A Context and Augmented Reality BPMN and BPMS Extension for Industrial Internet of Things Processes

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Abstract. In the context of Industry 4.0, smart factories enable a new level of highly individualized and very efficient production, driven by highly automated processes and connected Industrial Internet of Things (IIoT) devices. Yet the IIoT process context, crucial for operational process enactment, cannot be readily represented in processes as currently modeled. Despite automation progress, manual tasks performed by humans (such as maintenance) remain, and while complicated tasks can be supported by Augmented Reality (AR) devices, they remain insufficiently integrated into global production processes. To seamlessly integrate process automation, IIoT context, and AR, this paper contributes BPMN-CARX, a Context and Augmented Reality eXtension (CARX) for BPMN (Business Process Model and Notation) and the CARX Framework, which enables AR and IIoT context integration with existing Business Process Management Systems (BPMSs). An Industry 4.0 case study demonstrates its feasibility and applicability.

Keywords: Business Process Modeling · Industrial Internet of Things · Business Process Model and Notation · Augmented Reality · Context-awareness.

1 Introduction

The rise of smart factories with their highly automated processes and networked IIoT devices provides not only advantages, but also new challenges for workers and process engineers alike. First, while machines are becoming more sophisticated and digitized, the IIoT evolution provides many additional capabilities such as automatic sensor measurements and connected predictive maintenance solutions while improving and minimizing maintenance by providing *contextually-relevant data*. Second, *process automation* via Business Process Management (BPM) enables the creation and enactment of workflows that integrate business and factory processes; tasks can be decomposed into self-contained subtasks and a clearly structured model can represent each process, e.g., via BPMN 2.0 [4]. Third, the spread of AR devices enables completely new industrial (training or maintenance) scenarios for supporting humans - primarily via *visual augmentation*, where complex, dangerous, or expensive operations can be augmented or simulated for safety, effectiveness, and efficiency. While each of these three factors provides a focused solution for their area, none integrates or includes the other two factors comprehensively. Therefore, holistic solutions for smart factories remain scarce and are often limited to specific use cases. Consequently, further investigation is needed to improve this situation.

In prior work, we developed a holistic concept for contextual process management in the software engineering domain [8], while with VR-BPMN [11] we demonstrated BPMN model visualization in Virtual Reality (VR). This paper contributes BPMN-CARX, the Context and Augmented Reality eXtension for BPMN, a generic approach towards amalgamating IIoT context, process automation, and visual AR. A prototype extends a prevalent BPMN modeling tool and integrates with two commercial BPMSs. Its feasibility and applicability to address the aforementioned issues is demonstrated with a case study.

The paper is structured as follows: Section 2 elaborates related work, while Section 3 describes our solution concept. In Section 4 realization details are provided. Thereafter we introduce a case study conducted with CARX in Section 5. Finally, Section 6 provides a conclusion and outlook on further upcoming work.

2 Related Work

As to the integrating AR/VR with BPM, besides our prior work with VR-BPMN [11], Poppe et al. [12] implemented a collaborative process modeling approach utilizing AR, but it was limited to modeling and lacked an implementation for process enactment and IoT device integration. BPM to Go combined AR and sensor data with BPM and enactment on a mobile device [14], but does not address BPMN aspects for AR and IIoT context, nor shows how to generically integrate and extend BPMSs to consider AR and IIoT in a unified context.

A combination of AR, IoT, and BPM, can be found in the HoloFlows project [18] which provides process modeling software in mixed reality for the HoloLens, supporting end users during IoT device setup and interaction modeling. While HoloFlows guides users through processes and includes real-time sensor data, no tool to create or model these processes is mentioned. BPMN modeling is not supported. An IIoT solution with AR-supported worker tasks is as yet unrealized.

Regarding IoT with BPM, Schönig et al. [17] showed the feasibility of an IoT BPM framework utilizing BPMN. They designed and implemented an approach for IoT-aware business processes integrating IoT sensor data into predefined processes in a modern BPMS. The solution integrates a smart watch during process execution, providing workers with guidance and real-time sensor data. However, the approach lacks an easy way to model those processes, requiring knowledge in the IoT and BPMN domain. Further, it lacks AR support to augment the environment – only a smart watch interface was provided.

For extending BPMN processes with context, BPMN4SGA [19] extends BPMN with smart glasses, but lacks AR actions via a BPMS and is limited primarily to documentation. BPMN4CPS [7] describes an approach combining BPMN with cyber-physical systems, but lacks the capability to integrate AR directly.

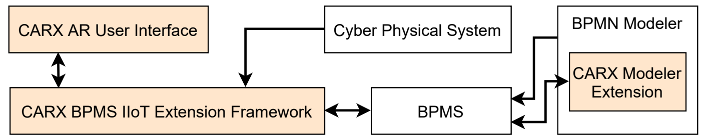


Fig. 1. High-level logical architecture

As to context modeling, domain-specific modeling (DSM) languages like SenSoMod [5] add context to mobile applications, but only cover conventional aspects like email, calendar, etc. Our approach works with predefined templates that are readily extensible and consider industrial process context.

3 Solution Concept

Our solution concept needs to address the following problems when combining IoT and BPMN, as elaborated by Hasić and Serral Asensio [9]: (P1) IoT resource-awareness in tasks; (P2) IoT resource binding at runtime; (P3) IoT resource malfunction event handling; (P4) IoT data retrieval: push vs. pull; (P5) IoT tasks and human resources communication. The CARX DSM extension for BPMN addresses the following requirements:

- R1 Natural modeling support for context-aware and AR business processes (i.e., conformance to current business process modeling norms and notations)
- R2 Easy integration with existing prevalent BPMSs
- R3 Ability to integrate IIoT context information during process modeling
- R4 Real-time sensor data for system and workers during task execution
- R5 Integrated AR support during business process enactment (no need to switch between software solutions or platforms)
- R6 Just-in-time rule execution utilizing the latest IIoT sensor data values
- R7 Worker task assignment in accord with the extended (comprehensive) context by utilizing available data in an intelligent way

The intent with the CARX architecture is to avoid a highly-tailored solution limited to a specific use case, or one that only addresses AR support or IIoT data in processes, or one that only enriches BPMN with additional context. Thus, we introduce our tripartite solution concept consisting of: AR user interface support, a BPMS IIoT extension framework, and our BPMN modeling extension CARX that links these three components. The high-level logical architecture can be seen Fig. 1, where the connections and information flow between the different components is originating from the BPMS extended with CARX.

CARX AR User Interface. The user interface must provide AR support to workers during execution and act as a device to control the BPM task without the need to switch clients (R 5), therefore hand free devices with input/output (IO) options like smart glasses should be preferred, as they can be used without limiting the users action range. To also provide a solution which can be integrated with less effort and cost (R2), other AR devices like smartphones and tablets should also be supported. The interface shall be capable of providing current IIoT sensor data to the user (R4, P 5).

CARX BPMS IIoT Extension Framework. Rather than extending a single BPMS, we want to provide a generic solution applicable for most BPMS and therefore reduce the integration effort (R2). To achieve this, we introduce a supporting framework providing necessary functionality via generic interfaces to the BPMS. This framework supports IIoT machine data utilization and IIoT context-aware rule execution (R6, P1, P2), which can also be used to resolve resource issues regarding IIoT machines (P3) and intelligent assignment (R7).

BPMN-CARX Realization and Modeler Extension. BPMN-CARX links the other components and enables easy modeling of new AR-supported, IIoT-aware processes. Rather than providing a new Domain Specific Language (DSL), we extend BPMN 2.0, easing the integration with existing process models and their associated tools (R2), providing a natural environment for process engineers (R1), and reusing BPMN elements. In order to handle a task assignment, we utilize a script task that requests the assignment calculation from the CARX Framework. The framework then calculates the optimal assignment in a synchronous way and sends the response to the script task, or, in asynchronous mode - directly handles the assignment via the REST API of the BPMS. To support the creation of new context-aware AR-supported process models, we also provide a CARX modeling tool extension. It guides process engineers for creating service tasks for assignments and adding associated data objects as in- and output data objects, while also displaying all associated context information. The reuse of existing elements further minimizes the integration effort for existing models, as only some generic script tasks have to be added.

4 Realization

The CARX framework was implemented with the Python Django framework [10] for fast prototyping and scalability. Our prototype demonstrates our generic BPMS integration concept via both Camunda [2] and the AristaFlow BPM Suite [15]. While the AristaFlow BPM Suite already provides data stores for users, resources, and machines, the Camunda BPMS only provides a minimal user store and no further context. It was therefore extended with data stores for users, resources, and machines containing all required information. Rather than implementing rule processing ourselves within the supporting framework, we integrated the prevalent Drools [13] rule engine to support easily customizable and accessible context-based logic. The communication between the different applications is handled via REST for the application logic which is supported by most modern BPMS, and MQTT utilizing a Mosquitto broker for the transmission of sensor data in compliance with the OPC-UA industry standard [6]. By utilizing a Publish/Subscribe architecture sensor values from the IIoT domain are available to interested parties, and the BPMS, support framework, or worker can choose when to consume these (solving P4).

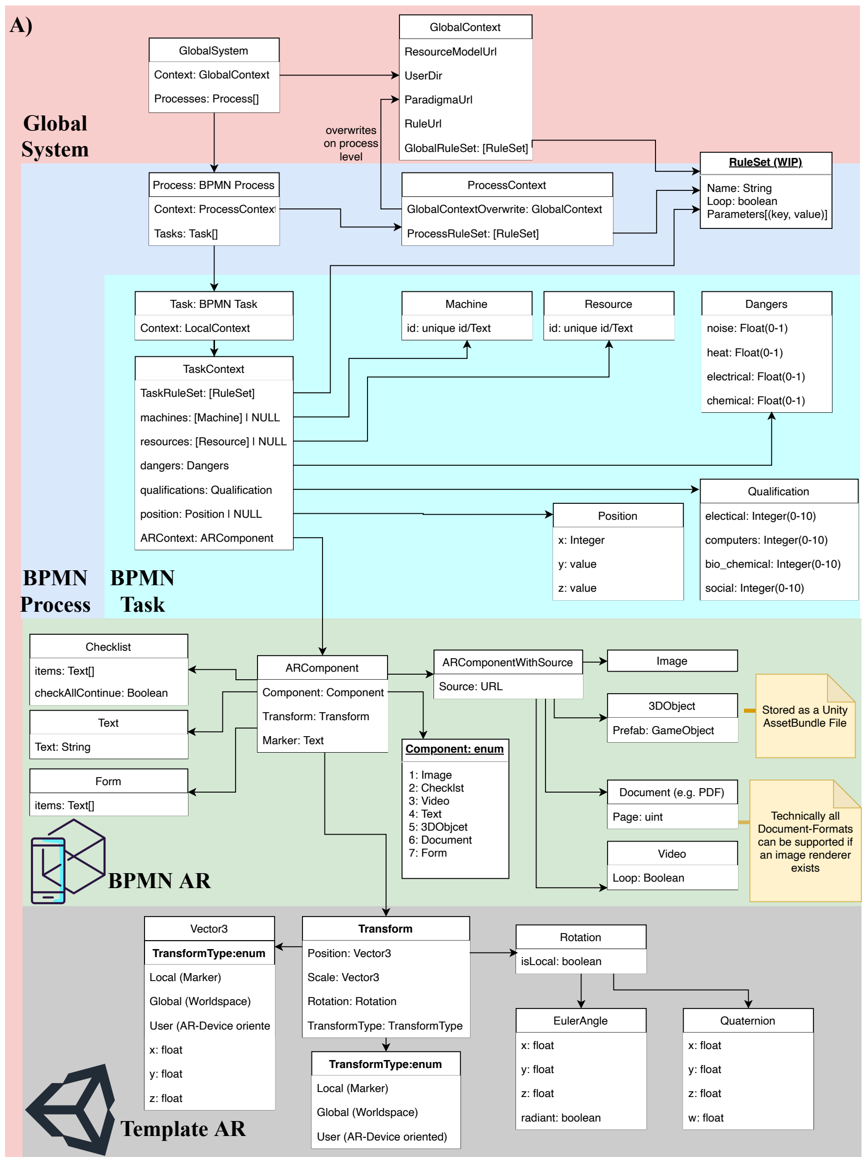
4.1 CARX Context Realization

The CARX context model consists of five major blocks (cf. Fig. 2A). The Global System (red) handles all organization-wide rules and context information. The BPMN Process context (violet) is responsible for the process-specific rules and data. The BPMN Task (blue) handles the BPM task specific rules, data, and AR configuration. The AR Context (BPMN-AR green and Template AR grey) consists of two parts and is only applicable for tasks utilizing AR support (R5). BPMN-AR Context is defined in the BPMN modeler, addressing how what to display in the AR-Component. The Template AR Context is defined in the specific AR template (e.g., Unity) and must be modeled in advance. In the following, these are described in more detail.

Global System (Global Context). This is the top-level object for all processes in CARX environment. It consists of a Global Context and the BPMN processes. The Global Context itself contains URLs to all required data stores, containing meta-data for workers, resources, machines, and an optionally connected rule engine. It includes the framework URL, where the intelligent assignment for tasks according to real-time sensor data and worker information can be requested. As a final component, the Global Context contains a rule set. This set defines default organizational rules which are executed before each task. A rule in this rule set consists of the rules name, a boolean indicating if it should be looped until the rule is successfully fulfilled, and an optional key/value list, providing information about which values have to be submitted to the rule engine with the request, e.g., which machine sensors.

BPMN Process (Process Context). The BPMN Process is a default BPMN 2.0 process extended with a Process Context. It further contains all BPMN tasks of the process. The Process Context itself contains a process rule set which contains rules to be executed by default before each task of the process. It is further possible to overwrite the Global Context on the process level, e.g., removing a global rule or changing the URL to a data store.

BPMN Task (Task Context). The BPMN Task consists of a default BPMN 2.0 task extended with the Task Context. Like the other contexts, it contains a rule set, allowing the addition of new rules and the option to remove rules from the Global Context or Process Context. Further, the Task Context must contain all information to provide a foundation for an intelligent task assignment (R7), enable AR support (R5), and provide real time sensor data from connected IIoT devices (R4). To provide real time sensor data during task execution, the context contains information about all connected machines in the machine variable. Rather than selecting a specific machine during creation, the type of machine is selected at design-time and then assigned during runtime by the supporting framework's assignment logic (P2). Smart assignments are enabled by the extension, with further context information consisting of the position where the task must be executed, dangers connected to the execution (e.g., noise or heat hazards), the worker qualification needed to successfully complete a task, and resources required during the task, which could also require special



B)

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...
<camunda:inputParameter name="machineUrl">https://paradigma.hs-aalen.de/api/types/machines</camunda:inputParameter>
<camunda:inputParameter name="machine">Roller</camunda:inputParameter>
<camunda:inputParameter name="rulesUrl">
      https://paradigma.hs-aalen.de:8180/kie-server/services/rest/server/containers/instances/
</camunda:inputParameter>
...
```

Fig. 2. A) CARX context data model B) Camunda CARX XML snippet

qualifications or hazard clearance. The information required for AR support is defined in the AR Context of the Task Context.

AR Context. The AR Context provides all information to display AR relevant elements to the workers during task execution, providing them with assistance and guidance (R5) while supporting workflow control from within the AR Client. The context itself is split in two parts, the BPMN-AR Context and Template AR Context (Fig. 2A). BPMN AR displays the configuration defined during process creation, while Template AR is predefined in the AR templates.

4.2 CARX Framework Realization

To connect the sensor data to the system, all IIoT devices are connected to the Mosquitto broker and provide their data regarding system-wide topics. If the information has to be shown to a worker during a task execution, the AR client can subscribe to the topic and display the latest sensor values. The information about which sensor value is required and to which topic it is published is contained in the machine's data store. To retrieve this metadata, the CARX machine information contains an ID that can be used by the framework to send a request to the machine data store and receive all required data. If sensor values are required during validation of rules defined in a rule set, the framework retrieves the latest sensor data from the Mosquitto broker and sends it, together with the rule requiring validation to the rule engine. In this case, the information as to which sensor values are required, is provided by the parameters values of the specific rule and the machine's properties provided in the Task Context.

To support modeling IIoT context-aware AR-supported processes with our model (Fig. 2A), we extended the Camunda Modeler. This enables context and CARX processes to be modeled in a guided manner without additional software. The required extended context information is then saved as Data Objects inside the XML Camunda Process template (cf. Fig. 2B). The integration of the context in the modeler is shown in Fig. 3. The Global Context (Fig. 3 A(1) and Fig. 3B)) can be added via the new tab in the top toolbar, clearly separating it from process-specific configuration. The Task Context and Process Context can be edited by selecting either a task or process and selecting the Context tab (Fig. 3(2)) of the respective element. The Task Context is displayed in Fig. 3C while the Process Context is identical to the Global Context in Fig. 3B. This mirrors the default Camunda Modeler control and eases the use of the extension.

Various facets of the realization address context integration. The URLs defined in the Global/Process Context define where to retrieve specific context information. In the Task Context, the required meta data is requested from the data stores defined at their URLs via REST and directly displayed in the modeler (as seen in Fig. 3 for the Machine or Group field). Both consist of dropdown values, displaying all possible types of Groups this task could be assigned to or Machines that could be used during task execution.

The AR client is realized with the Unity Engine and the AR Foundation framework [3], utilizing its support for the major device-specific AR frameworks ARCore, ARKit, Magic Leap, and HoloLens. According to the CARX concept

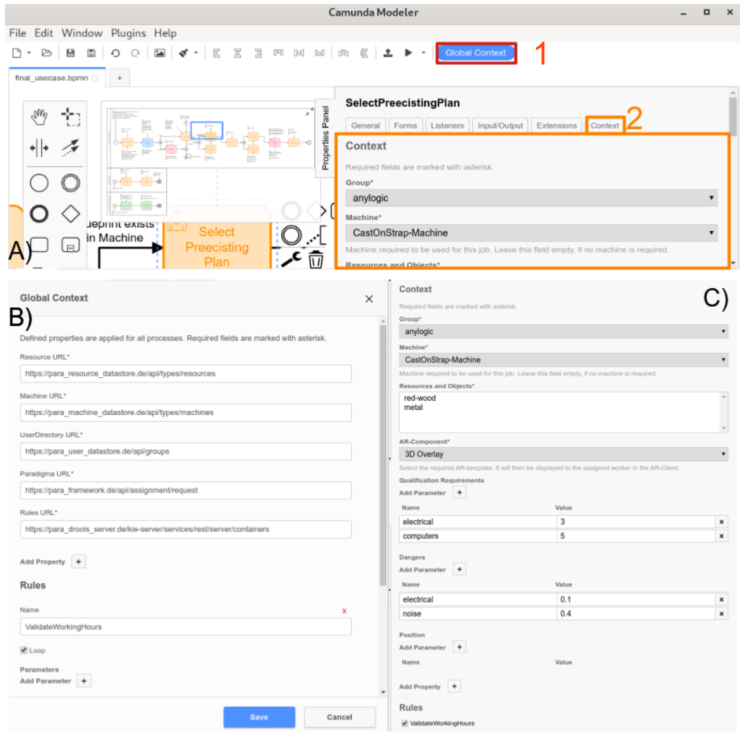

Fig. 3. The context-aware Camunda modeler

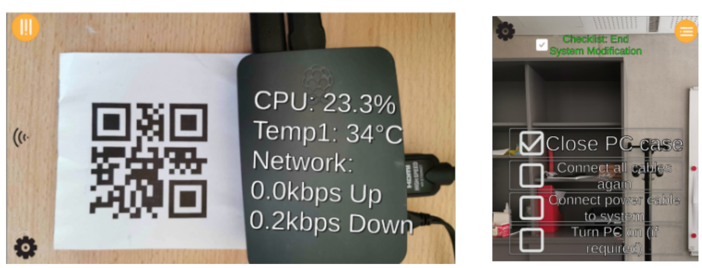

Fig. 4. AR image of live sensor data (left) amd task checklist (right)

in Fig. 2A) we implemented eight possible templates ranging from the display of simple images or documents to checklists (cf. Fig. 4), handling business logic, and 3D overlays, showing complicated procedures. Further, the AR client can display relevant real-time sensor values as shown in Fig. 4. Enabling the worker to react to changes in relevant machine values without the need to constantly check the machines directly or use different software interfaces provide direct IIoT context-aware AR support (R5). Adding further templates to the AR Context is currently supported by extending our Unity AR build.

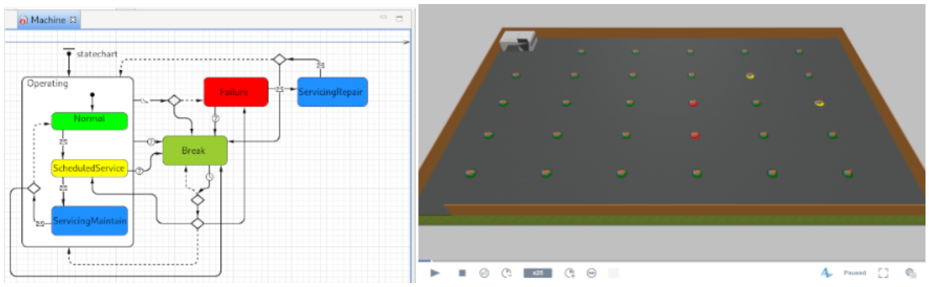

Fig. 5. AnyLogic simulation showing machine model and factory with machine state

5 Case Study

A case study using a simulation with AnyLogic [1] is used for the evaluation, due to COVID-restricted industrial access. A partial overview of the simulation structure can be seen in Fig. 5. All required systems for the case study (including the Camunda engine) were started with a single docker-compose file on a Linux server, minimizing deployment effort. This simulation consists of the maintenance and repair of 28 cast-on-strap machines in a factory hall using permanent employee and external specialist agents. The machines require a scheduled maintenance every 12 and require some kind of repair every 24 operational hours. If such an event is triggered, a worker is assigned via Staff Assignment Rules in a BPMS, the agent prints required information, navigates to the machine, checks if it is safe to perform the task (a machine has an oven - a potential hazard), uses the printed checklist, and walks back to a desktop client, completing the task via the BPMS interface. With CARX we utilize an intelligent assignment service that evaluates safety and other constraints, and further provide guidance to workers via AR-support and IIoT context awareness. OPC-UA was used for transmitting machine data to the system and workers. The simulation showed that by utilizing context, CARX reduced operational costs via better utilization of permanent employees versus external specialists; machine repair downtime was reduced, but at slightly higher maintenance delays.

The agents and machines were added to their respective data store. The maintenance and repair CARX processes are shown in Fig. 6 for AristaFlow and Camunda. The worker is assigned by the CARX BPMS IIoT Extension Framework, which pre-checks for any safety hazards, and is then guided by an AR navigation overlay to the machine while the temperature of the oven is displayed in the AR goggles as in Fig. 4. Fig. 7 shows AR preview in the Modeler (AR content was scaled/cropped to better recognize the checklist), where AR content such as AR checklists (e.g., for maintenance, cf. Fig. 4) or AR-based overlay and instruction documents such as multimedia video, audio, or PDF (e.g., for repair tasks). The worker can directly interact with the process in the AR client, so no additional software client is necessary to inform the BPMS.

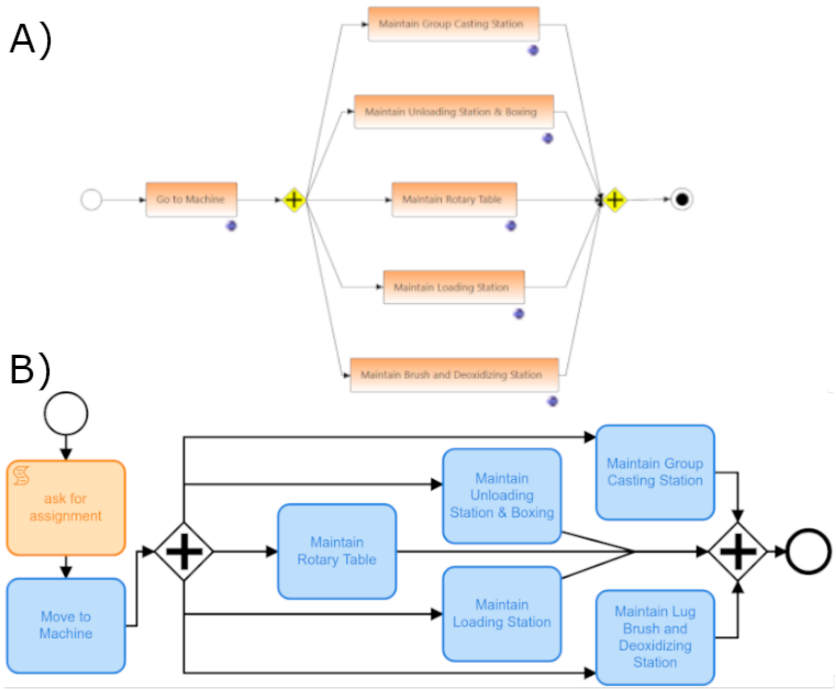

Fig. 6. CARX process maintenance in A) AristaFlow and B) Camunda

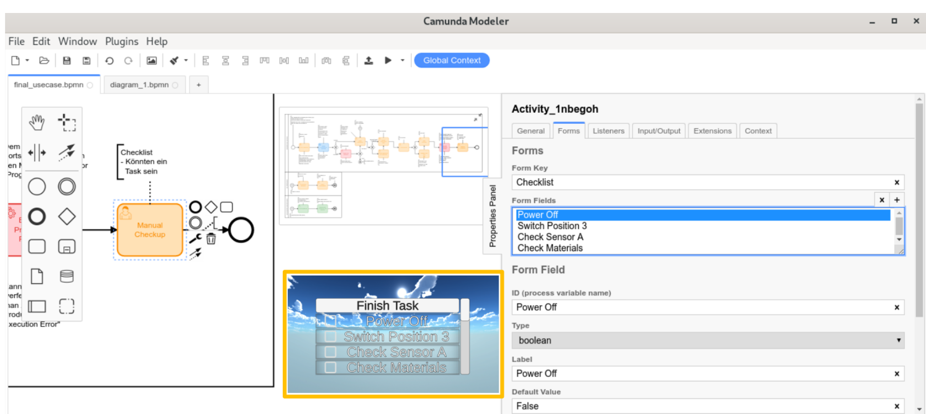

Fig. 7. AR preview in the BPMN-CARX extension in Camunda modeler

By directly including AR, IIoT context, and business processes via the BPMN-CARX modeling extension, the case study shows the feasibility and practicality of integrating AR and IIoT context within conventional process modeling. The CARX process enactment via our CARX BPMS IIoT Framework integration with two BPMSs shows the feasibility of our generic BPMS extension concept towards more holistic and comprehensive integration of AR and IIoT context in BPM automation process enactment. While the case study is directly applicable to real world factories, the navigation for each factory must be addressed individually.

6 Conclusion

This paper described CARX, our holistic solution concept for seamlessly integrating context-awareness for business processes in IIoT settings, visual AR support within business processes, and additional process modeling capabilities in BPMN. Our generic integration approach enables existing BPMS to be easily extended with AR and IIoT capabilities. Natural modeling support for context-aware and AR business processes is supported with the CARX-BPMN extension, conforming to current BPM norms without a totally new notation. AR and IoT domain context information can be integrated during process modeling, real-time sensor data provisioning to the system and workers during task execution is supported, and rule execution is incorporated to utilize real-time IIoT sensor data values. Worker tasks and resources can be assigned in an intelligent way by utilizing the extended comprehensive context. Support for AR is integrated during business process enactment, without the need for AR users to switch between software solutions or platforms. Context-aware AR support to workers provides data, assistance, and guidance during their tasks and next assignments and updates them on the latest data from relevant IIoT devices. BPMN-CARX links IIoT context, process enactment, and BPMN to support implementation of new IIoT context-aware processes or upgrading preexisting IIoT processes. Our realization demonstrated its feasibility, integrating with and extending two commercially available BPMS. The case study showed its applicability in a simulated smart factory environment utilizing OPC-UA, IIoT, and AR.

Future work includes: the optimization of our context-integrated process editor to improve its appearance and usability; integration of our framework and CARX with further BPMSs; further improvements to the CARX BPMN 2.0 extension; integration of human-robot colaboration concepts (e.g., [16]); and a comprehensive empirical evaluation in an industrial environment.

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