BUSINESS PROCESS MODELLING FOR INTERNET OF THINGS

A THESIS SUBMITTED TO AUCKLAND UNIVERSITY OF TECHNOLOGY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF PHILOSOPHY

Supervisors

Dr Jian Yu

Dr Alan T Litchfield

February 2018

By

Kusum Pradeepika Ratnayake

School of Engineering, Computer and Mathematical Sciences

Abstract

Business process management is an integral part of a business. Internet of things (IoT) is an emerging and fast improving technology. Traditional business process models have not given much attention to IoT. Yet, it has become a necessity to incorporate IoT systems and components when modelling business processes to obtain the many benefits IoT offers. Therefore, we aimed to fill this gap by identifying business process modelling requirements for IoT, i.e. IoT modelling elements and to demonstrate the applicability of them in a business process model. We identified seven key IoT modelling elements after deriving them from a typical problem scenario. We investigated the properties of IoT components in detail, illustrating them in class hierarchy design and describing common properties in super classes. We extended BPMN 2.0 in designing these IoT elements and implemented them in an IoT related business process model. We also developed a web based IoT aware BPMN and XPDL editor tool by extending an existing BPMN editor. Furthermore, we evaluated the applicability of this IoT aware BPMN modelling tool with a case study.

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the qualification of any other degree or diploma of a university or other institution of higher learning.

[illegible]

Signature of student

Acknowledgements

I would like to thank Dr Jian for accepting to supervise me, for his guidance, patience and valuable advices throughout this work. Without his support, this thesis would not exist.

I would like to thank Dr Alan for his help including Latex.

I wish to thank my family for assisting me financially and for motivating me.

I would also like to thank Terry Brydon, Karishma and Jenny from PhD team, Bumjun Kim for his continuous help in technical issues, Abid Shahzad (PhD student) for encouraging me to work and AUT security staff for their visits when we work during weekends.

Finally, I would like to thank AUT as a whole.

Chapter 1

Introduction

1.1 Background and Research Objectives

The term, *Internet of Things* was first introduced by Kevin Ashton around a decade back. It has been predicted that 50 billion IoT devices would be introduced to the world by 2020 (Holler et al., 2014) and there would be a trillion IoT devices by 2030 (Gate, 2016). Basic components of IoT are devices, which collect information such as *sensors*, *identifiers*, which recognise the source of data collection, *software*, which analyzes collected data and *internet* for communication. IoT can be taken as a network connecting physical elements with help of these components. Therefore, in (Rayes & Samer, 2017), IoT is defined as "IoT is the network of things, with clear element identification, embedded with software intelligence, sensors, and ubiquitous connectivity to the Internet". IoT facilitates physical objects (things), which are uniquely identifiable to connect via internet and controlled remotely. This connection between the physical world and virtual world provides the many benefits that IoT can offer. There are three basic requirements for IoT, namely uniquely identifiable thing, method to collect information from things, e.g. sensors and the communication capability and the method of communication. With these requirements in place it should be possible to monitor things from anywhere in the world. There are many benefits from monitoring things remotely over the internet such as checking a patient's blood pressure while she is home. Things in IoT include anything and everything such as machines, people, cars, buildings, trees and animals with connecting devices or capabilities. IoT can be identified in two ways, which supports humans (HIoT) and which supports Industries (IIoT). IoT promises many benefits for businesses such as automatic sensing and analysing products or services and making decisions for automatic action.

Sensor is the mostly used IoT element in the world today. Sensors are used in a variety of ways such as in agriculture, retailing, manufacturing and transportation services just to name a few. Among others, RFID (Radio Frequency Identification) technology has become very popular in IoT applications and used in many ways in businesses. RFID is a mechanism to capture information from physical objects or things and use it in RFID based IoT applications. Examples for RFID applications are access control management where RFID tags embedded in identification badges, passports containing RFID tags, health care systems, logistics and supply chain management and animal tracking.

Companies are already using IoT to reduce costs and improve productivity. An example of a latest IoT application is *Workforce Optimization* introduced by Bluvision, owned by HID Global (Global, 2017). This application applies identification and sensing technologies and detects location awareness of the workforce by using BLE (Bluetooth Low-Energy), Wi-Fi and Cloud technologies. This simple to implement IoT application consists of cloud service, portals and Bluetooth enabled smart cards. These cards are used for physical access as well as for indoor location detection.

When it comes to business processes, Business Process Management (BPM) and Business Process Management Systems (BPMS) have also been in existence for decades and they gradually have evolved to where it is today. BPM has its roots in 1980s with the start of *quality thinking* (Jeston, Nelis & Davenport, 2008). Then the concept of *process thinking* started and Business Process Reengineering (BPR) supported this in early 1990s. BPM emerged to the world as consequence of process orientation, which was popular in 1990s (Weske, 2012). From process-oriented techniques, it has evolved to process automation over the subsequent years (Meyer, Ruppen & Hilty, 2015). BPM is based on the theory that a company needs to go through a certain set of activities to manufacture its products and BPM improves these processes by organising these activities. In addition, technologies and concepts adopted by business administration and computer science have had a major impact on BPM.

As cited in (Van Der Aalst, La Rosa & Santoro, 2016), workflow management systems (WFM) influenced business process automation in business enterprises leading to business process reengineering (BPR) in the 1990s. This resulted in the emergence of commercial WFM systems such as IBM MQ Series Workflow, Staffware and COSA around 1995. Although, similar systems such as office information (OI) already started in the late 70s. Office information systems were based on process models and operational processes of OI systems such as Officetalk and SCOOP were modelled using Petri nets. These systems and early WFM systems were restrictive and did not provide much support for management involvement in the processes.

Business process management (BPM) started as an evolution of WFM systems. WFM systems mainly focus on process automation whereas, BPM aims for wider scope covering process automation, process analysis, operations management and organization of work. In addition, BPM aims at business process improvement not necessarily requiring new technologies. When analysing process models, the management may come up with a plan to reduce costs and to improve services at the same time. Moreover, in BPM operational processes are controlled and managed by software systems named business process management systems (BPMS). BPMS are flexible and can connect with other technologies such as cloud and mobile as well as some legacy systems.

As cited in (Barros, Gal & Kindler, 2012), most businesses will be process driven by 2020 making business process management to play a major role. A business model by using a suitable modelling language should represent the business processes. The modelling languages can range from visual notations, for example, BPMN to more formal representations such as petri nets, CCS, Pi calculus, etc.

In the traditional business process life cycle, modelling and executing IoT related processes were not well supported (Sungur, Spiess, Oertel & Kopp, 2013). IoT systems consist of products with electrical or mechanical parts and act as intelligent systems connecting software, hardware, control sensors and data storage, etc. in different ways. This type of processes need to be able to illustrate in business processes.

Therefore, it is beyond question that IoT systems need to integrate in business processes in order to derive its many advantages. Thus, it is a fundamental requirement to find out how IoT systems can be modelled in business processes to obtain the benefits it promises. The objective of this research is to help fill this gap by examining existing research in this area and contributing to it by identifying the business process modelling requirements for IoT. We choose existing scholarly articles, which aim to model IoT systems with business processes by extending BPMN. First, we study and evaluate each methodology introduced in them. Next, we introduce a problem scenario, which derives seven business process modelling requirements for IoT (IoT modelling elements). We design each identified IoT modelling element by extending BPMN 2.0. Moreover, we practically implement a web based IoT aware BPMN editor by extending an existing BPMN editor to illustrate the application of these IoT modelling elements. In a case study, we demonstrate the capability of this editor with an IoT related application process that models all seven IoT modelling elements identified.

1.2 Research Questions

Modelling IoT based systems with business processes is not successfully achieved yet even though there are existing literature work in this area. Therefore, it will be useful to address this issue and in addition, to contribute to the existing literature work. This thesis aims to address the following questions:

- What are the new business process modelling requirements and associated elements for IoT?
- How to extend BPMN to support modelling these new elements and build a software tool to support IoT related process modelling?

1.3 Research Contributions

- We identified seven key IoT modelling elements as requirements for business process modelling for IoT. We derived these elements from a typical problem scenario in IoT.
- We investigated the properties of IoT components in detail and illustrated in class hierarchy design, where common properties were described in super classes.
- We designed these IoT modelling elements by extending BPMN 2.0 graphical model as well as the meta-model and implemented them in an application. We also implemented a web based IoT aware BPMN editor tool with XPDL editing capability by extending an existing BPMN modelling tool. Furthermore, we evaluated this tool using a case study.

1.4 Thesis Structure

This thesis consists of five chapters. Literature review is carried out in Chapter 2. We talk about IoT in more detail in this chapter followed by more information on business process models and business process modelling for IoT. In the final section of this chapter, we present BPMN modelling frameworks for IoT. We have chosen seven frameworks of past researchers who have contributed to this area of work and describe their work in detail. In Chapter 3, we introduce a running problem scenario and illustrate its business process model in BPMN 2.0. Using this scenario, we derive business process modelling requirements for IoT and present them. We identify seven business process modelling requirements for IoT. They are sensor, actuator, reader, collector, event streaming, specific data object and intermediary operation. We describe each of these identified IoT modelling elements in detail and graphically illustrate categories of each element if applicable. We also divide each element into their sub elements wherever applicable illustrating in class diagrams with inherited properties. In Chapter 4, we practically implement a web based IoT aware BPMN & XPDL editor tool to incorporate these new IoT modelling elements we have identified as business process modelling requirements for IoT. In Chapter 5, we evaluate our implementation with a case study. We use this tool to model an IoT related application process in BPMN, which incorporates all identified IoT modelling elements. We further evaluate this work by comparing with similar work in the literature. The final chapter, chapter 5 concludes our work.

Chapter 2

Literature Review

2.1 Introduction

In this chapter, we discuss the literature reviewed. This chapter comprises of five main sections. Section 2.2 is allocated for describing internet of things in more detail with its relevance to our research. In section 2.3, we further explore business process management mainly describing process modelling. In these two sections, we try to elaborate both areas in more details in trying to be in line with our research interest. However, our focus is on the last section, section 2.4. In this section, we carry out a discussion of some chosen scholarly work on business process modelling for IoT. We have chosen seven BPMN modelling frameworks for IoT. We address each of them in detail, discussing their work and their contributions to business process modelling for IoT. In the summary sub section, we use a table to evaluate these frameworks against the IoT modelling elements they have introduced. In the final section, section 2.5 we conclude our work.

2.2 Internet of Things (IoT)

This section provides further information of IoT and is divided into subsections for easy reference. First subsection, 2.2.1 provides a brief history of IoT. In the second subsection, 2.2.2 we discuss IoT protocols and the subsection 2.2.3 is allocated for IoT technologies. In the final subsection, 2.2.4 we try to describe middleware support for IoT.

2.2.1 History of IoT

The businesses have been reaping benefits from the Internet since it emerged four decades ago in 1960s (Howe, 2016). Simultaneously, another technology, which digitally identify and manage things in the physical world started to emerge. That is the use of sensors, actuators, electronic tags, etc. to transfer physical world information via networks. A major difference between the *Internet* and *IoT* is that Internet represents a virtual world of services even though the content is physically stored in real servers. Whereas, IoT technology facilitates to interact with things in the physical world through the internet.

M2M (Machine-to-Machine) is a technology connecting devices via a network allowing communication among them without human interference (Rouse, 2010). M2M solutions facilitate remote monitoring and managing enterprise assets and the users to obtain information such as inventory levels. Organizations are embracing IoT solutions for their business needs for which they mainly depended on M2M solutions. The factors contributing to this trend are the rising need to obtain information on physical environment and its activities, technological advancements and improved networking capabilities and low cost of components, data collection and processing (Rayes & Samer, 2017).

2.2.2 IoT Protocols

Another important aspect of IoT is its protocols and networking technologies. Some of them are RFID (Radio Frequency Identification), low power wireless protocols such as NFC (Near Field Communication) and BLE (Bluetooth Low Energy), LTE (Long Term Evolution) Advanced, and Wi-Fi Direct (tutorialspoint.com, n.d.).

Radio Frequency Identification

RFID technology works using radio waves, which are a type of electromagnetic waves, in tracking and identifying RFID tags attached to physical objects. Unlike mechanical waves, electromagnetic waves can travel through media such as air, space and solid materials. Electromagnetic waves are similar to waves in the ocean having minimum wavelength size as a fraction of an atom and the estimated maximum wavelength size to be bigger than diameter of the planet (NASA, n.d.). RFID technology is capable of identifying objects, which are located at a distance without the need of line of sight, i.e. tags can be hidden from sight. Apart from unique identification details, FRID tags are also capable of storing additional information about the objects they represent. These tags survive in rough environments such as outdoors, with chemicals, high temperature and moisture. RFID technology not only can read information on a tag, it also is capable of measuring environmental conditions such as temperature.

Near Field Communication

NFC is a contactless communication standard with a short range (about up to four centimetres), based on RF technology (Center, n.d.). NFC technology has its roots in technologies such as contactless identification and interconnection (Minihold, 2011). NFC technology enables information exchange between two NFC enabled devices such as mobile phones, and between a mobile phone with NFC capability and a compatible contactless smart card with RFID chips or a reader, held within NFC range. Examples for some NFC based applications are mobile payments, secure logins, access control, peer to peer data transfer between NFC enabled devices such as smart phones, note books, cameras, etc. and ticketing.

Bluetooth Low Energy

Bluetooth Low Energy is a power saving version of Bluetooth technology developed for internet-based devices. Similar to Bluetooth, BLE also uses wireless technology in connecting with close by devices in its range. BLE allows wireless, short-range communication between devices with low battery power (Rouse, 2014). Power consumption during data transfer is an essential feature to consider when choosing a wireless protocol. BLE has a lower power consumption with a higher range than conventional Bluetooth (Weekly, n.d.). High-speed data transfer is another feature of BLE needing only five minutes of connection time to transfer data up to 100 metres. When there is no data transmission, the chips are in sleep mode and wakes up only when they receive signals. Some applications of BLE are wearables such as garments, wristbands, smart watches, shoes, etc.

LTE Advanced

LTE Advanced is a wireless communication technology and it is an advanced and standard version of LTE technology. It is capable of handling bigger data loads and is faster true G4 technology. Mobile carriers are eager in using LTE Advanced networks for mobiles due to its speed and reliability (Dashevsky, 2014)

Wi-Fi Direct

Wi-Fi Direct connects devices directly with each other without a wireless router. This functions as a P2P (Peer-to-Peer) connection not requiring a wireless router. For example Roku 3 remote controller (May, 2017) uses Wi-Fi Direct in communicating. The remote control connects to its own Wi-Fi network rather than to a wireless router and communicate with each other through the network. With Wi-Fi Direct, it is possible to connect to a remote wireless printer without its need to join any wireless network. Some applications of android devices are using its built-in Wi-Fi Direct facility.

Wireless Sensor Networks

Wireless sensor networks are networks of connected devices communicating via wireless links. These are sensor and actuator networks consisting of spatially distributed sensors in order to monitor environmental conditions such as sound, temperature, pressure, etc (Lee & Lee, 2015). It makes it more efficient to track movements, locations and environmental conditions of objects when WSN works together with RFID technology. WSN is a popular application in logistics involving transportation of temperature sensitive products. Other main applications of WSN are tracking systems, wind farms and systems involving preventive maintenance such as American airline's preventive maintenance services where sensors capture 30 terabytes of flight data.

2.2.3 Middleware Support for IoT

Middleware is software connecting the application layer and the operating system, in which the applications run on. Middleware facilitates communication and data transfer among distributed applications. A unique feature of that is functions hide the translation process (azure.microsoft.com, 2017). This feature of hiding technical details facilitates other IoT application developers who directly are not connected with the specific IoT application. The distributed nature of IoT applications involving different devices makes it necessary for middleware for new application development. For example, Global Sensor Network (GSN). GSN is a middleware platform for integrating heterogeneous wireless sensor networks. It facilitates sensor networks and data integration providing services such as sensor data querying, filtering, etc. (Aberer, Hauswirth & Salehi, 2006).

As cited in (Razzaque, Milojevic-Jevric, Palade & Clarke, 2016), in ubiquitous computing environment, IoT technology brings new challenges to developing IoT related applications while it may increase prevailing challenges. In such a situation, a middleware serves as a medium, which ease application development through common services it offers. A middleware integrates diverse computer and communication devices and supports interoperability within the applications run on these devices.

According to (Razzaque et al., 2016), four main components of IoT are WSN (wireless sensor networks, RFID, M2M (machine to machine) communication and SCADA (supervisory control and data acquisition). If a middleware to be fully functional, it should be able to integrate these four technologies to support various applications. Research on IoT middleware has been emerging since the recent past. However, most middleware proposed are WSN based and lacking full support for requirements of IoT applications. For example, such middleware does not support context awareness. Whereas, middleware proposals for RFID, M2M and SCADA are limited.

The authors propose a middleware for IoT by identifying main characteristics of IoT and the requirements of middleware for IoT.

Key Characteristics of IoT Infrastructure

- IoT devices generally use low cost computing platforms. In addition to sensors and embedded devices, IoT needs high end computing devices to perform tasks such as routing and data processing. Examples for various IoT devices are, high end computing devices e.g. SCADA front end processor, middle end computing devices such as onboard computing unit of vehicle for M2M communication, low end computing devices, wireless sensor and actuator networks and, RFID and NFC tags and devices.

- As IoT devices varies, the processing, memory and communication capacities vary as well in different levels according to the device type. For example, these capacities decrease from high end to low end devices.
- Interactions can happen in IoT applications when objects happen to be in another object's range of communication, which leads to spontaneous event generation. For instance when a smart phone coming to contact with a washing machine generating an event without user interaction.
- IoT is predicted to be consisting of ultra large scale networks with million or trillion nodes. Within an IoT environment such as a within a building, thousands of IoT devices or things can interact with each other. This interaction may result in large number of event production demanding proper event handling mechanism.
- Many IoT devices such as mobile devices connects through wireless networks using nodes. These are dynamic networks so the nodes may join or leave the network at any time. This environment fail to provide suitable infrastructure resulting unstable networks.
- Context awareness is an important aspect of IoT applications. Huge amounts of contextual data are collected and stored in context aware IoT applications. Context awareness can obtain through M2M communication with no need of user intervention.
- Intelligent devices, things, dynamic networks, systems, web services, SOA, EDA,

etc. of IoT can respond to environments in an independent nature based on the available context.

- IoT, similar to internet, consists of a distributed network globally as well as locally within application domain.

Main Characteristics of IoT Applications

- IoT applications extend to number of areas such as logistics, healthcare, smart environments, etc. needing different requirements and different architectures.
- IoT applications are generally real time e.g. Healthcare applications requiring real time service making delayed data or service useless.
- Xaas model of IoT is efficient and scalable making sensing as a service in WSNs.
- Interactive nature of IoT applications allowing access for anyone at any time in anywhere makes IoT applications and networks vulnerable to security attacks.
- Nature of IoT applications collecting individual information such as behavioural patterns, buying habits, travel, etc. may become a threat to individual privacy.

Requirements for IoT Middleware Support

A middleware connects the applications, operating systems and network communication layers by providing a software layer between these. In computing, a middleware typically provides a layer between system software and application software. When it comes to IoT, there is a huge diversification in system level technology as well as communication technology and a middleware should support both these aspects. Taking into account both the infrastructure of IoT and characteristics of IoT already outlined, some requirements for middleware in supporting IoT is introduced in (Razzaque et al., 2016). These requirements are two folded, services required of the middleware and supporting system architecture.

Service Requirements

Service requirements of middleware are divided into two groups, functional and non-functional requirements.

Functional requirements include, automated resource discovery, proper means to manage resources and application data such as sense data, managing many events present in IoT applications and code deployment management.

Non-functional requirements consist of scalability in accommodating expanding IoT services, real time service availability, reliability in operation of services, availability in all times, meeting security and privacy requirements, ease of deployment not requiring any expert knowledge and continuous support and improvement.

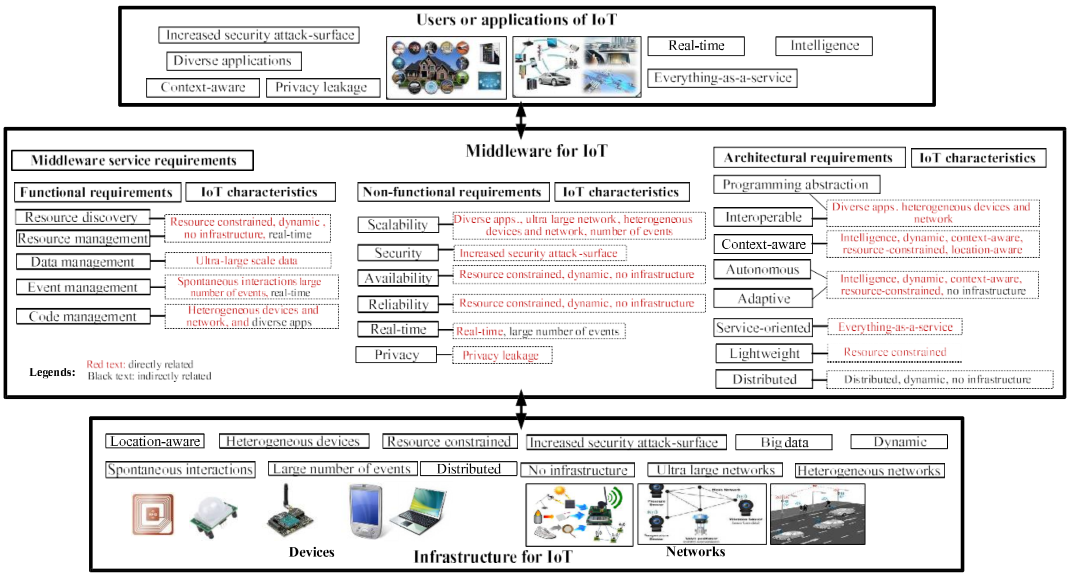

Users or applications of IoT
Increased security attack-surface
Diverse applications
Context-aware
Privacy leakage
Real-time
Intelligence
Everything-as-a-service
Middleware for IoT
Middleware service requirements
Functional requirements
IoT characteristics
Resource discovery
Resource management
Resource constrained, dynamic, no infrastructure, real-time
Data management
Ultra-large scale data
Event management
Spontaneous interactions large number of events, real-time
Code management
Heterogeneous devices and network, and diverse apps
Non-functional requirements
IoT characteristics
Scalability
Diverse apps., ultra large network, heterogeneous devices and network, number of events
Security
Increased security attack-surface
Availability
Resource constrained, dynamic, no infrastructure
Reliability
Resource constrained, dynamic, no infrastructure
Real-time
Real-time, large number of events
Privacy
Privacy leakage
Architectural requirements
IoT characteristics
Programming abstraction
Diverse apps. heterogeneous devices and network
Interoperable
Context-aware
Intelligence, dynamic, context-aware, resource-constrained, location-aware
Autonomous
Adaptive
Intelligence, dynamic, context-aware, resource-constrained, no infrastructure
Service-oriented
Everything-as-a-service
Lightweight
Resource constrained
Distributed
Distributed, dynamic, no infrastructure
Legends:
Red text: directly related
Black text: indirectly related
Location-aware
Heterogeneous devices
Resource constrained
Increased security attack-surface
Big data
Dynamic
Spontaneous interactions
Large number of events
Distributed
No infrastructure
Ultra large networks
Heterogeneous networks
Devices
Infrastructure for IoT
Networks

Figure 2.1: Relationships between the IoT's middleware requirements and its infrastructural and application characteristics.
Source: (Razzaque et al., 2016)

Architectural Requirements

Architectural requirements aim for application development. These include programming abstractions needed for application development e.g. interface level separation from the code, ease of interoperability of various IoT devices and applications, service based architecture providing enough flexibility, adaptability to dynamic environments, context aware architecture, autonomous devices, applications and technology interaction with no direct user support and lastly, distributed architecture to support geographically distributed resources. As illustrated in the Figure 2.1, many IoT middleware requirements identified have some direct relationship with IoT characteristics.

Middleware Frameworks for IoT

There are some existing middleware proposals by past researchers. Based on the design approach they follow, they may be categorised into different groups, such as event based, service oriented, VM based, agent based, tuple spaces, database oriented and application specific (Razzaque et al., 2016). Apart from these, there are hybrid approaches combining different design approaches.

Event Based Middleware

In event based middleware, interaction among all entities involved is by using events. This type of middleware is based on publish, subscribe pattern. Events are produced by the sending application (events producers) and are consumed by the receiving application (event consumers). Consumers need to register for events to obtain subscription. Subscribers are then allowed to access the publisher's database containing those events. This is depicted in Figure 2.2.

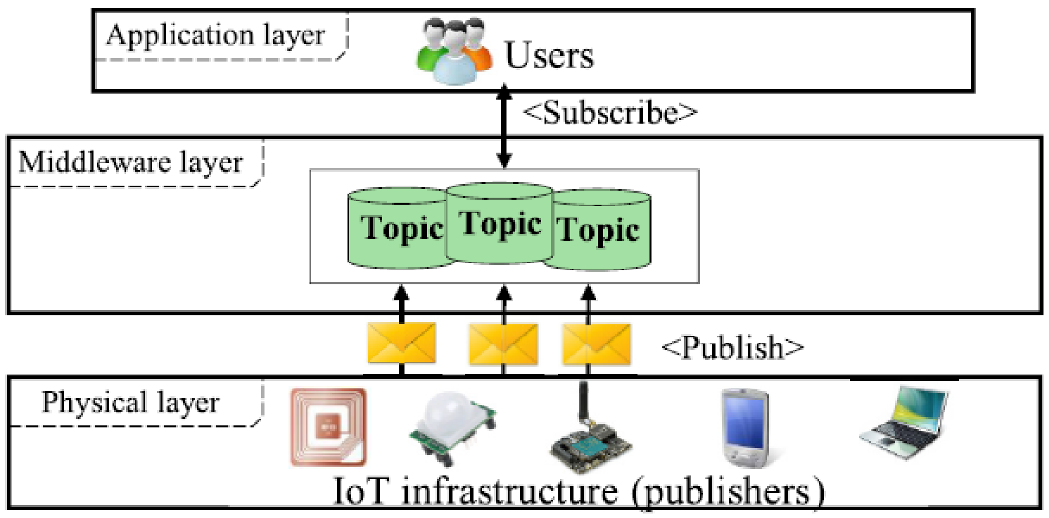


Figure 2.2: Design model for event based middleware.
Source: (Razzaque et al., 2016)

Service Oriented Middleware

Service oriented middleware facilitates building of software or applications as services. Features of service oriented computing (SOC), which is based on SOA (Service Oriented Architecture), such as loose coupling, reusability, composability and discoverability, provides benefits to IoT applications. Service discovery and composition is more challenging due to characteristics of IoT. Service oriented middleware ease these through relevant functionality for deploying, discovery, runtime access of services, etc. as shown in Figure 2.3. Service oriented middleware also facilitates adaptive service composition for unavailable services. These middleware can further divide as standalone middleware for IoT and cloud computing PaaS (platform as a service).

VM Based Middleware

VM based middleware facilitates high level abstractions in programming, adaptability, management, etc. In addition, it supports transparency of variety of distributed IoT

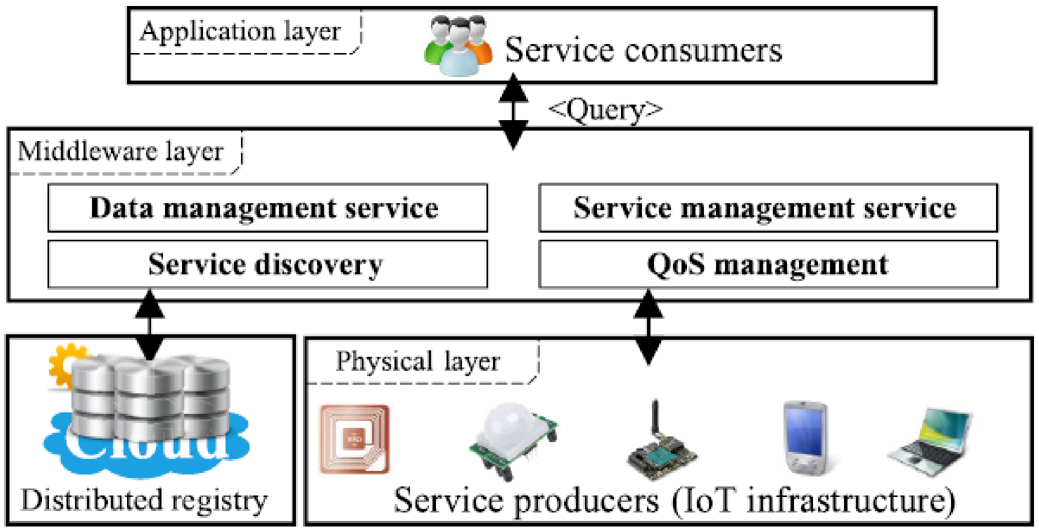


Figure 2.3: Design model for service oriented middleware.
Source: (Razzaque et al., 2016)

infrastructure. This middleware is designed to support safe application execution environment. Applications consist of range of modules, which are distributed through the network. Network nodes contain VMs interpreting the modules. VMs can be categorised as two types, middleware level and system level VMs. Middleware level VMs, which connect the operating system and the applications layer provide functionality such as concurrency to the OS. System level VMs, which act as substitutes for the OS or replacing it, make resources available for consumption.

Agent Based Middleware

In agent based middleware, applications are separated into modules to provide the distribution via networks by using mobile agents. The agents while transferring between nodes maintain the execution states. This feature provides the decentralised design facilitating some fault tolerance. These software agents can communicate with each other for data collection and any updates required for applications.

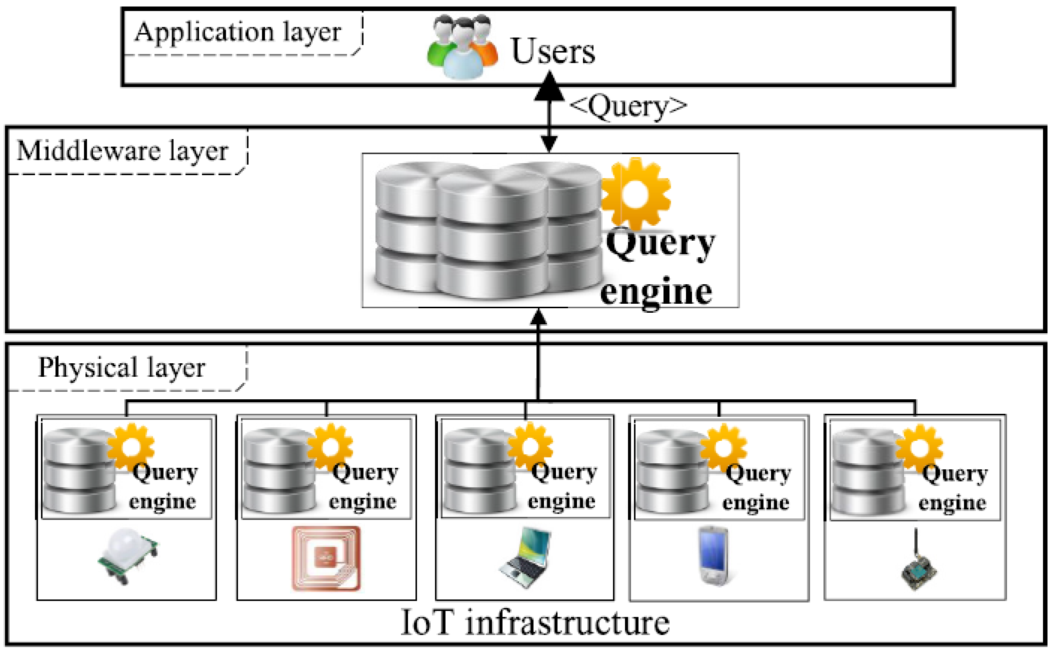


Figure 2.4: Design model for database oriented middleware.
Source: (Razzaque et al., 2016)

Tuple Space Middleware

In tuple space middleware, all members maintain their own local tuple space, i.e. a repository in the infrastructure. Concurrent access to tuple spaces are possible. A gateway contains a centralised tuple space containing all tuple spaces. Application interactions and communication take place through the central tuple space by writing and reading tuples as necessary.

Database Oriented Middleware

In database oriented middleware, virtual relational database system architecture represents a sensor network as 2.4 depicts. Applications can retrieve data by querying the databases using some type of SQL. Complex querying to databases is possible using a suitable query language. There is ongoing further research in this area focusing on distributed database systems to facilitate interoperability of systems as cites in (Razzaque et al., 2016).

Application Specific Middleware

In application specific middleware much importance is given to resource management for applications. This is achieved through an architecture that attends the requirements of the application domain by improving the network infrastructure.

2.3 Business Process Modelling (BPM)

Among other reasons, the main reason to model a process is to understand the process clearly by the people who model it and to make other people who are involved in the process (process participants) understand it the same way. This knowledge gained through process modelling is the initial step forward in conducting process analysis, process redesign and process automation. Further, process modelling highlights issues so that they can be prevented. In general, a model consists of three characteristics, i.e. mapping, abstraction and suitability for purpose. The model should be able to map for what it represents. For example, a building to construct should be able to map for its miniature model made in timber. A model only illustrates the relevant details of the object it represents, abstracting irrelevant details. When taken timber model as an example the model abstracts other materials of the building. The model needs to serve the purpose it was created for. In timber model example, the model illustrates the building's appearance when it will be built and this serves the purpose. Similarly, when it comes to business process modelling, the purpose of creating the model and the audience it targets for is vital. Business process modelling mainly serves two purposes, *organizational design*, and *application system design*. Modelling for organizational design is mainly for communication and knowledge but also serves benchmarking and improvement. These models are targeted for process owners, managers, and business analysts. Normally, these models are abstracted from features such as IT related aspects in order to be comprehended by different stakeholders. Business process models created for application system design are for automation purposes usually containing implementation details for creating BPMS or carry out software development. These models are IT based and systems engineers and developers create these models (Dumas, La Rosa, Mendling, Reijers et al., 2013).

2.3.1 History of Business Process Modelling

Many people have proposed techniques for process modelling in the past century. For example, Carl Adam Petri (1926 - 2010) in 1962 introduced Petri nets. Petri nets has a considerable impact on process modelling due to its graphical representation ability of the process and for its concurrent event representation feature. In business processes, many events can take place at the same time so that concurrency is a fundamental feature in a business process model. Petri nets is the first model, which is capable of modelling concurrency. Many BPM notations adopt Petri nets token system in their modelling notations.

The importance of data modelling began in the seventies, for example, the Relational Model introduced by Edgar F. Codd in 1969 and the Entity Relationship Model introduced by Peter Chen (published in 1976). In the beginning, information systems were developed by programming from scratch, including data storage and management. Later database management systems were used for storing and handling data, and tools automatically generated user interfaces. Business process management (BPM) systems are similar to this trend even though process management is a more diverse and complexed task than data management. BPM systems are for process related tasks.

Workflow management (WFM) systems emerged in mid 1990s and its primary focus was for automating business processes. Business process management can be considered as an extension of WFM (Van Der Aalst, 2013). However, WFM systems do not provide much support for functions such as process analysis and management and are not adequately flexible. Whereas, BPM systems provide better support than WFM systems for modelling business processes with its features such as support for business process intelligence, process simulation, case management, etc. In addition, BPM tries to improve business processes without essentially needing new technologies. Although BPM utilize software for operational processes, to control and manage them better. WFM also started with the same purpose in using software but traditional WFM, in automating the processes has given little attention to management and humans involved in the business processes.

Process Aware Information Systems (PAISs) comprise of WFM systems and BPM systems as well as Enterprise Resource Planning (ERP) systems such as SAP, Oracle, etc., Customer Relationship Management Systems (CRMS), middleware systems such as WebSphere and other systems like cash handling, call centre management, rule based systems. Common features to these systems are that the information systems, which support these systems, are aware of the processes they support and these processes possess defined notations. Information systems such as database systems and email systems also can execute some part of a business process though they are not aware of the processes they are executing. Therefore, these software systems are not process aware systems.

2.3.2 Business Process Modelling

Business process models represents business processes. Business process modelling is based on conceptual models. These models are usually depicted in UML. Figure 2.5 illustrates a conceptual model of a business process adopted from (Weske, 2010). Business processes comprise of some activities, which contribute towards achieving business goals. These activities can be categorised as system activities, manual activities and user interaction activities. System activities are those, which are executed using a software system without any human involvement such as receiving updated stock information or bank balance with automated input parameters. Manual activities are performed without an information system. An example for a manual activity is sending some items to a business partner. Information systems usually track manual activities by obtaining the state of the activity such as the acknowledgement of receipt of the items. Users as well as information systems are involved in user interaction activities. Knowledge workers using an information system such as entering customer claim information in an insurance application usually perform these activities. Workflow management systems ensure the execution of activities in the specified order, in a business process. In the UML diagram in Figure 2.5, the relationship between the system workflow and business process are illustrated using association between the relevant classes. The reason for this is, according to (Weske, 2010) workflow cannot be taken as a sub class of a business process since it manages a part of a business process. System activities can be represented in any workflow, i.e. System workflow, Human interaction workflow. Therefore, those two classes have a direct association between them in the conceptual model illustrated in Figure 2.5. However, the other two activities can only be represented in human interaction workflows.

Abstraction Concepts for Business Process Management

In business process modelling, different abstraction concepts are applied to handle the modelling complexity (Weske, 2010). One such concept that is traditional to computer science is, horizontal abstraction, which is the separation of modelling levels to instance, model and meta model levels. Vertical abstraction is another type of abstraction in which the main process model is divided into sub domains such as functions, information, organization and IT landscape. These are considered to be

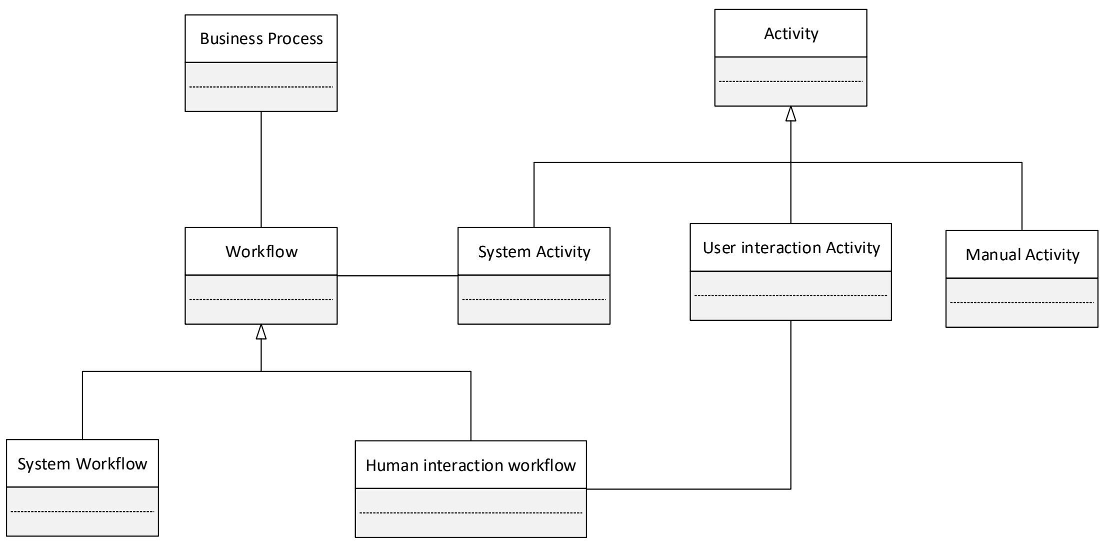


Figure 2.5: Conceptual model of a business process
Source: (Weske, 2010)

important for a business process. Further subdomains can be introduced according to the requirement of the particular business process. Yet another abstraction type is aggregation, which also handles complexity. In aggregation, in a higher level of abstraction, elements at lower level of abstraction can be categorized. For example, order management process consisting of activities such as receiving an order, checking inventory and order confirmation.

Business functions, Business processes, Activity models and Process models

Business functions provide a higher level representation of an organisations work. A business function is made up of one or more activity models. An activity model consists of some common activity instances similar to a process model consisting of process instances. The actual work of a business process is represented by activity instances for example an insurance claim process handled by an employee.

A process model comprises of process instances reflecting actual functioning of a business. Process meta models describe process models. Figure 2.6 illustrates a process model with its relationships and concepts adopted from (Weske, 2010). A process

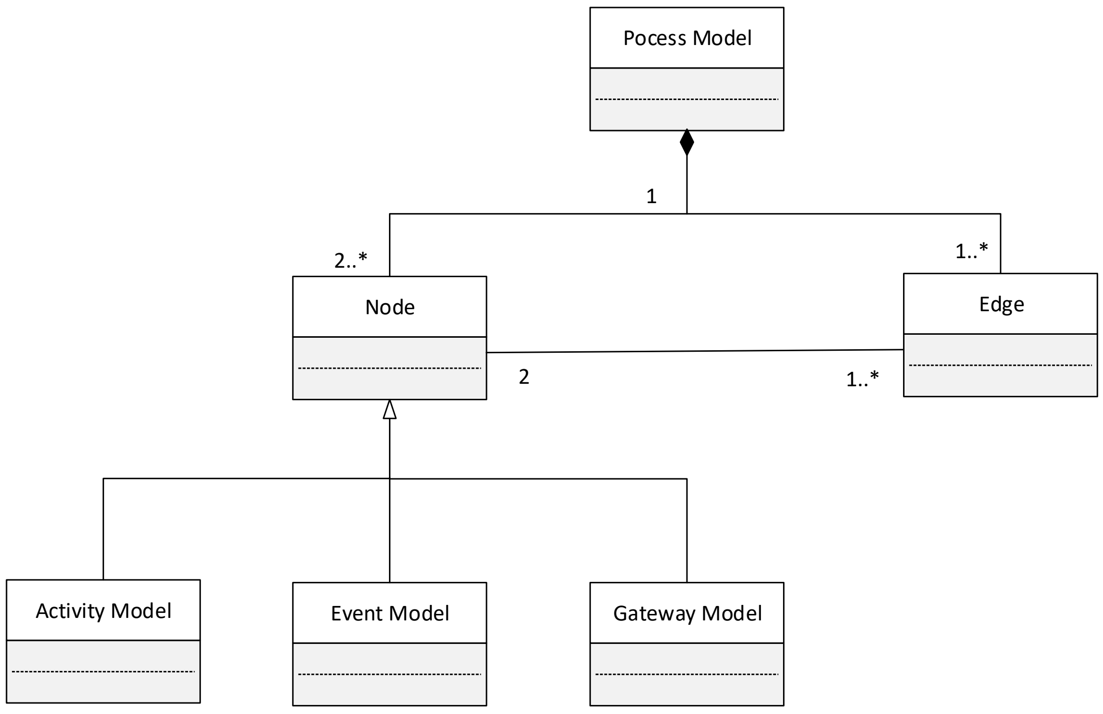


Figure 2.6: Business process metamodel
Source: (Weske, 2010)

model consists of nodes and edges. Edges represents the control flow of nodes and the nodes represent activity models, event models and gateway models.

Business Process Execution Architecture

Business process management systems control the execution of a business process using a business process model. Business process management systems architecture model consists of the ‘business process environment, a business process modelling sub system, a business process model repository, a process engine and a set of service providers. The business process modelling subsystem creates business process models. It generates the structure of the business process with activities, operations, etc. The business process environment triggers the initialisation and execution of the process instances of the process model. Business process model repository stores the created business process models. The process engine initializes and controls business process execution. This is the main component of a business process management system and business process environment triggers this component. Service providers in this architecture model provides hosting facilities for applications of business process activities.

Process Orchestrations and Process Choreographies

Process orchestrations describe the business process models containing activities and relationships performed within a single business organization. In process orchestrations, the process engine controls the processes acting as a centralized agent. In most cases, businesses collaborate with other businesses carrying out their activities making interaction among process orchestrations generally through passing messages. Process choreographies facilitate to realise these interactions among business to business collaborations.

2.3.3 Business Process Modelling Languages (BPMLs)

Main forces affecting changes in the business processes are improvements in computing and communication technologies. Business processes are becoming more and more complex with cross-organisational business processes and are mainly relying on information systems. Therefore, it is of great importance for organisations to have process modelling techniques to manage their business processes providing visibility into to the flow of processes and documenting them.

For business process management, the process-modelling notation is very important. There are number of modelling notations in existence, for example, BPMN, UML, Petri nets and EPCs. A feature common to all these notations are that a process can be described in activities and possibly in sub processes. In (List & Korherr, 2006), they identify these process-modelling notations as business process modelling languages (BPMLs). Examples of BPMLs are:

UML 2.0 Activity Diagram (AD)

AD started with development of software systems and, is for representing business processes and their flows in software systems. The main features of this modelling language is actions and, swim lanes representing roles participating in the process.

Business Process Definition Meta model (BPDM)

This is a product of OMG (Object Management Group). The purpose of BPDM is to provide a meta model for business processes to support mapping of various tools and languages. BPDM does not have its own graphical natation but uses UML 2.0.

Business Process Model and Notation (BPMN)

BPMN is developed by BPMI (Business Process Management Initiative) and, maintained by OMG (Object Management Group) since the two companies merged (WIKIDEDIA, 2017). BPMN is a graphical notation to represent business processes graphically in business process models. BPMN can be taken as the standard business process modelling notation for business process modelling (Wang, Ding, Dong & Ren, 2006). BPMN provides the organisations to represent their business procedures graphically and standardised communication of these business procedures. This graphical notation further facilitates organizations to understand their business collaborations among external participants. This allows businesses to quickly adjust to changing circumstances of their internal business procedures and procedures among external business to business participants (OMG, 2017). Events, activities and sequence flows or arcs are the three basic concepts of BPMN (Dumas et al., 2013). The basic symbols of BPMN are events, activities, gateways and connectors.

BPMN includes the aspects of other modelling languages such as graph based and petri net based process modelling languages, activity diagrams, UML and event driven process chains. BPMN supports all abstraction levels in an organization ranging from business levels to technical levels. Business process models are depicted in business process diagrams. Business process diagrams consist of modelling elements, set of core elements and complete elements. Core element set is simple and easy to understand which facilitates expressing simple business processes whereas, the complete element set provides additional power in elaborating business processes. There are certain rules set by the BPMN standard that governs these elements when using them. There is no restriction on BPMN when using a language to express something in the graph, simple English is possible depending on the situation. However, at technical level, a suitable programming language is required for translating the model for execution.

According to the BPMN standard, there are five basic categories of BPMN elements, flow objects, data, connecting objects, swim lanes and artifacts. Events, activities and gateways are the flow objects defining the behaviour of a business process. BPMN 'events' denote the states of real word occurrences related to business processes. Activities represent work carried out during a business process. Gateways illustrate the control flow of split and join behaviour between activities, events and gateways. BPMN pool element represents a participant such as a business partner in a business process. A pool consists of swim lanes. Lanes denotes organizational aspects such as a department within an organization.

BPMN elements under 'Artifacts' category represent additional information of business processes which, according to the BPMN standard are not directly associated with the sequence flow or message flow of a business process. Elements belonging to the artifact category are data objects, data stores, groups and text annotations. A data object mainly represents a process documentation, such as a paper and an electronic object. Text annotations document some business process part in textural form.

There are four main connecting elements, sequence flow, message flow, associations and data associations. Connecting elements connect other elements such as flow elements, swim lanes and artifacts.

Event Driven Process Chain (EPC)

This notation was designed aiming business people to understand and manage business processes easier. EPC comprises of functions and events where functions handle business process activities and events are results of processing of functions or events created by actors external to the model. This is an important and rather an informal notation for modelling domain aspects of a business process (Weske, 2010). Rather than technical details or formal aspects, the focus of this notation is on domain concepts and processes.

This was developed as a part of ARIS (Architecture of Integrated Information Systems) framework as a modelling approach by August-Wilhelm Scheer. This approach is generally known as ARIS house consisting of a roof and three pillars. The roof denotes the entire organisation while the three pillars stand for data, control and functions. Each section (pillar) consists of three levels of abstractions namely, concept level, architecture level and implementation level corresponding to requirements definition, design specification and implementation description respectively. Data, control and functions are modelled in the concept level, which being the highest level of abstraction. This level considers non-technical requirements of business processes such as business goals. At concept level, ERDs (Entity Relationship Diagrams) are used to model and express the data view. In the control view, business processes are modelled and expressed by using EPCs. In the organisational view, organisational structures are described by organisational diagrams. The architecture level bridges the gap between the concept level and the implementation level. The implementation level brings the necessary steps to realise business processes.

Integrated DEFinition Method 3 (IDEF3)

IDEF3 was developed to serve two purposes, the process schematics, i.e. to model a process sequence, and object schematics, i.e. to model an object and to represent state changes in a process. This captures how a process behaves explicitly describing a process. IDEF3 facilitates different views of organisational procedures. IDEF3 has two modes of modelling, i.e. process flow description (PFD) and object state transition description (OSTD). PFD describes actual work situation of a business whereas, OSTD describes permitted transitions of an object in a process (Aguilar-Saven, 2004).

Petri Nets

This notation is developed for modelling dynamic systems with concurrent and non-deterministic processes. These are used to workflow modelling. This graphical notation consists of two main nodes, place and transition. Different states of a system is represented by places and events or actions (caused by state changes) are represented by transitions.

Carl Adam Petri in his PhD thesis introduced Petri nets (Weske, 2010). Petri nets are capable of modelling dynamic systems with a static structure. Petri net illustrates the static structure whereas, the tokens placed in the nets represents the dynamic behaviour of the system. Circles in the graph represents places, rectangles represent transitions and directed arcs represents the connections. Tokens represents the dynamic and concurrent nature of petri nets. Tokens change their positions according to firing rules while the petri net structure is fixed. Petri net is very suitable for systems that are with characteristics such as concurrent, asynchronous distributed, parallel, nondeterministic or stochastic (Wang et al., 2006). Petri nets as graphical tools are similar to flow charts, block diagrams and networks.

Role Activity Diagram (RAD)

This notation started as coordination modelling and evolved to business process modelling. This represents external events, roles, activities and interactions. RAD is a graphically based process modelling language emphasising on individual roles and their relationships. These roles can be organisational functions, software systems, customers or suppliers (Aguilar-Saven, 2004).

BPMLs have their own execution languages. BPEL, also known as BPEL4WS is the common execution language for AD, BPDM and BPMN.

2.4 BPMN Modelling Frameworks for IoT

Emergence of information technology in general made a major impact on business processes. Now, with Internet of Things (IoT) technology, it forces the companies to revise their business processes to adapt to this new demand. IoT enables process design through product enhancement by facilitating physical objects to interact and communicate with each other leading to new service development (Zancul et al., 2016). Companies can make use of IoT technology in many business segments to achieve competitive advantage such as product service systems (PSS). According to (Zancul et al., 2016), IoT market segment consists of three categories:

- **Business to Consumer (B2C)** – This is the activity of a business trading between a business and a single buyer (shopify.co.nz, n.d.) In general, retailer transactions can be included in this category. For example, connected home, connected car, smart wearable devices, etc.
- **Business to Business (B2B)** – This refers to a business dealing between two companies. Most wholesale transactions fall into this category (investopedia.com,

n.d.). For example a business transaction between a manufacturer and a wholesaler. Examples for B2B IoT applications are, connected industry, connected buildings, connected agribusiness, etc.

- **Business to Business to Consumer (B2B2C)** – This model refers to business transaction connecting business to business and business to consumer. This is a collaboration process among participants, resulting beneficial channels of products and service delivery (techopedia.com, n.d.). Examples for IoT applications based on B2B2C are, smart cities, smart utilities, etc.

From the existing literature, we have chosen to review seven frameworks. These frameworks propose some IoT modelling elements for business process modelling by extending BPMN 2.0.

2.4.1 Framework: uBPMN

This framework (Yousfi, de Freitas, Dey & Saidi, 2016) illustrates how to model systems based on ubiquitous computing (ubicomp) in business processes. Ubiquitous computing aims to develop systems, which can adopt easily to dynamic business environments. *Context Awareness* and *Media Breaks* are two major aspects of ubicomp. When a system comes to a halt while processing, a media break occurs requiring human intervention to proceed. Ubicomp prevents media breaks by automating the processes so that they are human independent, improving both speed and quality and less errors. Context awareness improves business processes by taking into account the contextual environment in which the business operates. It allows business processes to collect data from the environment and react accordingly. Context for businesses is any information that is valuable to the business process. Context collection can be done by using Ubicomp technologies such as *location tracking* and *activity sensing*. Google Now is an example of a ubiquitous system where it responds to user requests by using ubicomp technologies such as location tracking and activity sensing. This framework incorporates ubiquitous computing with business process management and define a ubiquitous business process.

According to the authors, ubiquitous technologies such as sensors and smart readers cannot not be represented by BPMN v2.0 alone. Therefore, BPMN is extended to introduce *uBPMN* model to represent ubiquitous technologies. Authors think this model is capable of representing all existing ubiquitous technologies to date. The model introduces three new task elements, *Sensor Task*, *Reader Task* and *Collector Task* by extending BPMN Task element and *Smart Object* by extending BPMN Data Input. All three tasks inherit BMPN Task attributes and smart object inherits the attributes of BPMN Data Input class. Sensor Task includes smart sensors, wired and wireless sensors, and sense contextual information in a business environment. The sensor types can be categorised into temperature, speed, motion, GPS, etc. Similarly, Reader Task is a task that uses a smart reader, e.g. bar code, RFID, biometrics. Collector Task is a task that collects any context, which readers and sensors are not capable of collecting. The source of contextual information collection is a file, a database or another process.

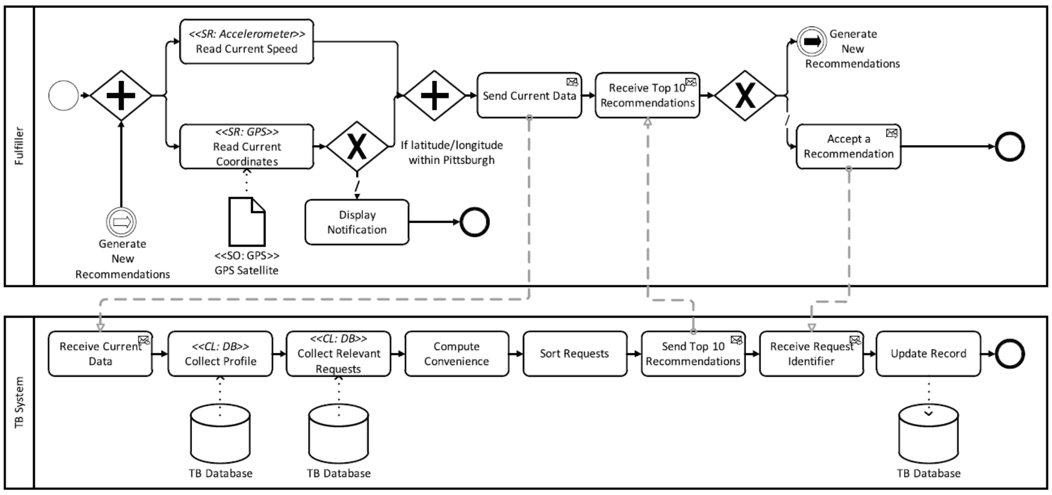

Fulfiller
<<SR: Accelerometer>> Read Current Speed
<<SR: GPS>> Read Current Coordinates
If latitude/longitude within Pittsburgh
Display Notification
<<SO: GPS>> GPS Satellite
Generate New Recommendations
Send Current Data
Receive Top 10 Recommendations
Generate New Recommendations
Accept a Recommendation
TB System
Receive Current Data
<<CL: DB>> Collect Profile
<<CL: DB>> Collect Relevant Requests
Compute Convenience
Sort Requests
Send Top 10 Recommendations
Receive Request Identifier
Update Record
TB Database
TB Database
TB Database

Figure 2.7: Ubiquitous fulfil request of time bank system using BPMN extensions (uBPMN).

Source: (Yousfi et al., 2016)

A case study is carried out to show that Ubiquitous computing can be used as a technique to improve business processes. A time banking information system, where a certain community exchanges services is used for this purpose. A user of this system either can be a requestor of a service or the person who undertakes to fulfil that service. A requester makes a request for a service via this system for a fee. The fees are in *time dollars*. When a service has been fulfilled, these dollars are debited from requesters account to the service provider's account. In the case study, *Fulfil Request* part of the system is used as a ubiquitous business process as depicted in Figure 2.7. Ubiquitous business process lists the top ten requests by considering the potential fulfiller's contextual information such as his current location, type of request, time it would take to fulfil the request, nature of the current activity, etc. The recommendation listings are generated by sensing the fulfiller's GPS coordinates and the speed and sending them to the system to compute. The request, *need a gallon of milk* is recommended for the potential fulfillers based on their context collected. The time spent on searching for a matching request is minimised and requests are suggested on the fly based on the user's current context. For example, if a user is in a supermarket, his recommendation list will include a request to buy groceries.

2.4.2 Framework: SPU

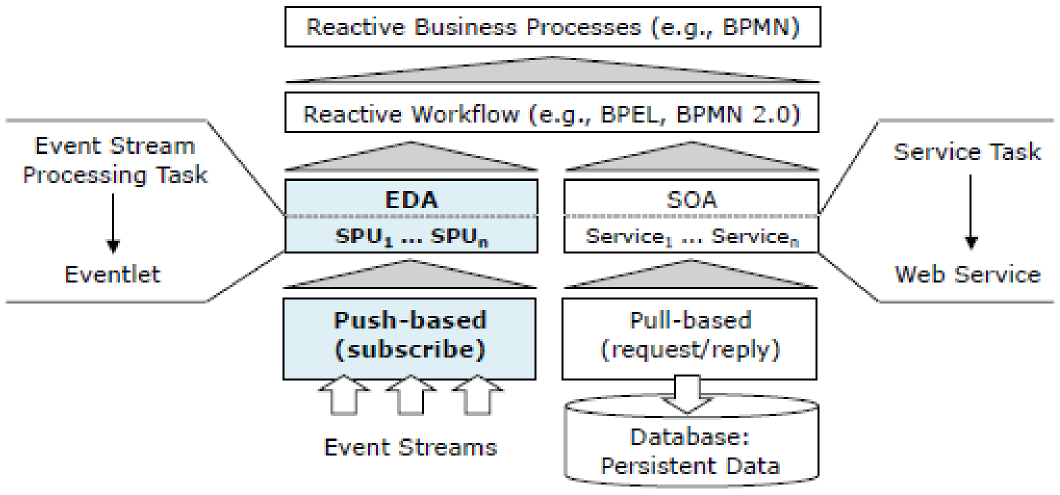
This paper (Appel, Kleber, Frischbier, Freudenreich & Buchmann, 2014) introduces IoT element, *event streams* to business process management systems. Occurrence of event streams are real world conditions and business processes can be improved by incorporating these. For example, monitoring temperature of goods while transporting them to see if the required temperature is maintained throughout the shipment. The temperature sensor reading continues throughout and this defines the term *stream*, which is continuous occurring of new events. New events are created (event producers) regardless if they are consumed (event consumers) or not. Due to this independence nature of events occurring, there needs to be a proper technique to distribute events. *Publish/ Subscribe* systems are such a common mechanism.

Though *single events* are common to business process modelling, there is no proper mechanism to handle streams of events. Therefore, Event Stream Processing Units (SPUs) are proposed as an integration concept for event stream processing to integrate with business processes. SPUs can be considered as equivalent to services in a SOA (Service Oriented Architecture) since it contains Complex Event Processing (CEP) functionality. Extensions to model SPUs in Event-driven Process Chains (EPCs) and a mapping between SPUs in EPCs and SPUs in BPMN to illustrate the application of the concept are proposed. As BPMN 2.0 modelling extension for SPUs, Event Stream Processing Tasks (ESPTs) are introduced. The project, *Software AG ARIS* illustrates the implementation of the EPC and BPMN extensions.

When implementing a business process, it goes through three stages, the design, execution and the IT infrastructure. In the design phase, the model is designed using a technique such EPC or BPMN. The model is executed by using a technique such as Business Process Execution Language (BPEL). IT support is provided by SOA and work flow management systems. Unlike SOA services, where services have to be invoked explicitly, SPUs encapsulate reactive business logic and reacts on streams of events.

To support SPUs at each layer of the model, *Event Stream Processing Services (ESPSs)*, ESPTs and *Eventlets* are introduced respectively at business process modelling, execution and IT infrastructure layer. Mapping between ESPT and Eventlets takes place at the execution layer. For SOA, services are the main building blocks whereas, for an Event Driven Architecture (EDA), SPUs are the main building blocks as shown in Figure 2.8.

EPC is popular for abstract modelling due to its features. BPMN is more powerful



Reactive Business Processes (e.g., BPMN)
Reactive Workflow (e.g., BPEL, BPMN 2.0)
Event Stream Processing Task
Eventlet
EDA
SPU$_1$ ... SPU$_n$
SOA
Service$_1$ ... Service$_n$
Service Task
Web Service
Push-based (subscribe)
Pull-based (request/reply)
Event Streams
Database: Persistent Data

Figure 2.8: Stream processing units (SPUs) as basic building blocks of an event driven architecture (EDA).
Source: (Appel et al., 2014)

in supporting both abstract and technical process models. Therefore, in *Software AG* project, both of them are used. EPC for abstract business models and BPMN for technical process models. To integrate SPUs with EPC and BPMN, an extension to the modelling notations is needed to illustrate some features of SPUs as follows:

- Execution semantics: SPUs needs to be stopped after the event completed since there is no automatic stopping after they started.
- Signalling: This is required for the continuous processing of SPUs.
- Event stream input and output: Event streams are the input for SPUs and output is specified by the events produced by SPUs.

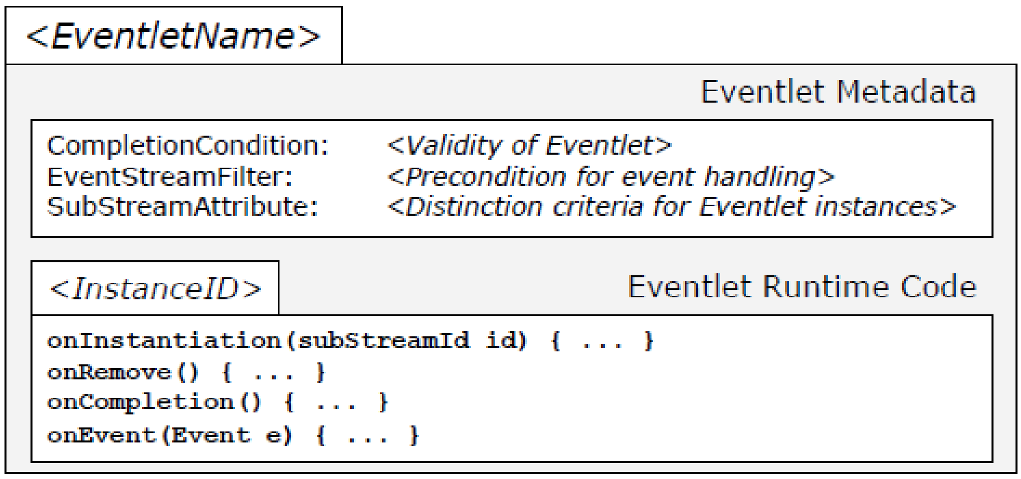
Event stream modelling can be done by using EPCs functions. An extension to EPC is required to model SPU in EPC. ESPS to use EPC functions for event stream processing and, Event Stream Specifications (ESS) to represent input and output in event streaming are introduced. The *Event Stream Processing Unit type* represents the technical part of SPUs.

Order processing example is used to illustrate the application of EPC extension. A SPU supported by ESPS is used to monitor the environment conditions, i.e. temperature in a shipment. ESPS initialises an SPU with implicit and explicit completion, which takes shipment monitoring events as input event screams. Implicit completion ends when the shipment is completed. Explicit completion is confirmed after the shipment completion by an additional process step. BPMN is extended to introduce ESSs for EPCs to show input and output data in event streams, and ESPTs for modelling SPUs. ESPT's implicit completion is achieved with a *modified conditional sequence flow* whereas, explicit completion is denoted by a *dedicated signal*. When the process is completed either explicitly or implicitly, it comes to a stop reflecting a clean shutdown. It is also possible to model an ESPT with both explicit and implicit completions combined together.

According to the authors, BPMN events are not suitable for modelling SPUs with event stream inputs and outputs. Even though BPMN contains task types containing SPU related features, such as *standard service tasks*, *business rule tasks*, *loop service tasks* and *multiple instance service tasks*, SPUs cannot be modelled with those. Therefore, BPMN is extended for ESPTs. To illustrate the BPMN extension, the shipment monitoring example already explained is used. In BPMN, ESPT is the shipment monitoring SPU. Shipment monitoring SPU receives inputs as streams of monitoring events. In case of a violation of monitoring conditions, the monitoring SPU sends a message concurrently indicating the violation, which triggers the exception handling process with explicit completion. The monitoring ends with a stop signal after the shipment is over.

For an implicit completion of a shipment, some condition should be matched such as destination address, which is executed in the SPU. It is possible to model ESPTs with implicit and explicit completions combined together as well. The default completion is implicit. However, an explicit completion is triggered if for an instance, the customer cancels the order. Output event streams of shipment monitoring SPU indicates threshold violations. On receipt of these events, *Report Threshold Violation* SPU in turn sends warning reports by email if violation detection continuous. Reporting SPU completes explicitly at the shipment arrival, whereas monitoring SPU triggers implicit completion. Implicit completion is the default termination that takes place when the shipment completes naturally. However, in case of a shipment cancellation, explicit completion takes place. If a threshold violation has been detected, the monitoring ends. On completion of the shipment monitoring ESPT, the goods are discarded and the customer is reimbursed upon cancellation of the order.

The authors have introduced a model with run time infrastructure to facilitate event scream processing. Event applets called ‘Eventlets’ are introduced for this purpose. Runtime engine is extended for integrating business process execution engine. Event stream processing logic is encapsulated within Eventlests. Figure 2.9 shows a basic Eventlet structure.


<EventletName>
Eventlet Metadata
CompletionCondition: <Validity of Eventlet>
EventStreamFilter: <Precondition for event handling>
SubStreamAttribute: <Distinction criteria for Eventlet instances>
<InstanceID>
Eventlet Runtime Code

```
onInstantiation(subStreamId id) { ... }
onRemove() { ... }
onCompletion() { ... }
onEvent(Event e) { ... }
```

Figure 2.9: Basic Eventlet structure: Eventlet metadata and Eventlet runtime methods. Source: (Appel et al., 2014)

Sub streams of events in an entity instance is called ‘Sub Stream Attribute’ in Eventlet metadata, e.g. shipment ID. Meta data also has other information such as 'completion condition' for an example, 'time out'. Eventlets can be created either implicitly or explicitly. For implicit creation, the middleware makes an Eventlet instance active for each sub stream attribute (e.g. for each shipment). For explicit instantiation, Eventlets are being created manually by using a fixed sub stream attribute, e.g. a particular shipment ID. Eventlet completion is specified implicitly by some condition or explicitly by a command. In the shipment monitoring example, Eventlets detects temperature violations. This is achieved by querying a database (at instantiation) and retrieving temperature information for a certain shipment. Complex event processing (CEP) queries can also be used for temperature violation detection. Authors state that Eventlets can process couple of thousand events for a second.

In the case of implicit instantiation, an 'Eventlet Monitor' is being created by the middleware. Eventlet instances are created as and when the events of new entity instances take place. E.g. 'new shipment'. Eventlets are identified as 'EsptName' and are stored in a repository. Java Message Service (JMS) is used for events distribution by Eventlet middleware. JMS is capable of handling publish/ subscribe communication. The model handles attribute value events and XML representation. To facilitate ESPT execution, the Eventlet middleware is extended. As shown in Figure 2.10, a 'Command Bus' connects and controls the Eventlet middleware and is programed as JMS queries. 'Eventlet Manager' has a web service interface, which is a Java Enterprise application.

The*software AG's ARIS* is used as a platform for SPU modelling for EPCs and BPMN. "ARIS is a business process platform for business process analysis, enterprise architecture, and governance, risk and compliance." ARIS supports modelling of processes with EPCs and BPMN. The model uses *ARIS Design Server 9.0 and the ARIS Architect 9.0* for SPU modelling in EPCs and BPMN. New notations and connection attributes for SPU modelling in EPCs and BPMN are introduced. ARIS server is designed as a central repository for process models and process model components.

Automated execution of business process models is an objective of business process

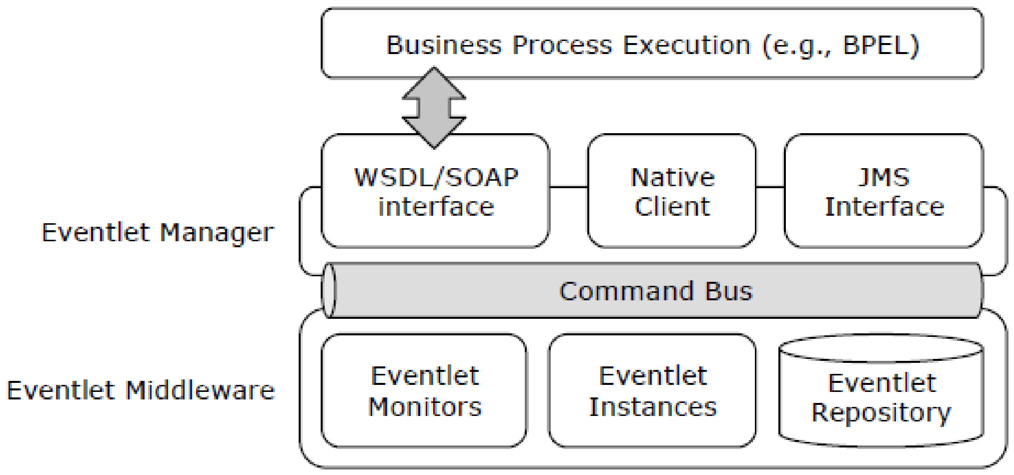


Figure 2.10: Eventlet middleware access via a web service.
Source: (Appel et al., 2014)

management. Authors believe they have introduced such a model to execute (M2E), by providing the foundation for M2E by introducing SPUs to encapsulate event stream processing. The extensions to BPMN facilitate for creating abstract process models with SPUs. Even though it is possible to map processes with ESPT to BPEL, it does not support complete mapping. Explicit instantiation and completion of ESPTs can be mapped to BPEL whereas, ESPTs with implicit instantiation and completion cannot be mapped to BPEL. Extensions to BPEL is proposed by existing literature to facilitate this.

2.4.3 Framework: BPMN4WSN

The framework (Sungur et al., 2013), models sensors, actuators and intermediary operations by incorporating a Wireless Sensor Network (WSN) in business processes using BPMN. WSN is developed by adding sensors and actuators in a network with remote sensing and actuating capabilities. A system model is created by scanning the network. WSN process communicates by means of messages. As authors state, it is possible to model a WSN with existing BPM standard, but with limitations. A meeting room ventilation process by using WSN is carried out as an example.

This process uses both sensors and actuators. Room number, start and end times of the meeting and the desired CO2 level are the system inputs. Once the meeting starts, sensors continuously detect the CO2 values in the room and the actuators change the temperature to the predefined input level. The process continues until the meeting ends. This process is modelled in standard BPMN initially and by extending BPMN as some aspects of WSN cannot be reflected in standard BPMN. This process with extensions to BPMN is named as *BPMN4WSN*. The extensions consist of *WSN Task*, *WSN Pool* and *Performance Annotations*. These are designed by extending BPMN modelling elements *Service Task*, *Pool* and *Groups* respectively.

- WSN Task: WSN Task represents the *tasks* in WSN process and is similar to BPMN tasks, but consists of additional icons.
- WSN Pool: Processes in WSN are represented by WSN Pools. WSN Pool extends the BPMN Pool. To distinguish the difference between the standard BPMN Pool and the WSN Pool, WSN Pools are marked with a WSN icon. WSN Pools illustrate WSN processes, making it separate from PBMN processes. This makes it possible to execute the same process simultaneously at different locations inside a WSN.
- Performance Annotation: This illustrates the performance aspects of the WSN. BPMN makes it possible to group common attributes in a group. Inheriting from this, WSN performance goals are defined. This completely satisfies the, *prioritising of performance goals*, which is one of the requirements to be met while modelling WSN.

Figure 2.11 illustrates a room ventilation process modelled using BPMN extensions.

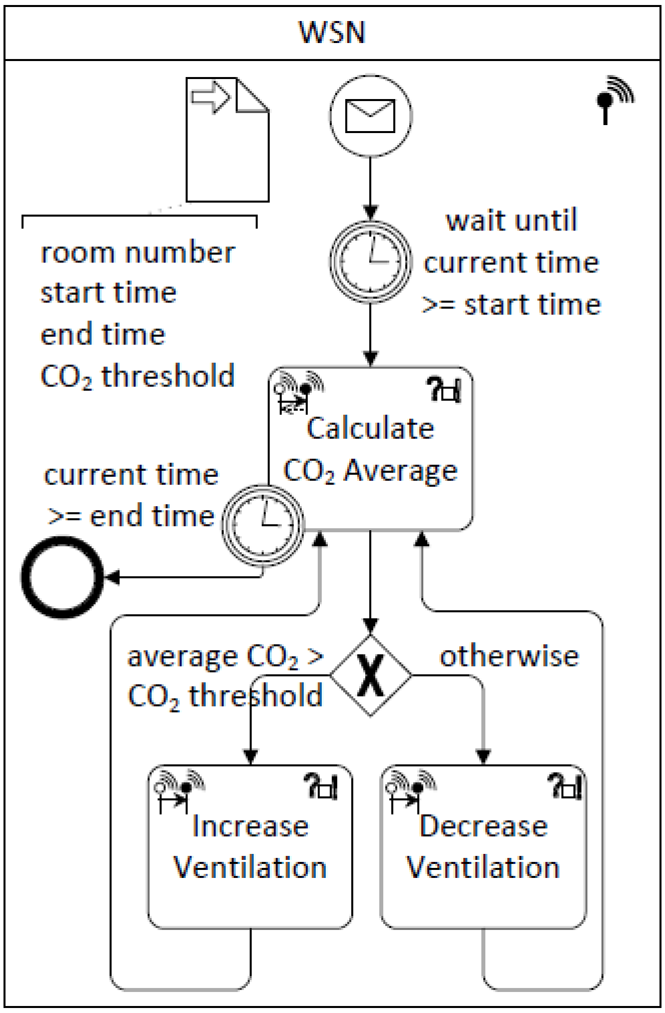


Figure 2.11: Room ventilation process with BPMN extensions, BPMN4WSN.
Source: (Sungur et al., 2013)

WSN has a collection of nodes, which link with each other. These networks are ad-hoc because it should be possible to add or remove sensors to increase sensing, decrease coverage or manage power issues. Therefore, to support this dynamic behaviour of nodes, it is required to access nodes indirect. WSN operations are of two types, i.e. *local action* and *command action*. In local action, the execution of an operation happens locally at the nodes where they are initiated. Whereas, in command action the execution takes place at remote nodes. Command actions are of dynamic nature and based on runtime decisions. E.g. based on a local sensing activity, an actuating can take place in a remote node by a command. Local action and command action both comes under one of the categories, *sense*, *actuate* or *intermediary operation*. E.g. *sense operation* sense the environment for temperature, and based on the output data, the *actuate operation* increase or decrease the temperature. The *intermediary operation* compares the sensed value with desired level of temperature and takes the decision to increase or decrease the temperature.

For these operations, *6-tuple*s are introduced. They are *actionType, isCommandAction, actionPerformer, outputTarget, targetOperation, and returnOperation*. A WSN application can run on different locations at the same time by using different instances of the same process. An example would be an air-conditioning system with WSN covering multiple rooms. WSN application execution is distributed among nodes than in a single node. This eliminates power failures and reduce power usage. Therefore, it is required to distinguish the particular node, which execute the WSN process. WSN nodes are subject to failures due to availability of limited resources such as battery failures. To overcome these limitations, this application specific behaviour should be taken into account when modelling BPMN.

WSN consists of event driven operations as well as periodic operations. Event driven operations take place based on an event's occurring (consuming lesser power) whereas, periodic operations happen at a set time. E.g. checking if a door is open. For example, in the event of opening a closed door, this information is communicated in an event driven operation. Thus, in periodic operation, it checks if the door is opened periodically even when it is closed. It should be possible to illustrate both these two types of operations in a BPMN model. It should also be flexible to make minor changes to WSN without affecting the model's stability.

Drawbacks of using standard BPMN for modelling WSN and the benefits of using BPMN4WSN with BPMN extensions are demonstrated by comparing against each requirement of WSN. In the extended model, *Support for Indirect and Dynamic Addressing of Nodes* is made possible by defining *expressions* which allows direct, indirect, static and dynamic access of nodes whereas, in BPMN, only pool names can be used as attributes to access nodes. Applying extensions, *Support and Restrict User to WSN Operation Categories* is fully supported while BPMN has no support for *sense*, *actuate* and *intermediary operations*. *Support for Multiple Instances of the Same Process* is achieved by using tasks in a pool with extensions, whereas standard BPMN processes are reflected by pools. In BPMN, there is no facility to achieve *Distribution of Execution Logic into WSN*, however with extensions; this is possible by using *orchestrationPerformer* of WSN Task. Standard BPMN does not support *Prioritization of Performance Goals*, while with extensions this is achieved by applying parameters to each task and also by adding performance goals at run time. *Support for Event-driven Actions in Modelling* is achieved through extensions though standard BPMN does not distinguish between event-driven and periodic tasks. The requirement, *Models should be stable on minor WSN changes* is achieved by extended BPMN, although in standard BPMN changes to WSN can only be accomplished by addition or removable of pools.

2.4.4 Framework: Things of IoT in BPMN

This framework (Meyer et al., 2015) models *physical entity* or the *thing* of IoT in a business process by extending BPMN. A reference model (IoT domain model) defines the main IoT components that can be mapped with BPMN elements. This model is referred to as guidance for this work. According to IoT reference model, it should be possible to transfer the main components of IoT meta-model to a BPMN specific meta-model to incorporate IoT based modelling into business processes. According this model, the main building blocks of IoT are:

- The *device* e.g. temperature sensor, which connects the physical world with digital word.

- The *thing* e.g. chocolate, which is a part of the physical environment.
- The *native service* e.g. sensing and actuating abilities, via which the connection is established.
- The *IoT Service* e.g software components for connection.

The example used for modelling IoT elements with business processes is " *A Web service shall measure the temperature of the physical entity chocolate by means of one currently available device that is accessible via the Internet*". Three elements of BPMN Meta model, which are suitable for modelling physical entity in business processes are identified. They are, *Text Annotation*, *Data Object* and *Participant*. In modelling physical entity the focus is on two main aspects, i.e. the process modeller's ability for graphical representation and machine readable output. While these are the main requirements, the other requirements include, the physical entity cannot belong to a message flow or a sequence flow, should not connect to any data association or process element and inability to assign to any pool or lane.

Text Annotation is a subclass of *Artifact.Artifacts* in the BPMN standard which facilitates presenting more information and available at machine-readable model. This is process related without any effect on the message flow. However, this is not suitable for representing *physical entity*. Therefore, in parallel to Text Annotation, a Custom Artifact class is created by extending the class Artifact. This also come with the disadvantage that it is assignable to a pool. Data Object is a subclass of ItemAwareElement and is related to process execution, which is not a feature of the *physical entity*. Therefore, a custom Item aware element to represent the *physical entity* is introduced. Participant class, which is a subclass of BaseElement in the BPMN standard, is not suitable for representing the physical entity because it is possible to represent it in a pool and can also be a part of a message flow. So that, a subclass of Participant is created to represent the physical entity. However, this still has the limitation of being a part of the message flow.

An assessment is carried out to find if the BPMN standard elements Text Annotation, DataObject, Participant and the extended elements CustomArtifact, CustomItemAwareElement and CustomParicipant are satisfying the requirements needed to represent the physical entity. The Collapsed Pool, which can represent the Participant element graphically, appears the most suitable. However, this also does not meet the requirement because it can be linked to a message flow. As a better solution to represent the physical entity, a complete change to the standard BPMN meta model by introducing a new element is proposed.

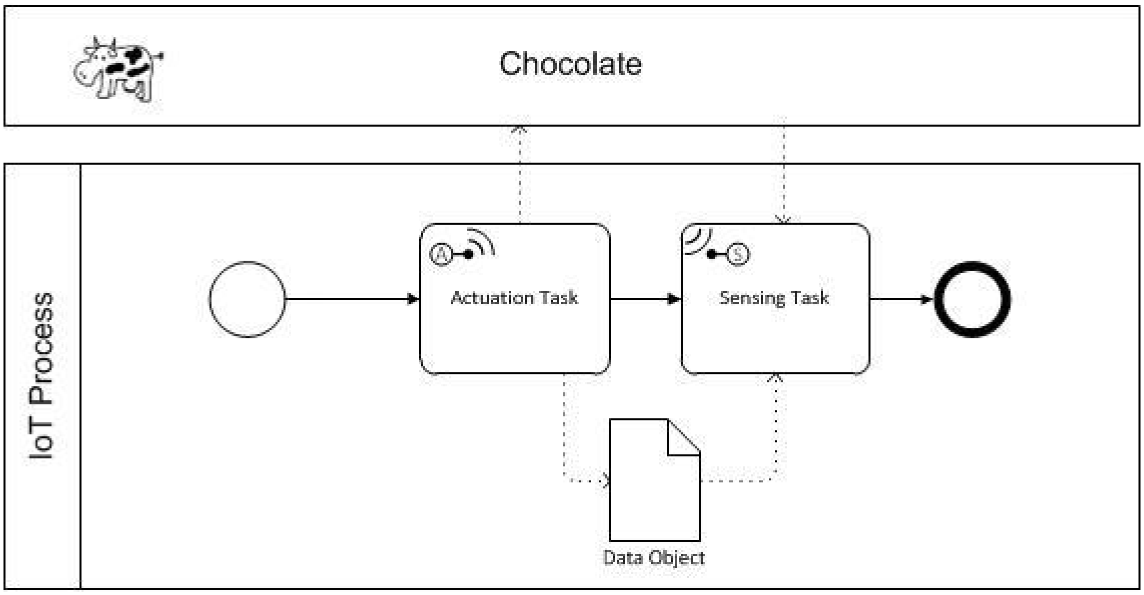


Figure 2.12: Graphical process representation of physical entity.
Source: (Meyer et al., 2015)

A graphical element linked to the BPMN Collapsed Pool as well as a machine readable element are introduced. Participant subclass (already introduced) but without extending any BPMN class and also with enhanced features to meet all requirements of physical entity is proposed. For the graphical representation, BPMN standard, Collapsed Pool is extended to represent the element Participant. Machine-readable model is created without confirming to the BPMN standard. This new extension satisfies the remaining requirement of not being a part of a message flow so that all requirements needed for representing physical entity are achieved.

Figure 2.12 illustrates the graphical process model, where two separate pools are used to represent the two participants, physical entity and the IoT process. The item *chocolate* denotes the physical entity and the *cow* symbolises that anything can be taken as a physical entity.

2.4.5 Framework: Crowdsourcing

This paper (Tranquillini, Daniel, Kucherbaev & Casati, 2015) introduces *micro-task crowdsourcing processes*, to BPMN. *Crowdsourcing* is a way of outsourcing work to many people (a crowd), on a crowdsourcing platform such as Amazon Mechanical Turk or CrowdFlower often for a reward in return. These are called *crowdsourcing processes*, which comprise of multiple tasks, actors and operations. These micro-tasks can be completed in parallel making it faster and efficient.

A scenario of reimbursing travel expenses of company employees is taken as an example in illustrating crowd sourcing processes. The receipts are scanned and uploaded to an online crowdsourcing platform. A request is sent out for offers to transcribe them one by one. For each two transcriptions, in another task, the crowd request the workers to check for their accuracy and to fix if there are any mistakes. A worker needs to handle two items together at a time since this process takes lesser time. Yet in another task, the transcribed receipts are categorized into their relevant types such as hotel, flight, food, etc. A worker handles four transcriptions together since this is even simpler. After transcription, parallel execution of these two tasks are possible. Upon completion of this process the admin is notified by an automatic email.

BPMN does not fully support modelling crowdsourcing processes to achieve the maximum benefits it offers. BPMN model consists of two main constructs, *tasks* and *control flow connectors*. Tasks are automatic, consist with start and end events. Multi instance tasks, which also have start and end events can execute in either parallel or sequence. However, the end event occurs only when all instances finished executing. For *crowdsourcing* this behaviour of the BPMN tasks is not suitable since multiple tasks instances needs to be executed in parallel without waiting for an end event. An example would be to upload a set of images and to label them. These two tasks should run in parallel. However, with BPMN tasks, the labelling only starts after the image uploading ends. Therefore, to model crowdsourcing processes, the authors propose an extension to BPMN.

Authors propose an extension to BPMN by introducing two new elements, *crowd task* and a *streaming connector*. A crowd task consists of some micro tasks collectively performed by a crowd of people on a crowdsourcing platform. Parallelization benefits are achieved through streaming the finished micro tasks, while other instances of the particular crowd task are still executing. Streaming connector supports screaming data grouping, splitting and multiplication and the data transfer between the process and crowd tasks. Data screaming is achieved through middleware between BPMN and the crowdsourcing platform. This monitors micro task end processes and grouping, splitting and multiplying of completed micro task instances. When these task instances end, the monitor sends a message to the process engine so that it can start with the next micro task. Two crowd tasks are connected by streaming connector and they can connect single or multiple times at run time depending on the *data transformation function*.

Streaming data transformation function can be of many types, flat, group, split or multiply. *Flat* indicates streaming without any data transformation. *Group* implies to stream in groups. *Split* defines to stream as they are without any data transformation and to separate the output into the elements they were before. *Multiply* is similar to split except that the output is copied to separate events.

To transform crowdsource specific modelling aspect to BPMN, the authors consider three possible methods. First is to create parallel branches, each executing a single task instance of the crowdsourcing process. Disadvantages of this being that the model will be unmanageable when there are several tasks available for streaming and can be expensive. The second option is *Multi-instance sub processes*. This one overcomes the issues of first method and is similar in behaviour except that the sub processes are executed together. The third one is, *Non-blocking event sub processes*, which limits the sub processes with a non blocking event sub process. Even though the option three is the best one, the second option is chosen since the third option is not supported in standard BPMN. The model transformation logic also helps data transformation functions i.e. flat, group, split and multiply already explained.

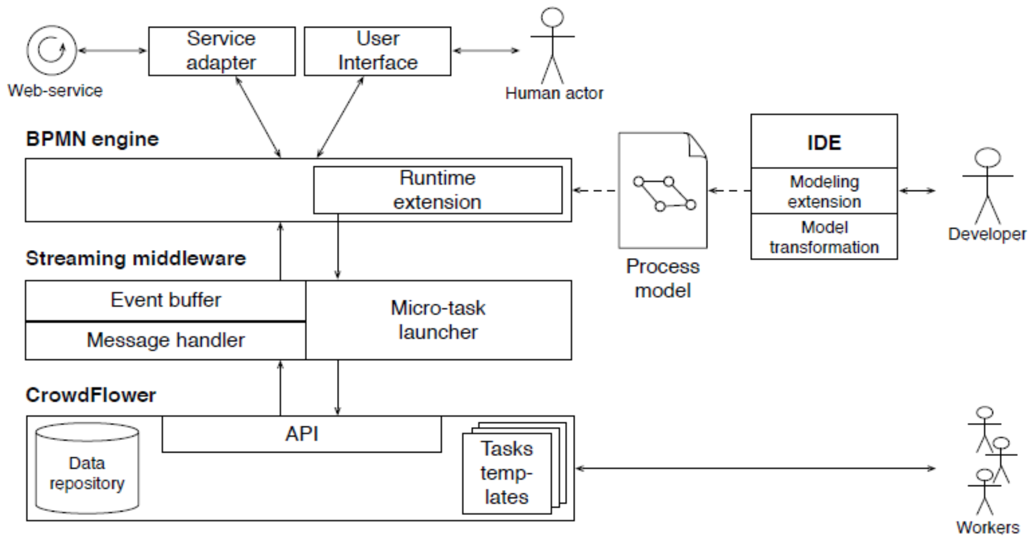


Figure 2.13: Architecture of runtime environment for crowdsourcing processes with streaming support. The middleware deploys micro-tasks and manages events and data. Source: (Tranquillini et al., 2015)

Software architecture of the crowdsourcing process is depicted in Figure 2.13. This software process model of the crowdsourcing process comprises of three parts. The BPMN engine, which executes the process, the streaming middleware that controls the events and data transformation, the crowdsourcing platform, Crowdflower, which handles the micro-task instances. After transforming the process model into an executable model, it is deployed in the BPMN engine. Business process engine executes both human tasks and machine tasks, while crowdsourcing platform executes the crowd tasks. User interface design is handled inside the crowdsourcing platform. The platform also enables programming access via APIs.

The extensions to BPMN model are implemented in a case study. Three templates to use in Crowdflower are created. These templates accept input data and outputs the results needed by the processes. The process evaluated by testing three times with streaming and another three times without streaming by uploading forty receipts manually. This highlighted the streaming benefits. With streaming, within ten minutes, 90 percent of receipts of all three crowd tasks are completed whereas, only transcription level is completed without streaming. Moreover, with streaming the first receipt completes all three tasks in a couple of minutes while without streaming it takes about one hour and 30 minutes to complete the first receipt.

However, with screaming it takes more time to complete all of the receipts when all receipts without streaming gets completed faster. According to existing research, the reason for this being the users in a crowdsourcing platform tend to select first two pages of micro tasks. This can be considered as a disadvantage. Furthermore, for some last micro task instances, the final stage is not completed specially for the receipts with streaming. In addition, there are some disadvantage to the implementation. Sub processes cannot be introduced at run time so that at design time this should be accommodated for. It is possible to divide streaming connectors into branches although it is not possible to re-connect them. Only BPMN related processes can be controlled whereas, how tasks are handled inside the crowdsourcing platform is beyond control. Therefore, for example, the instances when a few micro tasks not completed is not controlled. These disadvantages should be insignificant compared to the advantages of crowdsourcing.

2.4.6 Framework: Event Element for IoT

Authors in this paper (Chiu & Wang, 2015) state that BPMN events can represent IoT aspects better though many researchers focus on BPMN elements other than events when extending BPMN 2.0 for business process modelling for IoT. Majority of the work is based on extending BPMN elements activity, pool or lane, artifact, etc. This work extends BPMN element *event* for business process modelling for IoT.

According to BPMN 2.0 definition, an event is something that takes place during a process lifecycle usually triggering an action or result. This behaviour of events are closely related to IoT applications but traditional BPMN 2.0 events are not adequate enough for representing IoT related processes. Characteristics of IoT are evaluated for the purpose of finding out the requirements for extending BPMN element, event.

As event either triggers something or results something, most IoT based scenarios represent characteristics of events. For example, when air conditioning a room, once all conditions become true for starting the air conditioner, the process will start and an actuator turns on the air conditioner. Two types of IoT architectures are considered for the modelling example of events. 'Cloud centric IoT' where all IoT elements such as sensors, actuators and services are connected to each other in the cloud by providing a web service interface to internet. The second architecture is an 'IoT gateway' based, in which, sensors and actuators register to the IoT gateway initially and communicate with each other afterwards. The authors in theit modelling example uses the IoT gateway based architecture.

Nine BPMN event element extension requirements are identified through eight weaknesses in BPMN lacking support for business process modelling for IoT.

- Entity based concept – process modelling should adhere with entity based concept.

In a simple IoT aware process for an air-conditioning a room, the start event triggers simply when the room temperature is at a certain predefined value but as the process continuous, the sensors monitor the room temperature. Therefore, at design phase, some entity will define the start event and at run time, the control will pass to sensors.

- Distributed execution – processes should be capable of distributing their execution among many devices. IoT based processes can run on multiple gateways with collaboration among them. In an IoT application of air conditioning a room, the room is located at gateway 1 and the air conditioner is controlled by gateway 2 making the two gateways communicate with each other.
- Interactions – IoT aware business processes introduce two more interactions, device interactions and service interactions. For example, temperature is detected by a temperature sensor or obtaining average temperature by a web service.
- Distributed data – IoT applications may distribute data over many data storages. For example, temperature sensors located in a room and to obtain the average of all, the data should be collected from all sensors concurrently.
- Scalability – sensors and actuators in an IoT application may increase or decrease for some reason such as due to a failure in the device, requiring a control mechanism to handle these situations.
- Availability/ mobility – In IoT applications, sensors, actuators and physical objects should be able to move freely. For an example, the process of temperature detecting by sensors start only when a person move into the room.
- Fault tolerance – a business process heavily relies on availability of devices, services and the communication technology. In an IoT application, device availability is not always certain. Faults can occur due to two reasons, unstable networks

and faults of devices such as sensors and actuators. This makes two requirements, fault tolerance of network crashing and faulty devices.

- Quality of information – Quality levels of the information provided by the devices and services to business processes should be in certain levels of accuracy. In an IoT application, required accuracy level of information differs, depending on the context.

BPMN *conditional event*, *message event* and *error event* are extended to represent three new events and a new event to represent location is introduced. The *event definition* is also extended to facilitate the above identified requirements, entity concept, fault tolerance and quality of information.

BPMN conditional start event extension is considered more suitable for representing situations of IoT related processes such as collecting data from devices or physical entities (i.e. temperature at a certain value), status of a device or physical entity such as fault in a sensor and total number of devices or physical entities, for example number of cars exceeding a certain level in a car park.

The BPMN message event is extended to explain the interactions among process engines better. Two main interaction types are catch and throw, i.e. receiving a message from a process and sending a message to another process. For example in an IoT scenario, a message is passed from one IoT gateway to another when the temperature is at a certain value to start air conditioning a room. Extension of BPMN error event facilitates fault tolerance of IoT devices such as the actuator realizing some fault with an air conditioner while trying to start it and reporting to maintenance staff in a message. The new event created for location better represents the IoT location awareness feature. Location event represents situations such as position of a device or a physical entity and moving of a device or a physical entity. Event definition extension covers the entity concept, fault tolerance levels and information quality.

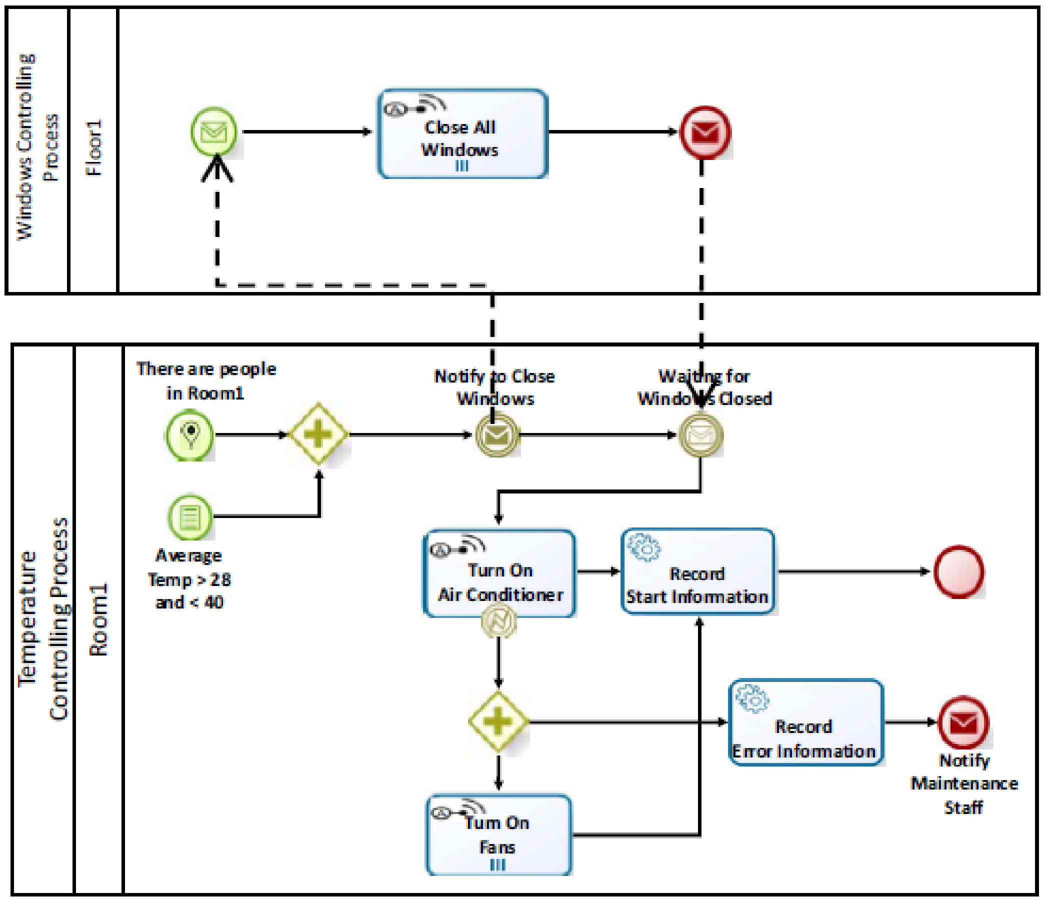


Figure 2.14: Completed temperature controlling process model with event extension of BPMN 2.0.
Source: (Chiu & Wang, 2015)

A sample IoT application models a temperature control process, which uses the introduced IoT modelling elements. This process starts when there are two start events that are satisfied, i.e. at least one person in the room and the room temperature is between a predefined range of values. When the conditions are true, the start event fires and gateway of the room sends a message to another gateway, which controls the window closing to request to close the windows. Once the first gateway receives the confirmation of window closure from the second gateway, the control is passed to an actuator to turn the air conditioner on. If the air conditioner is faulty, a message is passed to the maintenance staff for repair. The fans are turned on concurrently by another actuator task. This process is illustrated in Figure 2.14.

2.4.7 Framework: IoT Devices as Resources

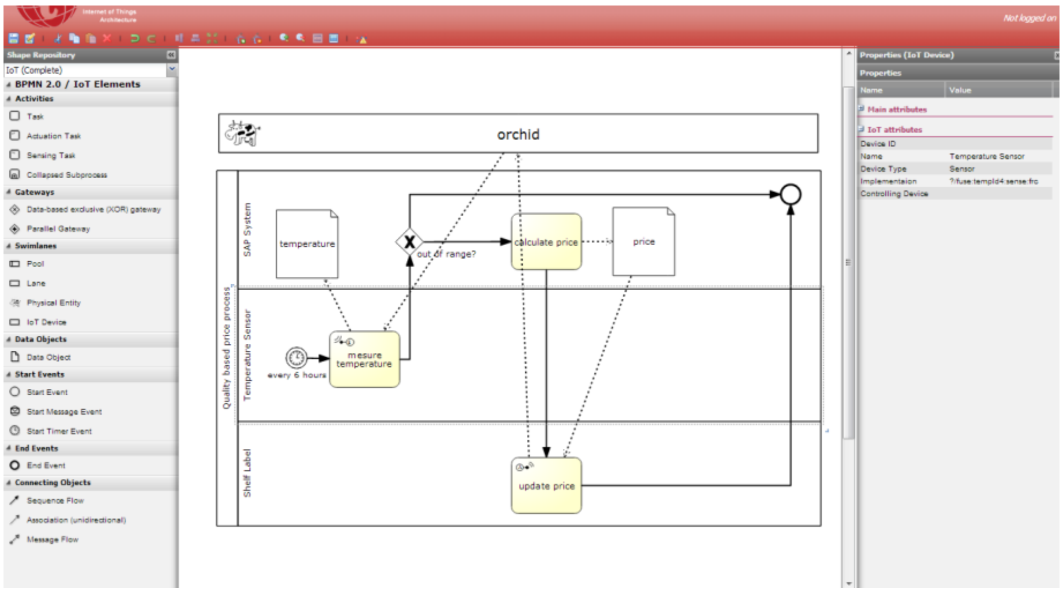
This paper (Meyer, Ruppen & Magerkurth, 2013) addresses integrating IoT devices with native software components as a new resource type in business processes as no sufficient attention is given to this area by past researchers. An IoT reference model defines the main building blocks of IoT. They are the physical entity or thing (e.g. flower), device (e.g. sensor), native service (e.g. sensing capability provided by the device's software) and IoT service (e.g. web service interface). The authors adhere to this in their work. IoT integration can add value to business solutions such as ERP systems and they try to integrate IoT with ERP systems. ERP systems are based on planned business processes with human resources, whereas IoT comprises of vast number of devices as resources based on web and constantly reacting to dynamic environment and adapting processes accordingly. As traditional business processes do not provide the facility to model IoT aware processes directly, this work attempts to integrate IoT devices as resources in business processes and build an IoT aware business process model. In trying to represent IoT devices and native services as resources in IoT aware process models, the authors come up with some contributions. They are, analyse and identifying IoT domain concepts, illustrate IoT device and software components in a swim lane and a resource model, integrate a general semantic model, extend the graphical model and test the graphical model in practice by extending a business process modelling tool.

In introducing the process model, authors propose extensions to BPMN 2.0 notation to include IoT devices and native software components. There are two challenges. First, the BPMN specification does not speak about IoT devices or native services. Second, there are two types of resources, IoT device and its native services, which are at different levels, are to be dealt with at the same time. BPMN standard does not facilitate concurrent dealing of different resources at different levels in a process model.

Unlike physical entity, an IoT device is a process performer like a human user who is a direct participant in the process. The other process resource is the native service or the software component of the device. In the graphical model, a separate pool represents IoT Process with one lane for normal processes and another lane containing IoT Device. IoT Device lane consists of a Sensing Task.

In the BPMN 2.0 machine-readable model, the authors have introduced four new classes trying to be in consistent with BPMN 2.0 standard, by overcoming the challenges they faced when positioning them. A new class IoTDevice is introduced as a sub class by extending the Lane class. Lane is a sub class of BaseElement so that the class, IoTDevice inherits all attributes and associations of the class BaseElement. The class ResourceRole is extended introducing a new class named NativeService under the class Performer to represent the device's software resources. Since Performer is a sub class of the class ResourceRole inheriting attributes and model associations of the parent class, the new class, NativeService inherits all those features as well. Third new class, IoTParameterDef is introduced in parallel to IoTDevice and this is used for parameter definitions by IoTDevice class. This class contains two attributes, name and extParameterRef. The attribute extParameterRef is used for referencing the parameters since those are not stored in BPMN model. The final new class, IoTAssignment is used for defining the resource assignment of IoT device and native services. The process model consists of both graphical and machine-readable aspects and it uses IoT as well as non IoT process tasks.

The authors carry out an implementation by extending a web based editor tool to illustrate a modelling example in practice. Figure 2.15 illustrates this process. A dynamic pricing process of an item in a store is modelled as an example. This application uses the two extensions to BPMN 2.0, IoT device and native service. This process is modelled by using a BPMN editor, which was extended to incorporate these IoT



Properties (IoT Device)

Properties

Name	Value
Main attributes	
IoT attributes	
Device ID	
Name	Temperature Sensor
Device Type	Sensor
Implementaion	?/fuse:templd4:sense:frc
Controlling Device	

Figure 2.15: Dynamic pricing process with the two IoT Devices temperature sensor and ESL

Source: (Meyer et al., 2013)

modelling elements. This example uses a flower, an orchid as a perishable good in a store and its quality is monitored by measuring the temperature and its price fluctuates according to the measured temperature, i.e. if the temperature is high, the price on an electronic shelf label (ESL), automatically is reduced. This example uses two IoT devices, a temperature sensor to measure the temperature of the flower and an actuator to increase or reduce the price accordingly. The IoT services or the native services in this scenario are measure temperature and update price. The process model uses a separate pool for representing physical entity, i.e. flower. The pool icon cow is borrowed from a past research in representing this. Both IoT devices, the sensor and the actuators are kept in two separate lanes and the normal process is in a separate lane of the same pool.

2.4.8 Summary

Table 2.1 illustrates each framework we reviewed in the literature against IoT modelling elements they proposed for business process modelling. This table is adapted from (Chang, Srirama & Buyya, 2015).

IoT modelling elements	uBPMN	SPUs	BPMN4 WSN	Things in BPMN	Crowd-sourcing	Event Elements	IoT Devices
Sensor	✓		✓	✓		✓	✓
Actuator			✓	✓		✓	✓
Reader	✓						
Collector	✓						
Event streaming task		✓					
Intermediary operation			✓				
Specific data object	✓	✓					
IoT device and native services							✓
Crowd-sourcing task					✓		
Location awareness						✓	
Physical entity				✓			✓

Frameworks: (1).uBPMN - (Yousfi et al., 2016), (2).SPUs - (Appel et al., 2014), (3).BPMN4WSN - (Sungur et al., 2013), (4).Things in BPMN - (Meyer et al., 2015), (5).Crowd-sourcing - (Tranquillini et al., 2015), (6).Event Elements - (Chiu & Wang, 2015), (7).IoT Devices - (Meyer et al., 2013).

Table 2.1: IoT modelling elements for business process modelling introduced by each framework

uBPMN (Yousfi et al., 2016) framework incorporates ubiquitous technologies into business processes. This models IoT elements sensor, reader, actuator and smart object by extending BPMN element task and data input respectively, without changing BPMN concepts and reflecting the additions in BPMN meta model. The case study, 'time banking' application process models the extended BPMN elements, sensor task, collector task and smart object. The system is deployed both web based and as a mobile app using the same web services.

The case study covers a scenario where people trade services in favour of money and tries to demonstrate the advantages of incorporating ubiquitous technologies with BPMN. The request lists presented to service providers are filtered with most suitable requests based on his location (context-awareness), time to fulfil request, etc. For an example, the request for 'gallon of milk' is included in the list of request provider who is already in a supermarket. Carrying out an implementation using the process model and conducting some tests distinguishes this study. However, the reader task introduced has not been incorporated in the process model and the implementation tests are limited to test cases.

Event stream processing in framework SPU (Appel et al., 2014) using event stream processing units (SPUs) introduces a concept for continuous reading of stream of events using sensors. The example illustrates how a shipment monitoring SPU, which receives streams of events as input would measure temperature during shipment to keep it under threshold limits and signal temperature violations if there are any. The process can terminate with either explicit completion by a given condition or implicit completion or the combination of both. In case a violation is detected, the exception handling process is called which, brings the process to an end explicitly. The customer can cancel the order with a refund rather than receiving spoiled or damaged goods. This result in maintaining business reputation and customer satisfaction. The process model is executed as well. However, the model comes with some technical limitations such as BPEL presently does not support implicit insanitation and completions of event stream processing tasks (ESPTs).

Real world interactive situations represented through events are closely related to IoT. Therefore, this work would immensely benefit in modelling IoT related business processes.

Moreover, at the execution layer of the business process implementation, the authors introduce EDA (event driven architecture) for SPUs. This can be considered important since IoT related business applications being interactive with the environment through devices such as sensors and reacting to event streams are not well supported by web services and SOA (Barros et al., 2012). This is due to two reasons. Primary reason being that the web services are based on request respond mechanism which is pull based whereas IoT based applications mainly require push based mechanism due to its reactive nature to occurrence of environmental events, etc. Second reason is that web services hide the middleware they run on.

BPMN4WSN (Sungur et al., 2013) uses BPMN to integrate sensors and actuators to a business process model by means of a wireless sensor network. The goal is to bridge the gap between technical experts who desire to build WSN and the domain experts who design business processes. The application demonstrates a meeting room ventilation process with WSN. Upon starting the meeting, the sensors continuously detect the CO2 levels in the meeting room and reports until the meeting is over. The actuators adjust the temperature level to a desired level, which was a predetermined input to the process at start. The process was modelled with standard BPMN and by extending BPMN illustrating how sensors, actuators and intermediary operations can be incorporated into BPMN. With extensions, the process became simpler and more efficient.

However, there is some possibility that this extension to BPMN could result in some confusion among domain experts. The model comes with some limitations as well. It is a challenging and a difficult task to create WSN since development requires low level programming languages. Some extensions to the model, e.g. the way pools are used in expressing processes can create confusion when understanding standard BPMN elements. Moreover, BPMN4WSN is not platform independent since the tool can only generate code for sensors based on the open source operating system for IoT, Contiki OS. The model is not tested enough in practical environments, though it is to be tested in areas such as logistics and predictive maintenance in the future.

The framework, Things of IoT in BPMN (Meyer et al., 2015) demonstrates how the *thing* of IoT or the physical entity can be better reflected in business processes. For representing physical entity with BPMN, three elements of BPMN model, text annotation, data object and participant are selected. When these elements could not satisfy all identified requirements in representing physical entity, each base class is extended to create custom classes. A test result indicates that custom participant class (collapsed pool) as most suitable for representing the physical entity in the standard BPMN. (This information would become useful for someone who would want to model physical entity without extending BPMN.)

Since this does not fully satisfy all requirements in representing physical entity, a fundamental change to the BPMN meta model is proposed. That is a separate graphical element linked to BPMN collapsed pool and, a machine readable element extending the participant subclass. In the graphical representation of the physical entity, the symbol ‘cow’ indicates that the physical entity can be a living being. This proposal is argumentatively viable except for the extensions are not conforming to BPMN standards and the consequences could be considerable.

Crowdsourcing (Tranquillini et al., 2015) framework proposes an extension to BPMN to accommodate crowdsourcing processes. A practical example of receipts feeding to a crowdsourcing platform demonstrates that streaming crowd tasks are more efficient than non-streaming tasks. Therefore, BPMN extensions are applied to model streaming crowd task processes.

Tasks and control flow connectors of standard BPMN is initially considered for modelling crowdsourcing processes. BPMN tasks has clearly defined start and end events and facilitate the runtime execution of multi-instance tasks in parallel or sequential. Crowdsourcing requires task instances to run in parallel. Even though the BPMN tasks have parallel execution, their end events limits obtaining the streaming benefits from crowdsourcing because one task has to end for the other to start.

Task instance streaming for micro-task crowdsourcing is a useful technique for business processes. However, this is platform dependent as it is only tested on open-source BPM platform, Activiti, and only a few micro tasks are used. The authors intend to stress test with some thousands of micro tasks and carry out experiments to find out the reasons for some micro tasks taking a long time to finish.

Authors in Event Element for IoT (Chiu & Wang, 2015) extend BPMN element *event* to facilitate business process modelling for IoT. The argument is that events reflect the characteristics of IoT better. As extensions to BPMN three event elements and one new modelling element representing location are introduced. The new events are conditional event, message event and error event. Context awareness is an important feature in IoT applications, therefore the new location event can be considered as an important addition. The modelling example uses all BPMN event extensions proposed as IoT modelling elements. For modelling the sample application process, an actuator task modelled by existing research was borrowed to use with the event extensions introduced, making the process more complete.

The framework, IoT Devices as resources (Meyer et al., 2013) proposes two extensions to BPMN 2.0, IoT device and the native service of IoT reference model. The extensions are illustrated in both graphical model and machine-readable model. The example models a sensor and an actuator as an IoT device. Though there is a statement of ERP system integration, the sample process model is not adequate in illustrating the IoT application in ERP systems. However, the authors have gone to an extend to practically implementing the modelling extensions to a BPMN editor, which we have not come across elsewhere in our literature review. A sensor task and an actuator task are added to the editor's toolkit as BPMN extensions. Existing BPMN editors already provide a pool and lanes and labelling each lane accordingly. The separate pool uses in representing physical entity contains the icon cow that is borrowed from a past literature work.

Overall, one common limitation in most works are that the models are not tested enough to see how their extensions would affect the standard BPMN, and the domain experts who design the business model. However, it is apparent that all have contributed in representing IoT modelling elements in business processes one way or the other.

In comparison, we introduce more IoT modelling elements and model them in our case study example. Moreover, we extend an existing web based BPMN editor to incorporate all modelling elements we have proposed as extensions to BPMN and an extra element, physical entity. We demonstrate the capability of our editor by practically modelling these elements in an IoT related process using this tool. Moreover, this editor incorporates an XPDL editor and we extend this XPDL editor as well to include our extensions. We generate XPDL code to store our IoT related business process model. Only one work (Meyer et al., 2013) has practical extended a BPMN editor tool. However, the extensions are limited to two new task elements, sensor and actuator and no specific method of storing and distributing the model, which we do through XPDL as already mentioned.

2.5 Conclusion

This chapter considered some literature related to business process modelling for IoT and mainly dedicated to discuss IoT modelling frameworks. We reviewed seven chosen IoT modelling frameworks, which integrate IoT modelling elements into business processes. We discussed each work in detail empathising on their contributions for business process modelling for IoT. Overall, they have identified IoT modelling elements sensor, actuator, reader, collector, event streaming, intermediary operation, specific data object, physical entity and, location awareness, crowdsourcing, IoT device and native service representation in business process models. In the summary section, we compared each framework with IoT modelling elements introduced by them in a table. Furthermore, we discussed each work by critically reviewing and highlighting the contributions.

Chapter 3

Running Scenario and Requirements Derivation

3.1 Introduction

This section consists of four subsections. In section 3.2, a running problem scenario is introduced. A part of supply chain management is taken as the problem scenario, mainly highlighting the inventory part of it. This example can be considered as a typical work scenario, which is capable of covering the key aspects of IoT modelling elements. The business process model of the problem scenario is modelled and illustrated in BPMN.

In section 3.3, we identify requirement elicitation of business process modelling for IoT. We derive business process modelling requirements for IoT using the problem scenario introduced in the previous sub section. We identify seven new IoT modelling elements as business process modelling requirements for IoT, which answers our first research question. We propose UML class diagrams to better illustrate these requirements with their attributes and relationships. Requirements, which are illustrated as UML classes, are further broken down into sub classes wherever applicable. As we have found different groups of characteristics for certain requirements, we categorise

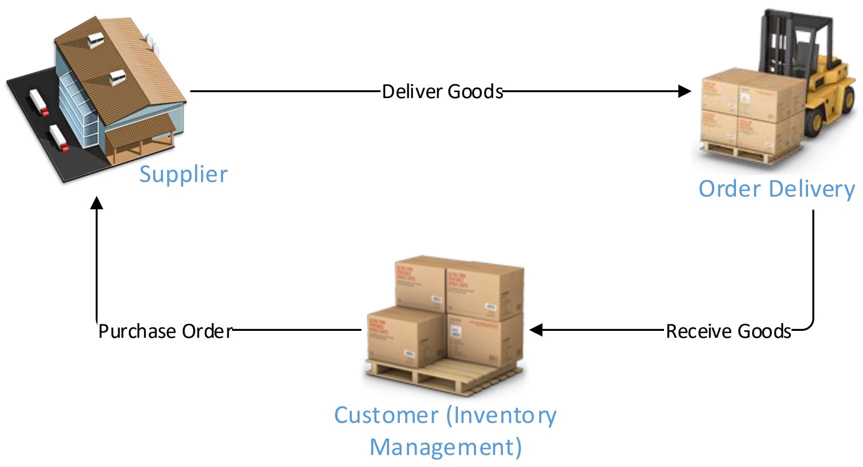


Figure 3.1: Part of a Supply Chain Management process

these and illustrate in diagrams highlighting common and shared features among these categories. Subsection 3.4 concludes our work.

3.2 Problem Scenario

IoT can affect the whole process of supply chain management, i.e. the manufacturing, transportation, warehousing and selling (Sun, 2012). The problem scenario we introduce in this section is based on part of supply chain management and the flow of the process is as follows.

A company's inventory control system triggers a purchase order request to the purchasing department when the stock reaches its re-order levels. Upon receiving this request, the purchasing section in turn issues purchase orders to selected suppliers with relevant re-order quantities. Once the suppliers receive these orders, they deliver the goods. This process is illustrated with symbols in Figure 3.1. The overall process is modelled in BPMN and illustrated in Figure 3.2. BPMN element *Text Annotation* is used to explain the IoT technology integration in each sub process of this scenario. The sub processes are expanded to demonstrate the use of IoT modelling elements in each of them. The business process modelling requirements for IoT are identified by using

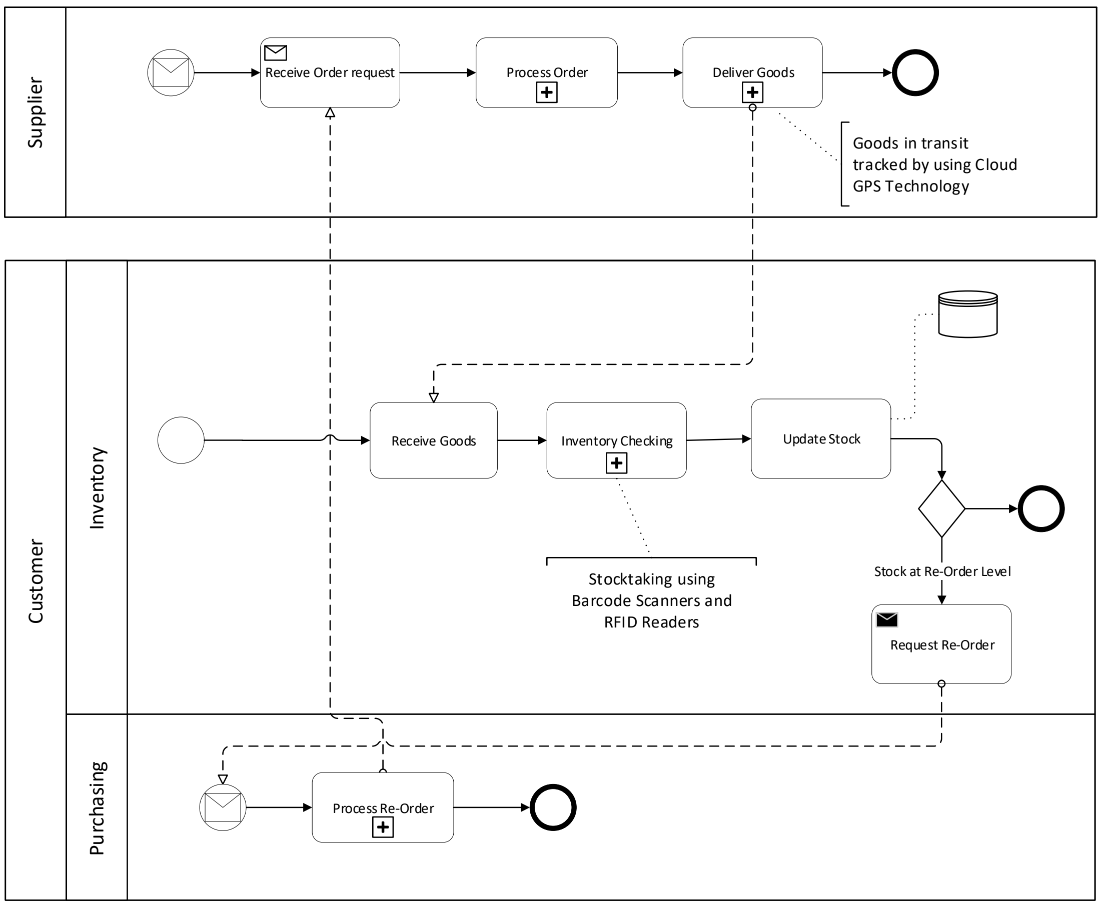


Figure 3.2: Problem Scenario process modelled in BPMN

R1.. Rn as identifiers. Each requirement is explained in detail in the next section.

Stocktaking can be conducted in several methods. A hand held device with a built-in barcode scanner and a RFID reader can read inventory in a store using barcodes or RFID tags. The device is programmed to store item information such as item code, description, location, and quantity. For reading stocks with barcodes, the barcode scanner is taken to a location in the store and scans the location barcode and each container of items in the location with barcodes. Quantity for each item category is fed to the device. Once all items are counted, the device it taken close to a PC in the store, which is programmed to scan nearby devices so that the information stored in the hand-held device is transferred to the inventory database stored in the PC updating the stock levels. Products with RFID tags can be read at once, which are in the working radius and update the inventory

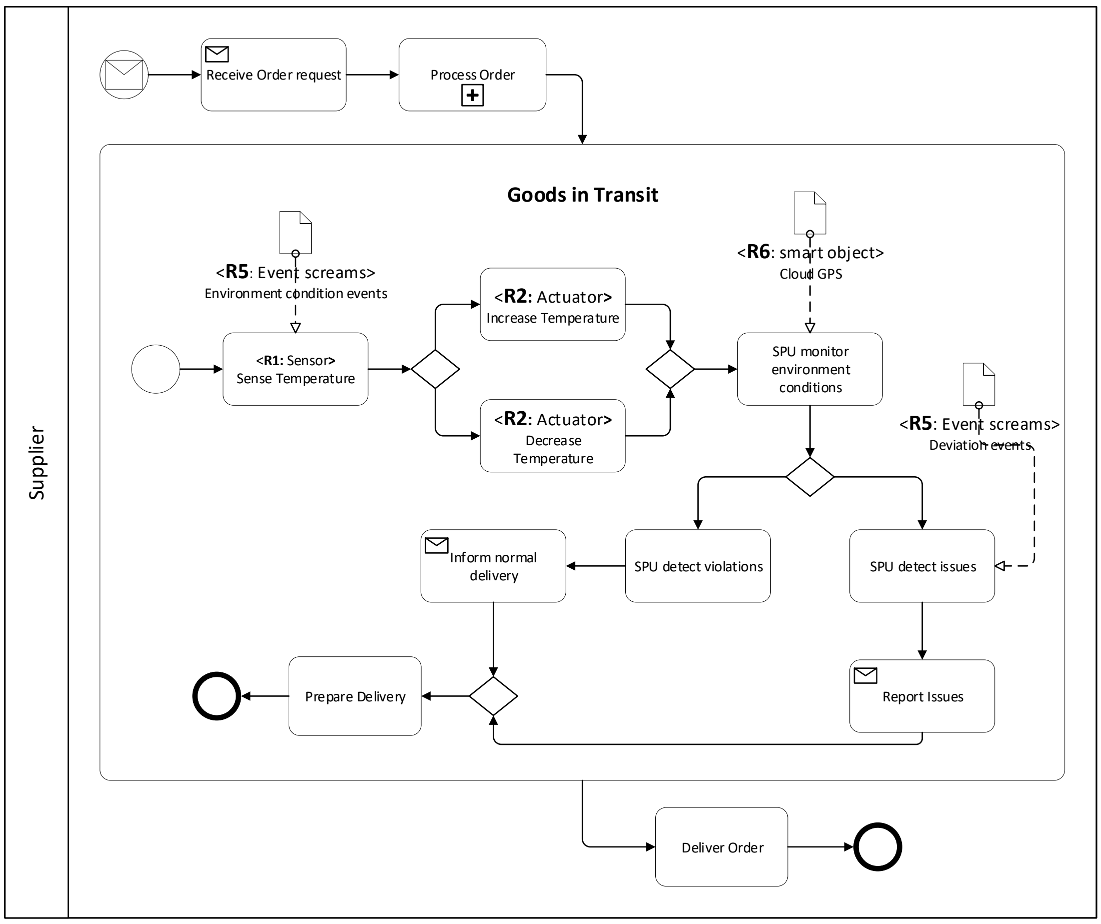


Figure 3.3: Deliver order sub process in the problem scenario expanded

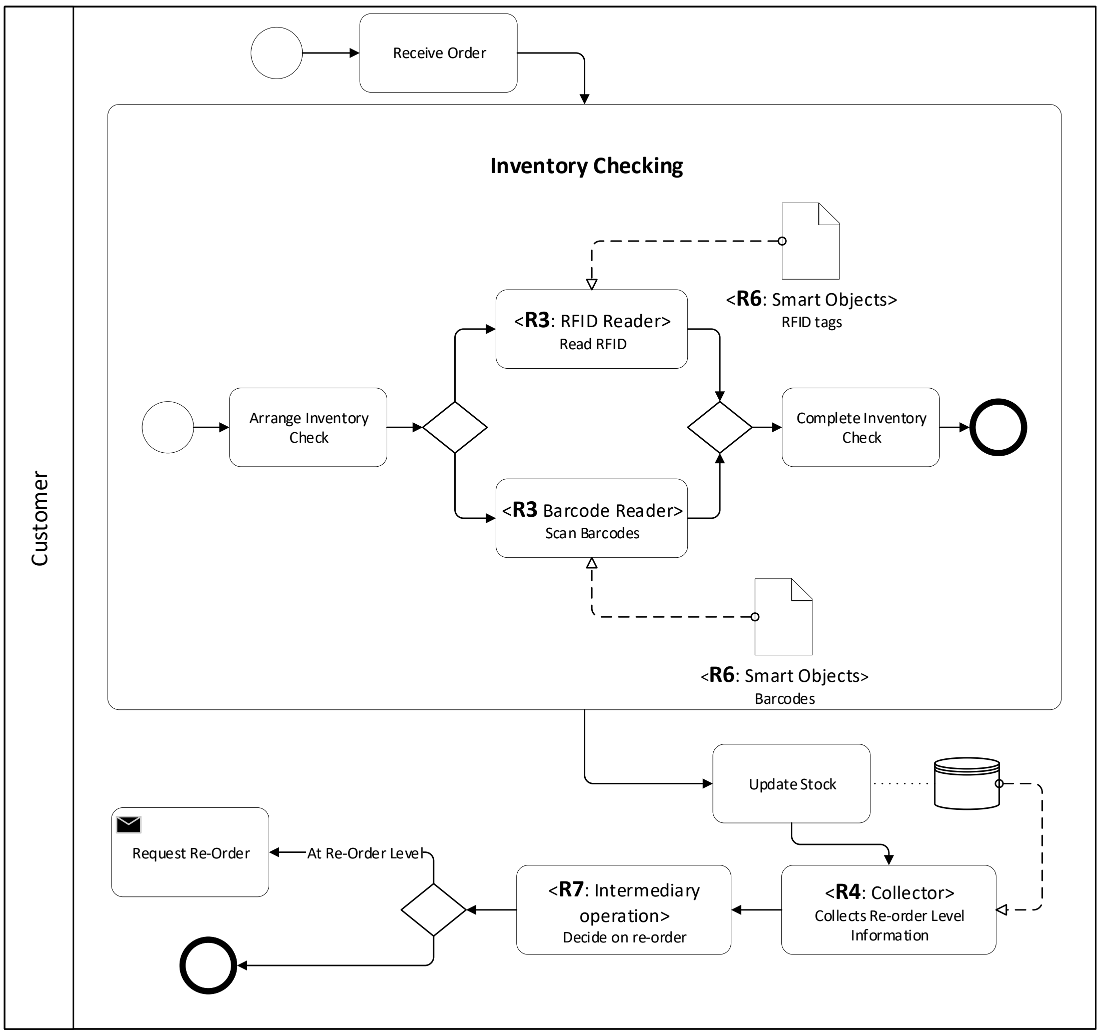

Customer
Receive Order
Inventory Checking
<R6: Smart Objects> RFID tags
<R3: RFID Reader> Read RFID
Arrange Inventory Check
Complete Inventory Check
<R3 Barcode Reader> Scan Barcodes
<R6: Smart Objects> Barcodes
Update Stock
Request Re-Order
At Re-Order Level
<R7: Intermediary operation> Decide on re-order
<R4: Collector> Collects Re-order Level Information

Figure 3.4: Inventory checking sub process in the problem scenario expanded

database the same way. Similarly, when a truckload of items with RFID tags arrive at the store, the full load can be read at once using RFID technology and update the stock levels.

When the stock reaches their re-order levels, this automatically indicates by retrieving information from the inventory database and the inventory control system can issue re-order requests to the purchasing department for the items at their re-order levels. The BPMN diagram for *Inventory checking* sub process is expanded and illustrated in Figure 3.4. The purchasing department selects suitable suppliers, generate, and send purchase orders to those suppliers with relevant re-order quantities.

Upon receiving purchase orders from the customer, the supplier in turn will deliver goods. RFID technology together with Cloud based GPS will track and monitor the goods in transit for traffic conditions, etc., affecting the transit time. Temperature sensors will continue to check for environment conditions during the shipment to maintain the quality of goods in transit. The BPMN diagram for the sub process, *Deliver order* is expanded and shown in Figure 3.3.

Once the customer receives the goods, stocktaking as already described, takes place updating the stock levels in the database.

3.3 Requirements Derivation

In this section, we explain the seven new business process modelling requirements for IoT identified by using the problem scenario introduced in the previous sub section. The requirements are linked to the sub processes modelled in BPMN, and illustrated in Figure 3.3 and Figure 3.4. Each requirement is explained first by introducing the requirement, followed by its uses in applications and finally, describing in what stages of the problem scenario it is being used.

In Figure 3.5, class diagram for business process modelling requirements for IoT is illustrated.

3.3.1 Requirement 1 (R1): *Sensor* as the Business Process Modelling Requirement for IoT

Sensors are popular in IoT systems. Sensors collect context information from the environment acting as input transducers. (Vladimer, 2015) states that “A sensor transforms interesting, useful energy into electrical data". Camera and microphone in a smart phone are examples of simple sensors. Sensors detect events or changes such as

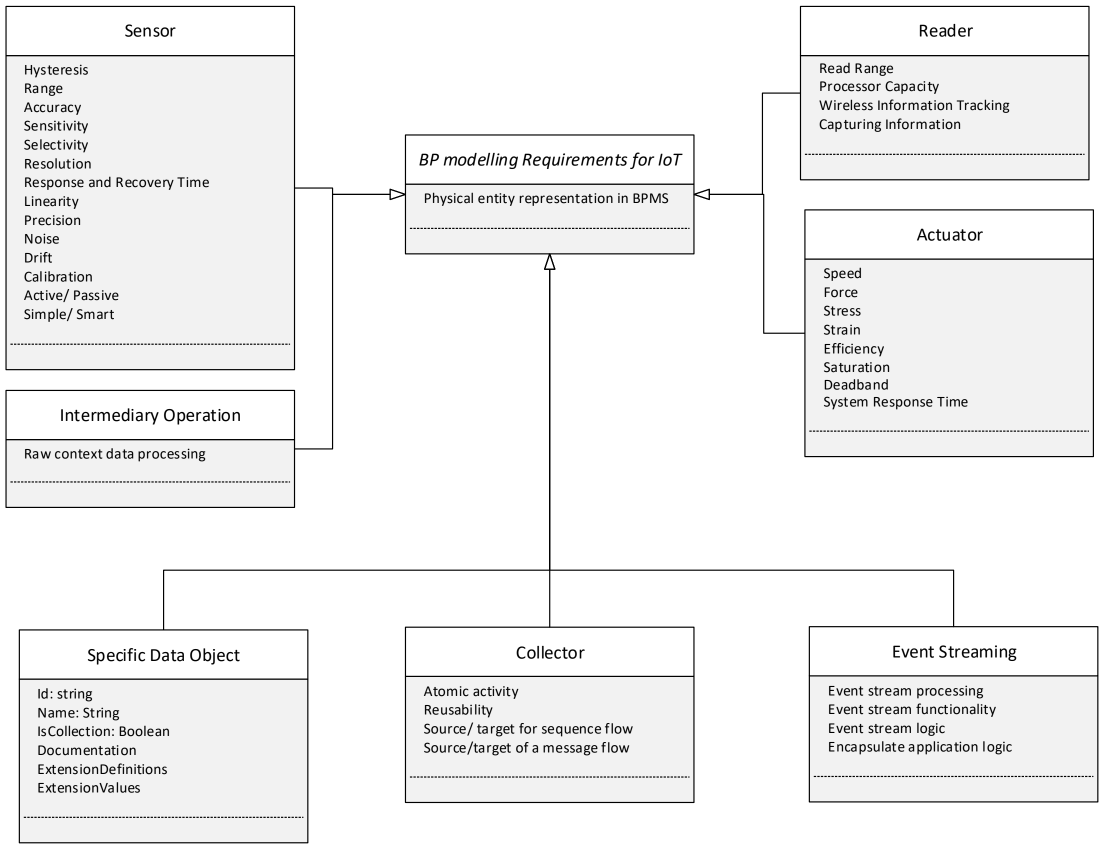


Figure 3.5: UML class diagram for business process modelling requirements for IoT

temperature, heat, sound, pressure and motion in the physical environment and provide relevant outputs. Most of them produce digital, mostly electrical outputs by taking analog inputs often requiring analog to digital converters. They collect data from any location at any time and transmit them real-time via IoT networks (Rayes & Samer, 2017).

Sensors can be *active* and *passive*. In active sensors, the signals they produce are reflected back to the sensors themselves, whereas passive sensors react to signals they receive such as sounds and heat. Example for active sensors are radar, GPS, x-ray and infrared and passive sensor examples are electric, heat, chemical and photographic (mpls.com, n.d.).

Sensors can also be categorised as *simple* or *smart*. *Smart sensors* are a type of sensors and, at their minimum, they comprise of a sensor, microprocessor and some communication connectivity. They process the inputs they take from their environments before releasing them as outputs (Rouse, 2015). Smart sensors provide additional functionality such as filter duplicate data and notify IoT gateway upon meeting specific conditions, thus needing certain programming logic in the sensors (Rayes & Samer, 2017). Smart sensors are an important part of IoT applications, particularly in business applications such as supply chain management (O'Donnell, 2017). Among other uses, these sensors have three main purposes, namely identifying items, locating them and measuring environment conditions. Sensors of this category detect the status of products being shipped throughout the shipment process and report any deviation in temperature or quality via messages. What is more, sensors with help of Cloud GPS services detect any delays or unexpected incidents in transportation in advance so that prompt decisions are feasible.

Retailers in their businesses use proximity sensors to trace customer movement and promote products by sending discount coupons to their phones. In the same way, sensors have become very useful in transporting goods. In agriculture, sensors such

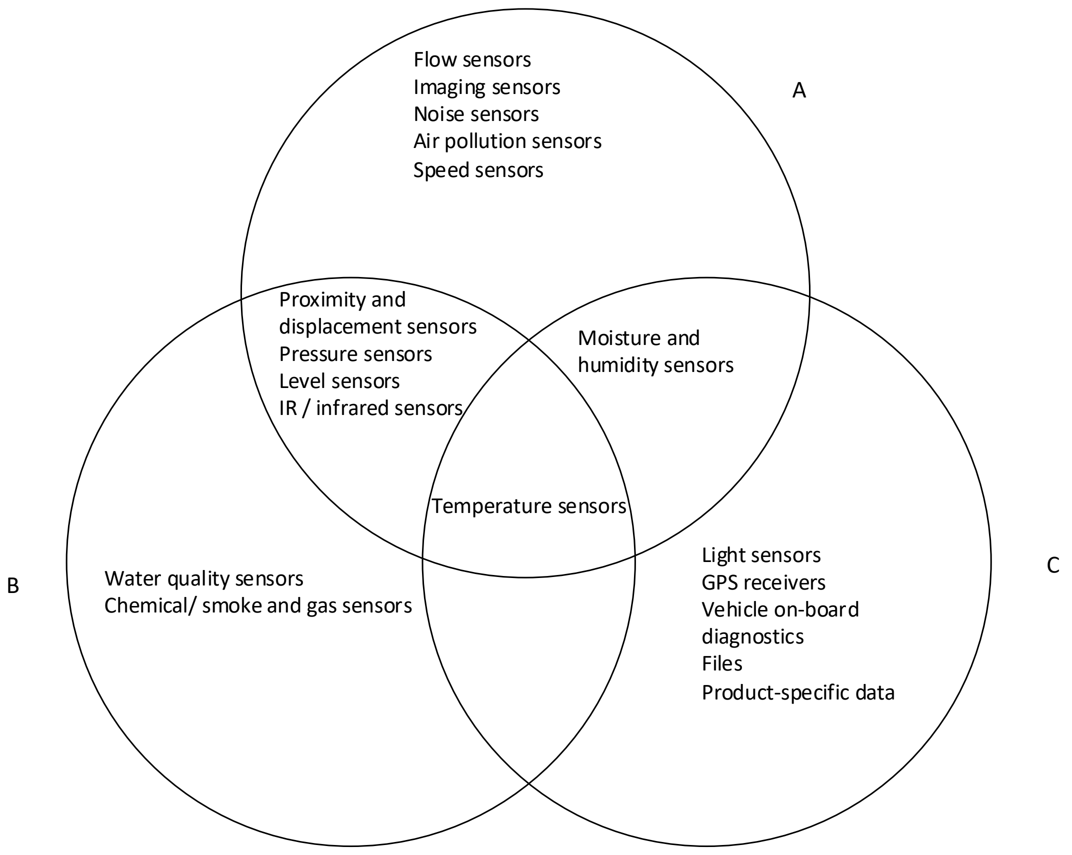


Figure 3.6: Categories of Sensor Types

as pressure sensors, temperature sensors and water quality sensors are used. Pressure sensors are used to detect the water flow through pipes and reduce water wastage and temperature sensors measure the temperature of plants, soil and water. Similarly, in manufacturing sensors are used for quality management by incorporating them in the machines so that if there is any change in the required quality levels, the sensors will detect them e.g. temperature sensors measure the temperature of machines.

In the problem scenario we introduced in subsection two, temperature sensors of smart sensor category are used to detect temperature in the environment while shipment is on its way from the supplier to the customer. Sensors keep monitoring temperature to maintain the quality and condition of the goods while transportation and any violations are reported back to suppliers by using Cloud GPS technology.

There are various types of sensors, which can be used in IoT applications. (Rayes & Samer, 2017) categorises sensors into eleven types. They are temperature sensors, pressure sensors, flow sensors, level sensors, imaging sensors, noise sensors, air pollution sensors, proximity and displacement sensors, infrared sensors, moisture and humidity sensors, and speed sensors. Sensor characteristics they identify are data filtering, minimum power consumption, compact, smart detection, high sensitivity, linearity, dynamic range, accuracy, hysteresis, limited noise, wide bandwidth, high resolution, minimum interruption, higher reliability and ease of use. According to (Tracy, 2016) sensor types for many IoT use-cases are temperature sensors, proximity sensors, pressure sensors, water quality sensors, chemical/smoke and gas sensors, level sensors and IR sensors.

(Biron & Follett, 2016) identifies sensors as, temperature sensors light sensors, moisture sensors, GPS receivers, vehicle on-board diagnostics, files, and product-specific data. (bootcamplab.com, 2017) describes sensor characteristics as range, drift, sensitivity, selectivity, resolution, response and recovery time, linearity, hysteresis, calibration, full-scale output, precision and accuracy. Whereas, according to (Kalantar-Zadeh, 2013) sensor characteristics are accuracy, precision, repeatability, reproducibility, stability,

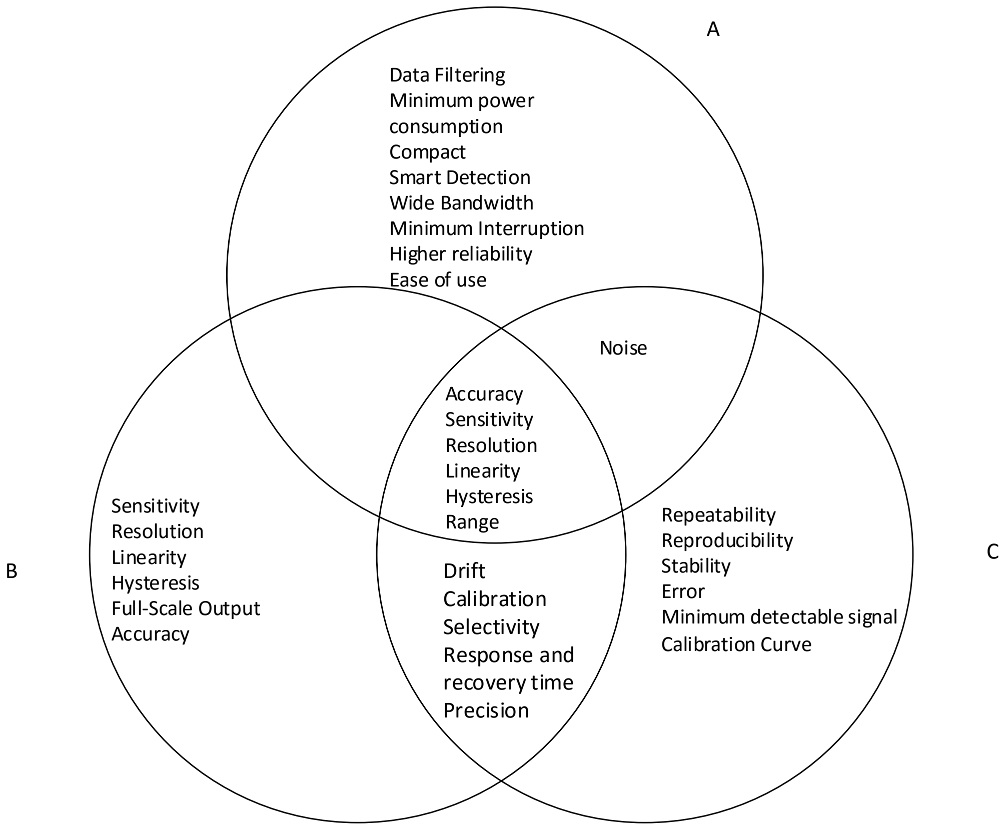


Figure 3.7: Categories of Sensor Characteristics

error, noise, drift, resolution, minimum detectable signal, calibration curve, sensitivity, linearity, selectivity, hysteresis, measurement range, and response and recovery time. Categories of sensor types are shown in Figure 3.6. Circle A denotes (Rayes & Samer, 2017), B - (Tracy, 2016) and C - (Biron & Follett, 2016). Temperature sensors are common to all three references. Moisture and humidity sensors are shared by (Rayes & Samer, 2017) and (Biron & Follett, 2016) whereas, proximity and displacement, pressure, level IR or infrared sensors are common to (Rayes & Samer, 2017) and (Tracy, 2016).

Sensor characteristics common to three of the references are accuracy, sensitivity, resolution, linearity, hysteresis and range. The characteristics, drift, calibration, selectivity, response and recovery time and precision are common to (bootcamplab.com, 2017) and (Kalantar-Zadeh, 2013) whereas, the characteristic noise is shared by (Rayes & Samer, 2017) and (Kalantar-Zadeh, 2013). Therefore, these common characteristics are chosen to represent sensor attributes.

- Range/ dynamic range/ span - Sensing range within which, the sensor works well. This range produces accurate and meaningful output (with an acceptable error).
- Accuracy - How correct the sensor output is compared with its true input value. For example if an oxygen gas sensor records 21.1 percent in a room with 21 percent oxygen level, it is more accurate than if it shows 22 percent.
- Sensitivity - The change in sensors output to the measured change in its input.
- Selectivity - The sensor's capability in selecting and differentiating the target to measure among other interfering targets. For example, a sensor for oxygen gas should not respond to other gases such as carbon dioxide or nitrogen dioxide.
- Resolution - Signal fluctuation of a sensor detected at its minimum. Minimum change in the target input will reflect a detectable change in the output signal.

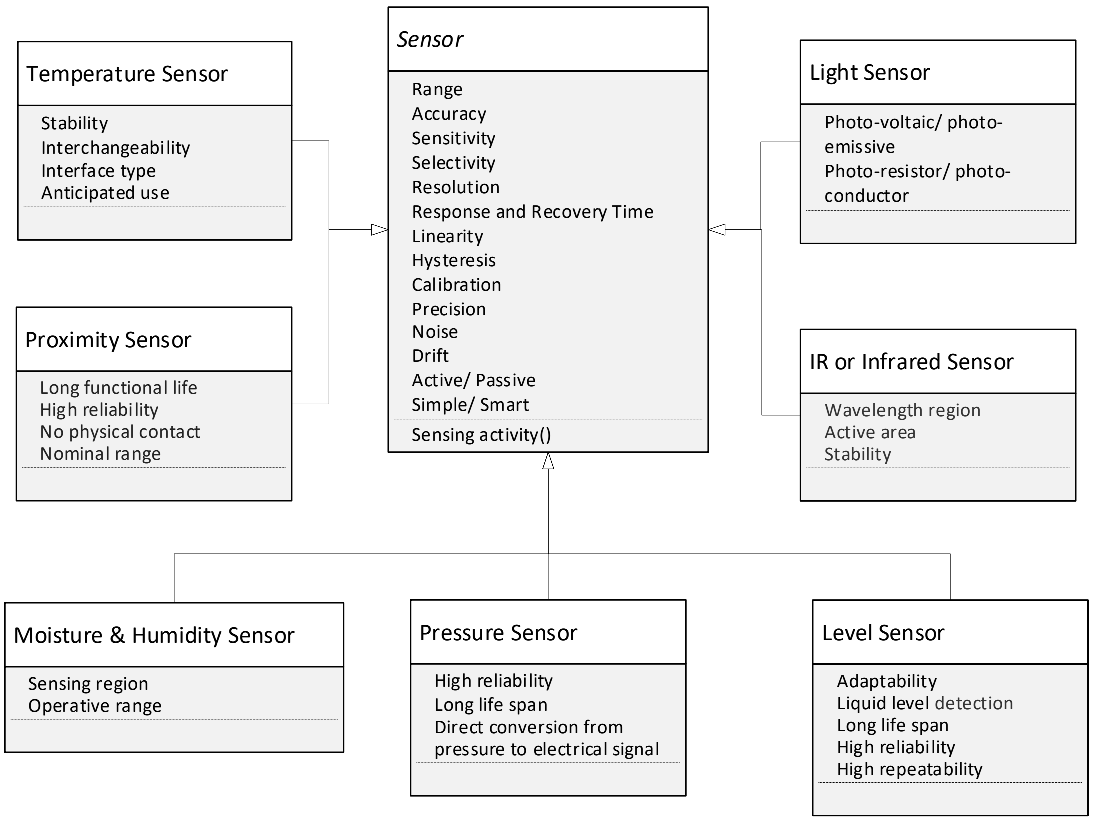


Figure 3.8: UML class diagram for Sensors

Any noise in the signal can affect resolution.

- Response and recovery time - Response time of a sensor is the time taken to produce a stable output or the output reaches a certain percentage such as 95 percent. Recovery time is the opposite.
- Linearity - The proportion of the sensor's output for its input values. A sensor maintaining constant sensitivity for its range is a linear sensor.
- Hysteresis - The difference between sensor's output readings for the same inputs.
- Calibration - Sensor should calibrate against known measured input to determine that its output is correct.
- Precision - The sensors ability of producing the same results repeatedly for a given input under the same conditions.
- Noise - Unnecessary fluctuations in the sensor's output signal when the measuring inputs are stable.
- Drift - Gradual change in sensor's signal levels while input remains unchanged. This is an undesired change, which can result in errors.

The category chart of sensor characteristic is shown in Figure 3.7. Circle A refers to the characteristics introduced by (Rayes & Samer, 2017), B refers to (bootcamplab.com, 2017) and C refers to (Kalantar-Zadeh, 2013).

Taking all sensor types into consideration, sensor types common to at least two of the categories are chosen. In addition, *light sensors* are included due to its importance in IoT applications. For example, (education.rec.ri.cmu.edu, n.d.) states that robots use light sensors to detect the "current ambient light level". According to (Vyas, 2008) light sensing robots use the light sensors for their movements, to decide if to move left, right or straight according to the light. Sensor characteristics common to at least two groups of characteristics are chosen as sensor properties. Figure 3.8 illustrates a UML class diagram for chosen sensor types and sensor properties. According to (coep.vlab.co.in, 2011), temperature sensor characteristics are

- Interface type – for example 15C.
- Anticipated use – what it is used for, for example heating or cooling a system.

Whereas, according to (coep.vlab.co.in, 2011) temperature sensor characteristics includes stability and interchangeability. (Mathas, 2012) states that light sensors can be separated into two groups.

- Photo-voltaic or photo-emissive which generates electricity once illuminated.
- Photo-resistor or photo-conductor which changes its electrical properties in some way

(OMRON, 2017) defines *Object detection without touch* and *longer service life* as two of the features of proximity sensors. (wikipedia, 2017) states that proximity sensors have a *nominal range* in which they detect objects, *high reliability*, *no physical contact* between the sensor and the object being sensed and *long functional life* due to no mechanical parts and no physical contact. According to (T.L.YeoT.SunK.T.V.Grattan, 2008) moisture and humidity sensors have a *sensing region* as a feature and (Yamazoe & Shimizu, 1986) defines *operative range* as another feature. According to (panasonic.biz, n.d.) pressure sensors have *high reliability and long life* due to lack of mechanical parts and have the ability of *direct conversion from pressure to an electrical signal* IR or Infrared sensor characteristics are *stability, active area and wavelength region*. (Kazuma Maekawa, 2017) defines *dynamic level detection* as a characteristic of level sensors and (Yao, 2017) defines adaptability, long life, high reliability, high repeatability as level sensor characteristics.

3.3.2 Requirement 2 (R2): *Actuator* as the Business Process Modelling Requirement for IoT

Actuators are the opposite of sensors where actuators act as output transducers in IoT applications. According to (Vladimer, 2015), “an actuator transforms electrical data into interesting, useful energy”. Example of simple actuators are loudspeaker and display screen of a smart phone. Sensors collect data through sensing activity and send to a control system, which in turn makes a decision based on the sensing data and sends to an actuator to take action. (Rouse, 2017) defines an actuator as a "mechanism for turning energy into motion" and based on the *energy source* actuators use to generate motion, they can be divided into four groups. They are:

- *Pneumatic actuators*, which generate motion using compressed air.
- *Hydraulic actuators*, which generate motion with the help of liquid.
- *Electric actuators*, which generate motion by an external power source like battery power.
- *Thermal actuators*, which generate motion by a source of heat.

(Rayes & Samer, 2017) defines actuators as certain types of motors, which control or perform some action in a system by converting data or energy to action. In an IoT system, actuators take action or control an IoT system by making use of collected data through sensing or by other means. For an example, an actuator increases or decreases temperature in an air-conditioned room depending on sensor readings for required levels of cooling. Some types of actuators are electrical actuators, mechanical linear actuators, hydraulic actuators, pneumatic actuators and manual actuators. (wdc65xx.com, 2016) categorises actuators into five main types. They are hydraulic, pneumatic, electrical, thermal or magnetic and mechanical. According to, (Biron & Follett, 2016) actuators are lights, valves, motors and commands.

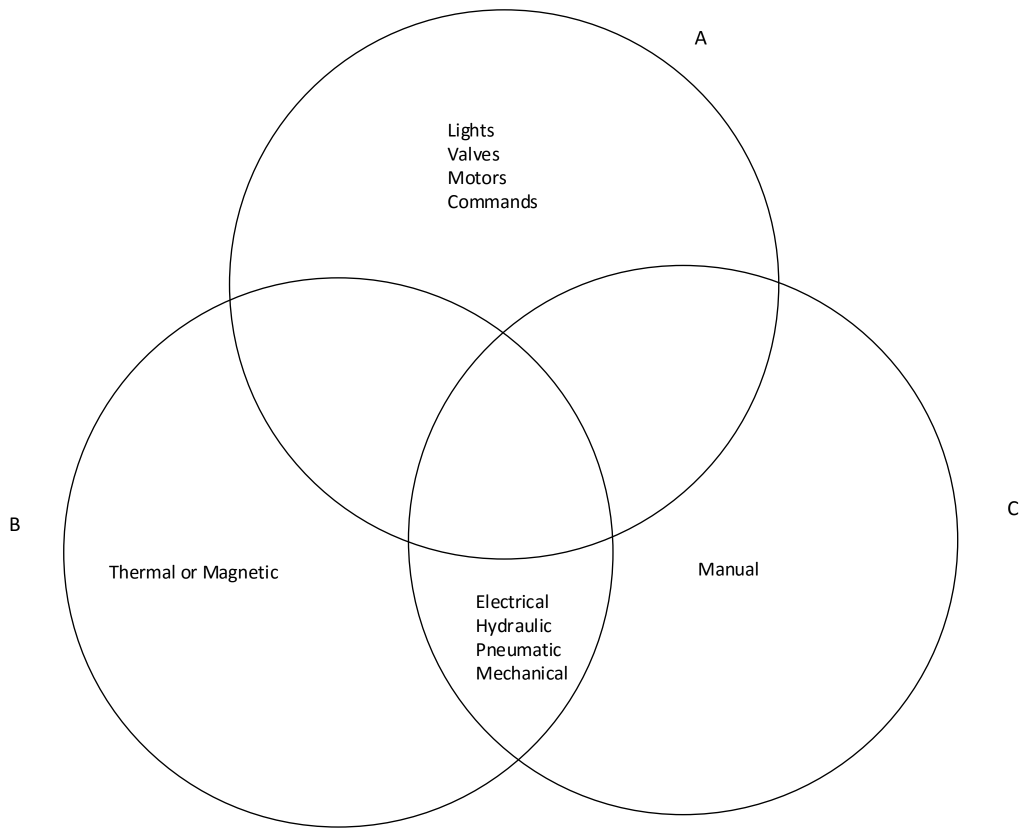


Figure 3.9: Actuators Categories

Figure 3.9 shows the three categories of actuator types. Circle A denotes the actuator types by (Biron & Follett, 2016) and circle B and C represent the actuator types by (wdc65xx.com, 2016) and (Rayes & Samer, 2017) respectively. The types common to at least two categories are chosen to represent actuator types.

According to (wikipedia.org, 2017), some actuator features are:

- Speed - Speed at no load pace.
- Force - Force capability of the actuator.

As some actuator characteristics, (Parker, 2006) identifies the following:

- Saturation - Maximum output capability without taking input, into consideration.
- Deadband - An input region closer to zero where the output is at zero.

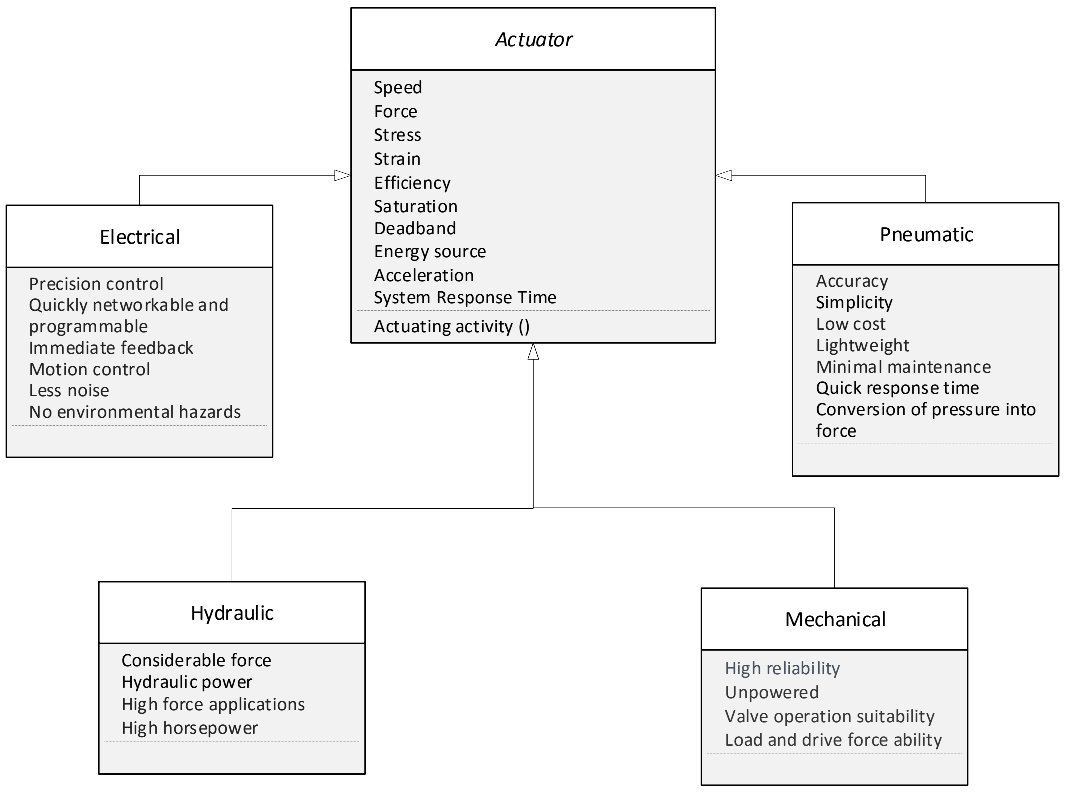


Figure 3.10: UML class diagram for Actuators

According to (Huber, Fleck & Ashby, 1997) some performance characteristics of actuators are:

- Force and displacement - force and displacement requirements of a task.
- Stress - The force applied per unit across an area of an actuator.
- Strain - The nominal strain an actuator produces.
- Efficiency - The ratio of work output to energy input in an cyclic operation.

According to (Gonzalez, 2015), some features of *electrical actuators* are highest precision control positioning, quickly programmable and networked, fast feedback facility for diagnostics and maintenance purposes, complete control over motion profiles (and possibility of encoders for controlling velocity, torque, position and force applied), less noise and no environment hazards due to lack of fluid leaks. (wdc65xx.com, 2016) mention that use of hydraulic power, ability to apply considerable force and limited acceleration are a few characteristics of *hydraulic actuators* and (Gonzalez, 2015) states that applicability for high force applications and possession of high horsepower include *hydraulic actuators* characteristics. (wdc65xx.com, 2016) states that quick response time, conversion of pressure into force as *pneumatic actuator* features and according to (Gonzalez, 2015) they are, simplicity, precise linear motion by resulting accuracy, low cost, lightweight and least maintenance. According to (wdc65xx.com, 2017), *mechanical actuators* possess the characteristics such as they are not powered, ability of specific load and drive force, mainly use for operation of valves and high reliability.

Figure 3.10 shows the UML class diagram for actuators. In the problem scenario we introduced, actuators are used to maintain the quality of goods by maintaining their required temperature levels while transporting them from supplier to customer.

3.3.3 Requirement 3 (R3): *Reader* as the Business Process Modelling Requirement for IoT

Readers are also input devices in IoT systems. They collect actual input data, which are to be transformed into an electronic form to be transferred via a network in order to be made available for use. Two important features of readers are *automatic identification* and automatic *data capture* (Journal, 2017), i.e. automatic identification of objects and obtaining information about them without any human mediation. Famous types of readers are Barcode Readers and RFID readers. According to (atlasrfid.com, 2017) some of the common features of readers are:

- Read rate – The rate at which the things can be read.

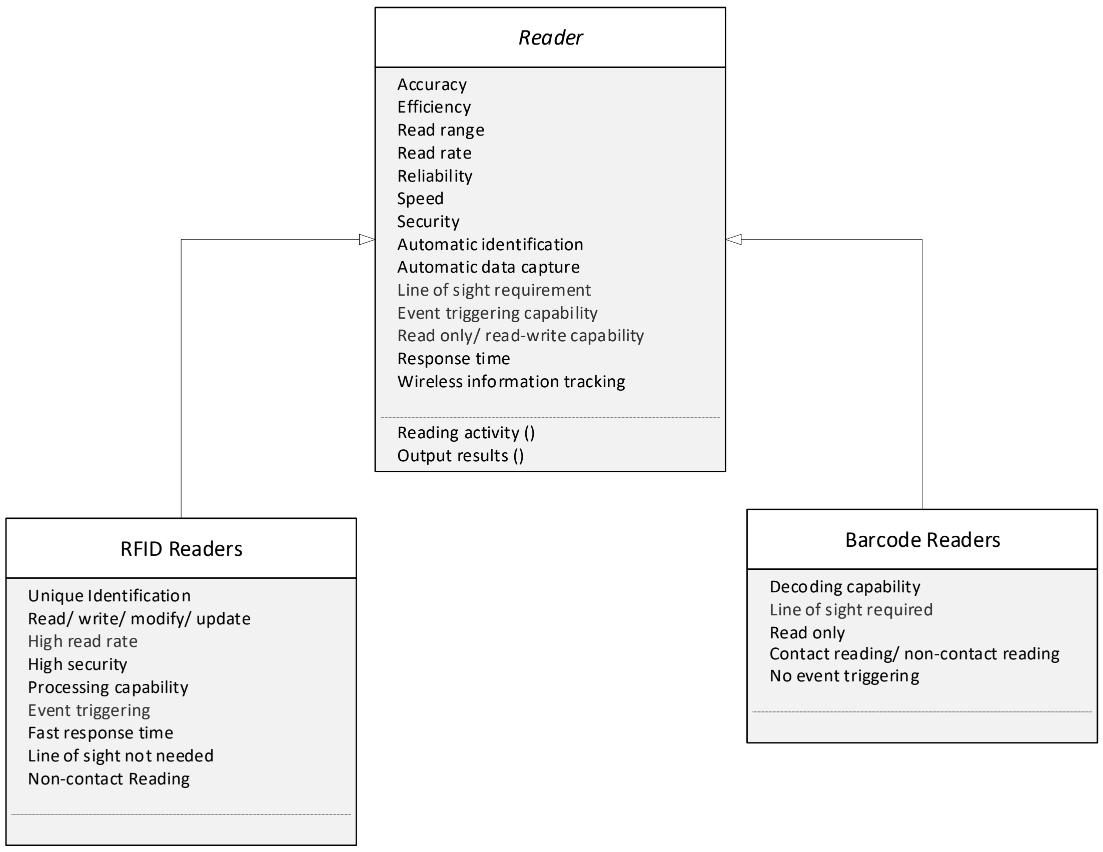


Figure 3.11: UML class diagram for Readers

- Line of sight requirement – If the item to read is required to position in a specific direction.
- Read and write capability – The ability to read and write or read only.
- Event triggering – The ability to trigger an event such as opening a door.
- Security – The ability to protect data such as encryption and to remove data after use.

Figure 3.11 illustrates the UML class diagram for Readers.

RFID readers

RFID has its advantages over bar codes due to its unique identification feature. RFID technology facilitates automatic identification of objects by use of radio waves, generally with help of serial numbers to uniquely identify objects. RFID reader and a tag make a RFID system. The tag consists of a microchip and an antenna. (Journal, 2017). The chip contains the information about the item it is attached to. The antenna receives and returns radio waves from the reader. Readers also contain an antenna, which sends out radio signals to the tags and receives returning signals from the tags. Readers capture unique identification information of the items the tags are attached to. In certain types, the reader possesses the ability to write information on the tags. The reader's software finally passes the item information to the back end system for processing and storage (redbeam.com, 2015).

Active RFID tags contain batteries to power their chips to send signals to the reader. Whereas, passive tags do not contain batteries. They receive power from the reader's electromagnetic signals, which power the tag's antenna. Semi passive tags contain battery power to run the chips though they communicate by obtaining power from the readers. (Journal, 2017). According to (atlasrfid.com, 2017), direct line of sight of items is not a requirement for RFID readers for reading. The items within the read range is sufficient. In addition, there is high security and event triggering, i.e. triggering an event as such as opening a door, is possible.

RFID has variety of uses in the world. Injectable RFID chips can be inserted in animals and used for livestock and wildlife tracking and also in patients who are unable to communicate to trace their medical history and information. RFID technology is used in many large retail companies in the word, such as fashion industry. They make use of this technology to benefit their businesses. This reduces time spent on stocktaking, making the process more accurate and finally guaranteeing customer satisfaction. By using a hand-held RFID reader, large items of stock can be counted at once saving time spent on stock taking as visible contact and line of sight of items is not a requirement for RFID readers. As a result of accurate stock taking, out of stock situations can be prevented. What is more, RFID tags can be attached to products to make it much easier to differentiate them according to their sizes, colours, etc. This makes stock taking accurate and losing the chances of ordering the wrong items when stock reaches the re order levels. Moreover, searching for a particular item such as a different size of the same brand in the back room where items are stored, while a customer waits in the show room becomes much quicker and easier using this technology, due to its unique identification feature. Furthermore, tamper-proof RFID technology is used to safeguard security sensitive items such as aircraft life jackets and valuable products.

Barcode Readers

Barcodes contain different information. Generally, there are three parts. First part contains the information of the country of manufacture, second part comes with the manufacture information and the final part consists of product information (Woodford, 2016). There are different types of barcode readers. Pen type readers use the light and a photo device as the technology in reading barcodes (TalTec, 2017). It reads as the reader passes through the barcode. The attached photo device measures the barcodes with the help of the light for the widths and the spaces in them. CCD (charge coupled device) readers contain hundreds of sensors attached to it. Each sensor consists of a small photo device, which measures the barcodes using light. Camera based barcode readers consist of a tiny video camera to read barcodes. The camera captures an image of the barcode and decodes it by using digital image processing techniques. Generally, barcode readers should be in line of sight of the bar-coded item in order to read it (redbeam.com, 2015). According to (streetdirectory.com, 2017), barcode readers can be categorised into two main categories, they are:

- Contact readers – These are generally hand held devices and the barcodes should touch the reader or come close contact with the reader for reading.
- Non-contact readers – These are opposite to the above where it is not required for the barcode to be close to the reader to read the code. These readers generally consist of a moving laser light beam.

Barcode technology offers automatic product identification and is famous in inventory management systems. They are simple and cheaper to use than RFID technology. Barcodes are used throughout supply chain management such as for inventory counts, receiving inventory, order picking and warehouse transfers. Barcode technology can be used alone or together with RFID technology in certain parts of supply chain management for better accuracy. For example, when RFID readers read boxes of items at once, the same boxes with bar-coded labels containing item counts of items inside the boxes can be compared with each other for accuracy.

3.3.4 Requirement 4 (R4): *Collector* as the Business Process Modelling Requirement for IoT

Collectors are input devices of IoT applications where they collect information from various resources. According to (Yousfi et al., 2016), collectors are used to collect context information apart from sensors and readers, unusually form databases, files or output of processes. Data collections from collectors are stored temporarily in data objects or permanently in data stores depending on the requirement. In the work of (Yousfi et al., 2016), collectors are represented by extending BPMN task and inherits the attributes of BPMN activities. According to (Model, 2011) some attributes of BPMN activities are atomic activity, re-usability, source or target for a sequence flow and source or target of a message flow.

In the problem scenario we have introduced, when the stock reaches their re-order levels, collectors automatically collect re-order level information from inventory database and issue re-order requests to purchasing department. Moreover, in purchasing section collectors are used to retrieve supplier information from supplier database to select suitable suppliers to send requests for stock.

3.3.5 Requirement 5 (R5): *Event streaming* (event stream processing units) as the Business Process Modelling Requirement for IoT

Events are inputs to IoT applications. Events can be single events or streams of events. Generally, in IoT systems events are represented as streams of events. Event streaming is continuous occurring of new events over a time period. For example, continuous reading of temperature sensors to track temperature changes in a shipment to monitor and maintain the quality of goods in transit. (Appel et al., 2014) in their work introduce SPUs (Event Stream Processing Units) for processing new events. SPUs process events as they occur and process continuous occurring of new events by streams rather than single events. Events are produced in an independent nature without any knowledge of their consumption. Therefore, the following can be derived as SPU attributes.

- Processing continuous occurring of events – SPUs are used to process events as streams as and when they occur.
- Event streaming functionality – SPUs contain functionality for event streaming.
- Event streaming logic – SPUs contain and process application logic.
- Encapsulate application logic – SPUs encapsulate event stream processing logic enabling a smooth transition between different layers.

SPUs introduced in (Appel et al., 2014) is used in our problem scenario, to process event streams produced by temperature changes during the shipping of goods from customer to supplier. Shipment is monitored for temperature conditions to maintain the quality of goods by use of temperature sensors. Temperature sensors continue to read temperature as streams of events during the shipment of goods from supplier to customer. Monitoring temperature as streams of events as new events continue to occur, any deviations to the required temperature levels of goods can be detected and eliminated.

3.3.6 Requirement 6 (R6): *Specific data object* as the Business Process Modelling Requirement for IoT

These are the input data or *things* in an IoT application such as RFID tags, Bar Codes, Magnetic stripes, etc. In (Yousfi et al., 2016), authors name *specific data Object* as *smart object* and define it as data collection by either sensors or readers such as RFID readers and Barcode readers. According to them, smart object inherits the attributes of BPMN *DataInput* element. In (Goumopoulos, Kameas & Hellas, n.d.), smart objects are seen as important components connecting the physical world and digital world by providing information on their physical environments. According to (Model, 2011) attributes of BPMN *DataInput* element are, *Name* (type: string) and *IsCollection* (type: boolean). DataInput element inherits the attributes and associations of *BaseElement* and *ItemAwareElement*. BaseElement contain the attributes, *Id* (type: string), *Documentation*, *ExtensionDefinitions* and *ExtensionValues*. ItemAwareElement contains the attribute *isCollection* (type: boolean = false). Furthermore, DataInput element has features such as *they may have incoming Data Associations*.

In our problem scenario, we relate *specific data Objects* to barcodes and RFID tags attached to items of stock enabling accurate stock taking.

3.3.7 Requirement 7 (R7): *Intermediary operation* as the Business Process Modelling Requirement for IoT

After receiving input, *Intermediary operation* performs some processing inside an IoT application before passing output. According to (Sungur et al., 2013), intermediary operations receive data from outside, do some computation within the system and send data to outer world. For example, in a wireless sensor network system, intermediary operation takes sensory temperature level as input to decide if the temperature of an air-conditioned room is maintained within the required level (Sungur et al., 2013). (Tranquillini et al., 2012) name this as *data operators* and state that it should be useful to apply some computations on data while in transmission before outputting the results. Therefore, intermediary operation can be taken as an element responsible for raw context data processing.

In the problem scenario we introduced, the intermediary operation is used to decide on re-order if certain items are at their re-order levels (after checking the inventory database).

3.4 Conclusion

In this chapter we identified seven IoT modelling elements as requirements for business process modelling for IoT. These are sensor, actuator, reader, collector, event streaming, intermediary operation and specific data object. We derived these requirements from a problem scenario based on an IoT aware business application, i.e. part of supply chain management. We modelled this process using BPMN 2.0. Each identified requirement was further elaborated in detail. Class diagrams were used for some cases illustrating the hierarchy and inherited properties.

Chapter 4

Implementation of IoT Modelling Elements

4.1 Introduction

In chapter three, we identified seven IoT modelling elements as business process modelling requirements for IoT. In this Chapter, we design those elements as extensions to BPMN 2.0 and implement them using a web based BPMN editor tool. For this purpose, we develop a web based IoT aware BPMN editor with XPDL capabilities by extending an existing software system to include new IoT modelling elements. We add these IoT modelling elements to the toolkit of the editor inside the relevant BPMN category. We introduce the new IoT modelling elements *sensor*, *actuator*, *reader*, *collector*, *intermediary operation*, *event stream processing* as Task elements under BPMN Activities in this system. We add IoT modelling element, *specific data object* as smart object to the BPMN Data and Artifacts category. Furthermore, we introduce three new IoT modelling elements, *input event stream*, *output event stream*, (as data objects) and *physical entity*, and include them in BPMN Data and Artifacts group. Section 4.2 introduces the BPMN editor we chose to extend. In section 4.3, we describe our extended web based IoT aware BPMN Editor and section 4.4 concludes our work.

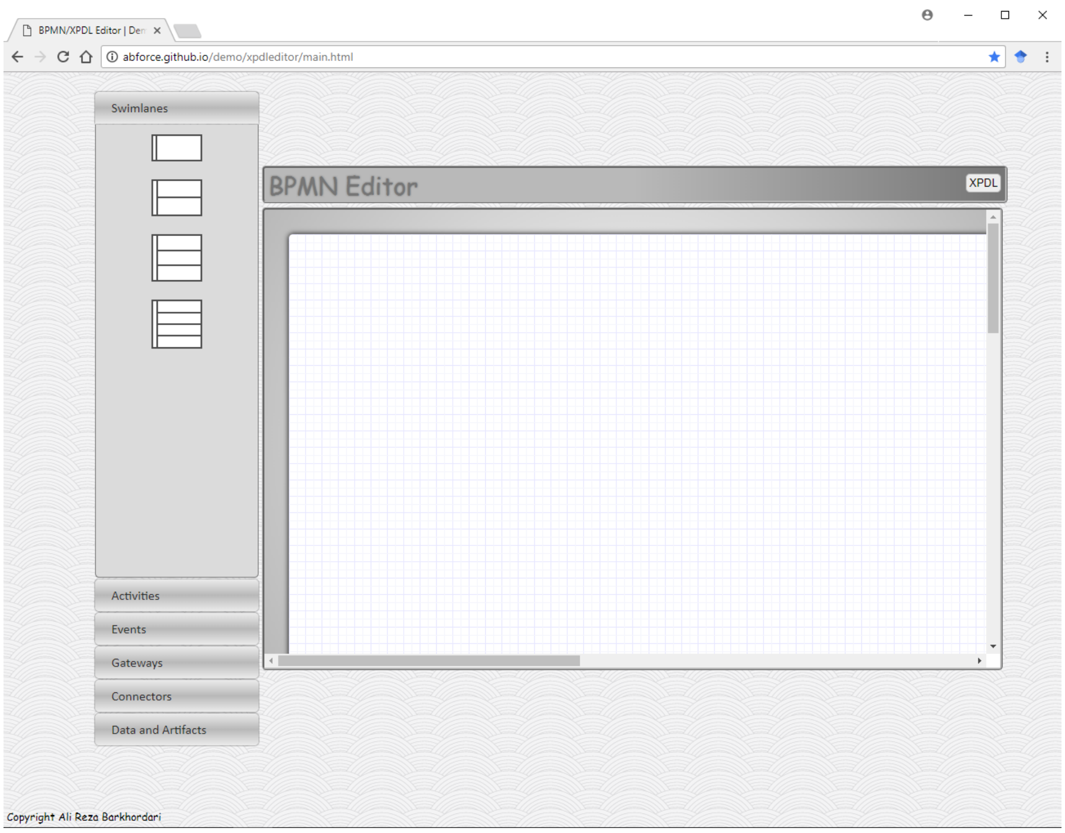


Figure 4.1: abforce BPMN Editor

4.2 Abforce Open Source BPMN Editor

In looking for an open source BPMN editor for extending to include IoT modelling elements, we searched the internet. We used google search engine and searches in GitHub for this purpose. After experimenting with few editors, we decided to extend 'abforce/BPMN-Editor', which we found after searching GiTHub for 'BPMN Editors'. This one was the best out of the few good editors our search resulted and this was best suited for our requirements. In addition to BPMN modelling facility, it incorporated XPDL code editing capabilities. We did not find any other open source web based BPMN editor with these capabilities. This editor had a clear, working codebase and a link to a demo unlike most editors that resulted the GitHub search we carried out.

This is a web based BPMN editor tool, which is a working system with cross browser and cross platform capabilities. This also comprises of an XPDL editor, which creates XPDL code for BPMN diagrams. This allows the facility to save the diagrams and load them again. The editor's toolkit is located at the left side of the screen. The toolkit comprises of all required BPMN 2.0 elements except for 'sub process' under BPMN 'Activities' and 'data store' which belongs to the BPMN category, 'Data and artifacts' (We have added them later). The BPMN elements in the toolkit of the system are categorised into six groups and are displayed in tabs making it clearly visible and easily navigated. The BPMN diagram drawer provided at the right side has ample space for BPMN graphs. The XPDL editor access is provided by clicking on a button at the top right side of the screen. XPDL editor appears as a popup window.

This system is developed by using jQuery, svg.js, CodeMirror and vkBeautify. The system demo can be found at http://abforce.github.io/demo/xpdleditor/main.html and the source code to this editor is located at https://github.com/abforce/BPMN-Editor. Figure 4.1 shows the selected BPMN editor for BPMN elements extension.

4.2.1 Limitations of the Chosen BPMN Editor and Our Contributions

The web based BPMN editor we chose to extend, only lacks the BPMN elements 'data store' under 'Data and Artifacts' and 'sub process' of 'Activities'. In our extensions to the BPMN editor, we have added these two elements. In addition, in the original system, adding descriptions to the objects under 'Data and Artifacts' section does not work, i.e. the text added to the objects does not stick. We corrected this as well in our extension. Moreover, the XPDL editor was not originally programmed to create code for items in the 'Data and Artifacts' section. We extended the code to include this section as well so that the complete diagram can be translated to XPDL for storing and distributing.

There are few minor limitations still exist in the system such as no multiple pool representation, limiting only to a single pool with multiple lanes. Therefore, representing business to business collaborations with process choreographies are not possible. In addition, when a pool consists of two or more lanes, each lane cannot be individually labelled, only the pool can have a common label. It is also not possible to resize any modelling element in this system.

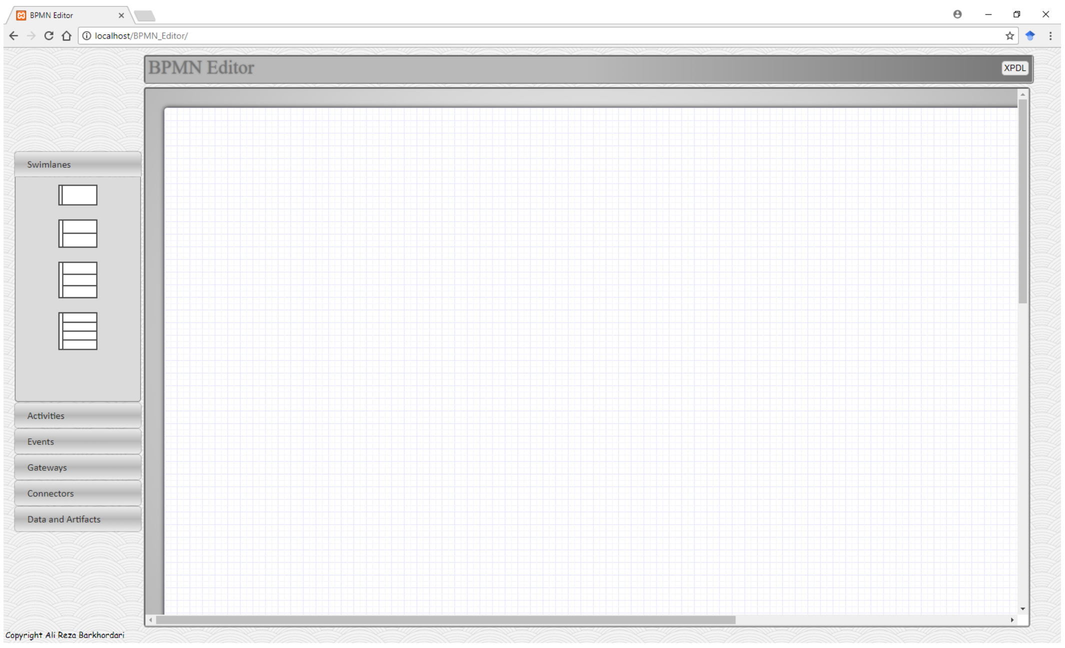


Figure 4.2: Appearance of our IoT aware BPMN and XPDL editor

4.2.2 How the Chosen System Works

Following are the instructions to use abforce BPMN Editor for BPMN diagrams.

- Choose a single, double, triple lane pool or a pool with four lanes by clicking on the required object under 'Swimlanes'.
- To use a 'task' element under 'Activities' section, you have to click on it and drag

it to the pool or lane on screen. The same process is to follow for the elements under ‘Events’, ‘Gateways’ and ‘Data and Artifacts’ sections.

- To use a ‘connector’ element under ‘Connectors’, click on it (it gets heighted), move the cursor to one of the two objects you want to connect with each another. The object changes its colour to yellow. Click on the object and drag the cursor to the other object you want to connect it. To deselect the connector, click on the connector (selected) in the toolkit again.
- To add text to an element, double click on it and a text area window will appear. Write on it and click on ‘Set’ button on it so that the text area will disappear and the written text would appear on the object. ‘Cancel’ button is to discard any change and exit the text area window. To modify what is already written, follow the same steps.
- To delete any element, right click on it and select the ‘Delete’ option from the menu, which will appear. This will delete the selected object and any associations as well. Make sure to deselect any connector elements if already selected from the ‘Connectors’ tab and is being highlighted since this will prevent the menu appearing on right click.
- There is an XPDL Editor, which can be opened by clicking on the XPDL button on the top right side of the screen. XPDL Editor creates the XPDL (XML Process Definition Language) code to store the diagram drawn and, which translate the code into diagrams as well. Therefore, to save a BPMN diagram, the code inside the XPDL editor should be saved into a file and to load the diagram back, the same code should be copied back to the editor.

4.3 Our Web Based IoT Aware BPMN and XPDL Editor

We extended the above mentioned BPMN and XPDL editor to facilitate business process modelling for IoT with BPMN. We have extended BPMN 2.0 modelling elements in introducing our IoT modelling elements into the editor's toolkit. The BPMN elements in this toolkit are divided into six categories, swimlanes, activities, events, gateways, connectors and, data and artifacts. We have introduced six new IoT modelling elements to BPMN 'Activities' and four new IoT modelling elements to 'Data and Artifacts'. Figure 4.2 shows the appearance of our IoT aware BPMN system.

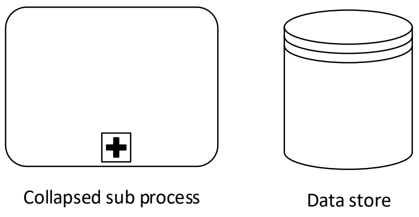


Figure 4.3: Two missing BPMN elements we have added to the system

The following two BPMN elements are not available in the original system and we have added them to our new system. Figure 4.3 shows these two new elements.

- Collapsed sub process under 'Activities'
- Data store under 'Data and Artifacts'.

4.3.1 Software Architecture

Figure 4.4 depicts a high-level software architecture of the system. This IoT aware BPMN modelling tool comprises of both graphical representation of BPMN process

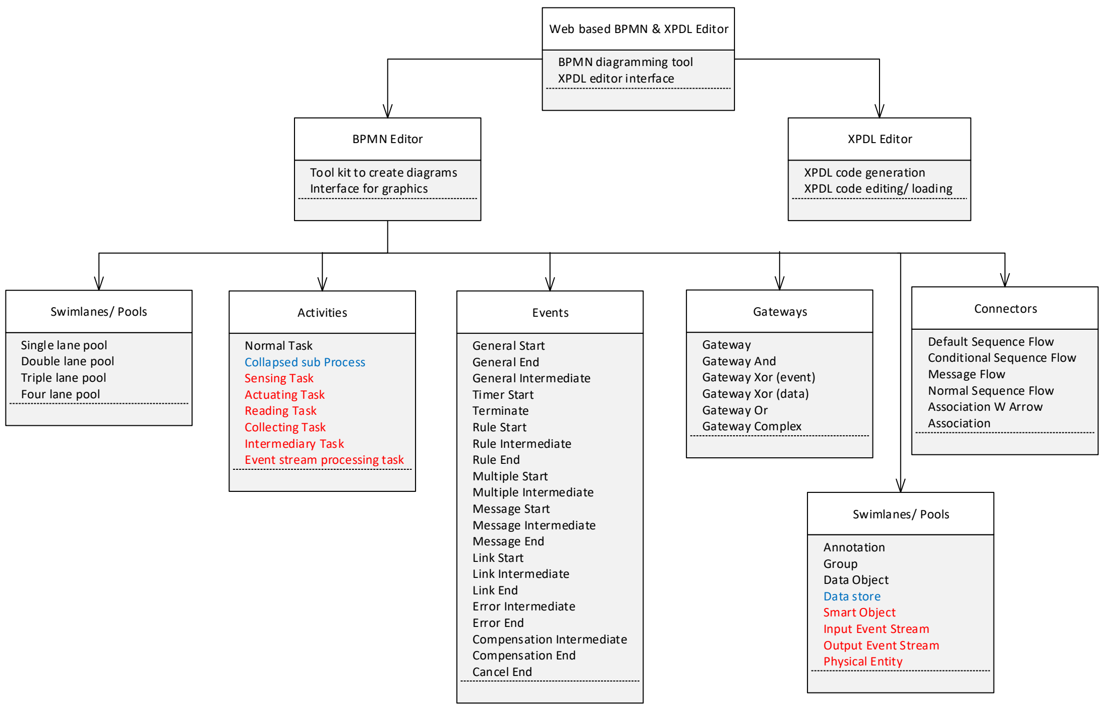


Figure 4.4: Software architecture of IoT aware BPMN and XPDL editor.

models as well as storing them using XPDL code. There are six categories of BPMN modelling elements. The first category, swimlanes/ pools contains four modelling elements, single lane pool, double lane pool, triple lane pool and four lane pool. Elements under the category, activities are, normal task, collapsed sub process, sensing task, actuating task, reading task, collecting task, intermediary task and event stream processing task. The category events, consists of the elements general start, general end, general intermediate, timer start, terminate, rule start, rule intermediate, rule end, multiple start, multiple intermediate, message start, message intermediate, message end, link start, link intermediate, link end, error intermediate, error end, compensation intermediate, compensation end and cancel end. Gateways category includes gateway, gateway and, gateway xor (event), gateway xor (data), gateway or, and gateway complex. Elements under connectors are default sequence flow, conditional sequence flow, message flow, normal sequence flow, association w arrow and association. Data and artifacts category has the modelling elements, annotation, group, data object, data store,

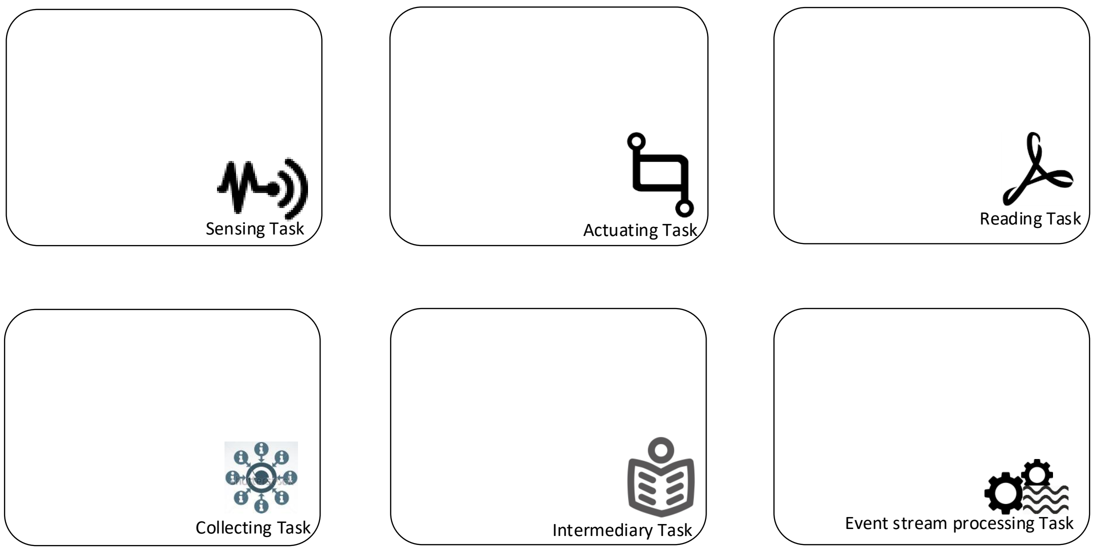


Figure 4.5: New IoT modelling elements proposed as extensions to BPMN task element

smart object, input event stream, output event stream and physical entity. In Figure 4.4, our corrections to the system depicts in blue coloured text whereas, our extensions to the system denotes text in red colour.

4.3.2 IoT Modelling Element Extensions to the BPMN Editor

We extended the editor's toolkit with BPMN 2.0 modelling elements to facilitate business process modelling for IoT. As extensions to BPMN task element under 'Activities', we have proposed six new task elements namely, sensing task, actuating task, reading task, collecting task, intermediary task and event stream processing task. These elements comprise of special icons to distinguish and identify them and their names are written below the icons. The new task elements we have introduced to this BPMN system are shown in Figure 4.5. As a guidance for sensing task, reading task, collecting task, we referred to the works of (Yousfi et al., 2016), (Meyer et al., 2015) and (Sungur et al., 2013), where they all extended BPMN task element to represent sensor as IoT modelling element for BPMN. In introducing actuating task element, we referred to the works of (Meyer et al., 2015) and (Sungur et al., 2013). In each study, they have extended BPMN task element. We followed the existing literature work of (Appel et al., 2014) in introducing the event stream processing task element to BPMN. In introducing intermediary task, we referred to the contribution made by the scholarly work of (Sungur et al., 2013).

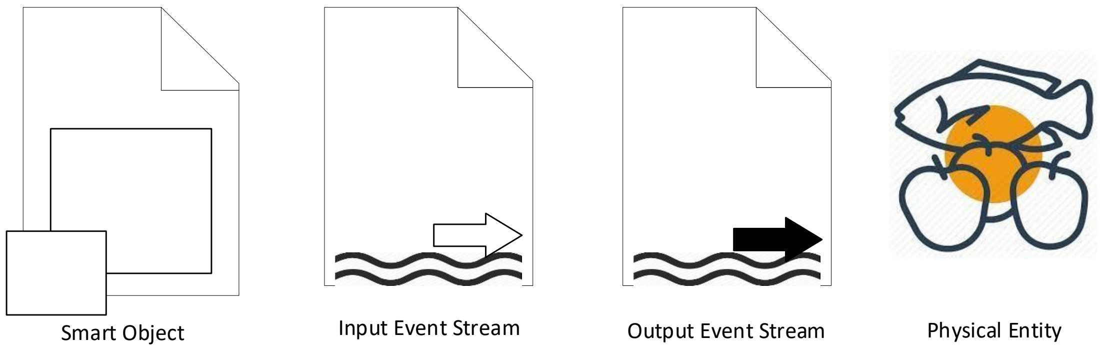


Figure 4.6: New IoT modelling elements proposed as extensions to BPMN data element.

We also have extended BPMN data object and introduced three new data objects, to the toolkit under 'Data and Artifact' category. They are smart object, input event stream object and output event stream object. Figure 4.6 illustrates these new extensions. We referred to the existing works of (Yousfi et al., 2016) and (Appel et al., 2014) for these extensions. These data objects have their unique symbols to distinguish them from BPMN data object.

We proposed an additional element to editor's toolkit to represent physical entity. It is represented by the symbol, 'perishable goods'. This element can contain text to describe what it represents (writable). We are inspired by the work of (Meyer et al., 2015), where they represent the physical entity 'chocolate' with the symbol of a 'cow' as a separate participant. All icons used in this system are borrowed from the internet. Figure 4.7 and 4.8 illustrate the new BPMN editor with our extensions to BPMN elements. We also extended the XPDL editor to reflect our extensions to the system so that BPMN diagrams with our extensions (IoT modelling elements) can be stored in a file and loaded back through the editor. Figure 4.9 illustrates the XPDL

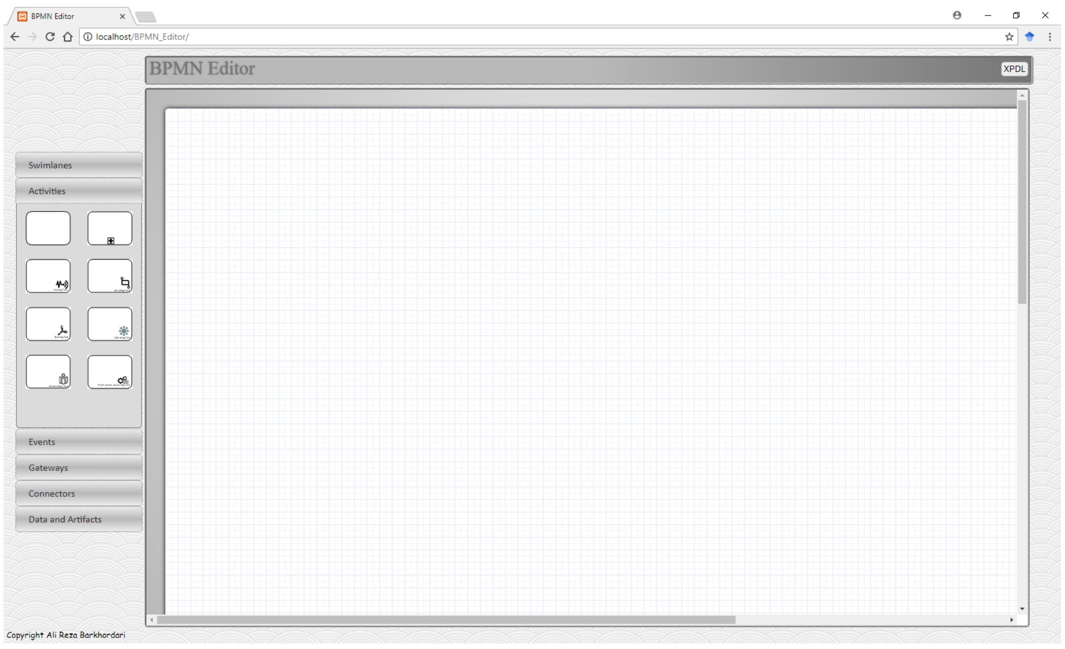


Figure 4.7: BPMN System after our extensions to BPMN task element

editor with its corresponding BPMN diagram in the background.

4.3.3 IoT Modelling Elements Extensions To BPMN Meta Model

In BPMN meta model, we illustrate our proposed IoT modelling element extensions to BPMN 2.0. Sensing task, reading task, collecting task, actuating task, event stream processing task and intermediary task are introduced by extending BPMN task element. So that they inherit the properties of its parent class, BPMN Activity's attributes and model associations. In proposing these modelling elements as extensions to BPMN standards, we considered extending BPMN Service Task since it appears most appropriate for such extensions as these can be taken as services, e.g. sensing physical elements. However, according to (Yousfi et al., 2016), BPMN Task is the most suitable for integrating these IoT modelling elements into the BPMN Meta model. This is in accordance with the BPMN standards. The authors have performed extensive research in representing ubiquitous technologies by extending BPMN standards. Therefore, we took the same

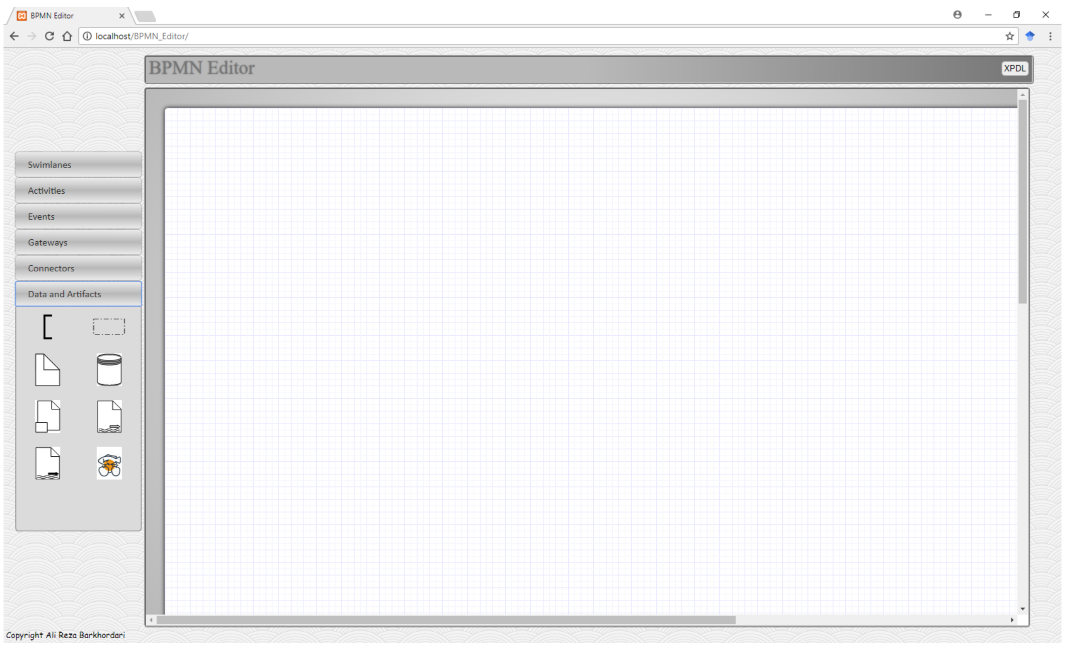
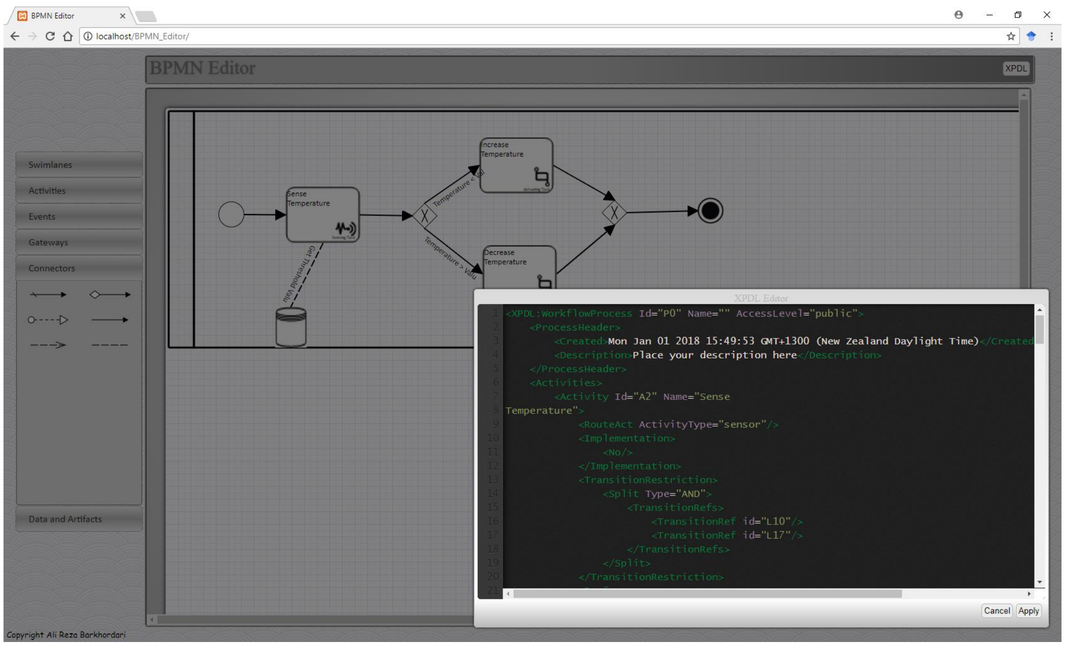


Figure 4.8: BPMN System after our extensions to BPMN data object

approach. The BPMN 2.0 class diagram for BPMN 2.0 Task (Model, 2011) element with our modifications to it is illustrated in Figure 4.10. The proposed IoT modelling elements we have added as extension to BPMN 2.0 are coloured in light blue in the diagram. A brief explanation of these new modelling elements is given below.

Sensing Task

The Sensing Task is to use a sensor, which obtains contextual information in a business environment. Sensors can be wired, wireless or smart (Yousfi et al., 2016). The Sensing task takes the shape of a rectangle with rounded corners and is similar to BPMN Task element in appearance. Its name is written below a special icon to distinguish it from other task elements. As shown in Figure 4.10, the Sensing Task inherits the attributes and model associations of the BPMN element, Activity. The attribute, ‘implementation’ describes the sensing technology implementation.



```
<XPDL:WorkflowProcess Id="P0" Name="" AccessLevel="public">
    <ProcessHeader>
        <Created>Mon Jan 01 2018 15:49:53 GMT+1300 (New Zealand Daylight Time)</Created
        <Description>Place your description here</Description>
    </ProcessHeader>
    <Activities>
        <Activity Id="A2" Name="Sense
Temperature">
            <RouteAct ActivityType="sensor"/>
            <Implementation>
                <No/>
            </Implementation>
            <TransitionRestriction>
                <Split Type="AND">
                    <TransitionRefs>
                        <TransitionRef id="L10"/>
                        <TransitionRef id="L17"/>
                    </TransitionRefs>
                </Split>
            </TransitionRestriction>
```

Figure 4.9: XPDL Editor

Actuating Task

The Actuating Task is for actuators to perform some operation in the system depending on input values such as contextual information obtained from sensors. Actuators also take the same shape as BPMN Task element, a rectangle with rounded corners. This has an additional symbol and the name written below it to separate it from similar task elements.

Reading Task

The Reading Task is for the purpose of using a smart reader such as barcode reader, RFID reader, biometrics reader, etc. This also is similar to BPMN Task, a rectangle with rounded corners. A special icon at the right bottom corner indicates that it is a reader task with the name written below it.

Collecting Task

The Collecting Task is to collect any other contextual information which the Sensing Task and Reading Task are incapable of collecting. The source of collection is usually from a database, a file or an outcome of a process. Collecting Task also takes the shape of BPMN Task, which is a rounded cornered rectangle. An icon symbolizing the collecting task is placed in the bottom right corner with its name right below.

Intermediary Task

The Intermediary Task is to represent intermediary operation, which takes information as input, perform some action on it such as making a decision and output the resulting data. Similar to other task elements, this also takes the same shape as BPMN Task, a rectangle with rounded corners. A special icon is inside at the right bottom corner with the name written below it to identify this task element.

Event Stream Processing Task

In BPMN, Stream Processing Units (SPUs) are modelled as Event Stream Processing Tasks (Appel et al., 2014). An Event Stream Specification (ESS) explains a stream of events and ESSs are used as input and output of Event Stream Processing Tasks. Event Stream Processing Tasks are also similar in appearance to BPMN Tasks and consisted of rectangles with rounded corners. The name is written below a particular symbol to distinguish it from other similar task elements.

Our proposed additions to BPMN 'Data and Artifacts' section namely smart object, input event stream object are output event stream object are extensions to BPMN DataInput and DataOutput objects respectively. Figure 4.11 shows the BPMN 2.0 ItemAware class diagram with our proposed extensions to the BPMN standards. The proposed IoT modelling elements we have added as extension to BPMN 2.0 are coloured in light blue in the diagram. Smart object and input event stream object inherit BPMN Data Input attributes and associations, whereas, output event stream inherits the attributes and associations of BPMN Data Output. The four new modelling elements are described briefly below.

Smart Object

Smart Object is to use contextual data collected by either Reading Task or Sensing Task. This is similar to BPMN Data Object in shape with two rectangles inside, a small rectangle overlapping a slightly larger one to symbolize it and differentiate it from BPMN Data Object. This inherits the attributes and model associations of BPMN Data Input.

Input Event Stream

Input Event Streams act as inputs to Event Stream Processing Tasks. Events occur as streams and are continuous inputs. This has the shape of BPMN Data Object with an unfilled arrow above waves to symbolize it. This inherits the attributes and model associations of BPMN Data Input.

Output Event Stream

Output Event Streams are opposite to Input Event Streams taking resulting events out of Event Stream Processing Tasks. This also takes the shape of BPMN Data Object with a symbol of a filled arrow above waves to differentiate it. This element inherits the attributes and model associations of BPMN Data Output.

Physical Entity

Physical Entity can be anything reflecting the ‘thing’ of IoT. According to (Meyer et al., 2015), “A thing is an identifiable, separable part of the physical environment, which is of particular interest for a business process”. Physical Entity is introduced to meet the requirements that cannot be covered by existing BPMN elements. In our system, Physical Entity is symbolized as perishable goods but irrespective of the symbol it represents anything including a living being.

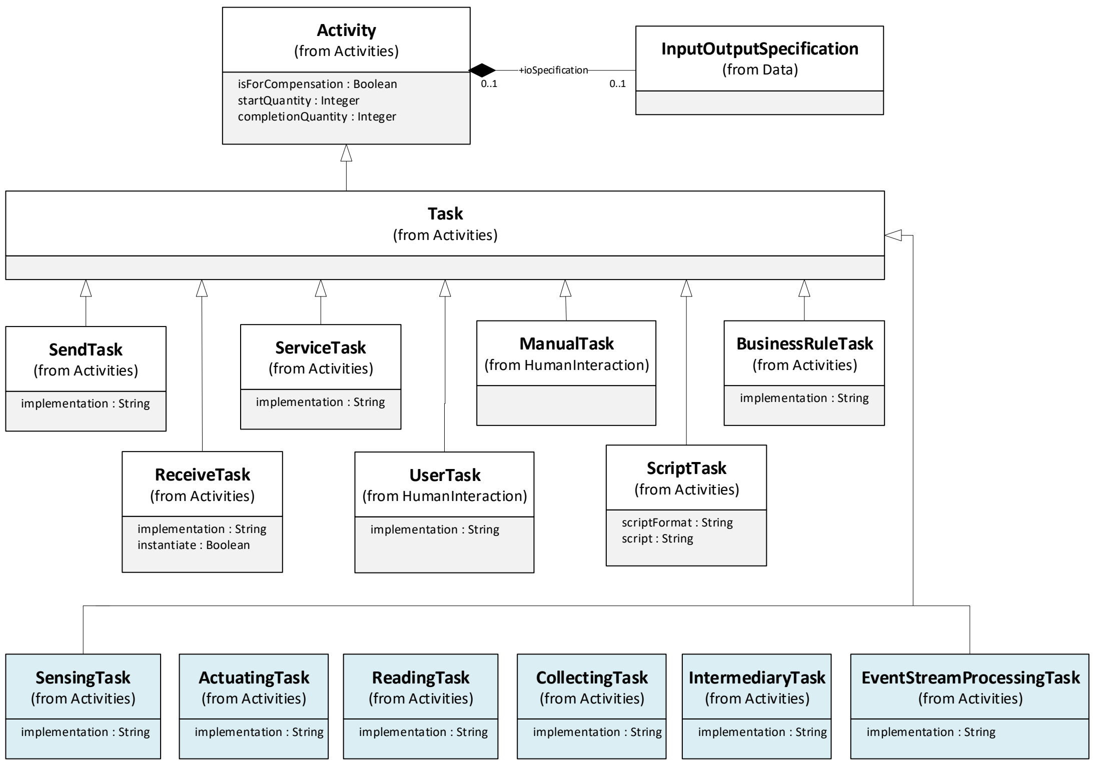


Figure 4.10: BPMN Task class diagram

The website link to our IoT aware BPMN editor is https://pradeerat.github.io/IoT-aware-BPMN-Editor/ and the source code link is https://github.com/pradeerat/IoT-aware-BPMN-Editor.

The instructions to use our IoT aware BPMN editor is given in Appendix B

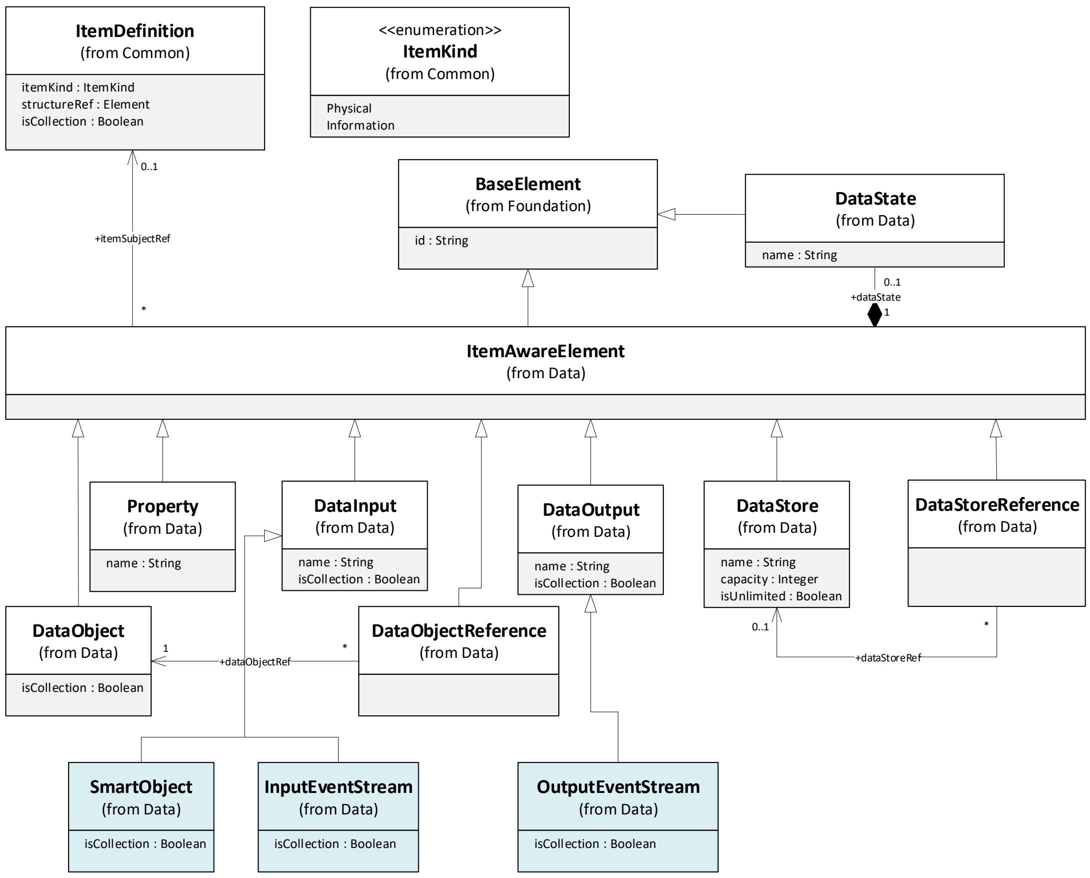


Figure 4.11: PBMN class diagram for ItemAware element

4.4 Conclusion

In this chapter, we have discussed the implementation of the seven IoT modelling elements we identified in chapter 3, as business process modelling requirements for IoT. We implemented them using an IoT aware BPMN and XPDL editor which we built using an existing editor by adding IoT aware capability in to it. We designed them by extending BPMN 2.0 and added them to the editor's toolkit under relevant BPMN element categories. We illustrated the system architecture showing where our extensions fitted in to the system. We added ten new IoT modelling elements to the system as proposed extensions to BPMN 2.0. Apart from the seven identified IoT modelling elements in chapter 3, we added three additional IoT modelling elements, input event stream object, output event stream object and physical entity. The IoT modelling elements Sensing Task, Actuating Task, Reading Task, Collecting Task, Intermediary Task, event stream processing Task and Smart Object represent the identified IoT modelling requirements, sensor, actuator, reader, collector, intermediary operation, event stream processing and specific data object respectively. We illustrated our extensions to BPMN meta model in class diagrams. We also extended the XPDL editor incorporated in the original BPMN editor to facilitate our extensions. In Appendix B, we provided detailed instructions to use our IoT aware BPMN editing tool.

Chapter 5

Case Study and Evaluation

5.1 Introduction

In this section, we conduct a case study in evaluating the capability of our web based IoT aware BPMN and XPDL editor. In section 5.2, we take an IoT aware shipment control scenario as a case study and model this shipment control process in BPMN 2.0 using our IoT aware BPMN and XPDL editor tool. This process model depicts perishable goods in transit and it includes the IoT modelling elements we introduced to the editor. We graphically illustrate this process in a diagram. We create XPDL code for this process as well and provide it in the appendix. Section 5.3 further qualitatively evaluates our IoT aware BPMN and XPDL editor by comparing it with related works and section 5.4 concludes our work.

5.2 Case Study

In evaluating the capability of our extended BPMN editor tool, we have conducted a case study. We have modelled an IoT aware shipment control process for monitoring the quality of perishable items while on shipment.

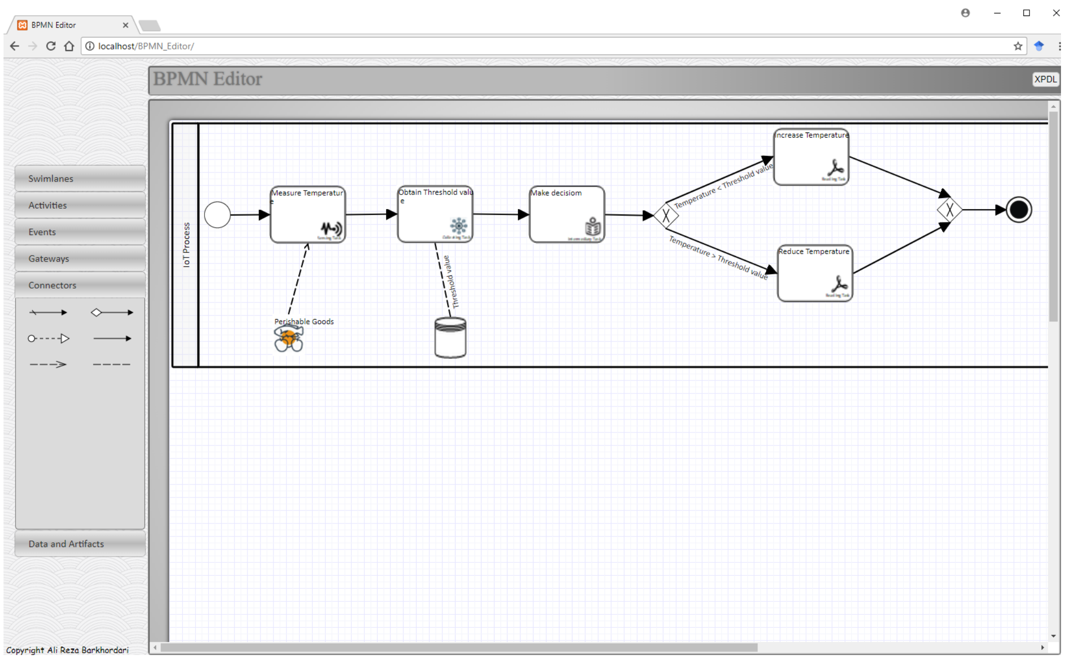


Figure 5.1: Shipment monitoring IoT process part1 depicted using our extended BPMN Editor

Part one of this process depicts goods of perishable nature are in transport. Temperature sensors continue to detect the temperature of these items. Threshold value of the temperature that has to be maintained throughout is obtained from a database connected to the cloud. Decision to increase or decrease the temperature is based on the prevailing temperature value. If the temperature exceeds the required temperature level, the control is passed to actuators to reduce it to the desired threshold level. In case of temperature being below the required level, the actuators will increase it to the desired level.

Part two of the shipment process illustrates monitoring of shipment to track physical location of the goods by using cloud GPS. The location is informed to the supplier. Apart from that, event stream processing technique is used to maintain quality of goods in transit. Streams of input events monitor shipment for environmental conditions. If events exceeding the required conditions are detected, the shipment is cancelled and the customer is notified, otherwise the normal shipment process continues.

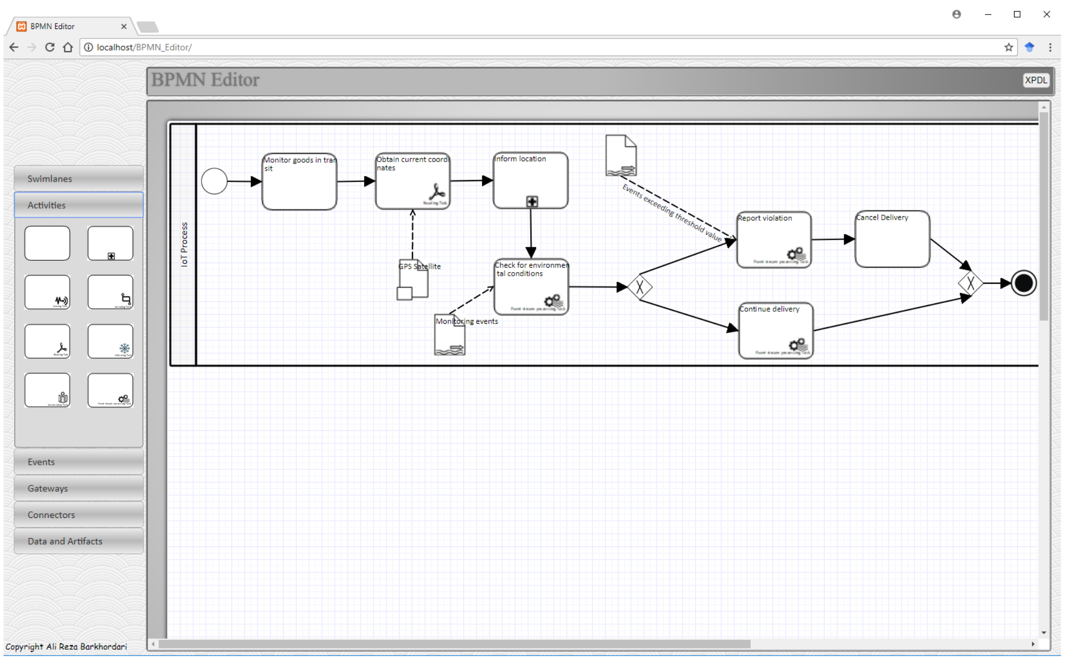


Figure 5.2: Shipment monitoring IoT process part2 depicted using our extended BPMN Editor

5.2.1 Case Study Evaluation

By conducting this case study, we demonstrate that the IoT modelling elements we have proposed as business process modelling requirements for IoT can be represented in this scenario and practically modelled in BPMN using the extended BPMN editor tool. We produce screen shots of this process as well as a machine executable version of the process in XPDL code. We also provide a web link to our IoT enabled BPMN editor. In this example, we include all IoT modelling elements we have proposed as business process modelling requirements. This IoT aware business process modelling scenario is depicted in Figures 5.1 and 5.2. The corresponding XPDL code is shown in Appendix A.

5.3 Capability of the IoT Aware BPMN Editor Tool

In this section, we examine the capability of our web based BPMN editor tool comprising of IoT modelling extensions by comparing it with BPMN modelling frameworks for IoT we have studied under the literature review in chapter 2. We compare their work with ours. In chapter 3, we identified seven IoT modelling elements as business process modelling requirements for IoT. In Table 5.1, we show how many of these IoT modelling elements each project has introduced. As we can see, none of those projects introduced as many IoT modelling elements as we do to facilitate business process modelling for IoT. As illustrated in the Table 5.1, our case study consists of all these elements. Further, we practically extend a web based BPMN editor tool to include these IoT modelling elements and illustrate how this case study example is practically implemented by using this editor tool.

Except for one work in the literature we reviewed, there is no evidence that any of others have extended a BPMN editor in practice. Authors (Meyer et al., 2013) in their framework, have extended a web based BPMN editor to include their IoT modelling elements as extensions to BPMN 2.0. However, they provide only a screen shot of the editor illustrating their IoT application process as an example, with no web address to the tool as further evidence. What is more, they only added two new task elements as extensions to their editor tool, representing sensor and actuator modelling elements. Whereas, we have added ten new modelling elements (including physical entity) to our IoT aware BPMN editor. Further, they have provided no evidence of a method to store and upload or distribute BPMN modelling diagrams or executables as we do. In addition, their IoT example, ‘dynamic price update process’ is not adequate in illustrating the modelling process as our case study example does.

bpmn is considered to be the standard file extension for BPMN files which store and distribute BPMN diagrams (filext.com, 2018), although this extension is not supported

Case Study	IoT modelling elements/ IoT modelling requirements	IoT application process	BPMN Editor Extension	XPDL Editor
uBPMN (Yousfi et al., 2016)	sensor (R1), reader (R3), collector (R4), smart object (R6)	Time banking system process	No Evidence	No Evidence
SPUs (Appel et al., 2014)	event streaming task(R5), specific data object(R6)	Shipment monitoring process	No Evidence	No Evidence
BPMN4WSN (Sungur et al., 2013)	sensor (R1), actuator (R2), intermediary operation (R7)	A room ventilating process	No Evidence	No Evidence
Things in BPMN (Meyer et al., 2015)	sensor (R1), actuator(R2), physical entity	A process representing physical entity	No Evidence	No Evidence
Crowdsourcing (Tranquillini et al., 2015)	crowdsourcing task and streaming connector	Crowdsourcing process of reimbursing company travel expenses	No Evidence	No Evidence
Event Element for IoT (Chiu & Wang, 2015)	sensor (R1), actuator(R2), location aware element, event definition	Temperature control process	No Evidence	No Evidence
IoT Devices as resources (Meyer et al., 2013)	IoT Device (sensor (R1), actuator (R2)), native service	Dynamic price update process	Extends BPMN Editor to include two elements	No Evidence
Our Case study	sensor (R1), actuator (R2), reader (R3), collector (R4), event streaming task(R5), smart object (R6), intermediary operation (R7), physical entity	Quality control process of goods in transit	Extends BPMN Editor to include ten elements	BPMN Editor incorporates an XPDL Editor

Table 5.1: Comparison of different case studies with their contributions towards IoT aware process modelling

by famous BPMN editors such as 'Visio'. However, BPMN editors such as bpmn.io (https://demo.bpmn.io/) and Yaoqiang BPMN Editor (https://sourceforge.net/projects/bpmn/)

use ‘bpmn’ file extension and their files are interchangeable. These files are written in XML. Whereas, XPDL (XML Process Definition Language), (fileinfo.com, 2011) is considered to be the widely acceptable standard for storing and distributing BPMN diagrams or the process definitions ((xpdl.org, 2018), (bizagi.com, 2018), (healthcareworkflow, n.d.)). According to (Wang et al., 2006), XPDL is introduced as a common file interchange format for BPMN. Some BPMN editors such as bizagi (http://help.bizagi.com/process-modeler/en/index.html?import_from_xpdl.htm) supports XPDL for importing and exporting BPMN diagrams. In our system we import and export BPMN diagrams via XPDL editor using XPDL coding. None of the above literature work has addressed this area of storing and distributing BPMN files and none of them has implemented an XPDL editor.

According to (Thakur, n.d.), feasibility is the evaluation of performance of a software project or a tool. Feasibility of a software can be categorized in to three types in general. They are economic feasibility, operational feasibility and technical feasibility. From these three types, more relevant to our system is the operational feasibility. Operational feasibility is that the software system should meet user requirements and solve business problems. In evaluating our web based BPMN editor, we have shown that this system meets user requirements as well as solve business problems. Technical feasibility speaks about the technology in use and its underline resources such as software and hardware of the system. Our BPMN editor is web based so that this can be accessed merely with a PC and an internet connection. (Gediga, 2002) states usability as the main evaluation criteria of a software system. Our web based BPMN editor extension reflects this feature with its ease of use and error free properties.

5.4 Conclusion

In this chapter, we conducted a case study with the purpose of evaluating our IoT aware web based BPMN and XPDL editor we introduced in the previous chapter. We took a shipment control process of transporting perishable items as an IoT aware business application scenario. We modelled this process with BPMN in our editor using the IoT modelling elements we introduced to the editors toolkit. We illustrated this graphical process and we provided the XPDL executable code generated of this process. We further evaluated our editor tool by comparing with similar work.

Chapter 6

Conclusion

Internet of things is a rapidly evolving technology in the world today. It is not an exaggeration to state that people and industry at large are already reaping the many benefits it offers. We see it in use in everyday life. IoT covers vast range of applications such as smart homes, smart cities, connected health, connected car, smart retail, etc. When it comes to industrial applications, IoT technology is largely used in supply chain management and agriculture, monitoring a product from its manufacturing stage to distribution. Examples of some other industries with IoT applications are airline, healthcare, retailing, energy, pharmaceutical, insurance, media and entertainment. Companies use business process models to depict their business processes making it efficient in managing the activities in different applications. Business process management systems are used to manage these applications. Modelling notations such as BPMN illustrates the process models so that everyone involved in the business hierarchy would understand the process. When IoT technology is involved in a certain business application, there should be a way to integrate the IoT aspects in to the process model. This makes it a necessity to investigate the methods to achieve this.

Therefore, this leads to finding out business process modelling requirements for IoT, in other words, IoT modelling elements that can represent IoT aspects in a business process model. This motivated us in conducting this research and we came up with seven requirements or IoT modelling elements for business process modelling for IoT. This answers our first research question. We designed these elements by extending BPMN 2.0. In answering our second question, this further motivated us to carry out an implementation where, we practically extended a web based BPMN editor tool to add these modelling elements. We have introduced ten IoT modelling elements into our extended BPMN editor including physical entity as an IoT modelling element.We have evaluated our work in a case study by modelling these IoT elements in an IoT related business application process in BPMN and illustrating it by using our extended BPMN editor. We also compared our work with similar work found in the literature.

6.1 Summary

Chapter one of this thesis contained the thesis introduction. We dedicated chapter two for our literature review where we addressed the chosen literature work of past scholars, which are relevant to our work. Even though we had already talked about IoT and BPM in the introduction chapter, we tried to address these areas a little bit further in related to our work. We described IoT, business process models and BPMN modelling frameworks for IoT. In the summary sub section of the same section, we analysed and evaluated each framework with IoT modelling elements they had introduced. In chapter three, we tried to identify business process modelling requirements for IoT. We introduced a problem scenario of an IoT related business process and derived those requirements. We modelled this IoT application process by using BPMN 2.0, and used Visio modelling tool for illustrating the model. This was a part of a supply chain management system involving as many IoT modelling elements as it was possible to incorporate with it. We took each element into account and did some intensive research in finding out different categories and their features. We depicted those in diagrams including class diagrams wherever applicable. In chapter four, we designed the IoT modelling elements we had found out as requirements for business process modelling, by extending BPMN 2.0. Next, we carried out an implementation of practically extending a web based BPMN and XPDL editor to facilitate adding those IoT modelling elements. In chapter, five we carried out a case study to evaluate our IoT aware BPMN modelling tool. We modelled an IoT related business process with BPMN, which comprised of the modelling elements we introduced. The model was illustrated by using our extended BPMN editor tool, which also generated XPDL code to store the model.

6.2 Limitations of the Research

We have extended BPMN 2.0 in proposing IoT modelling elements trying to adhere with BPMN standards and referring to similar work. Yet, this model is not tested in a practical environment to be certain that there are no consequences on the BPMN standards due to these extensions. Moreover, we have not implemented our model in a software system and carried out any testing. Due to the limited period of research, there was not enough time to enhance these areas.

6.3 Recommendations and Further Study

Internet of Things is a vast subject area, which demands attention from researchers due to its importance and usage in everyday life of people and businesses as a whole. Further research on this area will only contribute to its growth and efficient use. Therefore, we encourage further research on business process modelling for IoT mainly focussing on illustrating IoT aspects of business application in process models. We did not find any BPMN editor tool incorporated with IoT modelling elements available in the internet. There are existing research in extending BPMN 2.0 for modelling IoT elements with business processes. Therefore, we suggest researchers to consider practically extending BPMN modelling tools if possible and depict their models using their own tools. In addition, the BPMN editor we have extended is available via GitHub as an open source project so that anyone who would be interested in improving it further is encouraged to do so. URL to the source code: https://github.com/pradeerat/IoT-aware-BPMN-Editor. It is web based and is available free for modelling IoT aware business processes using BPMN 2.0. URL to the website: https://pradeerat.github.io/IoT-aware-BPMN-Editor/. This editor incorporates many if not all, important IoT modelling elements as extensions to BPMN 2.0. We suggest people to use this for modelling IoT based business applications as a start so that they can develop something better overcoming any weakness in this.

6.4 Conclusion

Internet of Things technology promises a new and improved market domain for businesses while it tends to serve people better in the future. In IoT, internet combines real world physical objects with the virtual world. In other words, IoT technology makes it possible to connect physical entities via internet. This includes human beings, who are connected through wearables with IoT aware features. This connection offers major benefits to humans as well as businesses. It is going to reshape human activities as well as the industry operations in a major way. Benefits to humans for example is that a doctor can distantly monitor the health condition of a patient through a wearable such as an IoT enabled wristwatch, when the patient is out of his home. One such example, which benefits a business, would be to track a vehicle in a parking spot, which did not make a payment. These two applications are examples of IoT aware business applications. Organisations in managing their businesses use business process models in illustrating their business processes. They use notations such as BPMN to model them so that everyone involved in the process from all hierarchical levels could understand it. Unfortunately, not enough attention is given yet to integrate these IoT related business applications in to business process models. In other words, business process modelling for IoT aspects in business applications are not well supported by existing process modelling notations. Therefore, it is a vital requirement to take necessary actions to support reflect IoT aspects such as location awareness, sensing, reading and actuating activities, etc. in business process models as we have addressed in our research.

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Appendix A

XPDL Code of Shipment Monitoring Process

A.1 Process Part 1

```
<XPDL:WorkflowProcess Id="P0" Name="IoT Process"
AccessLevel="public">
<ProcessHeader>
<Created>Thu Jan 11 2018 18:14:30 GMT+1300
(New Zealand Daylight Time)</Created>
<Description>Place your description here</Description>
</ProcessHeader>
<Activities>
<Activity Id="A2" Name="Measure Temperature">
<RouteAct ActivityType="sensor"/>
<Implementation>
<No/>
</Implementation>
<TransitionRestriction>
<Join Type="AND">
<TransitionRefs>
<TransitionRef id="L13"/>
<TransitionRef id="L22"/>
</TransitionRefs>
</Join>
```

```
</TransitionRestriction>
<Performers>
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</Performers>
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Height="91" Width="119" LaneId="S1">
<Coordinates XCoordinate="109" YCoordinate="95"/>
</NodeGraphicsInfo>
</NodeGraphicsInfos>
</Activity>
<Activity Id="A3" Name="Obtain Threshold value">
<RouteAct ActivityType="collector"/>
<Implementation>
<No/>
</Implementation>
<TransitionRestriction>
<Join Type="AND">
<TransitionRefs>
<TransitionRef id="L14"/>
<TransitionRef id="L23"/>
</TransitionRefs>
</Join>
</TransitionRestriction>
<Performers>
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</Performers>
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Height="91" Width="119" LaneId="S1">
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</NodeGraphicsInfos>
</Activity>
<Activity Id="A4" Name="Make decisiom">
<RouteAct ActivityType="intermediary"/>
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<Performers>
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<Coordinates XCoordinate="508" YCoordinate="95"/>
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</NodeGraphicsInfos>
</Activity>
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<Implementation>
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</Implementation>
<Performers>
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<Coordinates XCoordinate="884" YCoordinate="6"/>
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</NodeGraphicsInfos>
</Activity>
<Activity Id="A6" Name="Reduce Temperature">
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<Implementation>
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</Implementation>
<Performers>
<Performer></Performer>
</Performers>
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</NodeGraphicsInfos>
</Activity>
<Activity Id="E7">
<Event>
<XPDL:Start Trigger="None"/>
</Event>
<NodeGraphicsInfos>
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Height="42" Width="41" LaneId="S1">
<Coordinates XCoordinate="9" YCoordinate="120"/>
</NodeGraphicsInfo>
```

```
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</Activity>
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</Event>
<NodeGraphicsInfos>
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Height="42" Width="41" LaneId="S1">
<Coordinates XCoordinate="1243" YCoordinate="112"/>
</NodeGraphicsInfo>
</NodeGraphicsInfos>
</Activity>
<Activity Id="G9">
<Route GatewayType="XOR_Data"/>
<TransitionRestrictions>
<TransitionRestriction>
<Split Type="XOR_Data">
<TransitionRefs>
<TransitionRef id="L17"/>
<TransitionRef id="L18"/>
</TransitionRefs>
</Split>
</TransitionRestriction>
</TransitionRestrictions>
<NodeGraphicsInfos>
<NodeGraphicsInfo BorderColor="0,0,0" FillColor="255,255,255"
Height="40" Width="40" LaneId="S1">
<Coordinates XCoordinate="700" YCoordinate="122"/>
</NodeGraphicsInfo>
</NodeGraphicsInfos>
</Activity>
<Activity Id="G10">
<Route GatewayType="XOR_Data"/>
<TransitionRestrictions>
<TransitionRestriction>
<Join Type="XOR_Data">
<TransitionRefs>
<TransitionRef id="L19"/>
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</TransitionRefs>
</Join>
</TransitionRestriction>
</TransitionRestrictions>
```

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Height="40" Width="40" LaneId="S1">
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<RouteData DataType="Database"/>
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</Implementation>
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<TransitionRefs>
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</Split>
</TransitionRestriction>
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Height="65" Width="50" LaneId="S1">
<Coordinates XCoordinate="363" YCoordinate="297"/>
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</NodeGraphicsInfos>
</Activity>
<Activity Id="D12" Name="Perishable Goods">
<RouteData DataType="PhysicalEntity"/>
<Implementation>
<No/>
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<TransitionRestriction>
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<TransitionRefs>
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</TransitionRestriction>
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```

```
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Style="No_Routing_Splines"/>
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</Transition>
<Transition Name="" From="A2" Id="L14" To="A3">
<Condition Type="Normal Sequence"/>
<ConnectorGraphicsInfos>
<ConnectorGraphicsInfo FillColor="0,0,0"
Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
<Transition Name="" From="A3" Id="L15" To="A4">
<Condition Type="Normal Sequence"/>
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<ConnectorGraphicsInfo FillColor="0,0,0"
Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
<Transition Name="" From="A4" Id="L16" To="G9">
<Condition Type="Normal Sequence"/>
<ConnectorGraphicsInfos>
<ConnectorGraphicsInfo FillColor="0,0,0"
Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
<Transition Name="Temperature < Threshold value" From="G9"
Id="L17" To="A5">
<Condition Type="Normal Sequence"/>
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Style="No_Routing_Splines"/>
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```

```
</Transition>
<Transition Name="Temperature > Threshold value" From="G9"
Id="L18" To="A6">
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Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
<Transition Name="" From="A5" Id="L19" To="G10">
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<ConnectorGraphicsInfos>
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Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
<Transition Name="" From="A6" Id="L20" To="G10">
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</ConnectorGraphicsInfos>
</Transition>
<Transition Name="" From="G10" Id="L21" To="E8">
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<ConnectorGraphicsInfo FillColor="0,0,0"
Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
<Transition Name="" From="D12" Id="L22" To="A2">
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<ConnectorGraphicsInfo FillColor="0,0,0"
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<Transition Name="Threshold value" From="D11" Id="L23" To="A3">
<Condition Type="Association"/>
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Style="No_Routing_Splines"/>
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</Transition>
```

```
</Transitions>
</XPDL:WorkflowProcess>
```

A.2 Process Part 2

```
<XPDL:WorkflowProcess Id="P0" Name="IoT Process"
AccessLevel="public">
<ProcessHeader>
<Created>Thu Jan 11 2018 18:49:15 GMT+1300
(New Zealand Daylight Time)</Created>
<Description>Place your description here</Description>
</ProcessHeader>
<Activities>
<Activity Id="E2">
<Event>
<XPDL:Start Trigger="None"/>
</Event>
<NodeGraphicsInfos>
<NodeGraphicsInfo BorderColor="0,0,0" FillColor="255,255,255"
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<Coordinates XCoordinate="8" YCoordinate="68"/>
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</NodeGraphicsInfos>
</Activity>
<Activity Id="E3">
<Event>
<XPDL:Terminate Trigger="None"/>
</Event>
<NodeGraphicsInfos>
<NodeGraphicsInfo BorderColor="0,0,0" FillColor="255,255,255"
Height="42" Width="41" LaneId="S1">
<Coordinates XCoordinate="1265" YCoordinate="226"/>
</NodeGraphicsInfo>
</NodeGraphicsInfos>
</Activity>
<Activity Id="A4" Name="Monitor goods in transit">
<RouteAct ActivityType="process"/>
<Implementation>
<No/>
</Implementation>
<Performers>
<Performer></Performer>
</Performers>
```

```
<NodeGraphicsInfos>
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Height="91" Width="119" LaneId="S1">
<Coordinates XCoordinate="101" YCoordinate="44"/>
</NodeGraphicsInfo>
</NodeGraphicsInfos>
</Activity>
<Activity Id="A5" Name="Obtain current coordinates">
<RouteAct ActivityType="reader"/>
<Implementation>
<No/>
</Implementation>
<TransitionRestriction>
<Join Type="AND">
<TransitionRefs>
<TransitionRef id="L14"/>
<TransitionRef id="L27"/>
</TransitionRefs>
</Join>
</TransitionRestriction>
<Performers>
<Performer></Performer>
</Performers>
<NodeGraphicsInfos>
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Height="91" Width="119" LaneId="S1">
<Coordinates XCoordinate="277" YCoordinate="43"/>
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</NodeGraphicsInfos>
</Activity>
<Activity Id="A6" Name="Inform location">
<RouteAct ActivityType="subProcess"/>
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<No/>
</Implementation>
<Performers>
<Performer></Performer>
</Performers>
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<NodeGraphicsInfo BorderColor="0,0,0" FillColor="255,255,255"
Height="91" Width="119" LaneId="S1">
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</NodeGraphicsInfos>
```

```
</Activity>
<Activity Id="A7" Name="Check for environmental conditions">
<RouteAct ActivityType="eventstreams"/>
<Implementation>
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</Implementation>
<TransitionRestriction>
<Join Type="AND">
<TransitionRefs>
<TransitionRef id="L16"/>
<TransitionRef id="L28"/>
</TransitionRefs>
</Join>
</TransitionRestriction>
<Performers>
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Height="91" Width="119" LaneId="S1">
<Coordinates XCoordinate="461" YCoordinate="207"/>
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</Activity>
<Activity Id="A8" Name="Report violation">
<RouteAct ActivityType="eventstreams"/>
<Implementation>
<No/>
</Implementation>
<TransitionRestriction>
<Join Type="AND">
<TransitionRefs>
<TransitionRef id="L18"/>
<TransitionRef id="L29"/>
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</Join>
</TransitionRestriction>
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</Performers>
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Height="91" Width="119" LaneId="S1">
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```

```
</NodeGraphicsInfo>
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</Activity>
<Activity Id="A9" Name="Continue delivery">
<RouteAct ActivityType="eventstreams"/>
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</Implementation>
<Performers>
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Height="91" Width="119" LaneId="S1">
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</NodeGraphicsInfos>
</Activity>
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</Implementation>
<Performers>
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<NodeGraphicsInfos>
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Height="91" Width="119" LaneId="S1">
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</NodeGraphicsInfos>
</Activity>
<Activity Id="G11">
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<TransitionRefs>
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</TransitionRefs>
</Split>
</TransitionRestriction>
```

```
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Height="40" Width="40" LaneId="S1">
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<TransitionRestrictions>
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<Join Type="XOR_Data">
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</TransitionRefs>
</Join>
</TransitionRestriction>
</TransitionRestrictions>
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Height="40" Width="40" LaneId="S1">
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</Activity>
<Activity Id="D24" Name="">
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</Implementation>
<TransitionRestriction>
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<TransitionRefs>
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</Split>
</TransitionRestriction>
<Performers>
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</Performers>
<NodeGraphicsInfos>
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<Coordinates XCoordinate="635" YCoordinate="16"/>
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</NodeGraphicsInfos>
</Activity>
<Activity Id="D25" Name="Monitoring events">
<RouteData DataType="InputEvent"/>
<Implementation>
<No/>
</Implementation>
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<Split Type="AND">
<TransitionRefs>
<TransitionRef id="L28"/>
</TransitionRefs>
</Split>
</TransitionRestriction>
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</Performers>
<NodeGraphicsInfos>
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Height="65" Width="50" LaneId="S1">
<Coordinates XCoordinate="369" YCoordinate="294"/>
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</NodeGraphicsInfos>
</Activity>
<Activity Id="D26" Name="GPS Satellite">
<RouteData DataType="SmartObject"/>
<Implementation>
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</Implementation>
<TransitionRestriction>
<Split Type="AND">
<TransitionRefs>
<TransitionRef id="L27"/>
</TransitionRefs>
</Split>
</TransitionRestriction>
<Performers>
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</Performers>
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</Activity>
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Style="No_Routing_Splines"/>
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Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
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Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
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Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
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<ConnectorGraphicsInfos>
<ConnectorGraphicsInfo FillColor="0,0,0"
Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
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<Condition Type="Normal Sequence"/>
```

```
<ConnectorGraphicsInfos>
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Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
<Transition Name="" From="G11" Id="L19" To="A9">
<Condition Type="Normal Sequence"/>
<ConnectorGraphicsInfos>
<ConnectorGraphicsInfo FillColor="0,0,0"
Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
<Transition Name="" From="A8" Id="L20" To="A10">
<Condition Type="Normal Sequence"/>
<ConnectorGraphicsInfos>
<ConnectorGraphicsInfo FillColor="0,0,0"
Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
<Transition Name="" From="A9" Id="L21" To="G12">
<Condition Type="Normal Sequence"/>
<ConnectorGraphicsInfos>
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Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
<Transition Name="" From="A10" Id="L22" To="G12">
<Condition Type="Normal Sequence"/>
<ConnectorGraphicsInfos>
<ConnectorGraphicsInfo FillColor="0,0,0"
Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
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<Condition Type="Normal Sequence"/>
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Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
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<Condition Type="AssociationW"/>
<ConnectorGraphicsInfos>
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```

```
Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
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<Condition Type="AssociationW"/>
<ConnectorGraphicsInfos>
<ConnectorGraphicsInfo FillColor="0,0,0"
Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
<Transition Name="Events exceeding threshold value"
From="D24" Id="L29" To="A8">
<Condition Type="AssociationW"/>
<ConnectorGraphicsInfos>
<ConnectorGraphicsInfo FillColor="0,0,0"
Style="No_Routing_Splines"/>
</ConnectorGraphicsInfos>
</Transition>
</Transitions>
</XPDL:WorkflowProcess>
```

Appendix B

Instructions to use IoT aware BPMN and XPDL Editor

B.1 Steps to use IoT aware BPMN and XPDL Editor

- The left side toolbox consists of the tabs, Swimlanes , Activities, Events, Gateways, Connectors, Data and Artifacts.
- To open any tab in that toolbox, click on the required tab once.
- To start drawing a diagram, select a single lane or multiple lane pool (depending on the requirement) from the Swimlanes tab of the toolbox by clicking on the particular pool icon once. This will make it appear on the editor/ editing space at the right side. Figure B.1 illustrates this.
- If you want to place a start Event on the pool for example, move the cursor to that element, drag, and drop it on the pool on the editor as shown in Figure B.2. The same steps should be followed for elements under Activities, Gateways and Data and Artifacts.

- You can adjust the positon of these elements in the pool by dragging and moving to replace them on the pool.
- Now, if you want to connect a ‘sensing task’ for example with the start event, place the element on the pool following above steps and connect each other by using a connector under ‘Connectors’ from the toolbox.
- For this, click on the particular connector icon and it will be highlighted. The cursor icon will turn to “+”sign. When you move the cursor to each element, their colour will change to ‘yellow’. Now when you click on one element and drag the cursor to the other, the two elements will get connected by the chosen connector. Figure B.3 shows this.
- To deselect the chosen connector you need to click on it again at the toolbox so that the highlighting disappear. If you do not remove the selection, you cannot move any element on the pool in the editor.
- An element cannot be removed while a connector is chosen and being highlighted.
- To remove an element from the diagram, deselect any connector selections as already mentioned. Right click on the element you want to delete and this will bring a popup menu with ‘Delete’ as an option in it. When you select delete option, this will delete the element as well as any associations it has.
- To add text to any element, for example to add text to ‘sensing task’ from ‘Activities’ as shown in Figure B.4, double click on the element and a text area window will appear on screen. Type text and click on the button ‘Set’. Click on ‘Cancel’ button to discard the text. Same steps to be followed in editing any written text on an object.

- To write text on a connector, the same steps as above should be followed and text will appear on the connection as shown in Figure B.5.
- To use XPDL editor, click on the 'XPDL' button on top right side of the screen. This will bring a window with XPDL code in it if there is any element or a diagram present as shown in Figure B.6 or a blank screen.
- Copy this code to a file to save the diagram.
- To load the diagram again later, open the editor and paste the code on XPDL editor window that comes with a black screen and click on apply button. The diagram will appear on screen.
- It should be noted that when loading a diagram to the editor via XPDL code, the BPMN editor diagram drawer should be empty, i.e. there should not be any element present on screen including a 'pool' element. Once the website is loaded, simply open the XPDL editor that comes with a blank screen and paste the code there and click on 'Apply' button.

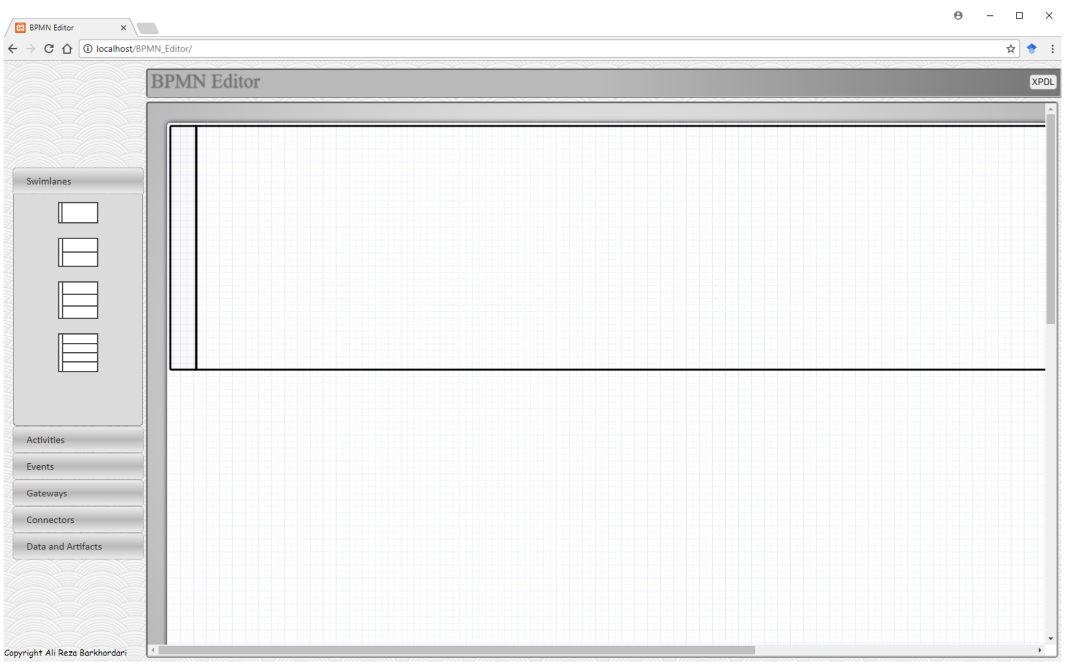


Figure B.1: BPMN and XPDL Editor with a pool

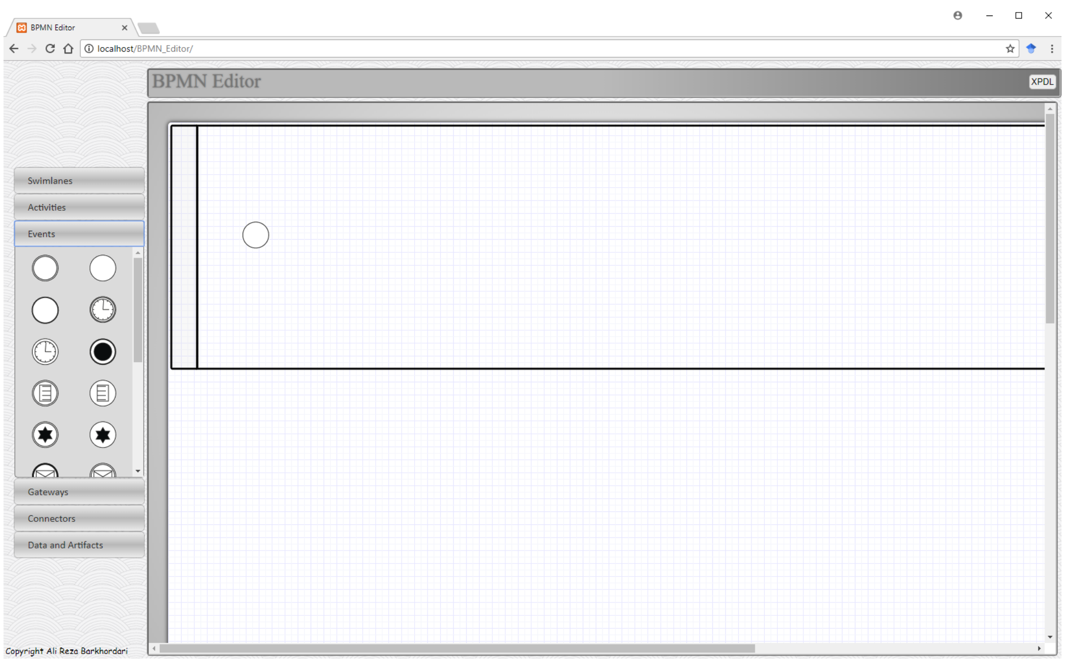


Figure B.2: BPMN and XPDL Editor, a start event placed on pool

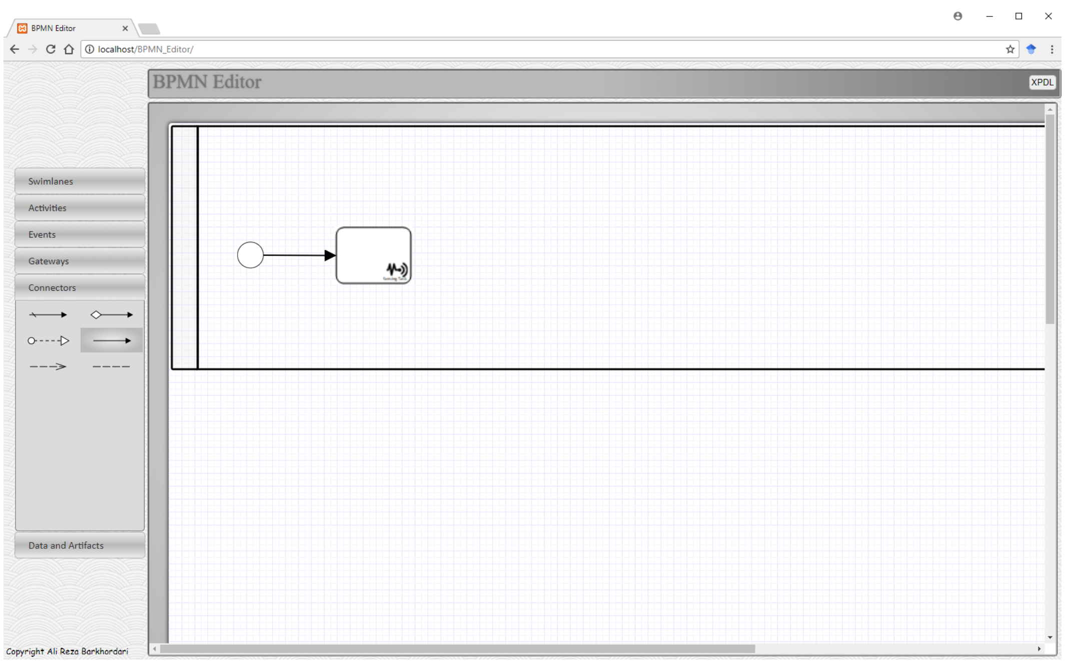


Figure B.3: BPMN and XPDL Editor, how to use a connector

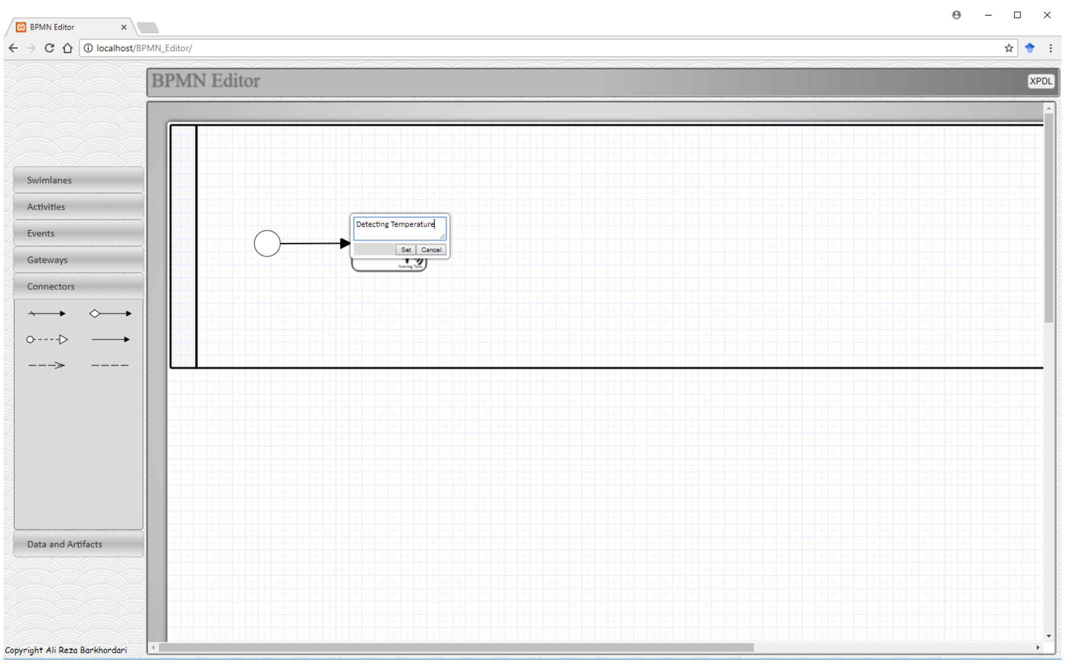


Figure B.4: BPMN and XPDL Editor, insert text in an element

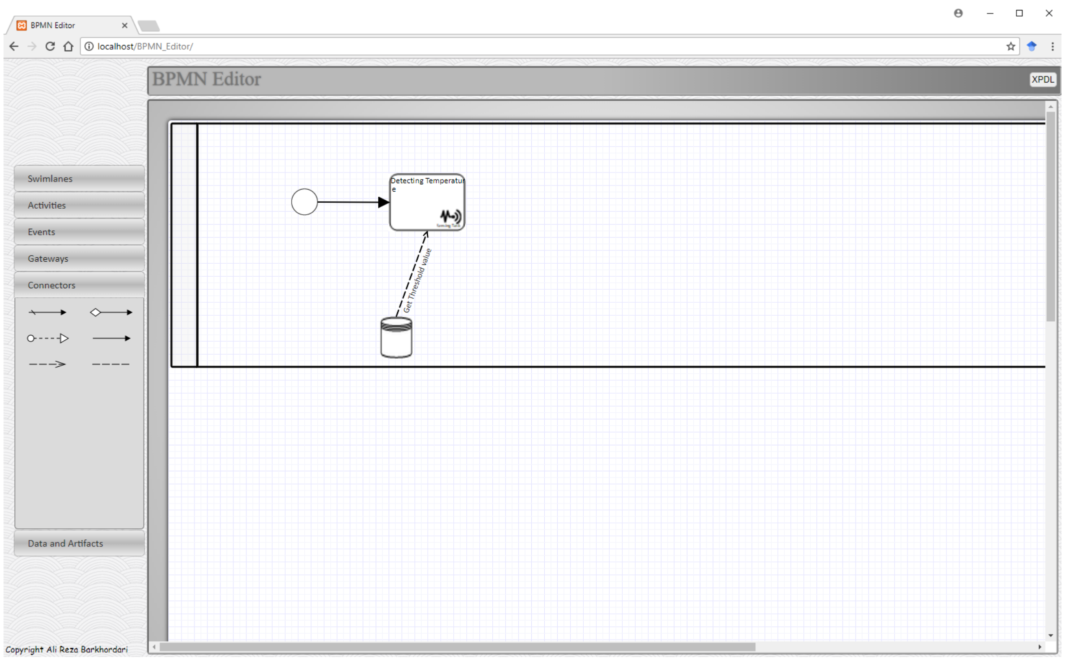
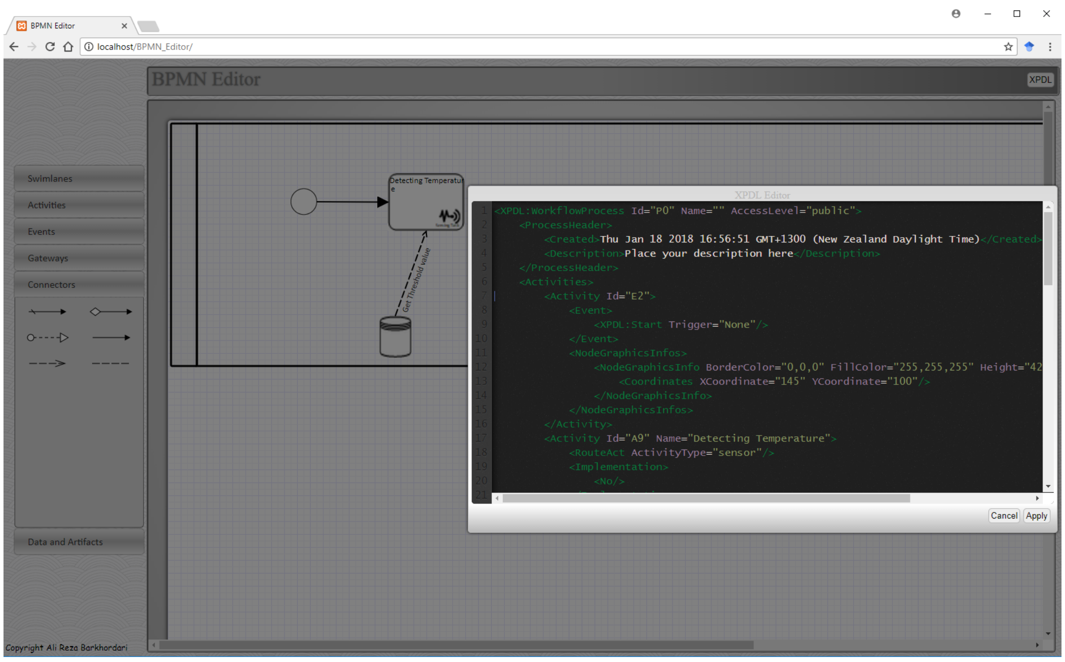


Figure B.5: BPMN and XPDL Editor, write text on a connector



```
<XPDL:WorkflowProcess Id="P0" Name="" AccessLevel="public">
    <ProcessHeader>
        <Created>Thu Jan 18 2018 16:56:51 GMT+1300 (New Zealand Daylight Time)</Created>
        <Description>Place your description here</Description>
    </ProcessHeader>
    <Activities>
        <Activity Id="E2">
            <Event>
                <XPDL:Start Trigger="None"/>
            </Event>
            <NodeGraphicsInfos>
                <NodeGraphicsInfo BorderColor="0,0,0" FillColor="255,255,255" Height="42
                    <Coordinates XCoordinate="145" YCoordinate="100"/>
                </NodeGraphicsInfo>
            </NodeGraphicsInfos>
        </Activity>
        <Activity Id="A9" Name="Detecting Temperature">
            <RouteAct ActivityType="sensor"/>
            <Implementation>
                <No/>
```

Figure B.6: BPMN and XPDL Editor with corresponding diagram code on XPDL editor