Process-Based Material Workflow Modeling in Inbound Logistics: Modeling Tools Evaluation

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Abstract: This paper evaluates the suitability of the workflow modeling tools through process-based material workflow perspective. A case example in inbound logistics system of "Resource Reception" workflow at the highest domain abstract level is examined with four nominated workflow modeling standards of Data Flow Diagram (DFD), Event-based Process Control (EPC), Business Process Model and Notation (BPMN) and Unified Modeling Language (UML) Activity Diagrams (AD). Focusing on the physical object diagraming syntax and semantics, the essential factors of the flows, consumption pattern and states for physical objects as well as readability, easiness and comprehensiveness of the modeling tools were discussed throughout the modeling development. The models and comparative evaluation results clearly demonstrates the superiority and advantages of using UML Ads at the workflow modeling providing an extensive view of the whole system functionalities and behavior fulfilling the necessity of capturing any undepicted entity that might hold the key of improvement in Business Process Management (BPM).

Key words: Computer-aided systems · Inbound logistics · Workflow modeling · BPM

INTRODUCTION

Business Process Modeling (BPM) as the main core in Business Process Management is the activity of representing the processes of an enterprise [1, 2] either at its current state (As-Is) or to what it should become (To-Be) [3]. The important aspects of business process management in terms of improvements of data as well as material flows are well recognized. However, there are a few attention are drawn to the material workflow in advanced workflow modeling tools. As an example, in BPMN or EPC, there are limited notations and semantics defined for material flow and basically the only thing that might be specifically applicable to capture its effects are through borrowing the concept from some of the pre-defined "Event" notation group. There are about 80 percent of all flows belong to the information [4] which can rather explicitly be addressed in these modeling tools such as BPMN through specific semantics like "Data Artefacts" and "Message Flows". The other 20 percent as the material flow which provide another analytical view of the system structure and functionalities however are less

concerned no matter how necessary they are at different stages of workflow business process modeling as another input or output of sequential upstream and downstream processes.

This paper aims to contribute in investigations on suitability of the most-practiced business process modeling tools for process-based material workflow. Even though, advanced modeling tools such as BPMN tends to be practiced and more applicable at the very highest level description of business operations [5, 6] but the problem of dealing with object flow and lack of appropriate semantic which provide essential insights available to system analysts and developers still remains. This problem is more noticeable at modeling the processes which information are not only sometimes attached to the objects but also are changed and modified with delays, locations and transformations. To provide a real world example, a case of "resource reception" workflow at inbound logistics system is discussed and the material workflow in this example is deliberately modeled at the highest domain level. Four state-of-the-art standard modeling languages are fully examined in this case

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including DFD, EPC, BPMN and UML Activity Diagram to highlight their general capabilities and implication of capturing the flow of the material as illustration of process-based physical object workflow modeling tool.

MATERIALS AND METHODS

There are several researches over the importance, quality and suitability of the modeling languages[7-9]. Since, business process modeling and designing is a complex and, thus, error prone task [10] a large number of methodologies for modeling and analyzing business process has been emerged. Many of these methodologies present rich design environments lacking accurate conceptual perception and the others have clear conceptual foundation but lacking graphical expressivity [11]. A profound generic review on suitability of the modeling tools in that sense is provided in another article by the same authors [12].

Furthermore, business process models are key factors toward integrating enterprise systems [13]. Conceptual modeling of business processes is deployed on a large scale to facilitate the development of software that supports the business processes and to permit the analysis and re-engineering to improve them [14]. Moreover, information models utilize the business process models and associated data resources as very essential inputs [15, 16]. If the processes are well described, designing data resources will be simpler [17]. In other words, if the business processes are not in line with the information system, the system implementation is unlikely to create any benefits [see for example: [18, 19]. In fact, Process-based information systems typically involve various kinds of process stakeholders. That, in turn, leads to multiple process models that capture a common process from different perspectives and at different levels of abstraction [20]. This clearly indicates, one should plan for quality BPMs covering all aspects of the system functionalities and behavior as the premier requirement to achieve a successful software development for the system [21].

Methodology: Basically we examined an actual case in inbound logistics called "Resource Reception" workflow with four nominated workflow modeling tools to highlight their capability to handle the process-based material (i.e. physical object) flows. The selected modeling tools of DFD, EPC, BPMN and UML AD, are considered as prominent standard language in their category in terms of diagraming syntax such as flowchart-based or swimlane-

based. In fact in workflow modeling, there are several well-known formats of diagramming a business process. The swimlane diagrams are the most popular way among others in modeling the workflow of business processes due to highlighting the relevant variables of Who, What and When in a simple notation that requires little or no training to perceive. There are different names with slight variations for these diagrams [22] such as:

- Process map
- Process Responsibility Diagram (PRD)
- Responsibility Process Matrix (RPM)
- Functional Deployment Chart
- People Process Chart
- Line of Visibility (LOV) chart
- Activity Diagram in Unified Modeling Language (UML AD)
- Business Process Model and Notation (BPMN)

Moreover, the EPC which is largely utilized in SAP and ARIS modeling platform is considered as one dominant candidate in flowchart-based workflow modeling tool for business process diagraming. Furthermore, the DFD as another early process-based workflow modeling tools hugely used in Structure System Analysis and Design at information model development. The selected modeling tools are used to model the case example to highlight their material workflow modeling capabilities on the factors of physical object state, physical object consumption pattern and physical object flow.

Case Description: Next, the case example which is the workflow of receiving the purchased resources, called the "Resource Reception" workflow as one main part in process-based inbound logistics workflow system is described. At the highest domain level of business process abstraction, two internal units for the enterprise including the Warehouse and Quality Dept. (i.e. Quality Department) are identified. Moreover, the Supplier and the Bidder are considered as two external units which together with internal units all are responsible actors for this workflow. The workflow is triggered to operate by receiving the purchased resources from the resource providers (i.e. Supplier or Bidder) and executing the first activity of "Docking" process at the Warehouse. Next, a notification is sent to Quality Dept. on arrival of the purchased resources. Quality operations are carried out at Quality Dept. and the results are issued to the Warehouse. Based on the received quality results at the

Warehouse, it will be decided whether or not the purchased resources are authorized to be stored at the Warehouse or should be returned back to the resource provider due to the quality issues. Thus, if the quality results are as "QC Accepted" then the next activity of "Store" business process is executed at the Warehouse. Otherwise, the purchased resources are subject to be returned and therefore the "Return Purchase" business process is executed. In the following sections, "Resource Reception" workflow is modeled with four prominent modeling tools and standards emphasizing on demonstration of the process control flow, data flows and more specifically on the physical object flows. The possibility of using syntax and semantics provided by the modeling tools in term of the proficiency capturing of process-based material flows for each modeling tools are conceptually highlighted.

Workflow Modeling with DFD: DFDs present an overview of system inputs, processes and outputs by graphically depicting the flow of data from external entities into the system, the flow of data from one process or transform to another and the logical storage of data. DFD notations are made up of four symbols including the Entity, Process, Data Store and Data Flow. Entities or External Entities are outside agents that send data to the system (i.e. source of data) and receive data from the system (i.e. sink of data). Processes transform the input received data to another form of data as output. Data flows represent the flow of data from one point to another. Data Stores indicate the repository of data where it can be stored or retrieved. There are two major well-known sets of notations used in DFD which comparatively has slightly difference including the Gane and Sarson [23] and Yurdon and Demarco [24] notations.

Generally, the development of a DFD begins with a context diagram that shows a single process representing the system as well as external entities and data flows to or from it. The next level, referred to as the Level 0 provides a detailed depiction of the functional decomposition of the context diagram by depicting system processes. Each process on Level 0 can be decomposed into a more detailed child diagram and these are generally referred to as Level 1 which can in turn be decomposed into Level 2 diagrams and so forth.

Next, the "Resource Reception" workflow modeling with DFD is discussed and started with DFD Level 0 due to the simplicity of the example using Gane and Sarson notations. Based on the case description, two main processes are identified at DFD Level 0 including Reception at the Warehouse and QC at the Quality Department. Moreover, the Supplier and Bidder are identified as two External Entities for the Resource Reception workflow model at DFD level 0. As shown in Fig 1, the *Purchased Resources* as the bolded bi-directional arrow lines and the *Samples* as the bolded arrow lines demonstrate the transmission of the *Purchased Resources* as the physical objects between External Entities and the Reception process as well as the *Samples* among the Reception and QC processes. The "QC Results" and "Purchase Arrival Notification" are two normal data flows between Process 1 and Process 2 which remains un-bolded. The blue color elements border lines are to highlight the actual active elements in each level which here in DFD Level 0 all elements are colored in blue.

The Reception process at DFD Level 0 is decomposed into four main processes at DFD Level 1 including Docking, Analyze QC Result, Store and Return Purchased processes labeled as 1.1 to 1.4 respectively as shown in Fig. 2. The bolded arrows demonstrating
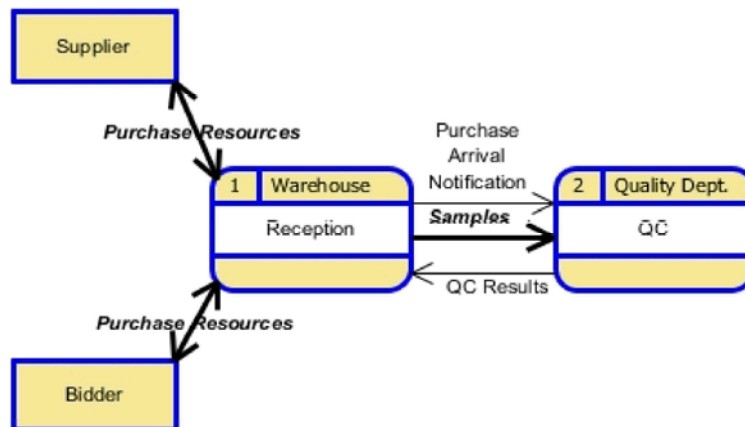

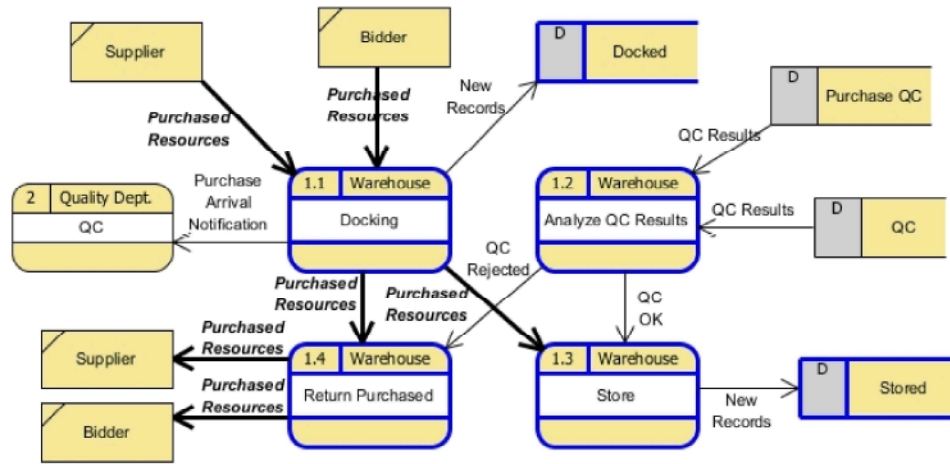Fig. 1: Resource Reception DFD Level 0

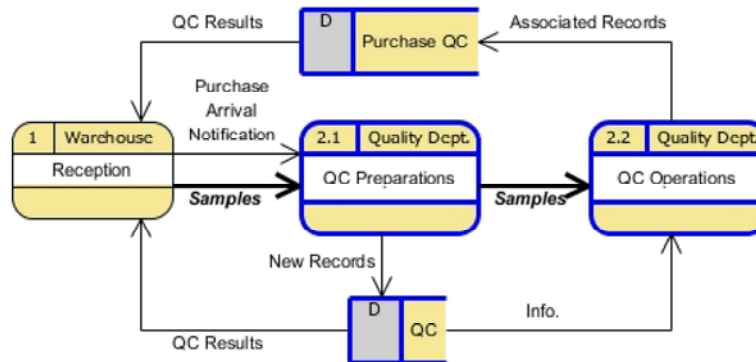Fig. 2: Resource Reception Workflow DFD Level 1 – Reception

Fig. 3: Resource Reception Workflow DFD Level 1 - Quality

the physical object flow of *Purchased Resources*. This flow starts from either the Supplier or Bidder up to the Store process at the Warehouse. However, in case of QC rejection, the *Purchased Resources* are returned back to the provider either Supplier or Bidder.

Upon receiving the *Purchased Resources*, Docking operations is carried out at Process 1.1 and as one output the "Purchase Arrival Notification" is sent to the QC process at Level 0. As another output, the whole process data is registered as a New Record at the Docked Data Store.

Later, based on the received and analyzed QC results at the Process 1.2, the QC OK as default message is sent to the Process 1.3 to proceed storing the *Purchased Resources* and the whole operation is registered at the Stored Data store. Otherwise, once the results are not accepted, the QC Rejected message is issued to the Process 1.4 to proceed for returning the *Purchased Resources* back to the providers.

The QC process at DFD Level 0 is decomposed into two main processes of QC Preparations and QC Operations labeled as 2.1 and 2.2 respectively in DFD Level 1 as shown in Fig 3. Based on receiving the "Purchased Arrival Notification" message from the Reception process at DFD Level 0 as well as receiving the required *Samples*, the Process 2.1 is executed. As the output, New Record is registered at QC Data Store which provides information for Process 2.2 and prepared *Samples* which are sent to the QC Operations (i.e. Process 2.2). The QC Data Stores holds the records based on the determined QC stations which normally are determined at the OPC documents of for each station. There might several QC operations been carried out and thus been registered at another associated repository which is the Purchase QC Data Store. Next, the "QC results" are issued to the Reception process at Level 0.

As shown at the workflow models with DFD, there is no possibility to demonstrate the Physical Object itself, its

state and its consumption behavior anyway. As one significant business process tool enormously used in Structure Analysis and Design Method (SSADM) and System Development Life-Cycle (SDLC) particularly at the highest domain level of abstractions, the DFD dramatically lacks appropriate semantics and incapable of addressing the process-based material workflow. This is where it is clearly known that in huge number of automated industrial systems the physical objects carry a number of data along with them that are subject to be updated or modified.

Workflow Modeling with EPC: As one prominent flowchart-type of business process modeling tools, EPC comprised of four general active and passive diagraming elements including the Activity (i.e. functions), Event (i.e. states), Rules or logical connectors (i.e. OR and , XOR) and the Connections. There are other annotations for objects, actors and supporting system that almost all of them are linked to the Function.

Next, the "Resource Reception" workflow modeling with EPC is discussed. An event in EPC triggers one-to-many sequential functions to launch; and a function may lead to one-to-many events. The workflow begins with the "Purchased Resources Received" Event at the Warehouse which is the output event for the "Delivery Resources" Function through either Supplier or the Bidder.

The modeling with EPC starts to have representation difficulty even at the beginning of the workflow modeling. Since we have a multiple starting event which is comes with the transmission of Physical Objects (i.e. *Purchased Resources*) that should be attached to a Function (i.e. "Delivery Object" which is not actively considered as a part of workflow model scope) and also is carried out via either the Supplier or the Bidder.

There, other six main Functions are identified at the highest domain level of the model including Docking, Analyze QC Result, Store and Return Purchased Functions at the Warehouse as well as QC Preparations and QC Operations at the Quality Dept. Moreover, there are five information resource are identified of which, one is a message of Purchased Arrival Notification and the rest are data stores including the Docked, Purchase Records, QC, Purchase QC and Stored.

Due to the lack of an appropriate semantic and notation for physical object and object flow in EPC, a technique is proposed and employed to cover the process-based material workflow modeling in EPC, namely, Event-Object (i.e. using the control flow and event notations).
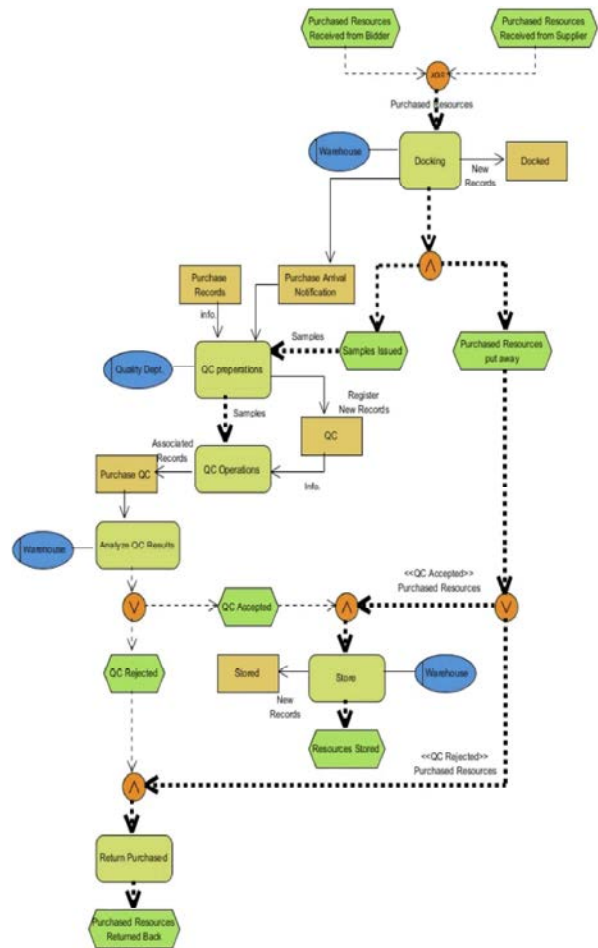

Fig. 4: Resource Reception Workflow with EPC event object

Next, the workflow model is discussed employing the Event-Object technique. The dashed arrow lines between Functions and Events in EPC are specifically defined to demonstrate the control flow of the business processes. Nonetheless, in this suggested technique, the bolded arrow lines are defined for the flow of objects and in this case are labeled as the *Purchased Resources* and *Samples* to conceptually demonstrate the flow of the physical objects (i.e. resources). Fig 4 illustrates the Resource Reception workflow model using Event-Object technique. The *Purchased Resources* as the output event of the functions are subject to change the states from the "received" to "put away", "stored" and "returned back" based on the control and object flows as is shown in the Fig 4. As the "Docking" Function output, the "Samples Issued" Event and "Purchased Resources Put Away" Event are generated with *Samples* flow and *Purchased Resources* flow.
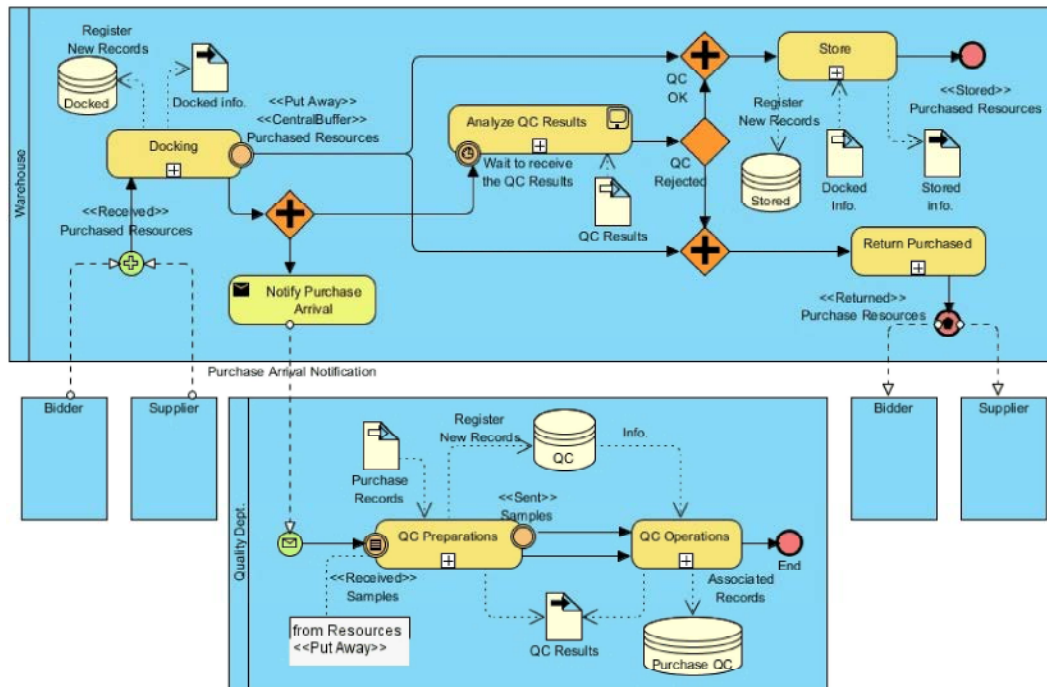
Fig. 5: Resource Reception Workflow with BPMN

Based on the "Analyze QC Results" Function at Quality Department, at "QC Accepted" Event, the Purchased Resources through conditional flow of << QC Accepted>> is sent to storing process at the "Store" Function and changes its state to the "Resources Stored" displayed by an ending Event. Otherwise, the Purchased Resources through conditional flow of <<QC Rejected>> is sent back to the providers through "Return Purchased" Function and changes its state to "Purchased Resources Returned Back" demonstrated with an ending Event.

Although, the used techniques can partly address the process-based workflow in terms of the states through Events notations as well as the object flows through bolded dashed arrow lines, yet still there is no possibility to fully capture the conditions, restrictions and consumption pattern of the objects properly such as in where the exact amounts of *Samples* that are sent for quality control operations.

Workflow Modeling with BPMN: BPMN is to provide a standard notation for business processes that is readily understandable ranging from the business analysts in early phase of system development who sketch the initial drafts of the processes [25] to the technical developers responsible for actually implementing them and finally to the business staff deploying and monitoring such processes [26].

It has four categories of graphical elements to build a diagram including the Flow Objects, Connecting Objects, Swimlanes and Artifacts. Flow Objects represent all the actions including Events, Activities and Gateways. Connecting Objects provide three different ways of connecting various objects: Sequence Flow, Message Flow and Association. Swimlanes have two elements to group other elements: Pools and Lanes. Artifacts are used to provide additional information about processes including the Data Object, Group and Annotation [1, 27].

Next, the "Resource Reception" workflow modeling with BPMN is discussed. The Warehouse and Quality Dept. considered as the Active Swimlanes and the Supplier and Bidder are two "Abstract" Swimlanes. There, four Sub-processes of Docking, Analyze QC Results, Store and Return Purchased at the Warehouse and two Sub-processes of QC Preparations and QC Operations at the Quality Department are identified as is illustrated at Fig. 5.

The Start, Intermediate and End Events and their associated control flows are conceptually used to partly demonstrate the physical objects and their flows. Moreover, a variety of pre-defined labeled of <<Stereotypes>> are set to demonstrate the state of the physical object in each stage. As is shown in the model, the workflow is triggered with a "Parallel Multiple" Start Event of the <<Received>> Purchased Resources from
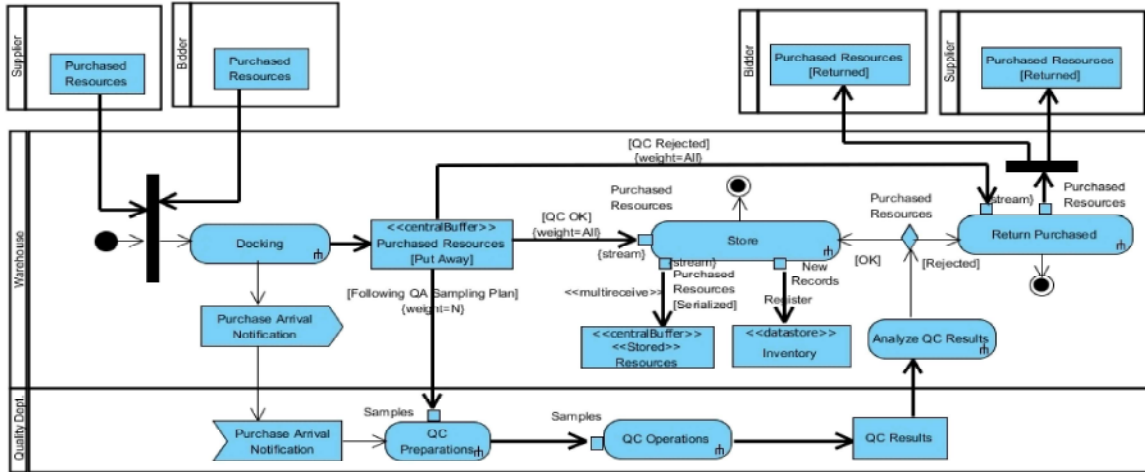
Fig. 6: Resource Reception Workflow with UML Activity Diagram

either the Supplier or the Bidder associated with the message flows. As an intermediated event of the Docking sub-process, the Purchased Resources are <<Put Away>> and considered as <<Central Buffer>> meaning as one repository to add or to retrieve resources from it.

At Quality Dept., Purchase Arrival Notification "Start Event" message is received and once "Conditional" Event of Samples <<Received>> occurs, then the QC Preparation sub-process is executed. Next, the Samples are <<Sent>> to the QC Operations sub-process. At the Warehouse, Based on the received QC Results Data Object artifact, the Purchased Resources are <<Stored>> only if the QC OK is issued. Otherwise, the Purchased Resources are <<Returned>> to the Supplier or the Bidder shown as "Multiple Result" End Event (i.e. the Purchased Resources are returned, compensation process of purchasing new resources is triggered, messages are sent to the providers, evaluation process of the providers are triggered, etc.)

Through this technique, the states of the physical objects and object flows within one Swimlane can rather systematically yet partly be addressed. However, as shown in the model, still it is not possible to demonstrate the physical object flow among the Swimlanes (e.g. the flow of Samples among Warehouse and Quality Dept., or the flow of Purchased Resources among the providers and the Warehouse). Moreover still, the consumption patterns (e.g. weights, guards, etc.) are not covered.

Workflow Modeling with UML AD: The UML covers five major aspects at process modeling, namely (1) actions and control flow, (2) data and object flow, (3) organizational structure, (4) interaction centric views on business processes and (5) system-specific process models used for process enactment [28]. The basic building block of a process description in UML is the activity. An activity is a behavior consisting of a coordinated sequencing of actions; and is represented by an activity diagram. UML Activity diagrams are the fundamental tool for process modeling through integrating the control flow concepts and constructs with the object flow. Activity diagrams visualize sequences of actions to be performed including control, data and object flows. It has several visual syntaxes to represent the construct elements of Activity; Action, Object and Control Nodes; Expansion Region; and Partition. An overview of basic and advanced elements of the activity diagram syntaxes are thoroughly discussed by Khabbazi *et al*. [See: 12].

Next, the "Resource Reception" workflow modeling with UML AD is discussed. The Warehouse, Quality Dept., Supplier and Bidder are partitioned using Swimlanes and based on identifying set of nodes to handle *Purchased Resources* as shown in Fig 6. Using already available syntaxes of object nodes and object flows, it is possible to model how objects are directed through the different actions of an activity and by using pins how they are assigned to the input and output parameters of the various actions. An action can start execution only if all its input pins hold an object token. Then, the action consumes the tokens from its input pins and, after completion, places new object tokens on all of its output pins.

It starts with receiving the *Purchased Resources* "Object Node" indicating the physical object directed to a vertical "Join Node" through Control Flows indicating it is received either from the Supplier or the Bidder.

It is then followed by Docking "Action" and as the output the Purchased Arrival Notification "Send Signal Action" is issued to the Quality Department. As another output, the received *Purchased Resources* "Object Node" is transformed into <<Central Buffer>> Node with [Put Away] status. A <<Central Buffer>> Node is used once there are inputs or outputs from or to several other Nodes.

The Purchased Arrival Notification is received as an "Accept Event Action" at the Quality department and connected to the QC Operations "Action". The required *Samples* are collected from [Put Away] *Purchased Resources*<<Central Buffer>> Node through *Samples* input "Pin Node" of QC Operation Activity which indicates the necessity of its receipt as one triggering requirement. The Object Flow with {Weight= N} and [Guard: Following QA Sampling Plan] visually demonstrates some details of the consumption patterns.

Later, the QC Results Object Node as QC Operations Action output is consumed by the Analyze QC Results Action at the Warehouse. Over received Control Flow with [Guard: OK], the Store Action is executed only when the *Purchased Resources* are received at the Input Pin with {Stream} parameter through the Object Flow [QC Ok] Guard and {weight= All} from the *Purchased Resources*<<Central Buffer>> [Put Away] Node. The {Stream} parameter demonstrates the input pattern of the tokens. As the output, the Resources <<Stored>><<Central Buffer>> Node is generated which holds the Purchased Resources [Serialized] in a <<Multireceive>> way from Output Pin with {Stream} parameter of the Store Action.

Over received Control Flow with [Guard: Rejected], the Return Purchased Action is executed only when the Purchased Resources are received at the Input Pin with {Stream} parameter through the Object Flow [QC Rejected] Guard and {Weight= All} from the Purchased Resources <<Central Buffer>> [Put Away] Node. As the Output the Purchased Resources are sent back to the Providers demonstrating as with a vertical Fork Node.

Using UML AD, generally the main states of the physical objects in workflow modeling as well as the Consumption patterns and the object flows are addressed. However, using the labeling and stereotypes decrease the simplicity and readability of the model particularly at dealing with more complex systems such as where the flows overlapping.

DISCUSSION

As explained throughout the modeling development, the possibility to illustrate the physical object flows, physical object consumption pattern and physical object states as three important factors was examined with four state-of-the-art modeling language in a real-world case example of "Resource Reception" workflow. The readability and modeling easiness as well as the comprehensiveness of modeling tool in terms of available semantics and syntaxes were highlighted. As the result as shown in Table 1, UML AD is considered as the best candidate to demonstrate the process-based material (i.e. physical object) workflow modeling tool. It more comprehensively supports dealing with the object details and the flows as well as possibility to illustrate visually the consumption patterns using guards, weights and values.

Moreover, as an object-oriented modeling tool, it supports other possible links toward developing the comprehensive business process modeling and data modeling goals with connection capability to the other unified modeling tools in UML such as state diagrams, component diagram, class diagrams and etc. to fully address systematically the whole system behavior and structure.

In the other hand, as more analytical and descriptive tools on the business process itself, the BPMN and EPC, simultaneously stand at the second tier in terms of process-based physical object workflow modeling capability where the DFD is considered as the weakest candidate to be utilized in that matter. Rather merely focusing on modeling the events that occurs to start a

Table 1: Comparison of Process-based Material Workflow Modeling Tools

	Object Flow	Object Consumption Pattern	Object State	Readability	ModelingEasiness	Comprehensiveness	Sum
DFD	1	0	0	4	4	1	*10*
EPC	2	0	3	2	3	2	*13*
BPMN	2	0	3	3	3	2	*13*
UML AD	4	4	4	3	3	4	*22*

Legend: 0=Not Covered 1= Weakest 5= Strongest

process, the detail process execution and end results in BPMN and EPC, as well as focusing on the Process-based data objects and flows in DFD, the material workflow cannot elaborately been modeled neither in BPMN, EPC, nor in DFD. Although, using the proposed techniques, it is still possible to demonstrate the flows in a rather explicit way; nonetheless the required details still cannot fully be covered generally.

Hence, it is greatly beneficial to diagram a process-based material workflow by employing the UML activity diagrams to provide a perceptive portray of yet another perspective of system behavior and control which is the material workflows.

CONCLUSION

This paper focused on the suitability of the dominant material workflow modeling tools of DFD, EPC, BPMN and UML. A real-world industrial case of Resource Reception workflow in inbound logistics system was examined and with each modeling tools a process-based workflow model were developed. The capabilities of the modeling tools in terms of handling the material workflow modeling syntax and semantics over three main factors of the physical object flow, physical object consumption pattern and physical object state were evaluated base on the developed models. Furthermore, the readability, modeling easiness and comprehensiveness of the workflow modeling tools were discussed and evaluated. As the consequence and based on the evaluation, the Activity Diagrams as part of UML bundle not only captures adequately all business process but also are distinctively more reliable tools at diagraming a process-based material workflow scenario. The limitations of the study are within the number of examined modeling tools and simplicity of the case example. Nonetheless, the outstanding comparison results in terms of physical object diagramming provide useful input in modeling tool selections.

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