# Visual Decision Modeling in IoT-Aware Processes

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**Abstract.** The enactment of real-world-aware business processes involves multiple interconnected devices. While the latter form the basis of the Internet of Things (IoT) and enable the exchange and collection of physical data via the Internet, Business Process Management (BPM) enables analyzing, modeling, implementing, executing, and monitoring business processes. In IoT-aware processes decision making may depend on the data provided by multiple IoT devices, which results in decision rules of complex structure. In this paper, we present two approaches for the visual modeling of decisions in IoT-aware processes. The first approach allows for the visual representation of complex decision rules by extending Business Process Model and Notation (BPMN) 2.0. The second approach separates decision logic from process logic using a drag&drop modeler. With both these approaches, IoT involvement in decision making becomes apparent and complex decisions can be represented in an intuitive and simple manner.

**Keywords:** BPM · Decision making · IoT-Aware Process

## 1 Introduction

The Internet of Things (IoT) is a network of physical objects that enable the collection and exchange of data via a network connection [1]. On one hand IoT devices allow for the acquisition and collection of data by sensors. On the other they support the response to an event by actuators. In particular, IoT enables bridging the gap between physical and digital world [6]. In turn, BPM enables optimizing, modeling, executing, and monitoring business processes [9]. By integrating BPM with IoT capabilities, process modeling, execution and monitoring can be enhanced. Furthermore, this integration enables the confirmation of manual steps through the use of IoT devices such as sensors and cameras [1]. In addition, low-level data generated by individual IoT devices (e.g., temperature, humidity or switch state) may be aggregated and combined, in high-level information that can be used for decision making. Moreover, high-level information enables BPM to understand the dynamic context of the physical world during process execution, which makes IoT-aware processes context-aware [6].

In contemporary approaches combining BPM and IoT, devices are added to process models as resources. Consequently, IoT data is used without linking it to other contextual process data. The potential of gaining additional insights is not exploited [6]. As another challenge of using IoT devices for decision making, IoT-aware processes become decision-intensive [15]. In turn, this leads to an increased complexity due to a high number of decisions as opposed to IoT-unaware processes. In contemporary approaches, the involvement of IoT devices in decision making is not explicitly addressed. In addition, complex decision-making rules can only be represented in tables or gateways, which affects model readability and comprehensibility.

In this paper, we present two approaches for visually representing decisions in IoT-aware processes. One of these approaches is based on BPMN, whereas the other separates decision from process logic. The approaches aim to explicitly display the IoT devices involved. Furthermore, complex decision rules become more intuitive due to the chosen visualization. The remainder of this paper is organized as follows: Section 2 discusses related work. Section 3 presents the two solution approaches. Finally, Section 4 provides a summary and outlook.

## 2 Related Work

There exists a variety of approaches [2][4][7] that embed IoT into BPMN-based process models in terms of IoT tasks, physical entities, and resources. However, none of these approaches aggregates IoT data into higher-level information, which then can serve as input for decision making.

The Decision Model and Notation (DMN) standard provides a solution to separate decision from process logic [12]. In [14], the combination of BPMN and DMN is considered for IoT-aware processes. Note that the involvement of IoT devices actually neither becomes apparent in BPMN nor in DMN.

In [16], an approach for converting DMN models into DMN decision tables is presented. In particular, complex decision tables can be created automatically. Still, the problem remains that complex decision tables are difficult to read and comprehend. Furthermore, involved IoT devices are not explicitly represented or highlighted in [16].

## 3 IoT-aware visual decision modeling

This section presents the approaches for visual decision modeling in IoT-aware processes. Based on literature review and expert interviews we identified the challenge to model complex IoT decisions. To the lack of space we can not provide more details. First of all, a BPMN-based decision modeling approach is introduced, followed by an approach that separates decision modeling from the process logic using a drag&drop modeler.

### 3.1 Approach 1: Decision modeling in BPMN

To enable decision modeling directly in BPMN, the following extensions are introduced in BPMN (Figure 1); *IoT representative (1), IoT decision container*

*(2,3&4)*, and *IoT decision table (5)*. Each *IoT decision container* contains an *IoT decision table*, which can be filled using the properties panel (7). The *IoT representatives* may be inserted into the *IoT decision container* via drag&drop. An *IoT representative* visualizes IoT sensors such as limit switches, temperature sensors, pressure sensors or light sensors.

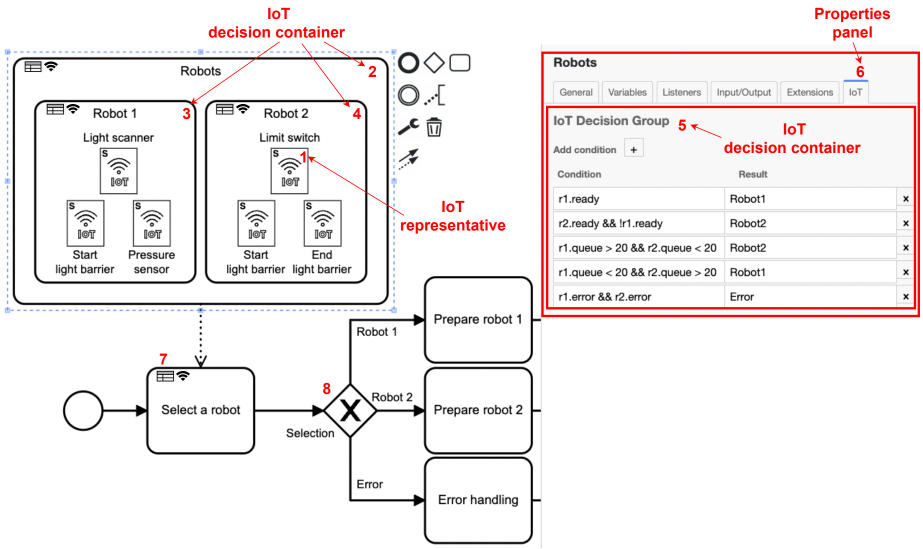


Fig. 1: IoT-aware decision modeling in BPMN

Figure 1 shows the modeling of the decision as well as its logic. First, the light scanner, start light barrier, and pressure sensor are queried (low-level information). The query results are then used for defining conditions in the decision table based on boolean algebra (high-level information). In turn, the results of Robot 1 (3) and Robot 2 (4) are used to define conditions for the root decision container Robots (2). The evaluation of this top-level decision, is then considered for controlling the flow of the corresponding process (8). When clicking on the *IoT decision* icon of the corresponding task (7), the root IoT decision container may be expanded/collapsed. Each IoT decision container may contain $n$ IoT decision containers and likewise $n$ IoT representatives, which results in a tree data structure. The latter is read bottom-up (i.e., the results of the nodes are passed from the bottom to the top) until the final decision is made by the root IoT decision container.

### 3.2 Approach 2: Separate Decision modeling

To separate the decision from the process logic, a drag&drop modeler is used. This allows the insertion and movement of elements on a modeling area (Figure 2). For modeling the decision logic the following elements are available; *IoT decision* *container (1)*, *IoT representative and attached comparison (2)*, *logical gates (4&5)* and *result module (6)*.

First, the IoT representative queries the physical sensor. Then, the attached condition is checked. Depending on the result, the IoT representative returns a corresponding boolean value. Each *IoT decision container* may contain any number of *IoT representatives*, *comparison modules*, and *decision containers (1)*. In turn, *IoT representatives* are connected to logical gates, which process multiple boolean input signals into a boolean output signal based on logical operators, such as conjunction (AND gate 4), disjunction (OR gate 5), or negation (3). The output signals of the logical blocks may either lead to a final result or be nested with other *logical blocks*. The final result may be of any data type and be represented by a result module (6). The transfer of the final decision from the drag&drop modeler to the BPMN model is done via an IoT decision task.

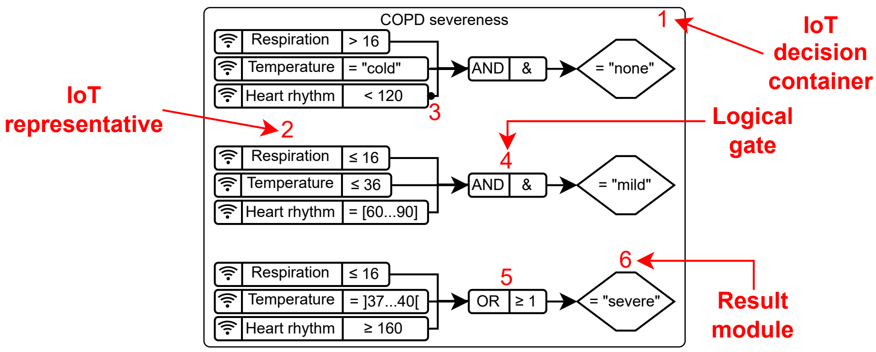


Fig. 2: IoT-aware decision modeling separated from BPMN

## 4 Summary and Outlook

We presented two approaches for visually modeling decisions in IoT-aware processes. The first one enables explicit decision modeling in BPMN using an IoT decision container with a corresponding IoT decision table. The IoT representatives are dragged and dropped into the IoT decision container. These representatives query the physical sensors and store the retrieved values in the decision table. As each IoT decision container has its own decision table, complexity is reduced. Each IoT decision container passes its final decision upwards until reaching the root IoT decision container. The latter makes a final decision, which then flows into the process and can be used in BPMN. As opposed to Approach 1, Approach 2 separates decision modeling from process modeling.

In future work, we will implement the two approaches and evaluate their usability and benefits in a case study. Moreover, we will develop an engine, for processing decision rules in IoT-aware processes. Finally, we will model IoT-aware processes from different domains to further verify the approaches.

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