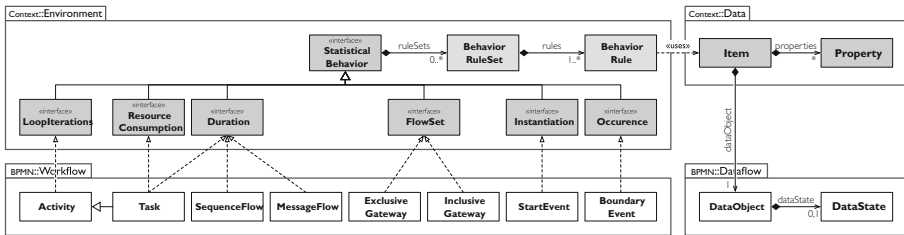
The *NonHumanResource* class may be used to define resources such as goods and services. *ConsumableResource* extends it by introducing the concept of “residual amount” and it is suited for available-if-in-stock resources. *SchedulableResource* represents a generic resource whose availability is defined by one or more calendars where each *Calendar* represents a set of time intervals in which the resource is available to the whole system; the most common calendar based resource is the *HumanResource* (HR) which represents the physical person who, in turn, occupies an *OrganizationalPosition* within an *OrganizationalGroup* structure such as an *OrganizationalUnit* structure (organizational chart).

### 3.3 Environment Model

We discuss the factors that are external to the process logic but that are anyway capable of affecting the process execution. In the literature, researchers [5] have identified numerous aspects that designers either tend to neglect or are not able to account for at design time, and that have a negative impact when the process executes. Some of those are the employment of oversimplified (or even incorrect) models, the discontinuous availability of data and resources, the inhomogeneous skill of the employed human resources (which leads to non deterministic human tasks’ duration), the lack of knowledge about the exact arrival time of process’ external stimuli, and so on.

Our objective is to provide the process designers with a tool to simulate the effects that external factors may have on the process dynamics and performance. Basically, we introduce a model which provides for the representation of non-deterministic behaviors of the process elements. The proposed model is an extension of the one proposed in an earlier work [14]. Figure 5 shows the BPMN elements which have been associated a statistical behaviour, and the categories of statistical behaviors that have been modeled.

*StatisticalBehavior* is the root class representing a generic behavior which is affected by non-deterministic deviations. It includes several probability distribution models (uniform, normal, binomial to cite a few) that can be used and adequately combined to build specific behaviors.



**Fig. 5.** Environment model class diagram representation and relationships to the BPMN and the data models

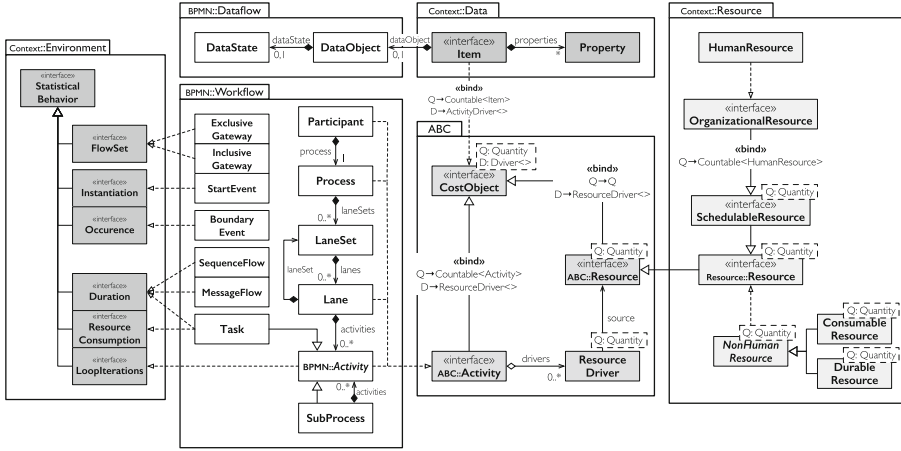
*Duration* models the temporal length a certain event is expected to last. This concept will be used to specify the expected duration of the following BPMN elements: *tasks*, *sequence flows* and *message flows*. Tasks, in fact, may have a variable duration in respect, for instance, to the skills of the specific person in charge of it or, in the case of a non-human task, to the capability of a machine to work it out. A sequence flow may have a variable duration too. It is not rare, in fact, that time may pass since the end of a preceding task to the beginning of the next one (think about a very simple case when documents need to be moved from one desk to another desk in a different room). Finally, message flows fall in this category too since they are not “instant” messages, and the time to reach the destination may vary from case to case.

*ResourceConsumption* models the uncertainty regarding the unpredictability of the consumption of a *Resource* by a given *Task*.

The implemented statistical behavior concerns the *amount* of a given resource type that can be consumed by a task. For instance, in the case of human type of resource, it is possible to model a task consuming a discrete number of resource units which is computed by a statistical function; whereas in the case of a non-human resource type, it will be possible to specify the statistical amount of the resource expressed in its unit of measure (kilowatts, kilograms, meters, liters, etc.). *LoopIteration* models the uncertainty of the number of iterations for a specific looped activity. This is the case of both BPMN’s *standard loop* and *multi-instance loop activities*, i.e., tasks or sub-processes that have to be executed a certain number of times which either is prefixed or depends on a condition. *ConditionalFlowSet* models the uncertainty introduced by the conditional gateways (both inclusive and exclusive). It will be used to select which of the gateway’s available output flow(s) are to be taken. The *Instantiation* concept models the rate at which a specific event responsible for instantiating a process may occur. In particular, it will be used to model the behavior of the BPMN’s *Start Event* elements that are not triggered by the flow. The *Occurrence* models the delay after which an event attached to an activity may occur. The event is triggered exactly when the activity work-time exceeds the delay.

The novelty introduced with respect to our former proposal and to other solutions proposed in the literature is the influence of the *Data* (whose model depicted on the right end of the Fig. 5) on the *Environment*. At runtime, the *StatisticalBehavior* associated to the BPMN elements is not statically defined; rather, it may change depending on the values of the Data that are flowing along the BPMN Element itself. This feature is modeled through rules. A rule states which are the conditions under which a *StatisticalBehavior* will have to dynamically change. The conditions are expressed through combinations of data values that trigger the behavior change. In the figure, the rules are represented by the *BehaviorRuleset* and *BehaviorRule* concepts respectively. The introduced feature enables the process designers to design more refined process models. They are now able to get the Data involved in the process dynamics by simply defining the rules by which Data affect the process workflow.





**Fig. 6.** Overall business process simulation model. Class diagram representation

To make a simple example of what a typical use of this feature may be, think about the duration of a task. Suppose that the task is performed by a human person who has to work an item (a document, for instance). Suppose also that there are two types of document that can be worked. Depending on the type of document, the duration of the task may sensibly vary. In this case, the process modeler would just have to define a rule which, depending on the document's type that is being worked, output the one or the other configuration of parameters for the duration's *StatisticalBehavior*. The reader will find a more concrete example of rule definition in the Sect. 4.

Finally, the Fig. 6 depicts the class diagram of the overall Business Process Simulation Model. The reader may notice that the sub-models are perfectly integrated and that the ABC package plays a pivotal role in such integration.

### 3.4 Context Model's Serialized Notation

So far, we have given a conceptual description of all the entities that populate the Context Model. We have used the UML's class diagram notation in order to describe the concepts and explain how concepts are related to each other. The next effort was to devise a notation which can be used to serialize the presented Context model and use the serialized model to feed a Business Process Simulator. We therefore devised an XML-based notation that process designers can use as a language to define process models. For space reason it was not possible to show the serialized form of all concepts. In Listing 1 we reported a schema excerpt describing the Durable Resource element and the Usage that a Task makes of a Resource. The statistical behavior rules are defined by rule tables and applied at simulation time. An excerpt of the rule definitions for ResourceConsumption and FlowSet can be seen in the next section.

**Listing 1.** XSD excerpt of the (Durable) Resource element and its Usage in Task

```

<xsd:schema xmlns="http://www.unict.it/bpmn/2.0/sim" ...>

<xsd:complexType name="Resource" abstract="true">
  <xsd:complexContent>
    <xsd:extension base="SimItem" />
  </xsd:complexContent>
</xsd:complexType>

<xsd:complexType name="ResourceUsage" abstract="true">
  <xsd:complexContent>
    <xsd:extension base="Usage">
      <xsd:sequence>
        <xsd:choice>
          <xsd:element ref="integerAmount" />
          <xsd:element ref="realAmount" />
        </xsd:choice>
        <xsd:element name="unitCost" type="RealAmount" />
      </xsd:sequence>
      <xsd:attribute name="unit" type="Unit" use="required" />
      <xsd:attribute name="moneyUnit" type="MoneyUnit"
        use="required" />
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>

<xsd:element name="durable" type="Durable" />
<xsd:complexType name="Durable">
  <xsd:complexContent>
    <xsd:extension base="Resource">
      <xsd:sequence>
        <xsd:element name="usage" type="DurableUsage"
          maxOccurs="unbounded" />
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>

<xsd:complexType name="DurableUsage">
  <xsd:complexContent>
    <xsd:extension base="ResourceUsage">
      <xsd:attribute name="timeUnit" type="TimeUnit"
        use="required" />
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>

<xsd:complexType name="TaskUsage">
  <xsd:complexContent>
    <xsd:extension base="ActivityUsage">
      <xsd:sequence>
        <xsd:element ref="timeSpan" minOccurs="0" />
        <xsd:element ref="resourceConsumption" minOccurs="0"
          maxOccurs="unbounded" />
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>

```

To ease the work of process designers, we implemented a web modeler<sup>2</sup> that lets designers draw process models in the BPMN, define all the features of the process Context and finally serialize it in the just mentioned notation.

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<sup>2</sup> <http://business-engineering.it/sim-editor>.

## 4 Case Study

The objective of this work was to devise a business process meta-model that process designers may use to define process models and characterize its context features; next step was to implement a simulator capable of running long-term, context-aware simulations of those processes and producing cost-sensitive results useful for ABC analysis. In an earlier work [14] the design and implementation of a preliminary version of the simulator was presented. It was compatible with an earlier version of the business process model. The reader may refer to that work for details on the simulator design.

A BPMN description of the investigated case study process is shown in Fig. 7. It represents the process of release of a construction permit run by the Building Authority of a Municipality. The whole process involves different actors who interacts to each other exchanging information and/or documents (represented in the model as specific messages). The involved actors are: *Applicant*, the private citizen/company who applies to obtain the building permit; *Clerk*, the front-office employee of the Building Authority who receives the Application and is in charge of (a) checking the documentation of the application, (b) interacting with the applicant in order to obtain required documents and (c) sending back the result of the application; *Senior Clerk*, the back-office employee of the Building Authority who evaluates and decides on the application; *Expert*, an external expert who may be called upon by the Senior Clerk whenever specific technical issues arise and the final decision may not be autonomously taken.

The business process spans four swimlanes, one for each actor. Both the Applicant and the Expert are external entities, i.e., are not part of the enterprise’s business process dynamics. While there was no reason to represent the Applicant in the resource model, the Expert was modeled as a *DurableResource* (paid by the hour). The Clerk and the Senior Clerk were modeled as *OrganizationalPosition*. Other considered resources in the scenario are energy, modeled as *DurableResource*, paper and stamps, both modeled as *ConsumableResource*.

We defined a context scenario (say *scenario1*) where we employed all the above mentioned resources. Also, we set up a calendar (*official-calendar*) to state that for human resources the working days are Monday through Friday and the working hours follow the pattern [8:00AM to 12:00AM, 1:00PM to 5:00PM]. We then specified four different types of application (“cost object”, in the ABC terminology) that potential applicants may submit: Maintenance, building and renovation, preservation and restoration and urban restructuring. Further, in the specific scenario we required 1 unit of the Clerk resource type and 2 units of Senior Clerk resource type, whose hourly costs are 10€ and 20€ respectively.

The process context was populated with data capable of influencing the process workflow. The *autonomous decision?* Gateway is associated a FlowSet statistical behavior, while the *decide on application* Task is associated the ResourceConsumption and Duration statistical behaviors. Such BPMN elements are bound to the statistical behaviors by means of rule tables, where each table row represents a specific rule that applies when a condition on data holds true. Excerpts of these rule tables (with priorities and activation groups hidden for

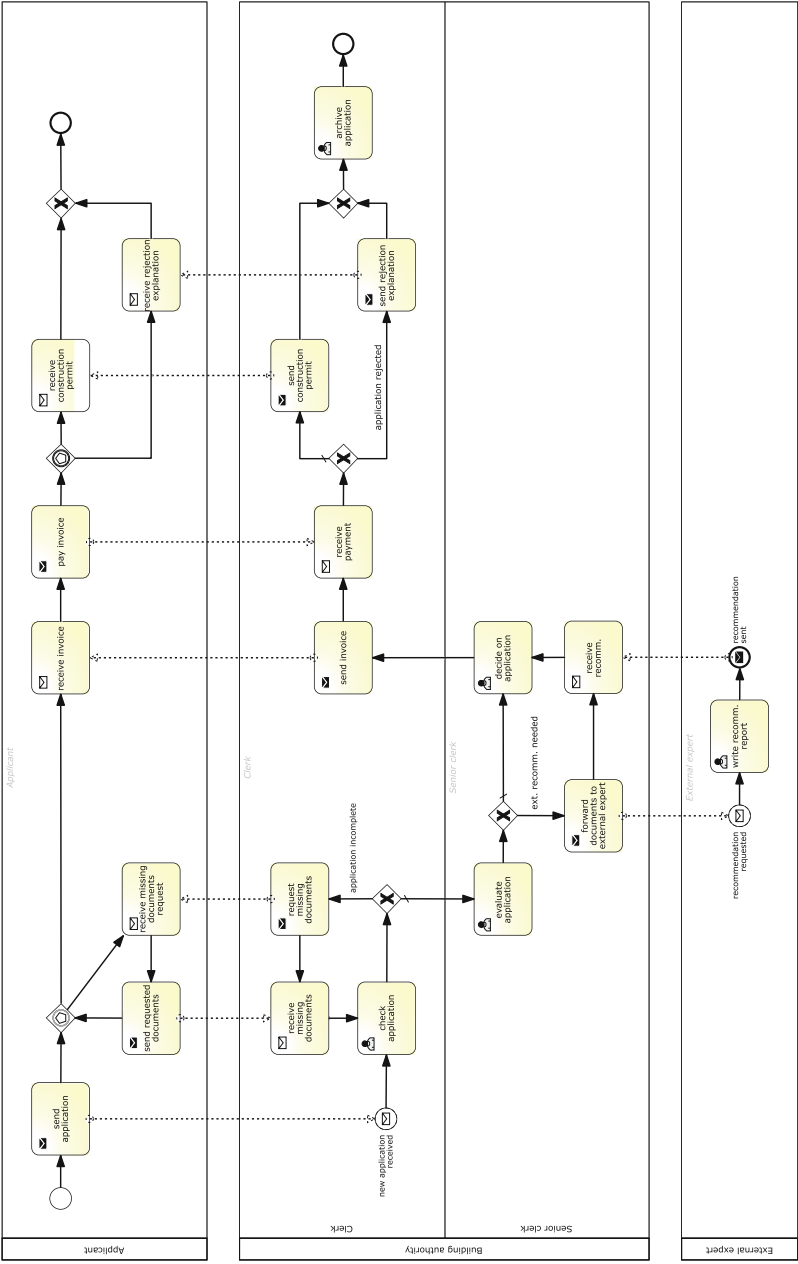


Fig. 7. BPMN model of the example process

readability) are shown in the Tables 1 and 2 respectively. Rules in Table 1 state that if the user has applied for a “preservation-and-restoration” permit, then the workflow is diverted to flow-id “sid-A1F...92B” with 100 % probability. For all other types of application, in the 80 % of cases the workflow proceeds through the sequence flow “sid-A1F...92B” and in the remaining 20 % through the sequence flow “sid-595...1E1”. Similarly, Rules in Table 2 state which distribution of probability has to be chosen for the duration of the *decide on application* task depending on (a) the user’s application type and (b) the involvement of the external expert in the process instance.

A simulation was finally run on the described process scenario. The cost-sensitive approach adopted to design the Business Process Simulation Model eventually allowed us to gather data produced by the simulation and easily put them in a form that facilitates the ABC analysis. In particular, the focus is put on the user application. As mentioned earlier, each submitted user application is a *cost-object*, in the sense that it accumulates the costs produced by every activity that works the application itself. Also, when traversing the activities an application is also capable of recording both the time spent in every activity’s queue and the time for being processed.

Three simple process KPIs are going to be assessed through the simulation: the *monetary costs* incurred by the Building Authority to serve the requests, the *work times* spent by the activities to process applications and the *queue times* applications had to wait before being processed by the activities. Figure 8 depicts a report of analytical costs and times computed for the scenario. In particular, costs incurred for the allocation of resources to activities and activity costs are reported in the “cost allocations” section; the unit times absorbed by the four types of application are instead shown in the section “time allocations”. The resource pools are spliced into internal resources (Building Authority) and external resources (External Expert) and further classified by type; the activity pools coincide with those of the BPMN model.

**Table 1.** FlowSet behavior excerpt

| Name                 | Element.id    | Item.name   | Item.type                    | Flow.id       | Probability |
|----------------------|---------------|-------------|------------------------------|---------------|-------------|
| Autonomous decision? | sid-4A2...1D4 | Application | Preservation-and-restoration | sid-A1F...92B | 1.0         |
|                      |               |             |                              | sid-595...1E1 | 0.0         |
|                      |               | Application |                              | sid-A1F...92B | 0.8         |
|                      |               |             |                              | sid-595...1E1 | 0.2         |

**Table 2.** Duration behavior excerpt

| Name                  | Element.id    | Item.name   | Item.type                    | Item.ext-expert | Duration              |
|-----------------------|---------------|-------------|------------------------------|-----------------|-----------------------|
| Decide on application | sid-461...732 | Application | Maintenance                  |                 | h, norm, 24, 1        |
|                       |               | Application | Building-renovation          | False           | h, norm, 48, 2        |
|                       |               |             |                              | True            | h, norm, 24, 1.15     |
|                       |               | Application | Preservation-and-restoration |                 | h, pert, 0.8, 1, 1.33 |
|                       |               | Application | Urban-restructuring          |                 | h, norm, 24, 2        |

|                     |                                       | activities                                                        |                                  |                                                          |                                                          |                                                          |                         |                          |                          |                          |                          |                          |                          |                          |                 |            |           |            |           |           |           |
|---------------------|---------------------------------------|-------------------------------------------------------------------|----------------------------------|----------------------------------------------------------|----------------------------------------------------------|----------------------------------------------------------|-------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|-----------------|------------|-----------|------------|-----------|-----------|-----------|
|                     |                                       | Clerk                                                             |                                  |                                                          |                                                          |                                                          | Building Authority      |                          |                          |                          |                          | Senior Clerk             |                          |                          | External Expert |            |           |            |           |           |           |
|                     |                                       | check application<br>and receive<br>receipt payment<br>for permit | active application<br>for permit | review missing<br>documents<br>and reject<br>application | review missing<br>documents<br>and reject<br>application | review missing<br>documents<br>and reject<br>application | evaluate<br>application | decide on<br>application | decide on<br>application | decide on<br>application | decide on<br>application | decide on<br>application | decide on<br>application | decide on<br>application |                 |            |           |            |           |           |           |
| resources           | Organizational                        | Clerk<br>Senior Clerk                                             | 2,892.24                         | 670.44                                                   | 316.96                                                   | 605.80                                                   | 1,060.31                | 419.95                   | 83.51                    | 121.11                   | 6,170.33                 | 271,167.48               | 706.67                   | 43.94                    | 30,771,944.95   | 271,167.48 | 6,170.33  | 271,167.48 |           |           |           |
|                     |                                       |                                                                   | Durable                          | Energy<br>External Expert                                | 26.03                                                    | 6.03                                                     | 5.45                    | 3.78                     | 1.09                     | 42.39                    | 488.10                   | 0.20                     | 0.14                     | 488.44                   | 530.82          | 56,308.91  | 56,308.91 | 56,308.91  | 56,308.91 |           |           |
|                     |                                       |                                                                   |                                  |                                                          | Consumable                                               | Paper<br>Stamp                                           | 26.03                   | 6.03                     | 5.45                     | 3.78                     | 1.09                     | 42.39                    | 488.10                   | 0.20                     | 0.14            | 488.44     | 530.82    | 56,308.91  | 56,308.91 | 56,308.91 | 56,308.91 |
| 2.12                | 3.80                                  | 1.12                                                              |                                  |                                                          |                                                          |                                                          | 0.64                    | 7.48                     | 7.48                     | 7.48                     | 7.48                     | 7.48                     | 7.48                     | 7.48                     | 7.48            | 7.48       | 7.48      | 7.48       |           |           |           |
| 339.20              | 2,132.00                              | 179.20                                                            | 70.40                            | 2,132.00                                                 |                                                          |                                                          | 2,132.00                | 2,132.00                 | 2,132.00                 | 2,132.00                 | 2,132.00                 | 2,132.00                 | 2,132.00                 | 2,132.00                 | 2,132.00        | 2,132.00   | 2,132.00  |            |           |           |           |
| time allocations    | 2,918.28                              | 717.79                                                            | 316.96                           | 2,135.05                                                 | 1,060.31                                                 | 604.05                                                   | 83.51                   | 191.04                   | 192.89                   | 271,655.58               | 706.67                   | 44.14                    | 30,772,437.29            | 280,765.28               | 2,136.80        | 56,308.91  | 57,070.20 |            |           |           |           |
|                     | Application Unit Costs [€/unit]       | Maintenance                                                       | 10.80                            | 4.81                                                     | 1.50                                                     | 11.26                                                    | 5.00                    | 10.84                    | 1.48                     | 8.64                     | 54.19                    | 1,188.19                 | 3.33                     | 0.72                     | 0.50            | 1,292.74   | 1,347.07  | 902.41     | 902.41    | 2,498.48  |           |
|                     |                                       |                                                                   | Preservation & Restoration       | 10.80                                                    | 4.76                                                     | 1.49                                                     | 11.11                   | 4.99                     | 10.56                    | 1.51                     | 8.60                     | 54.19                    | 1,171.71                 | 3.33                     | 0.67            | 0.50       | 1,228.26  | 1,280.45   | 912.41    | 913.48    | 2,498.48  |
| Urban Restructuring |                                       |                                                                   |                                  | 13.27                                                    | 4.88                                                     | 1.60                                                     | 11.41                   | 5.10                     | 11.40                    | 1.58                     | 11.14                    | 60.30                    | 1,261.91                 | 3.33                     | 0.73            | 0.50       | 1,265.60  | 1,325.61   | 920.05    | 920.05    | 2,498.48  |
|                     | Application Time Unit Costs [€/h]     | Maintenance                                                       |                                  | 10.89                                                    | 4.90                                                     | 1.52                                                     | 11.24                   | 5.00                     | 10.79                    | 1.49                     | 8.77                     | 39.29                    | 1,281.39                 | 3.33                     | 0.71            | 0.50       | 1,285.08  | 1,324.73   | 908.21    | 908.21    | 1,598.92  |
|                     |                                       |                                                                   | Preservation & Restoration       | 10.89                                                    | 4.85                                                     | 1.50                                                     | 11.07                   | 4.99                     | 10.79                    | 1.49                     | 8.77                     | 39.29                    | 1,261.39                 | 3.33                     | 0.69            | 0.50       | 1,265.08  | 1,304.73   | 908.21    | 908.21    | 1,598.92  |
| Urban Restructuring |                                       |                                                                   |                                  | 10.09                                                    | 15.28                                                    | 10.00                                                    | 36.31                   | 10.00                    | 14.52                    | 10.00                    | 15.91                    | 13.35                    | 20.04                    | 20.04                    | 20.09           | 20.09      | 20.04     | 19.70      | 30.00     | 30.00     | 21.97     |
|                     | Application Unit Work Times [h/unit]  | Maintenance                                                       |                                  | 10.09                                                    | 15.00                                                    | 10.00                                                    | 33.95                   | 10.00                    | 14.06                    | 10.00                    | 14.19                    | 13.35                    | 20.04                    | 20.04                    | 20.09           | 20.09      | 20.04     | 19.71      | 30.00     | 30.00     | 22.97     |
|                     |                                       |                                                                   | Preservation & Restoration       | 10.09                                                    | 15.00                                                    | 10.00                                                    | 36.44                   | 10.00                    | 14.06                    | 10.00                    | 14.19                    | 13.35                    | 20.04                    | 20.04                    | 20.09           | 20.09      | 20.04     | 19.87      | 30.00     | 30.00     | 20.87     |
| Urban Restructuring |                                       |                                                                   |                                  | 10.09                                                    | 15.18                                                    | 10.00                                                    | 35.24                   | 10.00                    | 14.38                    | 10.00                    | 15.94                    | 13.35                    | 20.04                    | 20.04                    | 20.09           | 20.09      | 20.04     | 19.75      | 30.00     | 30.00     | 20.95     |
|                     | Application Unit Queue Times [h/unit] | Maintenance                                                       |                                  | 1.070                                                    | 0.317                                                    | 0.150                                                    | 0.321                   | 0.500                    | 0.756                    | 0.148                    | 0.531                    | 2.866                    | 64.294                   | 0.167                    | 0.036           | 0.025      | 64.475    | 67.341     | 31.080    | 30.000    | 74.729    |
|                     |                                       |                                                                   | Preservation & Restoration       | 1.091                                                    | 0.310                                                    | 0.147                                                    | 0.306                   | 0.499                    | 0.727                    | 0.151                    | 0.531                    | 3.309                    | 60.978                   | 0.167                    | 0.033           | 0.025      | 64.616    | 66.374     | 30.000    | 29.000    | 74.640    |
| Urban Restructuring |                                       |                                                                   |                                  | 1.115                                                    | 0.324                                                    | 0.160                                                    | 0.336                   | 0.510                    | 0.811                    | 0.158                    | 0.793                    | 3.100                    | 61.912                   | 0.167                    | 0.038           | 0.024      | 64.141    | 66.241     | 30.000    | 30.668    | 74.661    |
|                     | Application Unit Queue Times [h/unit] | Maintenance                                                       |                                  | 0.928                                                    | 0.328                                                    | 0.148                                                    | 0.304                   | 0.498                    | 0.720                    | 0.149                    | 0.530                    | 2.253                    | 74.083                   | 0.167                    | 0.040           | 0.025      | 74.266    | 75.159     | 33.731    | 33.731    | 84.951    |
|                     |                                       |                                                                   | Preservation & Restoration       | 0.919                                                    | 0.316                                                    | 0.150                                                    | 0.319                   | 0.500                    | 0.750                    | 0.149                    | 0.530                    | 2.911                    | 61.955                   | 0.167                    | 0.035           | 0.025      | 63.191    | 67.049     | 30.274    | 29.274    | 75.063    |
| Urban Restructuring |                                       |                                                                   |                                  | 0.935                                                    | 0.310                                                    | 0.159                                                    | 0.320                   | 0.507                    | 0.767                    | 0.150                    | 0.531                    | 94.638                   | 64.364                   | 0.166                    | 0.039           | 0.026      | 65.361    | 129.971    | 30.000    | 29.000    | 74.661    |
|                     | Application Unit Queue Times [h/unit] | Maintenance                                                       |                                  | 0.036                                                    | 0.08                                                     | 0.027                                                    | 0.028                   | 0.026                    | 0.736                    | 0.061                    | 0.051                    | 100.524                  | 33.350                   | 0.166                    | 0.033           | 0.025      | 63.141    | 134.064    | 30.000    | 29.000    | 134.064   |
|                     |                                       |                                                                   | Preservation & Restoration       | 0.040                                                    | 0.113                                                    | 0.108                                                    | 0.031                   | 0.027                    | 0.434                    | 0.067                    | 0.021                    | 93.790                   | 34.408                   | 0.166                    | 0.037           | 0.025      | 64.362    | 118.366    | 30.000    | 29.000    | 134.066   |
| Urban Restructuring |                                       |                                                                   |                                  | 0.035                                                    | 0.110                                                    | 0.115                                                    | 0.028                   | 0.026                    | 0.434                    | 0.067                    | 0.021                    | 94.638                   | 34.408                   | 0.166                    | 0.037           | 0.025      | 64.362    | 118.375    | 30.000    | 29.000    | 134.066   |
|                     | Application Unit Queue Times [h/unit] | Maintenance                                                       |                                  | 0.035                                                    | 0.110                                                    | 0.178                                                    | 0.029                   | 0.027                    | 0.200                    | 0.879                    | 0.051                    | 86.960                   | 34.978                   | 0.165                    | 0.035           | 0.025      | 64.362    | 118.375    | 30.000    | 29.000    | 134.066   |
|                     |                                       |                                                                   | Preservation & Restoration       | 0.035                                                    | 0.110                                                    | 0.178                                                    | 0.029                   | 0.027                    | 0.200                    | 0.879                    | 0.051                    | 86.960                   | 34.978                   | 0.165                    | 0.035           | 0.025      | 64.362    | 118.375    | 30.000    | 29.000    | 134.066   |
| Urban Restructuring |                                       |                                                                   |                                  | 0.035                                                    | 0.110                                                    | 0.178                                                    | 0.029                   | 0.027                    | 0.200                    | 0.879                    | 0.051                    | 86.960                   | 34.978                   | 0.165                    | 0.035           | 0.025      | 64.362    | 118.375    | 30.000    | 29.000    | 134.066   |

**Fig. 8.** Simulator generated report of costs and times allocation

The obtained data provide a picture of the performance of the process in terms of costs and times. Process designers may use those data to ground their analysis, and guess which part of the process (workflow, resource assignments) should undergo further improvement. If we focus on the “activities” grand total column, we can observe the unit cost and the time unit cost of each application type (*Maintenance*, *Building Renovation*, ...) in correspondence with the intersection of the cost object’s “Application Unit Costs [€/unit]” and “Application Time Unit Costs [€/h]” row. So, for instance, the unit cost of the *Maintenance* application is 2,249.48 €/ #application, i.e., every *Maintenance* application has an average cost of 2,249.48 €. Similarly, if we look at the time unit cost, the hourly cost of the *Maintenance* application is 20.77€/h, i.e., every work hour on the *Maintenance* application has an average cost of 20.77€.

## 5 Conclusion

Field experts agree that one of the most critical step in the business processes management is process analysis and modeling. Good models are the base for governing enterprise processes and getting them to quickly adapt to new business goals. The design of business process models is a complex activity that requires, on the one hand, the identification and the modeling of all the tasks that, adequately sequenced, lead to the attainment of the business goal, and on the other hand the characterization of the context where the process executes and that strongly influences the process dynamics. This work proposed a conceptual representation of the business process from both the workflow and the data flow perspectives. The conceptual model was translated into a machine-readable form, and may be used by process designers as a language to craft concrete business process models. We also designed and implemented a business process simulator that is compliant with the introduced notation. In the paper

we discussed a case study example that showed how to practically model and simulate business processes. In the future, the “cost” concept will be further abstracted to also cover non-monetary aspects. The objective will be to study a design framework where process stakeholders get involved too.

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