Modeling and Using Context in Business Process Management: A Research Agenda

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ABSTRACT. Business Process Management (BPM) is the art and science of monitoring how the work is performed within an organization to ensure consistent results and opportunities for improvement. One important research topic on BPM relates to the issue of flexibility. Unplanned conditions may occur at any time during process execution. In dynamic environments, changes must be performed more frequently and systematically and considering not only pre-established rules, but also contextual information. The literature indicates context as a source of information that should be considered in the modeling of business processes in order to contribute to their flexibility when in the execution phase. In this paper, we present the results from our studies about context in the whole cycle of BPM. The goal is to describe an approach that comprises solutions for modeling, gathering, using and evolving context in a BPM oriented environment.
KEYWORDS. Business Process Management, Context, Context-Aware BPM.

1. Introduction

According to [28] business processes describe sets of activities performed in a coordinated/collaborative manner in a (multi-) organizational and technical environment with the view to achieve a business goal. Business Process Management (BPM) is the art and science of monitoring how the work is performed to ensure consistent results and opportunities for improvement. BPM is not just about improving the way single activities are performed; but somewhat, it is about managing the entire chain of events, activities and decisions that add value to the organization and its customers.

Figure 1 depicts a typical BPM lifecycle [8]. In the Process Identification Phase, a process architecture that provides an overall view of the processes in an organization and their relationships is defined. Then, in Process Discovery Phase, it is necessary to carefully understand the operation of a business process, and represent it in a model properly. Therefore, multiple stakeholders with different and complementary skills might collaborate on this task, which typically involves communication and information gathering. During the Process Analysis Phase, the identification and assessment of the opportunities for process improvement take place. Furthermore, the ideas and directions elicited inform the Process Redesign Phase; and then a redesign is conducted not always in a systematic way, but is rather a creative activity. The Process Implementation Phase comprises the execution of the to-be process by bringing into practice the necessary changes in the ways of working (organizational change management) and in the Information Systems (process automation). Finally, the Process Monitoring and Controlling Phase closes the ‘cycle’ and serves as a basis for the new loop. [8] affirm that once the implementation is completed, continuous monitoring and controlling of the process execution is required in order to identify, whether any adjustments are needed.

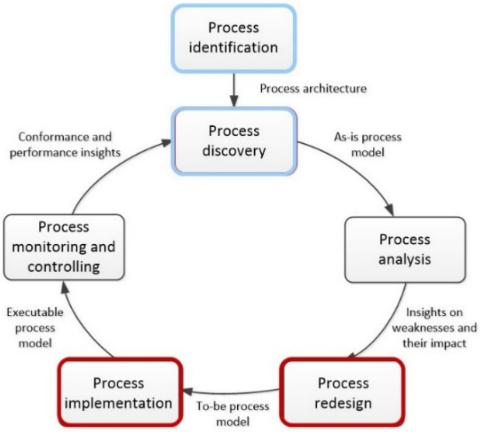

Figure 1. *BPM Lifecycle [8]*

One important research topic on BPM, transversal to its lifecycle, relates to the issue of flexibility. Unplanned conditions may occur at any time during process execution. So, the design of a complete process model, predicting all possibilities that might occur, is not fully possible. In practice, many variants of a process may exist within the same organization to deal with different business situations, such as: targeting different customer types, relying on particular Information Systems, considering personal or group specific characteristics, or complying with specific regulations. According to [3], we cannot predict everything that might occur during process execution at design time, since new circumstances and events arise, changing its scenario. Also, representing all possible decisions can make the understanding and use the model very hard. Changes may be required only to a specific process instance because of an isolated case, or they represent the need for restructuring the process model for a period of time or permanently [27].

Process adaptation is the action of customizing a process instance to make it applicable to a particular context. It requires experience and involves knowledge about various aspects of the business such as environment, people, technologies, organization, and external aspects. A relevant facet about process adaptation is that, in highly dynamic environments that require immediate adaptation, a fully human intervention is no longer acceptable since business processes can be very large and complex and there are thousands of concurrent process instances running.

A typical scenario that illustrates this problem is an emergency, such as the volcanic ash cloud crises that massively disrupted air traffic in Europe in 2010 and Latin America in 2011, calls for immediate intervention. Those complex environments often lack the necessary guidance to become automatically aware of a given situation, i.e., the closure of the air space above a certain height or due to bad weather. In industrial settings, the configuration is usually performed on an *ad hoc* basis, guided solely by the analyst's experience and a minimal set of standard adaptation rules. But in dynamic environments, changes must be performed more frequently and systematically and considering not only pre-established rules, but also contextual information.

[20] and [21] have argued that flexibility is an important requirement in business process design. [20] state that extrinsic drivers, which they classify as context, are the root-cause that really stimulates the demand for more flexible processes. The literature indicates context as a source of information that should be considered in the modeling of business processes in order to contribute to their flexibility when in the execution phase.

In this paper, we present the results from our studies about context management in the whole cycle of BPM. The goal is to describe an approach that comprises solutions for modeling, gathering, using and evolving context in a BPM oriented environment. The paper is organized as follows. Section 2 describes the relevance of context in BPM along with literature. Section 3 presents the proposal for a

Context-Aware BPM. Section 4 suggests a research agenda based on lessons learned. Section 5 concludes the paper.

2. Context in Business Process Management

Addressing context in BPM involves the identification of relevant information to be considered for analysis and adaptation in response to emerging demands. [17] advocate that current process modeling techniques only capture the intrinsic part of process flexibility, but lack contextualization. As stated by the authors, the conceptualization of the system and environment in which a process is embedded would be a base for the specification of truly context-aware processes. Thus, it would lead to context-aware analysis, design and implementation of systems typically used to enact processes, such as ERP (Enterprise Resource Planning) and BPMS (Business Process Management Systems).

[19] present an approach to goal-oriented process modeling, in which context can be conceptualized, classified and integrated. The proposal includes the framework Onion, a metamodel for classifying context, and a basic procedure of how to apply the framework. The procedure indicates how to identify and classify context through the Onion framework in five steps: (i) identify the goals of the process; (ii) decompose the process into a set of information relevant to the goals; (iii) determine the relevance of context, (iv) identify contextual elements; and, (v) categorize contextual elements. In [15], the authors provide a set of questions to raise insights with respect to contextual elements: What is relevant context? Where do changes in context impact processes? How do changes in context impact on processes? When do changes in context occur and when do they impact the process?

[9] state that a context-aware BPM should provide adequate knowledge at the right time for the user who will be working in a specific task. A task may depend on other (s) task (s) because its problem depends on a context attribute of a previous task and/or rely on a problem linked to a previous task. To identify the relevant context, the authors suggest six actions: establish any issues that may arise in each task; for each issue, identify context attributes that can help to decide if the issue deserves attention; define important properties for each context attribute; establish conditions under which a context attribute can be considered as being in a critical level; express rules on the possible values of attributes and context; and, present ways to solve the issues.

[5] affirm that "*while the role of context has been studied intensively in the field of organizational behavior, it is still in its early stages for the area of BPM*". They argue the relevance of context to a proper application of BPM approach within an organization, and propose a framework to derive contextual elements for BPM as a whole. The framework is based on the following dimensions of context: (i) goals of BPM, (ii) characteristics of the process, (iii) specifics about the organization in which BPM is applied, and (iv) the broader business environment in which BPM is embedded.

Literature highlights the relevance of context and points to the need of addressing it in BPM to provide flexibility. In the next section, we present our approach that considers contextual elements in BPM lifecycle.

3. A Proposal for Context-Aware BPM

We propose an approach for a Context-Aware Business Process Management that contemplates context in the lifecycle of processes within an organization. In this sense, context associated with the processes should be discovered, modeled, gathered, and used, and in a continuous way monitored and maintained. Figure 2 depicts the introduction of tasks intended to address context. Context should be part of the cycle to address flexibility and support improvement and innovation. We describe each step in the following sub-sections.

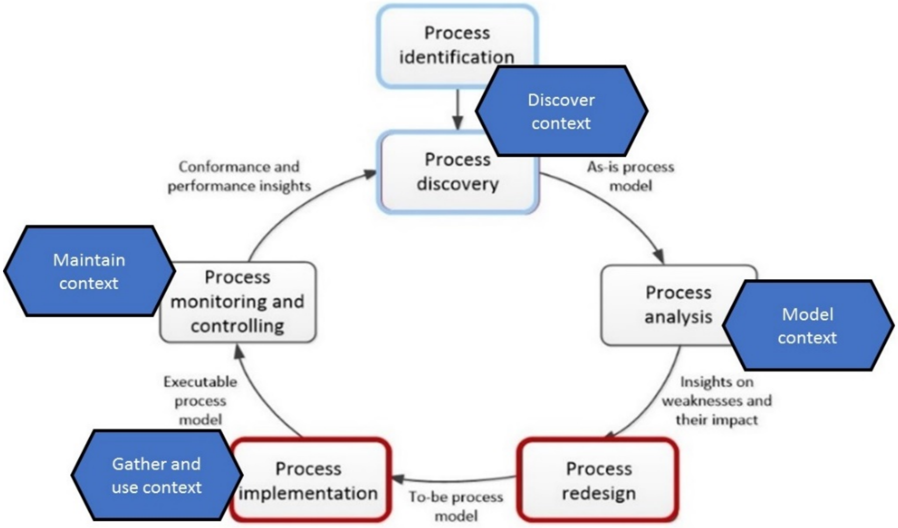

Figure 2. *Context-aware BPM lifecycle*

3.1. *Discover Context*

Discovering which are the relevant context elements associated to the process is the first step for a Context-Aware BPM. Part of this information is related to internal elements of the process, but there are also contextual elements that relies on external environment. Therefore, two different methods to support the discovering of contextual elements were proposed: ORGANON [2] and BPCREL [16].

The ORGANON method [2] aims at supporting the identification of internal contextual elements in business processes, through the analysis of process models. The method is based on the following concepts: Essential activity, derived from [22]; Essential Business Entity (EBE), derived from [14]; and Ontological transactions, from the work of [7]. We specify the method in terms of a semi-structured procedural model, which comprises two main steps: (i) identify the business process essential activities and (ii) analyze the impact of their attributes on a business process goal. The method aims at distinguishing, among the number of types of information provided in a process model, the set of attributes that could potentially undermine the goal of this process, and which should thus be classified as context. We use the term 'attribute' as an element associated with an activity in a process model (e.g., business rule, artifact, system, and input/output data). Figure 3 provides a graphical model of the ORGANON method, and describes the two steps alongside with relevant inputs and the outputs produced.

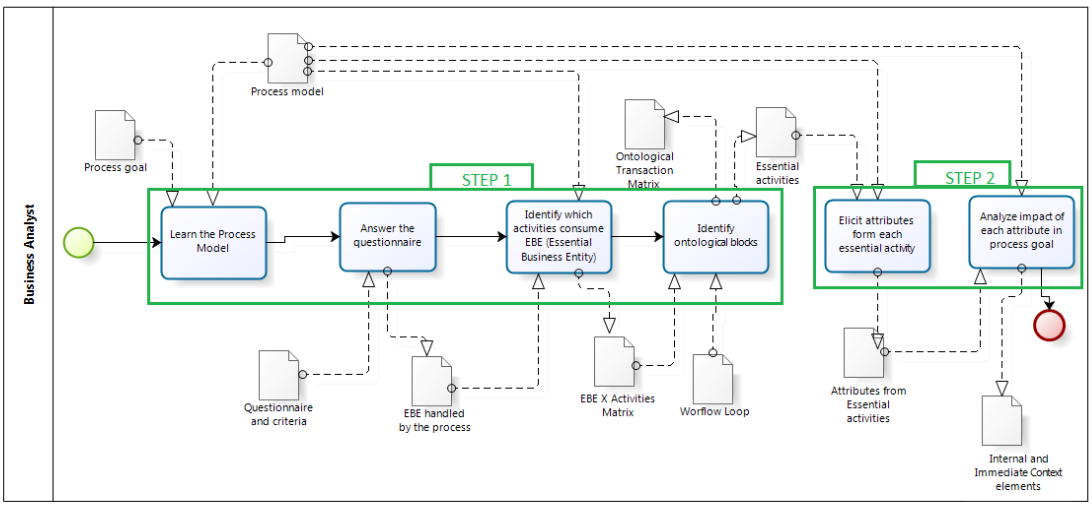

Figure 3. *Organon Method Procedural Model [ANA 2016]*

The BPCREL method [16] supports the identification of external context elements that may not be part of the organizational memory, but are relevant for achieving process goals. This method also shows which specific process activities are impacted by the external context elements. BPCREL is based on Key Intelligence Topic (KIT) [9] and Data Mining techniques, through the steps illustrated in Figure 4. KIT technique supports the specification, definition and prioritization of information needs at the strategic level of the organization. KITs are items that must be constantly monitored to guarantee business success. They should be detailed with the help of KIQs (Key Information Questions), which specify the content of each KIT. For example, for a KIT "Strategic Investment Decisions" to be monitored, several KIQs such as: "What is the involvement of other investors in competitors?" and "What are the critical investments from competitors?" could be used. KITs are identified through interviews with managers. The method steps are detailed in [16].

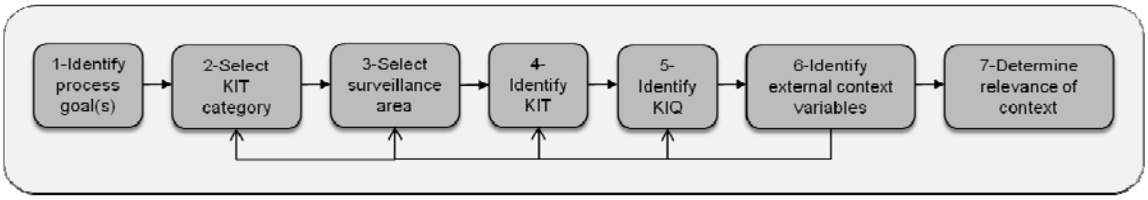

Figure 4. *Procedure for external context elements identification*

Our work focuses on the events that occur external to the process, or ultimately to the organization where it runs, but somehow interfere within this process, provoking some good or bad effects. There are few proposals to categorize this kind of context information. [19] propose the following types of external context: suppliers, capital providers, workforce, partners, customers, lobbies, states, competitors. Based on that, we propose the categories of contextual elements, depicted in Figure 5.

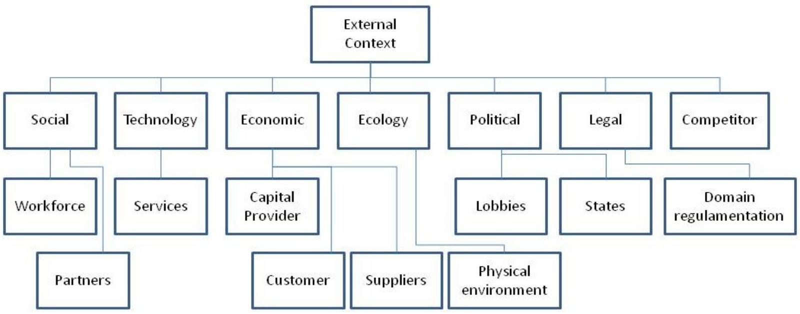

Figure 5. *External Context Categories*

The last step of the method classifies the elements by relevance using data mining (discovering of patterns and evidences). From the potential elements identified in the previous stages, a data mining technique is applied to discover which of them presents the most relevant results concerning their relationships with the business process. The application of specific mining techniques, such as association rules, will provide managers with evidence-based knowledge about in which circumstances the variation of a given external element actually related to the moment in which the process was (or should have been) executed in a different way, thus outputting unpredictable results (or preventing the process to achieve better results) towards its goal. This step requires a log of process activities, and historical data of the external environment elements, thus a preliminary selection of data sources available to collect these elements is mandatory.

3.2. *Model Context*

The next step of the context-aware BPM cycle is building a context model, i.e., to organize and establish adequate relationships among context and the elements of the process. Metamodels define context at an abstract conceptual level, establishing the basis for constructing context models to support system designers in their decisions about which context elements must be considered.

Our proposal is based on [26], who adopted the definition of context proposed by [4] and distinguished between the concepts of contextual element and context: (i) a contextual element is any piece of data or information that allows an entity to be characterized within a domain; and (ii) context is the set of instantiated contextual elements that are needed to support a task performed by an agent (human or software). Additionally, the elements that compose context have a relevant relationship with the task that an agent is performing. Moreover, a contextual element is stable and can be set at designated time, whereas context is dynamic and must be constructed at runtime, when the interaction occurs. [26] metamodel defines the concept of context, but it was not specifically suited for business processes; therefore, it does not make explicit the relationships between the relevant concepts and the domain of a business. Furthermore, in order to use the metamodel in a real domain, it is necessary to extend the concept of contextual element to the specific domain concepts. We argue that the domain model should be built separately for the sake of modularity and to express better the three groups of concepts: context, process and domain.

The fundamental concept adopted here is that context is the set of instantiated and proceduralized (Situation) contextual elements that are necessary to support an activity in a business process. A layered approach provides a conceptualization of the various aspects related to context. Thus, it is possible to isolate the elements belonging to each layer and thereby establish their relationships. Moreover, the modular characteristic of this proposal should facilitate the maintenance and development of the model. An ontology formalism [24], depicted in Figure 6, was adopted to build the conceptual metamodels. Classes are represented by rectangles, and relationships by arrows. This work was reported in details in [11].

The first layer is the **Context Metamodel**, which refers to the elements of context, including the concept of Situation and its relationships with the other classes such as Contextual Element and Focus. The analyst responsible for building this context model should decide how to instantiate the classes depending on the specific environment. The context model, in turn, will be employed for each instance of the process, enabling the relationship between the layers to be determined. This metamodel is based on [25].

The second layer is the **Business Process Metamodel**, which should be taken as a basis for building the process models. Depending on the elements of the business process and of the domain, only a subset of them will be considered relevant to actually be monitored as context. A process model element or a domain element becomes a contextual element if their corresponding classes are extensions of the Contextual Element class. For example, in a specific process, an artifact can be chosen as relevant information to be monitored; thus, the Artifact class will be an extension of the Contextual class for this domain. Therefore, there is a possible inheritance relationship between all elements in the process layer and the Contextual Element in the context layer.

The third layer represents the **Domain Metamodel**, which is responsible for the definition of the data structure, functions, relationships and constraints of the knowledge area. This metamodel specifies the basic concepts required to build a domain model. We adopted a standard Domain Metamodel from the package of classes Foundations|Core of the Unified Modeling Language [23]. This package is the language component that specifies the static structure of the models and contains the sub-packages Core, Extension Mechanisms, and Data Types. Domain models created based on the Domain Metamodel aim to represent the vocabulary and key concepts of a specific knowledge area through the description of the entities, attributes, roles, and relationships involved, as well as restrictions that ensure the integrity of a particular domain.

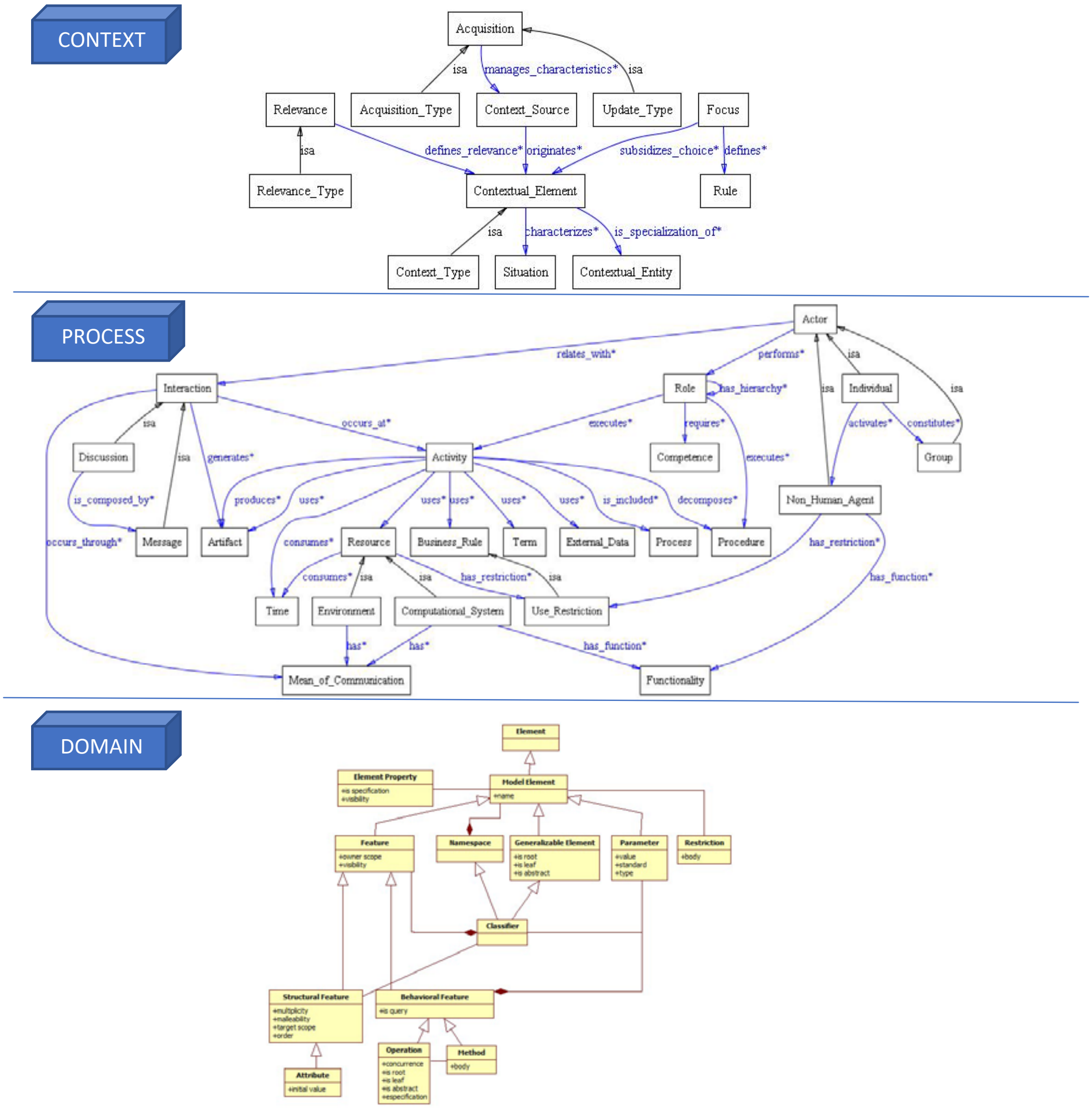

Figure 6. *Layered Metamodel for Context-Aware Business Processes [MAT 2014]*

Relationship among the Metamodel Layers

As mentioned previously, the three layers Context, Business Process and Domain constitute an approach to context-aware business process representation, and therefore, they are linked. In this proposal, the relationships between layers are defined by rules. Rules connecting Context and the Business Process Metamodels are generic, and they define fundamental relationships and constraints between some of their elements. Furthermore, the definition of the rules guarantees that a relationship exists between the models built from the metamodels. The rules are described as follows.

Rule 1 (Formalization of the Relationship between Contextual Element and Situation):

Given CE as the set of contextual elements, for all contextual elements $ce_i \in CE$, where $1 \leq i \leq n$ and $n=|CE|$, a domain (Dom (ce_i)) is associated, indicating the possible values that the contextual element can assume.

Given Dom (ce_i)= $\{d_{i1}, d_{i2}, ..., d_{iMi}\}$, where $M_i=|Dom(ce_i)|$, the set E is defined as the set of all contextual elements with their associated values:

$E= \{ce_1=d_{11}, ..., ce_1=d_{1M1}, ce_2=d_{21}, ..., ce_2=d_{2M2}, ..., ce_n=d_{n1}, ..., ce_n=d_{nMn}\}$

A Situation is defined as a sub-set of E ($S \subseteq E$), where a certain contextual element only appears once.

Rule 2 (Formalization of the Relationship between Focus and Contextual Element):
IF Focus(is_active = True)
AND Contextual Element (name = X)
THEN the Contextual Element instantiated X is associated with Focus

Rule 3 (Formalization of the Relationship between Focus and Activity):
IF Activity (name = A, expected goal = Z, action = L)
AND Focus (is_active = True)
THEN Focus= L.

Rule 4 (Formalization of the Relationship between Contextual Element and Contextual Entity)
IF Contextual Entity (is_charaterized= Active)
AND Contextual Element (name = A)
THEN the Contextual Entity is characterized by Contextual Element A

The first rule relates Contextual Element and Situation. A Situation is a set of values associated with Contextual Elements. The second rule relates Contextual Element and Focus. The Focus provides a reference for the determination of Contextual Elements that must be instantiated to compose the Situation. Thus, if we have the Focus active for a Contextual Element X, then we can assume that this instantiated Contextual Element is associated with the Focus. The third rule relates Focus and Activity. An Activity is a set of actions aimed to achieve one or more goals, hence setting the Focus. Thus, if we have an Activity A, goal Z and action L and the Focus is active, then we can infer that the focus is equal to L. The fourth rule relates Contextual Entity and Contextual Element. A Contextual Entity represents entities to be considered for manipulating context information and is characterized by at least one Contextual Element. Therefore, if we have a Contextual Entity characterized and a Contextual Element occurrence A, then the Contextual Entity is characterized by the Contextual Element A. For example, Contextual Entity = Airport Lane X and a possible Contextual Element = Lane (information about the lane). Thus, the Contextual Entity and Contextual Element are related, and this relationship depends on the Focus, as specified in Rule 2.

3.3. *Gather and Use Context*

Once relevant contextual elements are identified and modeled, the context-aware BPM cycle collects this information from the environment and analyze it to support process adaptation whenever it is necessary. Due to availability of contextual elements and the need for making a decision based on that, an architecture needs to link the capture mechanisms and mediator, namely the role of an aggregator. Thus, we proposed an architecture to manage context and adapt running instances of a process as described in details in [13]. GCAdapt is a Context Management framework for dynamic process adaptation, which provides a central server supporting the whole context management life cycle for dynamic process adaptation integrated to a Process-Aware Information System (PAIS) or Business Process Management System (BMPS). Figure 7 depicts the modules of GCAdapt, which are briefly described as follows.

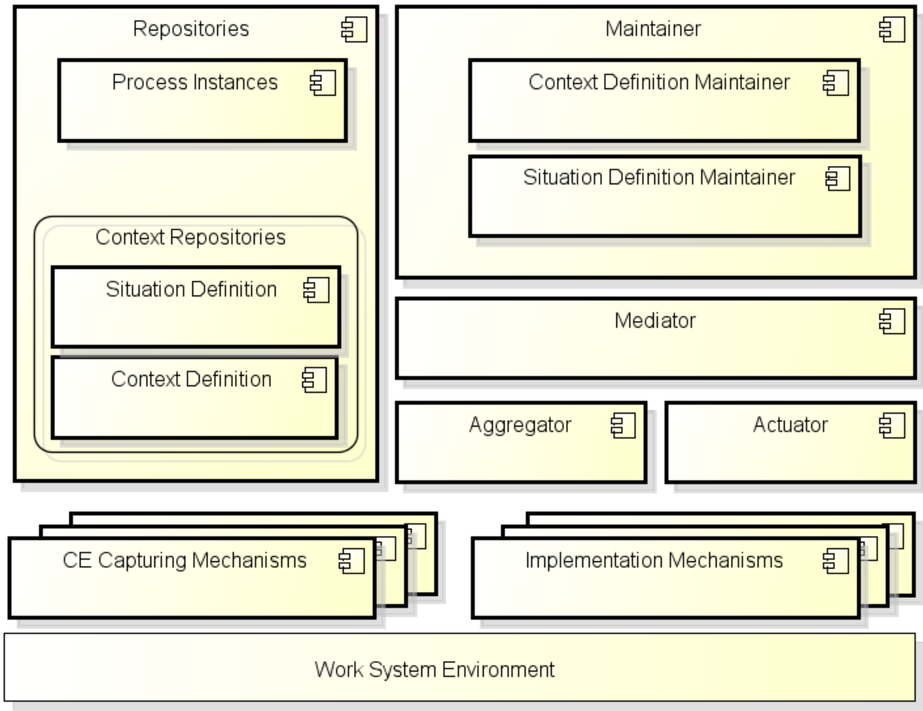

Figure 7. *GCAdapt - Context Management Framework for dynamic process adaptation [NUN 2016]*

CE Capturing Mechanisms: The capture of Contextual Elements (CEs) is directly related to the way they are presented in the environment and how the activity of a process is performed. Manual, semi or fully automatic, "CE Capturing Mechanisms" may capture CE when they occur or after the performance of a task. In the case of manual mechanisms, the capture is purely human where the person who participates in the activity registers relevant information (requested by the PAIS). GCAdapt allows the coupling of different mechanisms to capture CE in different formats and media. By separating how it is acquired from how it is used, GCAdapt can use contextual elements without to suppress the details of a sensor (agent, service, any software or hardware component able to collect contextual elements) and how to acquire context from it. CE Capturing Mechanism also transforms raw data into interpretable data by GCAdapt.

Maintainer manages **CE** and **Situation** definitions. The "Context Definition Maintainer" is responsible for continuously maintaining CE definitions updated. It involves identifying context model evolution by adding / changing / deleting CE and relationships among them. The "Situation Definition Maintainer" is responsible for continuously maintaining (and storing in the Situation Definition Repository) Situation rules updated. The Context Repositories manages the storage of the context model as well as the Situation rules associated with the actions performed while the process is running. It also stores the context model, which contains the description of the internal structure that states how this information is stored.

Mediator identifies the need for adaptation when a **Situation,** that will not lead the process instance to achieve its goal or into its best performance**,** occurs. It uses intelligent behavior and decision-making support skills. It is responsible for identifying possible adaptations during at runtime, when they should be performed and the impact in relation to **goals**. When re-planning process instance, Mediator tries to fulfill goals and satisfy preferences planning actions as its best achievement. It may find more than one possible adaptation, each of satisfying goals in different degrees.

A Situation, which is activated in the context model, represents what has changed within the organizational work system (i.e., process and process elements - systems, people, organization and outside data). We represent it in terms of Event-Condition-Action (ECA) rules:

IF Situation S_i is activated

THEN Act on representing the changing in the work system representation (domain and problem).

It reasons over the new representation of the current state of the work system in order to continue satisfying the goals at best.

IF work system representation has changed

THEN Replan process instance and adapt

Aggregator receives a collection of CEs and activate Situations, through the use of Situation Rules (see context metamodel). Identified Situations during process instance execution are stored in the Log Repository for future process learning. Aggregation can be seen as a middleware between the capturing mechanisms and the Mediator.

Actuator receives the decisions taken by the Mediator, and triggers adaptations in the **process instance** through the **implementation mechanisms**. It is responsible for automatic process adaptation based on the results sent by the Mediator. It involves sending commands to PAIS to perform the necessary adjustment to change the process instance. Actuator may also present change needs and adaptation possibilities to the process manager if it is his/her responsibility to make the decision and manually perform the necessary adaptations. The Implementation Mechanisms, either from the PAIS or from the environment, are responsible for the implementation of the necessary changes.

The technologies chosen for this implementation were SAPA (planner) and YAWL (PAIS). SAPA was selected because of its great achievements in the AIPS 2002[1,2] Planning Competition and because it was considered stable during the studies of a number of Planners in this thesis. YAWL is a widely used PAIS on Academia and is implemented in a service-oriented way that already offer interfaces for developers to implement external services that communicate with the YAWL workflow engine. YAWL[3] is a PAIS that supports the workflow language also named YAWL (Yet Another Workflow Language) based on workflow patterns[4]. It supports dynamic process adaptation through the so-called worklets. Worklets are self-contained process models that might be called as compensatory processes to run independently of the process instance, or might replace, or postpone some activity. Currently it enables adaptation at design time, by deviation at runtime (through the Exception service), by underspecification (late specification and late selection through the Selection service), and by change.

GCAdapt Mediator module was implemented on top of the YAWL, coupled to Aggregator and Actuator as a unique service. YAWL handles dynamic exceptions through self-contained processes associated to rules (named worklets). For each exception that can be anticipated, it is possible to define an exception handling process, which includes exception handling primitives (for removing, suspending, continuing, completing, failing and restarting a workitem) and one or more compensatory processes (i.e., worklets, executed as a replacement for a workitem or as compensatory processes). When a task is enabled, a choice may be taken from the worklets repertoire based on the contextual data values within the task, using a set of ripple-down rules to determine the most appropriate substitution. The task is checked out of the YAWL engine, the corresponding data inputs of the original task are mapped to the inputs of the worklet, and the selected worklet is launched as a separate case. When the worklet has completed, its output data are mapped back to the original task, which is then checked back into the engine, allowing the original process to continue.

[1] http://ipc.icaps-conference.org/

[2] http://rakaposhi.eas.asu.edu/sapa.html/

[3] http://www.yawlfoundation.org/

[4] http://www.workflowpatterns.com/

Figure 8 depicts the integration among a PAIS, the GCAdapt modules and the Planner.

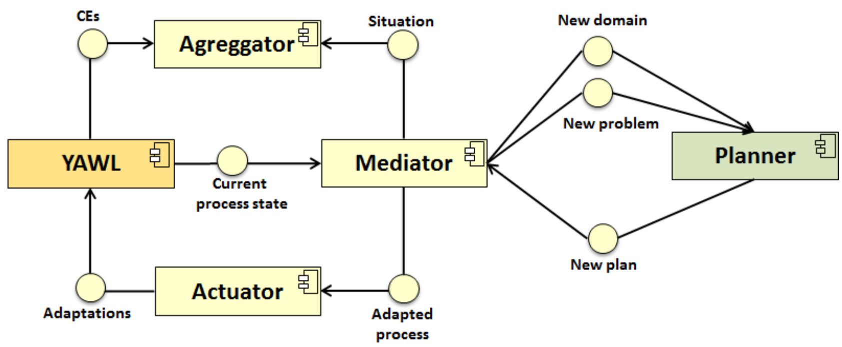

Figure 8. *General Architecture for the association among PAIS, GCAdapt main modules and Planner*

SAPA is a domain–independent JAVA forward chaining planner, which can handle durative actions, metric resource constraints and goals. SAPA can handle PDDL 2.1, Level 3. The Mediator implementation includes: (i) Routines to parse the domain and problem XML files defined from PAIS process, variant, goals and constraints definitions, to PDDL files. A pattern from Business Process Management Notation (BPMN) to domain and problem XML representation was developed; (ii) The interface with SAPA Planner; (iii) Changes in the output file to represent the new plan; (iv) The interface with YAWL worklet methods to run the available adaptation actions.

3.4. *Maintain Context*

Context could be highly dynamic, i.e., it could change over time, situations and adaptation rules become obsolete over time. So, the evolution of the Situation and Context Rules should be checked, and the Context Model should evolve continuously. Thus, for the next step of the context-aware BPM cycle, we proposed a method, detailed in [CAR 2015], to maintain the context model updated continuously. It aims to (i) suggest new situations; (ii) indicate the need for changes in the adaptation rules; and (iii) point to the need to identify new contextual elements. Since the process is automated, it is essential that the system log stores the information about all process instances. It is necessary also to store situations that take place during the activities and the adaptation rules eventually applied to address them.

As stated before, one of the premises of this proposal is the existence of a repository with information about the process instances that are running (the process log). This repository will be established through the log generated by the PAIS or BPMS, and should consist of:

– **Process**: name and identification;

– **Process Instance**: execution date, goal achieved and actors involved;

– **Objective**: description of the goals associated with the process;

– **Goal**: description of the objective broken down in goals;

– **Activity**: each activity that composes the process, including name and point to the next one to be executed in the sequence;

– **Situation**: description of the situation in terms of contextual elements that composes it, identified and related to each activity of the process;

– **Contextual Element**: name, capturing mechanism, period of time to collect data about it and possible values that it can assume (its domain);

– **Adaptation Rule**: description of actions to be taken to address a situation associated to it; when the situation is removed, the related adaptation rule no longer exists either;

– **Activity Instance**: information of each activity performed, such as, time stamp, resource; besides it should be related to any situation that might have occurred during its execution and the adaptation rule applied.

The main steps of the method are depicted in Figure 9. A statistical analysis of instances of activities is made in order to identify cases in which the goal of the process was not reached. If the percentage of cases that did not have their results aligned with the goals is greater than a parameter previously stipulated by specialists, then there is a need to determine the potential reason for the problem. We apply the Apriori algorithm [1] to provide suggestions on the need to define new situations or adaptation rules. Two scenarios compose the solution:

– Scenario A: Suggest new situations and update the situations' database or Indicate the need for changes in the adaptation rules;

– Scenario B: Indicate the need to identify new contextual elements.

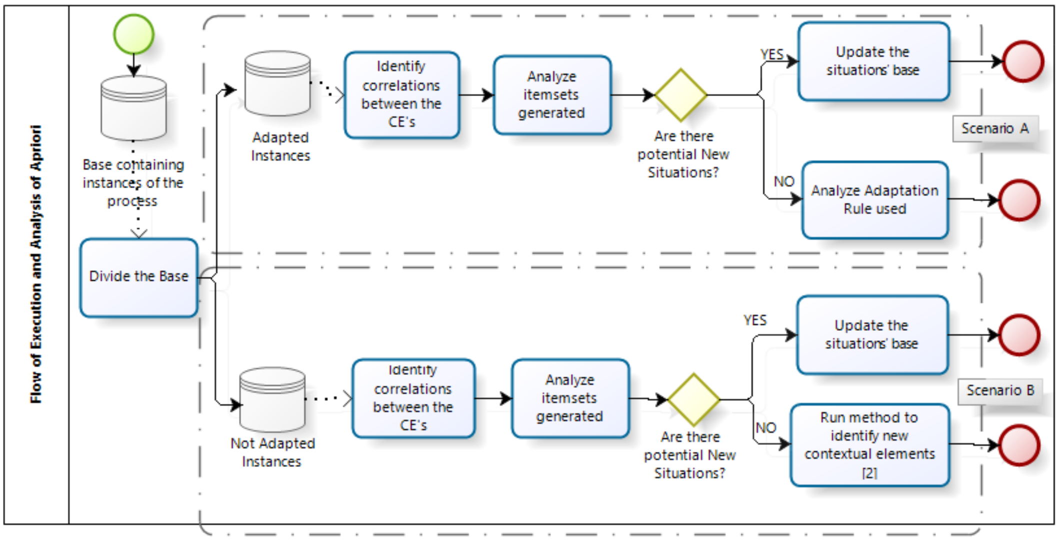

Figure 9. *Method Steps [CAR 2015]*

The data extraction should be performed over time, in a period defined by specialists. The goal is to ensure that the context model is always updated, by examining continuously the relevance of predefined situations and adaptation rules. It should be applied in two different conditions: (i) adapted instances. After that, in both conditions, an analysis of the itemsets generated by Apriori must be taken to identify those ones that have at least one contextual element with a non-default value and is not part of a pre-defined situation; these itemsets are strong candidates to explain a new situation. The default value of a contextual element is one that normally allows the process achieving its goal. So, any contextual element that takes a value different from the default may compromise the outcome of the process thus making it a candidate to define a new situation.

Among the instances that have been adapted at runtime, i.e., which suffered interference from a situation and thus an adaptation rule was applied, there are the following subdivisions:

A. Apply the algorithm to all these instances adapted, regardless which rule was applied, but choose only those ones that have not reached the goal of the process;
B. Apply the algorithm for each set of instances in which a given rule was applied, but choose only those ones that have not reached the goal of the process;
C. Apply the algorithm to all these instances adapted, regardless the rule applied and regardless the result of its application;
D. Apply the algorithm for each set of instances in which a given rule was applied, regardless the result of its application.

Among the instances that have not undergone any adaptation at runtime, since no situation was identified during execution there are the following subdivisions:

E. Apply the algorithm to all these not adapted instances, but choose only those ones that have not reached the goal of the process;
F. Apply the algorithm for all these not adapted instances, regardless the result.

The method should be run periodically to capture and analyze each of the two likely scenarios that may have occurred among process instances in the log. However, the implementation of the method does not need to be performed for each new instance. This periodicity is more related to the tolerance to the occurrence of instances that have not reached the goal within the set of all instances already executed, and should be determined by the analyst in charge of the process.

3.5. *Results from evaluations*

Each part of the Context-Aware BPM proposal was evaluated, and the results can be found in: [16][2][11][6][13]. We summarize here one of the evaluations made involving the broad proposal. We made a case study in order to collect evidences about the ability of the proposal to identify relevant context and adapt the process whenever necessary.

The case study was developed in the domain of the Air Traffic Control (ATC), more specifically the Takeoff process which is a knowledge-intensive process affected by many contextual elements. ATC is a service provided by ground controllers to guide and monitor aircraft in the air and on the ground to ensure a safe and organized traffic flow. Air traffic controllers provide indications and authorizations, regarding things like route, altitude and/or speed, to fly in accordance with the aircraft operating characteristics and traffic conditions. Pilots must comply with the instructions and authorizations received. ATC aims to guarantee everybody's safety, speed up aircraft deployment, preventing delays and reducing operating costs for users. The process applies to aerodromes that have a control tower, which constitutes most flights conducted in Brazilian airspace.

The original flow of activities in the Aircraft Takeoff process can be found in [12]. The takeoff process starts with the filling and submission of the flight plan. The flight plan is analyzed, authorized and ground procedures are performed so as the aircraft is put in position and finally can take off. A sample of real data regarding instances of the Aircraft Takeoff Process was used to define some of the situations. The process goal is: "guarantee passengers and staff safety in all flight stages; Optimize ground time, which involves reducing ground time (preventing delays) and operational costs in a co-related cost benefit".

Data related to process execution were extracted from daily reports released by the Center for Management of Air Navigation (CGNA). CGNA centralizes information regarding the operational components of the infrastructure needed to manage the use of airspace in Brazil. By managing this information, CGNA can monitor the status of SISCEAB (Brazilian Airspace Control System) to eliminate or reduce uncertainty in decision making and planning in the short, medium and long terms. It is also responsible, in conjunction with the Brazilian Airport Infrastructure Company (Infraero), for the analysis of intentions to fly in Brazilian airspace.

The daily report, which aims to support the evaluation of the quality of services provided, generates indicators for aeronautical infrastructure planning and presents wide-ranging information, including rates of flight delays, weather conditions at airports, adverse weather conditions, airport infrastructure (inoperativeness of technical equipment, problems on runways), flow management measures and other occurrences. These reports provided a rich amount of information, which has allowed us to explore the Contextual Elements (CE) and to define the Situations. The reports were collected from a period of six months (June to December 2011). CEs, Situations and the corresponding possible adaptations (called process worklets) were modeled with the help of a professional who works with specialized systems at the Brazilian Airspace Control System.

According to our proposal, first it was necessary to discover (Section 3.1) and model (Section 3.2) context. We applied the method described in Section 3.1 to discover which were the relevant contextual elements in that scenario. The interviews and validations were made with domain experts (pilots and controllers). The context-modeling step requires also to include the Situations (combination of contextual elements, see Section 3.2).

So, the Situations should be defined and then the adaptation needs for all of them should be specified, and finally, implement those mechanisms in a PAIS. From the validated model and the CE domain model [11], situations and process components were identified and validated with the modeling analysts. Several CE that could possibly affect the process were identified, such as "RainfallLevelDestination" and "MeteorologicalStatus". The combination of them provided the model with nine Situations. For example, Situation 1 is described as follows.

Situation S1: Unfavorable meteorological condition: After the execution of activity "Allow flight plan" a situation is triggered indicating that a situation related to the flow management is occurring.

S1 = {"Fill fight plan" activity status = completed,
Amount of rain fall in destination (RainfallLevelDestination) = high,
Meteorological Status = unfavorable}

As described in Section 3.3, for each Situation, a plan for adaptation should be defined. Since we implemented our proposal in YAWL, the way to do this is creating the so-called process worklets. They will be invoked any time the process is re-planed, i.e., an adaptation is applied. For example, Situation S1 configures that it is raining over an accepted limit in the destination of the flight, and besides, at the same time the status provided by the meteorological service is not favorable for a flight. When these two elements occur, there is an indication to adapt the process. Situations were analyzed and a total of 7 process components (YAWL worklets) were created. Process component PC_04 is shown in Figure 10.

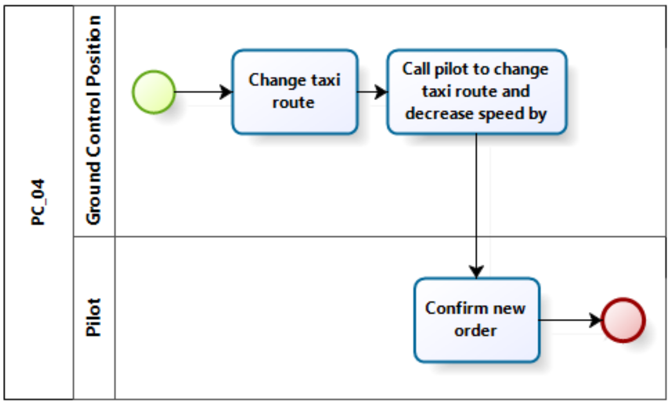

Figure 10. *Air traffic takeoff Process - BPMN designed Process Component PC_04 [NUN 2016]*

The methods used to evaluate the proposal as well as the results are discussed accordingly to the three research questions, described as follows.

Research Question 1: Was GCAdapt able to adapt the process correctly?

Five process instances (tests) were randomly created, and for each adaptation the new process model was analyzed. In test #1, right before executing "Transmit flight plan", the element that states the status of the communicator is set to false for uhf and true to telephone (uhf = false, telephone = true). Situation S09 was activated and PC_07 activated to be executed. PC_07 instance was activated in YAWL engine as shown in Figure 11 (process instances 75 – default process and 76 – PC_07).

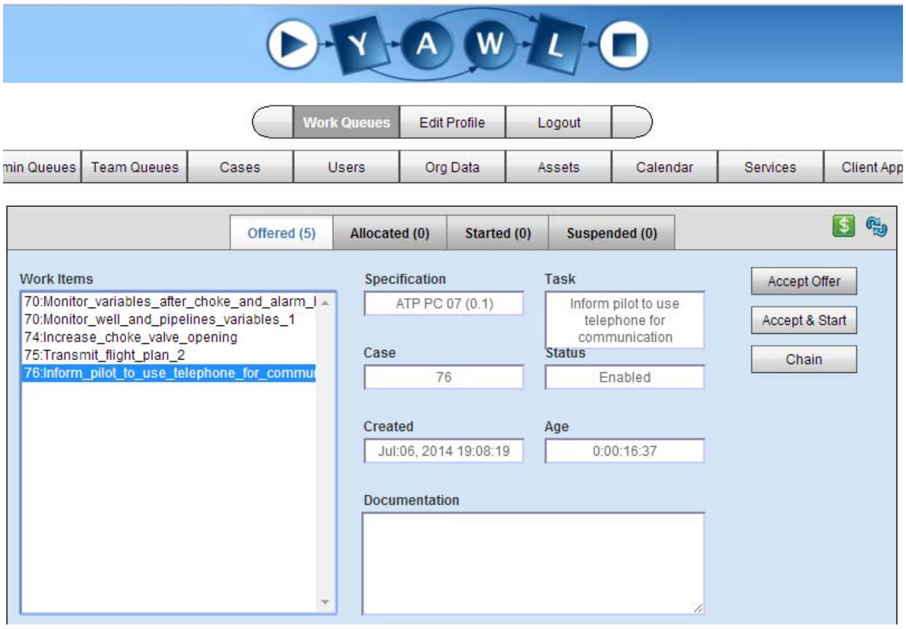

Figure 11. *Aircraft takeoff process instance – Test #1 [NUN 2016]*

Service log shows that right before the execution of "Transmit flight plan", the problem file is updated with the process and process adaptation planning starts. SAPA is executed and searches for a solution. The process new plan is presented and the first activity (transmit_flight_plan) passes the calling of worklet PC_07 as a condition that enables the worklet (a compensatory process "Inform_pilot_to_use_telephone_for_communication").

All 5 tests worked properly. The correct worklets were enacted as soon as the plan definition called them, considering that all adaptations were to be executed right after situations that triggered them were activated. Based on these observations, we concluded that the prototype correctly activated the adaptations and the instances ran until the completion without errors.

An interview with four domain specialists (pilots) was conducted in order to evaluate questions 2 and 3. The questions were related to (i) the possible actions they would choose for the Situations; and (ii) their opinion about the approach as a whole and the support of information they have in order to take decisions on the fly.

Research Question 2: Were the adapted instances more adherent to current demands (the goals) than the standard process would be?

The specialists (pilots) analyzed the nine Situations and 4 possible actions to react to them. Table 1 summarizes GCAdapt decisions as well as the answer of the 4 pilots that participated in the study (none of the pilots participated in the definition of the process, situations and possible adaptations).

In general, the specialists chose one of the adaptations previously modeled. The exception was in Situations 2 and 3, because of an overall aspect cited by all of them related to the fact that the number of significant "factors" (i.e., the CEs) to decide what to do is innumerous. But they all agreed with the actions chosen by the Mediator. In Situation 2, the pilot said that it would depend on the equipment and its importance for the flight mission. In Situation 3, all three military pilots said that it would not affect the mission (i.e., the flight) because in military aviation that would not be a reason to change flight plan and they would proceed normally.

S	Activated actions	P2	P3	P4	Correlated answers
S1	c	b, c, e	b, c, d	C	c
S2	c	b	b, d	B	e
S3	c	c	a	A	a
S4	c	c	c	C	e
S5	b	b, c	b, c	B	b, d
S6	c	a, c	c	B	c
S7	b	b	b, c	B	c
S8	c	d	c, e, f	C	f
S9	c	c	b, d	B	c

Table 1. *Aircraft takeoff process – Questionnaire of Situations*

Pilot P1 reported that a great amount of information as type of mission (commercial or military), distance from destination, destination airport infrastructure, aircraft technology, flight security parameters, etc. are data to be taken in account when reasoning over all the Situations described. Pilots P2, P3 and P4 also reported the same influences.

Pilot P3 observed that to understand the research conducted, situations were correctly elicited, and adaptations apply. But he stated that realistically speaking, decisions are made based on a much more complex combination of information. Pilots P1 and P2 also commented on the fact that not all possible "events" (e.g., situations) can be predicted in advance, even though the problems that arise by the combination of all CE´s are known. In order words, P1 stated that all the problems may be known but not all the possible Situations that characterize their occurrence. Pilot P3 said that it could be obtained from flight reports and incident/accident reports elaborated by the pilot for every flight (which is done manually by a special department). Pilots' opinions met our requirements for a context management mechanism for process adaptations purposes. Learning from previous process executions is indeed primordial for maintaining and improving the quality of the reasoning mechanism.

During the interviews, it was explained that the GCAdapt approach aims at learning from the takeoff procedure executions already performed to improve reasoning by understanding what situations trigger nonstandard actions. They argued that it is of high relevance in order to rely on a system with these purposes. From the pilots' viewpoint, it is feasible to perform computational reasoning based on the monitoring of contextual elements. But "this system" needs to have a very high level of confidence, because "we deal with people´s lives in a very complex environment". P3, who flies in an aircraft with the highest technology among the four pilots, mentioned that he has access to a system that shows information classified in warning, caution and advisory, and the information is revealed at an appropriate time so as not to influence the pilot in taking decisions about things that are not relevant. This system shows information but it is the pilot responsibility to reason over it. He also mentioned that there have been a lot of tests with Unmanned Aerial Vehicle (UAV) and scientists say this is the future of aviation. Pilots are increasingly becoming a system other than "only command flight operations". Based on these observations, it is possible to infer that the approach is feasible.

Research Question 3: Is the process representation (process and variations separately) within the proposed approach more efficient than the conventional one contained in a unique model?

In the study, from the pilots' viewpoint, the number of elements (CE) and combinations of values are numerous and result in different Situations that can lead to different reactions. Table 2 summarizes the answers from pilots when questioned about the benefits of using an intelligent system to help taking actions during unexpected situations. Note that there are benefits related to the process of aircraft takeoff to which pilots have assigned scores from 1 to 5 (1 – strongly disagree, 2- partially disagree, 3 – impartial, 4 – partially agree, 5 – strongly agree).

All pilots agreed with the potential of GCAdapt approach. Pilot P1 disagreed with the topic of disseminating information among participants of the process, because he flies commercial flights and due to commercial interests, some decisions are not usually in the pilots' hands. The others are military pilots that, by the Army laws, have total power of decisions over a flight operation. In pilots P1 point of view, being aware of information he has no managerial power might lead to a sense of frustration. The specialists also saw benefits in maintaining a "clean" default process with standard procedures and having access to exceptional procedures/activities in a separate way, although all of them were unanimous about the timing to have access to information over situations and possible reactions. Since this is a high-risk procedure, pilots cannot lose focus of the main tasks in order to safely takeoff aircrafts.

Based on these observations, it was considered that GCAdapt approach might bring more benefits not only in the interpretation of standard processes and possible adaptations, but also in the reaction to unexpected situations. The prototype decides over possible adaptations in a reasonable time that could enhance the chances of the process to keep aligned to its goals.

Benefits	P1	P2	P3	P4
Decrease in time perception of unexpected events	4	4	5	5
Dissemination of information to all participants of the takeoff procedure	1	3	5	5
Decision making and suggestion of actions to react to unexpected events	5	5	5	5
Maintenance of standard process documentation, simple, easy to understand. Independently representation of different (re)actions to be taken depending on the Situation.	5	4	5	5
Learning based on previous takeoff over actions related to unexpected events and the outcome of the takeoff procedure in order to improve computational reasoning.	5	5	5	5

Table 2. *Aircraft takeoff process – Questionnaire answers*

4. Lessons Learned and Research Agenda

The results reported in this paper are the long-term research that allowed for the proposal of a Context-Aware BPM approach aligned with the BPM lifecycle broadly adopted in literature. Our main contributions rely twofold: first the conceptual solution that establishes clear relationships among context and business process with a strong theoretical foundation; and second, the technical solution proposed, a framework which addresses context management (capturing, analyzing context and adapting the running instance, as well as taking care of context model evolvement) integrated within a Process-Aware Information System.

Moreover, we argue that our proposal extends current business process modeling techniques of in order to identify contextual elements that impact on business processes. An important challenge faced by context-aware business process is to decide which context elements are relevant enough to be considered in the adaptation of the process. This paper advances the notion of internal context by suggesting that the process model by itself is able to provide sources to elicit the relevant contextual elements. In this sense, the context metamodel plays the fundamental role, not only to guide the definition of context, but also to provide a conceptual foundation to support the business analysts.

The results from case studies allowed us to observe the effects of the absence of the element Relevance. Relevance is the level of importance of a contextual element in relation to the Focus. The effects of the element's absence were made evident when experts indicated the importance of considering the weights of each Contextual Element to make better decisions about the Situation. This finding brings us to the issue of which other elements of the metamodel context may also be relevant as components of the proposed approach and are not yet being considered as components of the context model. Two concepts to consider are Focus and Context Entity. Because the Focus determines what can be considered relevant in a context, it might be explored in conjunction with Relevance to establish more precise situations. In addition, Contextual Entity, for which information is provided by contextual elements, can be applied to help characterize situations, which in turn facilitate decision making regarding the course of a process.

We also started a discussion on the relationship between process goal and its contextual elements, which plays a fundamental link to study proposals for flexible business processes. One important assumption of our proposal is that process goals are formally defined. However, we understand that the lack of an explicit formalization of the business process goal can be a common situation in companies, resulting in additional work when applying our approach. It would invalidate the assessment of the implications of an attribute variation on the process. Even though in our proposal we have defined the concept of variation, it could be more precisely defined on the metamodel.

Future work includes: (i) The evolution of GCAdapt into a multi-agent paradigm; (ii) The design of Aggregator module so as to treat CEs captured in the environment and discover (more complex) contextual elements by analyzing multiple CEs values and trends considering a time variation; and (iii) The use of mining techniques in a goal-oriented approach to discover new CEs. We also aim to apply and evaluate the proposal in other scenarios, in order to confirm and further validate our findings.

Another line of research that can be developed from this work is support decision making for process improvements. We can examine the instances that have suffered interference of situations and determine whether such interference is frequent enough to justify a definite change in the process model, rather than just adapting a specific instance to achieve a local goal. Besides, another important investigation to be taken is the decision problems due to the situations overlapping.

One point that should also be considered in our research agenda is how to address the contextual element issues in knowledge-intensive processes (KIP). Even though they cannot be captured by structured process models, such as the ones we deal with here, KIP are still considered to be processes because individual tasks need to be coordinated, performed by process participants using organizational resources. However, the coordination patterns, even the tasks themselves often evolve, as the work progresses. In this context, the concept of context also becomes highly dynamic and evolving and furthermore many other elements should be considered. The first steps in this direction could be understood in [18].

5. Concluding remarks

Complexity and dynamism of day-to-day activities are inextricably linked, thus the need for constant adaptation in business processes to address emerging demands has grown. In this scenario, context is a key concept to deal with flexibility in Business Process Management. Context-awareness is a paradigm of BPM that deals with dynamic business process environments, in which processes need to be rapidly changed and adapted to changes under a certain context.

Most research efforts to use context in BPM are limited to the analysis of user information, devices and environment. The motivation of our proposal is the focus on the use of context to adapt business processes. Thus, our main contribution is an approach that is more comprehensive and flexible and that can be applied in any domain and process of an organization.

The proposal goes from conceptualization to implementation of such notion. The approach proposed here is to deal with relevant variations as "context" and address them adapting the process in real time when they occur. In addition, the domain in which it is applied is constantly maintained through the establishment of specific concepts, data structures, functions, properties, rules and constraints. Also, we implemented a systematic support for capture, storage and reasoning of situations that arise while process instances are performed, in order to identify adaptation needs addressing organization's goals, and to create a body of knowledge about the organizations processes.

This work has implications for research and practice. For industry application, we expect that an approach for a context-aware BPM can improve BPM initiatives and their challenges within organizations. Moreover, we claim that the notion of context enables companies and groups to understand the way agents address goals aligned with a holistic view of business. For the research perspective, we argue that each part of the approach could be used for further developments: the context metamodel could be extended and the mechanisms for adaptation could be improved and other techniques could be evaluated. The approach could be used in other domains and scenarios.

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