# Accelerating Industrial IoT Application Deployment through Reusable AI Components

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***Abstract*—The Internet of Things (IoT) is penetrating almost all sectors of the global economy, addressing a wide range of opportunities by applying different Artificial Intelligence (AI) tools to IoT data. Due to the diversity in challenges and applications, IoT solutions are often bespoke and highly domain specific. With the surge of IoT applications, this approach to solutions becomes very costly and time consuming if there is a lack of reusability and replicability across different IoT sectors. This work presents a step towards reusability of IoT solution components applied to Industrial IoT (IIoT). We start from the challenging position of two unique AI-driven applications stemming from two separate IIoT verticals - applications which may be realized using the same components. We identify a set of application independent reusable AI-centric components and show how they can be orchestrated into the unique IoT applications. Our approach shortens the time to market and reduces costs for developing IIoT solutions, and opens a path towards reusability and replicability of IIoT components, thus accelerating the IoT market uptake.**

***Keywords*-Internet of Things (IoT); Industrial IoT (IIoT); reusable components; application development; orchestration; smart contracts; Artificial Intelligence (AI) planning; condition monitoring**

## I. INTRODUCTION

IoT can be applied in virtually any sector of the global economy or society, and in each sector there is an abundance of application examples that address different use cases. The application diversity is very wide and problem solving easily becomes niche and highly domain specific. The prevalent practice today is to build IoT end-user applications on top of an IoT Application Enablement Platform (AEP) that abstracts a set of common functions from the specific application logic [1]. Even though building applications on top of an AEP enables reuse, it is limited to either infrastructure services such as connectivity and device management, or basic application logic. Specifically, Industrial IoT (IIoT) end-user applications are about insights and automation of business processes using various Artificial Intelligence (AI) and Machine Learning (ML) models and algorithms, and tend to be complex, thus requiring highly capable application logic [2]. Due to the application diversity, developing IoT applications using traditional software development and engineering practices can be costly and time consuming if there is no or little reuse of software and solution practices across the range of applications in different sectors.

Our proposition and overall approach is to identify replicability of applications by identifying recurring use case patterns, and reusability of different AI-based software components that are part of an IoT AEP, advancing the work presented in [3]. This process involves the identification of a set of reusable software components with an appropriate level of abstraction, with each component being application and domain independent, yet having well defined purposes. Further on, by orchestrating the components according to an appropriate blueprint, the particular application is realized. This paper focuses on the reusability aspect. We demonstrate the reusability of four different and concrete AI-centric application-independent components by constructing two diverse IIoT applications from two separate industry domains: Smart Logistics from Intelligent Transport Systems (ITS) and Predictive Maintenance from Manufacturing.

The rest of the paper is structured as follows: in Section II we present the two use cases and identify the reusable components, which are described in more detail in Section III. In Section IV we present the related work, and in Section V we highlight the main findings and point to the future direction.

## II. INDUSTRIAL IOT APPLICATIONS WITH REUSABLE COMPONENTS

The selected IIoT applications, Smart Logistics and Predictive Maintenance, are rich in terms of involved actors, associated data and their process flow interactions. Actors include suppliers, purchasers, logistics providers, transportation vehicles, containers, pallets, manufacturing machines, robots, workforce etc. These actors are both consumers and producers of data employed by the reusable components. Next we present the two applications in more detail.

### A. Smart Logistics

A logistics application typically implies the movement of goods exchanged between participating stakeholders . It also involves the tracking and monitoring of these goods,


978-1-7281-2171-0/19/$31.00 ©2019 IEEE

including handling and environmental conditions . What IoT will bring to logistics is a fully automated and adaptive end-to-end process that provides optimization across all involved actors[1]. Figure 1 provides an overview of the smart logistics application together with the components and actors involved.

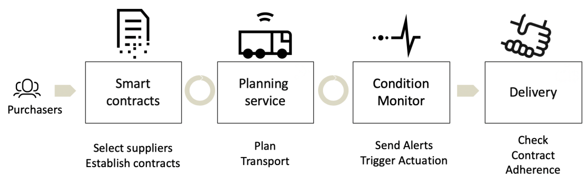


Figure 1. Smart Logistics overview

We identify the following components specific to the logistics solution, which are depicted in Figure 2: a) Smart Contract (SC) to provide an optimal selection of suppliers for a given purchase, and to monitor and verify the fulfillment of the contract along the process, b) AI Planner (AIP) for computing an optimized routing of goods by the distribution network of trucks, containers, and warehouses according to conditions established in the contract, c) Analytics Component (AC) to define how the system is expected to behave according to the conditions of the contract and to provide the valid models to the Condition Monitor (CM) and AIP for any given situation and d) Condition Monitor (CM) to provide a system that continuously monitors the products and notifies the SC and AIP when the conditions are deviating and triggers actuation when needed. More details on a specific implementation of a Smart Logistics solution are available in [4].

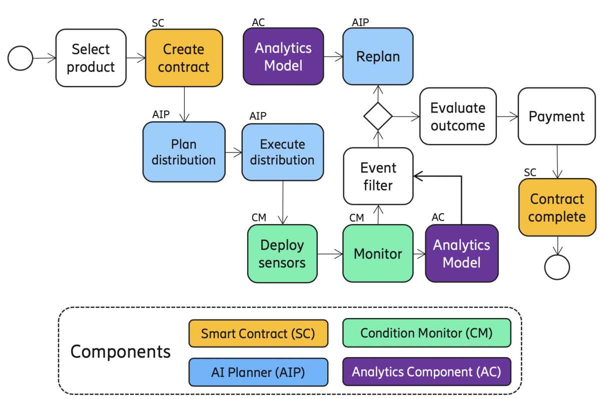


Figure 2. Smart Logistics flow and constituting components

## B. Predictive Maintenance

Predictive Maintenance in manufacturing is used to predict when machines in a production line need servicing, either due to unexpected machine failure, or due to expected wear of machine parts, and plan for and execute the maintenance with a minimized disruption to the production plan. The root cause of 80% of the problems which trigger maintenance is almost never identified [5], so applying Predictive Maintenance techniques in order to solve the above mentioned problems is a necessity to avoid cost inefficiency. In addition to this, pre-emptive detection of unexpected failures can help in achieving improved operator safety in a factory environment. Figure 3 gives an overview of a typical Predictive Maintenance application.

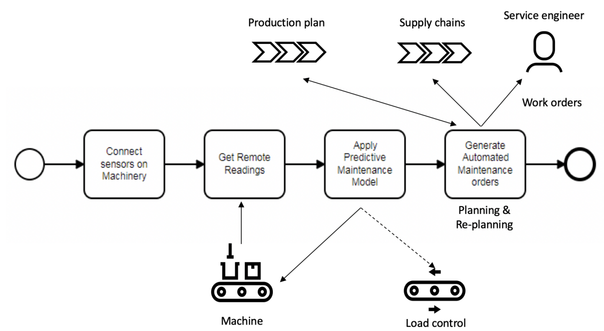


Figure 3. Predictive Maintenance overview

Figure 4 depicts the components identified in the Predictive Maintenance solution: a) Analytics Component (AC) to provide models to predict the type of service and an appropriate time window for the service of a machine based on input received from Condition Monitor (CM), b) Condition Monitor to provide continuous monitoring of all machines and robots and notify the AIP when the maintenance has to be planned, c) AI Planner (AIP) to optimize the process of maintenance by reducing the production line downtime taking into consideration the production line load schedule, resources, spare parts availability and d) Smart Contract (SC) in-conjunction with the respective Enterprise Resource Planning (ERP) systems to select subcontractors required to perform the maintenance given the cost and estimated time.

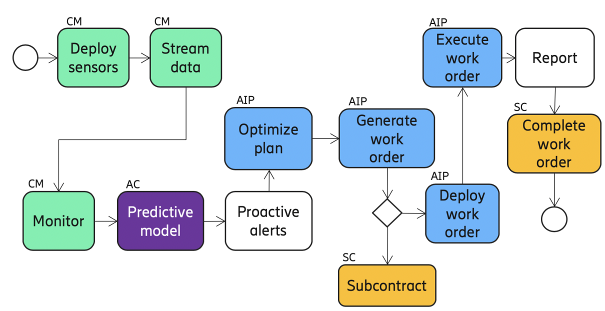


Figure 4. Predictive Maintenance flow

In both examples, we observe the four components solving particular problems like planning, monitoring etc. recurring

[1]https://www.forbes.com/sites/insights-inteliot/2018/06/14/logistics-4-0-how-iot-is-transforming-the-supply-chain/

in the applications, but that they are orchestrated differently depending on the application. It demonstrates the reusability aspect, and that the application differences lie in the process flow. In the following section we will present these components in more detail.

## III. Description of reusable components

In this section we present the reusable components identified in the two Industrial IoT (IIoT) applications. Our focus is to: a) describe why the component presented is selected for reusability, b) describe how the reusability could be enabled and which generalizations and specializations are needed to provide the interfaces and c) present what are the potential or existing implementations.

### A. Smart Contract (SC)

In 1997, Nick Szabo described a smart contract as a set of promises, specified in digital form, including protocols within which the parties perform on these promises [6]. The SC component helps to automate the entire smart contract life-cycle using a blockchain based substrate encompassing contract negotiation, partner selection, contract finalization,contract enactment, contract monitoring and issue resolution during contract enactment. This component can be modeled according to the business needs of the application and setup to achieve the above mentioned tasks seamlessly. Advancements in generation of smart contracts from existing artifacts like natural language, business process, state machines, non smart-contract code makes it possible to reuse the generic object models facilitating reusability.

In the Smart Logistics use case, the SC identifies and recommends suitable suppliers for the purchaser and enables the negotiation of pricing and contract terms with these suppliers. Once the contract terms are accepted by both suppliers and the purchaser, a purchase order is created. Features such as quality and the delivery time are considered as the key obligation terms in the contract and are provided as an input to the CM module. More details on the functionality of this component can be found in [4].

### B. AI Planner (AIP)

This is a component consisting of two inter-related pieces: (a) an AI planner and (b) an execution engine. The AI planner is often used in creating a required action sequence for a given intent. In order to provide high degree of automation, the intent needs to be specified in some formal way and similarly the available actuations also need to be specified in a related way so that the system may derive the plan. In our work we use Planning Domain Definition Language (PDDL) [7] to specify the intention and the action semantics. A standard AI planner is then able to convert the intent to an action sequence. The advantage is that that the planner itself is domain independent, however the inputs to the planner require some degree of modeling. The execution engine is closely related to the planner. It takes a plan and then dispatches individual steps so as to orchestrate its execution. It also monitors both the plan itself to see that the agents it is dispatching to are making progress, and also it monitors the individual actions themselves to make sure it has the desired effect. Since we aim that the component would be reusable, we require a few additions to it. We need to have knowledge reflecting the state of the world and sufficient details of a formal model to enable planning. Additionally we need to have an API driven interface and our experience suggests a REST based interface is suitable for the task.

### C. Condition Monitor (CM)

The digital transformation starts by deploying sensors and monitoring any relevant characteristics to the IoT application in question. Gathering data and orchestrating all sensors is a task on its own. The IoT ecosystem is heterogeneous and there is a variety of devices in terms of software and hardware capabilities. In addition to this, the devices use a large number of communication protocols both in short and wide range. Once the data is collected from the different sources, specialized processing is required in order to be able to perform the computation and retrieve insights and knowledge.

Reusability can be achieved by providing a flexible and configurable component that supports data collection, transformation and analytics. This enables different types of applications with a simple definition of the data and intelligence pipeline.

An implementation of the CM is described in [4] as an abstraction layer built on top of the Analytics Component, which exposes a REST-based interface.

### D. Analytics Component (AC)

Designing reusable ACs is needed to support other components in different solution blueprints in the path to achieving replicability. ACs are also necessary to scale Internet of Things (IoT) operations, especially when multiple analytics nodes need to be distributed for coping with the large variety of pools of heterogeneous devices required in different applications. Reusability can be enabled in AC by ensuring the component can offer supporting features for different types of incoming data and analytics requests.

Architecture-wise, REST-based query front-ends capable of routing analytics requests to appropriate analytics models served either in Cloud or at the network Edge are recommended. This approach enables integrating advanced data routing decision-making into analytics model server capable of handling meta-data describing different types of incoming data (e.g. numeric, symbolic, structured), of processing requirements (e.g. batch, stream), of data flow characteristics (e.g. time-stamped vs. partially-ordered data), and of analytics parameters (e.g. prediction horizon, scalar vs. interval-valued, deterministic vs. probabilistic output). Hiding such complexity in query front-end allows for better isolating an AC so it can be reused in different domains.

One example of AC was introduced within the context of [4]. An AC was realized using a distributed system based on an actor-based model which provided data and intelligence composition across the whole IoT landscape, from edge gateways to cloud datacenters.

## IV. Related work

Mineraud et al. [8] make an extensive study of the IoT platforms identifying their capabilities and limitations and also the availability of the IoT marketplace. One of their important findings is that reusable components are seldom supported in IoT platforms, and this is an obstacle in treating the IoT domain as a single ecosystem.

Current research of reusable IoT components targets the lower layers of the stack, where connectivity and device management are the main concerns. To the best of our knowledge, reusability at the higher layers of IoT is still an unexplored space. Bandyopadhyay et al. [9] address reusability in IoT from a middleware perspective, where heterogeneous domains are integrated. We argue however that existing IoT middlewares do not tame IoT application development complexity but rather enable plug-and-play capabilities for on-boarding devices and data.

Christidis and Devetsikiotis [10] perform a study on the feasibility of employing smart contracts in IoT applications. They identify issues in current implementations such as lower transaction processing throughput compared with traditional databases, but also highlight the benefits such as cryptographically verifiable automation of workflows. In a recent exercise, AI planning is used in a reusable fashion in creating system integrated within larger applications [11]. Zaki et al. [12] provide an early example of how predictive analytics can be used to anticipate plan execution failures in order to building monitors that trigger alarms for re-planing and mitigation actions.

## V. Conclusion and future work

This paper presents an approach to create IIoT solutions in an AI-centric manner based on reusable components to reduce the time and costs for being applied in diverse sectors. Taking the logistics and manufacturing scenarios as examples, a set of decoupled, flexible, and configurable AI-centric IIoT components have been proposed, namely the Smart Contracts, the AI Planner, the Condition Monitor, and the Analytics Components. Instead of providing a full-stack static solution, these components can be adapted and reintegrated for application solutions in various sectors.

The future work will continue with investigating the application replicability aspects via identification of recurring patterns and arriving at domain independent blueprints, including the use of process engineering technologies for composition and orchestration. Further investigations will be carried out to define models for matching stakeholder needs with solution blueprints and reusable components.

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