DYNAMIC PROCESS ADAPTATION: PLANNING IN A CONTEXT-AWARE APPROACH

Vanessa Tavares Nunes

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Orientador(es): Cláudia Maria Lima Werner
Flávia Maria Santoro

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DYNAMIC PROCESS ADAPTATION: PLANNING IN A CONTEXT-AWARE APPROACH

Vanessa Tavares Nunes

Agosto/2014

Orientadores: Cláudia Maria Lima Werner
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Programa: Engenharia de Sistemas e Computação

A complexidade e dinamismo das atividades do dia-a-dia estão intimamente ligados, aumentando a necessidade de adaptações constantes na forma de organizar o trabalho para atender a demandas emergentes. Adaptação de processos é o ato de customizar um processo para torná-lo aplicável a uma situação específica. Entretanto, situações não planejadas podem ocorrer a qualquer momento durante a execução de um processo. Portanto, a concepção de um modelo de processo completo, que prevê todas as possibilidades de situações que podem ocorrer, deu lugar a uma modelagem mais flexível ou "orgânica", baseada em reúso e adaptação. Esta tese aborda o problema de como fornecer mecanismos para a adaptação dinâmica de processos em sistemas de informação orientados por processos (PAIS). A abordagem proposta foi construída tendo como base o conceito de contexto e planejamento em Inteligência Artificial. Fundamentando-se em uma teoria para sistemas de informação sensíveis a contexto, argumenta-se que uma situação pode ser caracterizada por uma série de elementos contextuais e deve orientar a tarefa de replanejar o fluxo da instância de um processo, a fim de mantê-lo alinhado aos objetivos pretendidos.

Abstract of Thesis presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Doctor of Science (D.Sc.)

DYNAMIC PROCESS ADAPTATION: PLANNING IN A CONTEXT-AWARE APPROACH

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Complexity and dynamism of day-to-day activities are inextricably linked, thus the need for constant adaptation of the way to organize work to address emerging demands has grown. Process adaptation is the action of customizing a process instance to make it applicable to a particular situation. However, unplanned conditions may occur at any time during process execution. So, the design of a complete process model, predicting all possibilities that might occur, has given place to a more flexible or "organic" design based on reuse and adaptation. This thesis addresses the problem of how to provide mechanisms for dynamic adaptation in a Process-Aware Information System (PAIS). The proposed approach is constructed under the concept of context and planning from the Artificial Intelligence field. On top of a theory for context-aware information systems, it is argued that a situation can be characterized by a number of contextual elements and should guide the task of re-planning the flow of the process in a specific instance, in order to keep the intended goals.

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1. INTRODUCTION

1.1. Motivation

“A major challenge faced by organizations in today’s environment is to transform ideas and concepts into products and services at an ever-increasing pace” (DUMAS *et al.*, 2005). The institutionalization of process-oriented approaches is already a reality and there is a consensus that managing processes in general (at different levels of abstraction) is essential for an organization´s performance (SHARP and MCDERMOTT, 2001).

According to WESKE (2007), business processes represent a set of activities performed in a coordinated/collaborative manner in an (multi) organizational and technical environment towards a business goal. So, business processes are the key instrument to organize these activities and to improve the understanding of their interrelationships and the impact among them (DUMAS *et al.*, 2005). Along with this, AALST (2009) discusses that information technology (IT) has changed business process within and between enterprises in the sense that work processes are increasingly being conducted under the supervision of information systems, which are themselves driven by process models. Technologies that aim to ensure the enactment of business processes are called Process-Aware Information System (PAIS), which can be defined as “a software system that manages and executes operational processes involving people, applications, and information sources on the basis of process models" (DUMAS *et al.*, 2005). Examples of such systems include ERPs (Enterprise Resource Planning systems), BPMS (Business Process Management Systems) and WFMS (Workflow Management Systems).

PAIS are becoming pervasive in the business environment, and the system focus has shifted from the data-driven approaches to a more holistic notion of a business process (LA ROSA, 2009). In this scenario, due to the fact that complexity and dynamism of day-to-day activities are inextricably linked, the need for constant adaptation of the way to organize work, through its processes, to address emerging demands has grown. Process adaptation is the action of customizing a process instance to make it applicable to a particular situation. It requires experience and involves knowledge about various aspects of the business such as environment, people, used technologies, the organization itself, and external aspects. Therefore, the identification of possible adaptations by humans (i.e., adaptation on flow, roles, information, resources, etc.) within a process instance to address specific situations occurring at a certain moment is not a trivial task.

On the other hand, there are limitations regarding the support for automatic decision-making in dynamic process adaptation, because unplanned conditions may occur at any time during process execution. So, the design of a complete process model, predicting all possibilities that might occur, has given place to a more flexible or "organic" design based on reuse and adaptation (DUMAS *et al.*, 2005). In practice, business processes do not exist only under a single version which covers all the issues of the whole market. Instead, many variants of a process may exist within the same enterprise in order to deal with different business situations, such as: targeting different customer types, relying on particular IT systems or complying with specific regulations.

Furthermore, according to BIDER (2005), it is possible to predict up to 90% of the situations that may happen, but not 100%, i.e., we cannot predict everything that can occur during process execution at design time, as new circumstances and events arise, changing its scenario. Certain events cannot be expected since they are associated with events whose impact on the process has not been analyzed and identified yet.

Also, describing all possible paths in a process model can harm its understanding and its stability due to the high degree of complexity and changes required (BIDER, 2005, KUMAR and NARASIPURAM, 2006). So, an important aspect of the flexibility strategies is the ability to react to situations that may occur during runtime by dynamically adapting the process.

Another important aspect about process adaptation is that, in highly dynamic and complex environments that require immediate adaptation, a fully human intervention is no longer acceptable due to the fact that business processes can be very large and complex and there are thousands of concurrently process instances in execution simultaneously. In this scenario it has been observed that a representation that effectively support dynamic process adaptation is still a challenge and is still been incorporated through the use of static adaptation rules.

1.2. Thesis Statement

Dynamic process adaptation occurs cyclically, basically in four stages (Figure 1.1) (ROSEMANN *et al.*, 2008, LA ROSA, 2009, MEJIA BERNAL *et al.*, 2010):

i. Identify the situation that demands adaptation: understand what is happening in the environment that causes adaptation needs.
ii. Identify opportunities for adaptation and associated impacts: define which process elements need and can be adapted and the impact of that change on the work environment.

iii. Redesign the process instance: change the process instance (the non-executed part of the process instance) to contemplate the set of changes.

iv. Implement the changes: modify the existing infrastructure to adapt to process instance changes.

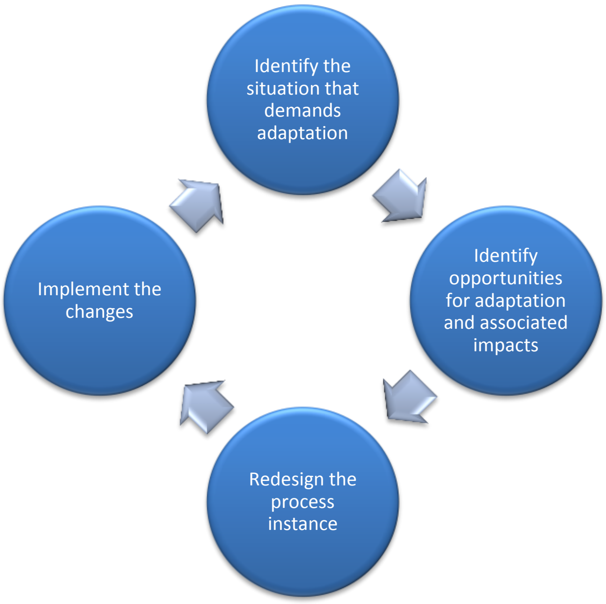

Figure 1.1 - Dynamic process adaptation stages

The ability to analyze and make dynamic adaptations in processes can be translated into procedures and technologies to detect changes in process instances without compromising their execution, support the effective and necessary changes and reduce associated costs (MEJIA BERNAL *et al.*, 2010), besides supporting the maintenance of product quality generated. In other words, in dynamic environments it must be possible to quickly implement new business processes, to enable deviations and adaptations on-demand by dynamically adding, deleting or moving process parts (i.e., activities, roles, information etc) and to support dynamic process evolution (i.e., to propagate process schema changes to already running process instances).

SNOWDON *et al.* (2007) and JABLONSKY and AALST (2000) highlighted that there may be a large number and variety of information that requires flexibility, involving questions such as: What may cause the need to adapt a process?; What needs to be adapted?; What are the possible adaptations?; and When is it possible or viable to accomplish them?;

This research thesis argues that the concept of context (BRÉZILLON, 1999) appears as a pointer to distinguish among the available information during the execution of a process, those that are relevant in order to provide inputs for the analysis of the process instance adequacy to a current situation, addressing organizations goals and strategy. Through context analysis, it is possible to assess the occurrence of situations that characterize the need for process instance progress.

Considering context reasoning for these purposes, an approach to the dynamic process adaptation problem is to conceive it as an Artificial Intelligence planning task. This enables us to bring to bear many of the theoretical and computational advances for reasoning on process flexibility in a more dynamic basis.

So, the problem addressed by this research is: how to provide mechanisms for dynamic adaptation in process-aware information systems? The approach proposed is constructed under the concept of context and planning from the Artificial Intelligence field. On the top of a theory for context-aware information systems (PLOESSER, 2013), we argue that a situation can be characterized by a number of contextual elements and should guide the task of re-planning the path of the process in a specific instance, in order to keep alignment to desired goals.

1.3. Goals

Given computer-interpretable descriptions of processes to be performed, the properties and capabilities of available process components, and definition of information about the organizational context, the goals of this thesis is to provide an automated solution for dynamic process adaptation that helps to improve process achievements while respecting existing constraints.

This thesis aims to implement a solution for dynamic process adaptation trough GCAdapt, an infrastructure that:

- independently of the PAIS platform, is able to access contextual elements, identify situations, associate them to activities in execution, reason over possible adaptations, implements them and access results so as to improve reasoning mechanisms;
- improves context-awareness by attaining it to existing definitions of organizational domain without the additional effort and cost to define (and maintain) static adaptation rules;
- improves context-awareness by attaining it to organizational current expectations (goals and desires);
- handles unexpected situations at runtime instead of analyzing all possible situations at design time and embedding the corresponding adapted activities in the business process, it decreases process model maintenance and optimize process evolution of non-recurrent actions to be added in order to support adaptations;

- generates possible other future works proposed and discussed hereinafter in this manuscript.

1.4. Research Methodology

This research is based on the Design Science paradigm (HEVNER and CHATTERJEE 2010, HEVNER *et al.*, 2004) which is fundamentally a problem solving paradigm, where artifacts developed with the intention of solving organizational problems are created and evaluated.

In this sense, the methodology used in this thesis is shown in Figure 1.2. The conduction of this research aimed to continually identify their viability through the use of simple assessments (such as toy-examples based on real cases) due to its practical nature.

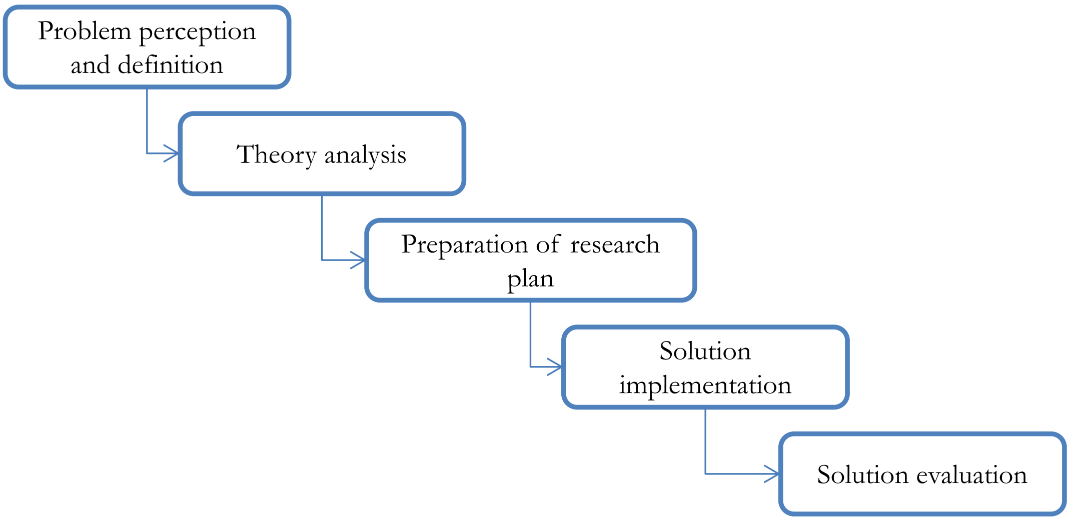

Figure 1.2 - Research methodology

During the perception and definition of the problem it was identified the relevance and open questions on the dynamic process adaptation field of research, and context management and AI Planning as joint solution to this problem, which justifies the investment on this thesis. The theory analysis was performed in order to confirm the problem, discussing approaches that deal already with the problem (or partially) and what the remaining challenges are.

The preparation of the research plan was the first contribution of this thesis aimed to establish a complete model for context-aware dynamic process adaptation from design to runtime. The goal was to set up the problem in its entirety. Thus, it concerned to isolate the problem of reasoning, and propose the solution developed and evaluated using real organizational processes from two different domains.

1.5. Thesis Outline

This thesis is organized as shown in Figure 1.3.

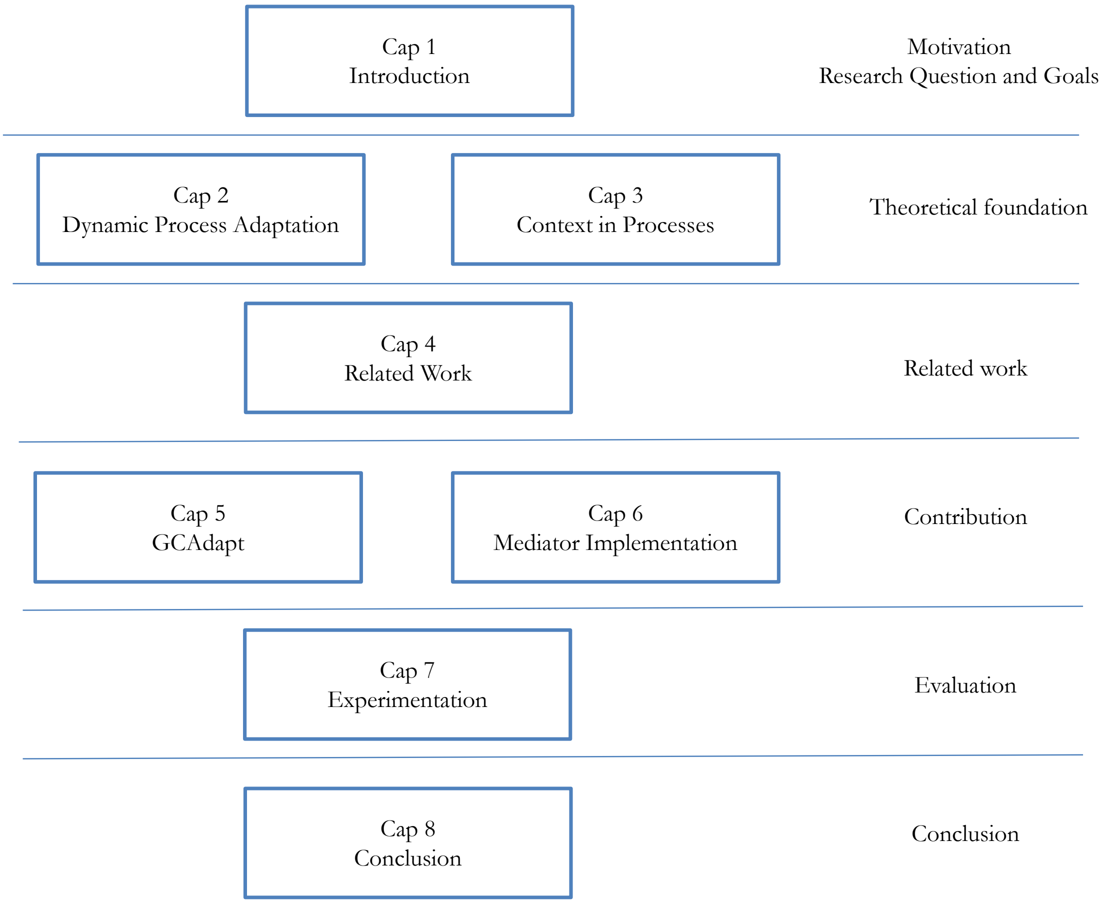

Figure 1.3 - Thesis Outline

Chapters 2 and 3 are related to the theoretical foundation based on the three pillars of this thesis discussed in order to approach the problem of dynamic process adaptation: context, planning and a theory for context-aware information systems (CAIS). Chapter 2 starts by positioning this research and discussing the relevance of dynamic process adaptation in organizations, as well as flexibility perspectives and their view as an Artificial Intelligence planning task. Chapter 3 discusses context definition and its interpretation when associated to business processes supported by information systems. Context and business process concepts are also discussed for dynamic process adaptation purposes and associated to a design theory for context-aware information systems used as a foundational conceptual base.

In Chapter 4, well-known PAIS approaches are presented together with planning-based approaches oriented to process adaptation purposes that were analyzed against flexibility aspects, resulting in a discussion of still open challenges.

In Chapters 5 and 6, the concepts theory described in Chapter 3 are operationalized (and extended at some extent) in order to define the features to be implemented in a context-aware PAIS (which is considered a special case of CAIS). Based on the concepts, features were structured and a set of procedures were proposed to be integrated into GCAdapt, Context Management architecture model for dynamic process adaptation. Chapter 6 presents the core of GAdapt (the Mediator module) reasoning orchestration mechanisms and general Architecture and an implementation using a selected PAIS and AI Planner.

In Chapter 7, the approach is evaluated through observational studies in two different domains. The results are discussed to show dynamic process adaptation feasibility, technically and through the interviewed professionals work point of view.

Chapter 8 concludes this manuscript presenting main contributions, limitations and future perspectives of this thesis research.

2. DYNAMIC PROCESS ADAPTATION

This chapter argues the relevance of dynamic process adaptation to which this thesis is concerned, discussing flexibility perspectives and its view as an Artificial Intelligence planning task.

2.1. Flexibility in Process-Aware Information System Approach

The Process-Aware Information Systems are becoming pervasive in the business environment and system focus has shifted from the data-driven approaches to a more holistic notion of a business process (LA ROSA, 2009). This reorientation of information systems from performing tasks to performing processes has the following advantages: (i) Explicit process models provide a better way of communication between people and the IT responsible for designing, implementing and maintaining a technological infrastructure to support these processes; (ii) Process orientation allows for changes without re-encoding; (iii) Process orientation allows to improve the efficiency of automatically routing and disseminating information; (iv) Explicit representation of process models optimizes redesign and evaluation, and supports monitoring and control.

In this context, a challenge discussed by both academia and industry is related to the ability of an organization to respond to changes efficiently and effectively. Thus, research on design (identification, discovery, analysis and redesign), implementation, monitor and controlling of business processes, as shown in Figure 2.1, has gained a new focus of attention: the flexibility in processes due to the continuous changes in people´s work environment. Flexibility is the ability to change without losing its identity (REGEV *et al.*, 2007). Flexibility in business process is the ability of a process to adapt itself as a result of changes in the environment and, at the same time, to maintain its stability (adherence to policies, culture, goals, etc.).

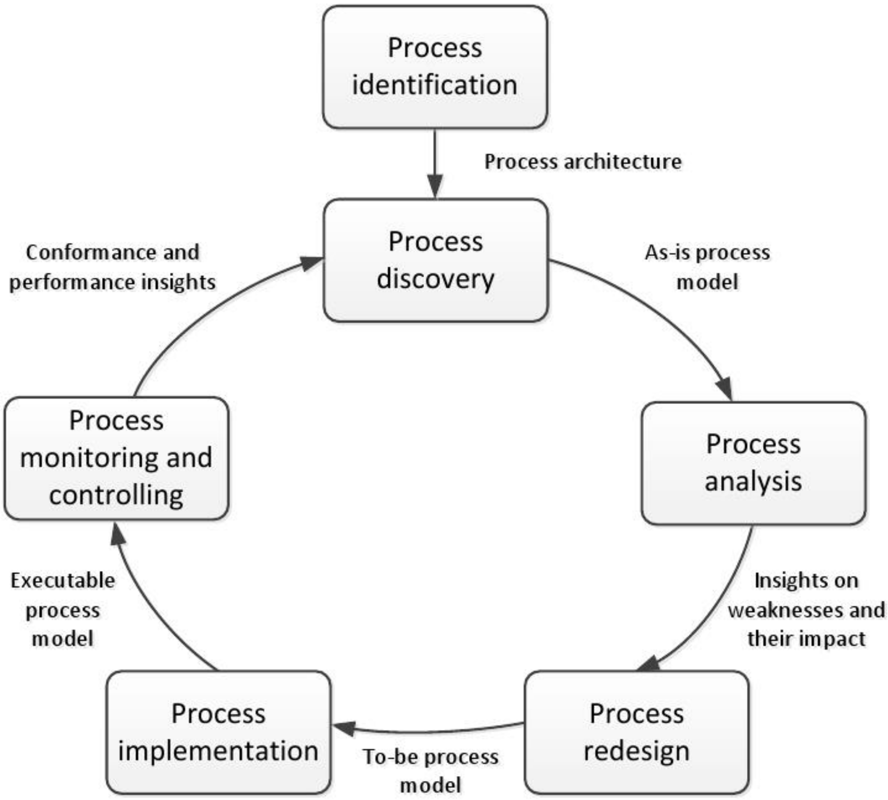

Figure 2.1 – Business Process Lifecycle (DUMAS *et al.*, 2013)

Nevertheless, identifying and analyzing the requirements for flexibility from process modeling to its execution brings challenges within a number of tasks, as shown in Figure 2.2.

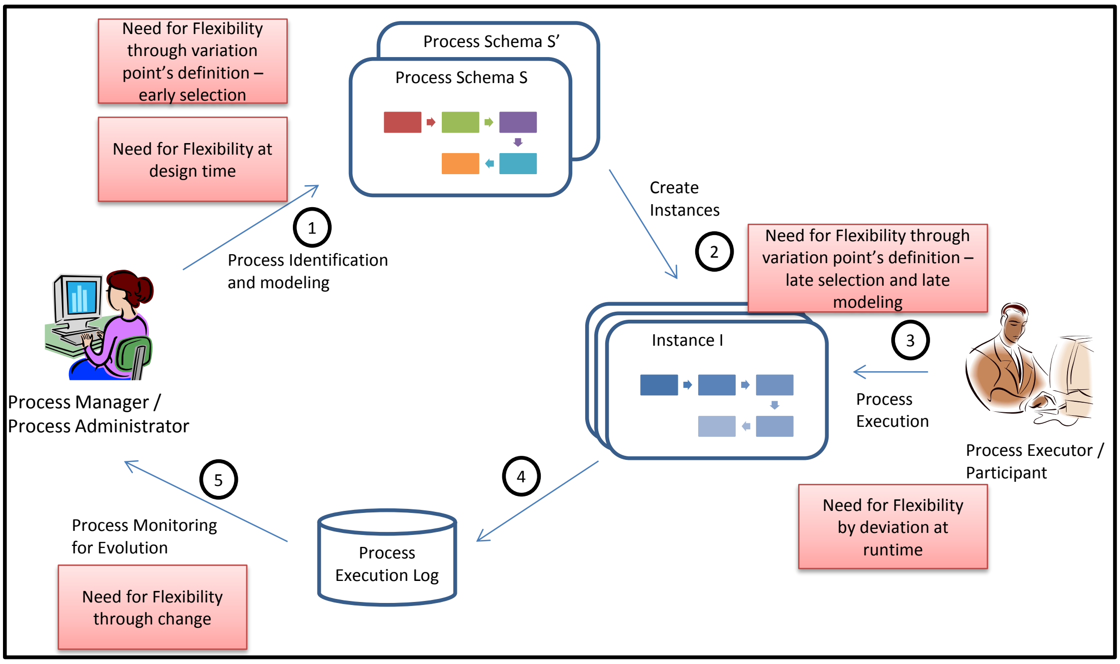

Figure 2.2 - Process modeling and execution: flexibility requirements (based on WEBER *et al.*, 2009)

The steps highlighted in Figure 2.2 were also discussed by SCHONENBERG *et al.* (2008), who classified the strategies for flexibility as follows:

- Flexibility at design time: all possible variations are defined and modeled during process design (composition). All process instances follow the same process model. The selection of paths is performed at runtime.
- Flexibility by deviation at runtime: specific process instances may deviate temporarily changing what has been prescribed, in order to accommodate changes in the environment. Changes in one (or some) instance does not reflect changes in the process model, only in the specific instance(s) that is(are) running. This kind of flexibility is also called momentary change (AALST and JABLONSKI, 2000) and can be based on pre-specified constraints and rules or manual (in an ad-hoc manner).
- Flexibility through variation point's definition (underspecification): during process model design and configuration, one can predict the need to incorporate new possibilities for adaptation in the future. Since one cannot foresee all possible situations in advance, it is useful to perform a process model whose variable parts can be added dynamically. In addition, new variations can be made available without the need to change the process model. Changes in one instance do not reflect changes in the process model, only the instance that is running. The points where variations occur should be defined a priori. Three situations may occur :
    - Late selection (late binding): during the execution, at the point where variations occur, a variant (alternative) is selected from the available options.
    - Late specification: during the execution, at the point where variations occur, it is noticed that there is not a variant that is appropriate to the current situation. This variant can be composed by combining two or more variants, or by modeling, at runtime, the variant part (however, this may cause some delay in the process).
    - Early selection (early binding): occurs before the process instance reaches the variation point, i.e., before its execution. When it is possible to predict the situations that will happen based on previous events, the selection of appropriate process variants can be carried out before the variation point's execution. In addition, a standard variation can be set if no other is selected.
- Flexibility through change: during the process instance execution, situations may require changes in the process model, which can impact the process instances already in progress or only in instances generated from the model modification. This kind of flexibility can be a result of an evolutionary change (AALST and JABLONSKI, 2000).

2.2. Dynamic process adaptation

Process adaptation is the action of customizing a process instance to make it applicable to a particular situation. It requires experience and involves knowledge about various aspects of the business such as environment, people, used technologies, the organization itself, and external aspects. Therefore, human identification of possible adaptations (i.e., adaptation on flow, roles, information, resources, etc.) within a process instance to address specific situations occurring at a certain moment is not a trivial task. Furthermore, there are limitations regarding the support for automatic decision-making in dynamic process adaptation.

Business process adaptation may happen in two moments combining the flexibility strategies described earlier: at design time and at runtime. In general, process adaptation decisions are defined at design time (reflected in process models through the representation and use of conditional rules and constraints) by the process manager (who is responsible for the process to execute properly), allowing the paths to be chosen at runtime. This is the most explicit form of adaptation since flexibility is already predicted in advance. Flexibility can also be treated in levels of granularity, into more versions of the same process and/or sub processes. So, in this view, all default deviations and decisions should be detected and modeled before execution.

However, unplanned conditions may occur at any time during process execution. So, the design of a complete process model, predicting all possibilities that might occur, has given place to a more flexible or "organic" design based on reuse and adaptation (DUMAS *et al.*, 2005). In practice, business processes do not exist only under a single version which covers all the issues of the whole market. Instead, many variants of a process may exist within the same enterprise in order to deal with different business situations such as: targeting different customer types, relying on particular IT systems or complying with specific regulations.

Another important aspect about process adaptation is that, in highly dynamic and complex environments that require immediate adaptation, a fully human intervention is no longer acceptable due to the fact that: business processes can be very large and complex nowadays (Figure 2.3) and there are thousands of concurrently process instances in execution. So, there is a need for configuration, flexibility and evolution. Organizations also need feedback and to learn from real process executions and using process-aware technologies enforces correctness and robustness, which are important characteristics (REICHERT and WEBER, 2012). For example, 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.

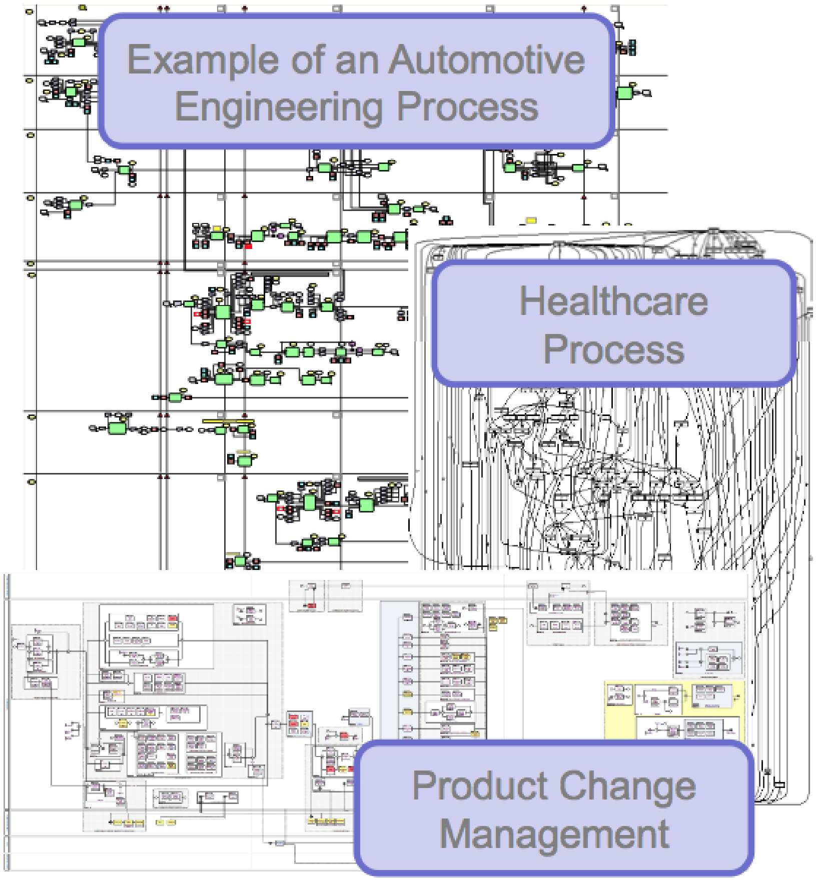

Figure 2.3 – Processes in the Wild World (REICHERT and WEBER, 2012)

However, those complex environments often lack the necessary guidance to become automatically aware of a given situation, for example 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. In such dynamic environments, the changes have to be performed more frequently and systematically.

2.2.1. Dynamic process adaptation perspectives

Besides the flexibility strategies already described, there are other perspectives in the literature based on the characteristics (or level of requirements) that a process adaptation approach should implement (WESKE, 2007, LA ROSA 2009, DUMAS *et al.*, 2005, BALDAUF *et al.*, 2007, SCHONENBERG *et al.*, 2008):

- **Perspective of adaptation**, which is directly related to the level of semantic expressiveness of the representation language used. The process adaptations perspectives can be classified as follows (AALST and JABLONSKI, 2000, LA ROSA, 2009):

- Flow control perspective: addresses process adaptation and flexibility strategies issues in relation to the activities and the relationship between them.
- Organizational perspective: addresses the issue of adaptation and flexibility under the aspect of human resources adaptation, i.e., the relations between the roles and the impact that this kind of adaptation causes on the running process.
- Information and products consumed/generated perspective: is related to information and products (process objects) adaptation, consumed and generated in a process and its impact on the running process.
- Operational perspective: is related to the implemented operations through systems and the adaptation of technologies on the running process.
- Integration perspective: deals with the impacts caused by adaptations in the four perspectives discussed, since the process flow relates to those responsible for executing each activity, the objects transacted by the activities and systems and other technological resources that operationalize some or all of the process(es).

- **Decision making support** (LA ROSA, 2009): related to the support mechanisms for the selection of alternatives for the process adaptation. These mechanisms can be manual, where the user selects the adaptation to be held, or automated, where the system decides what will be done.
- **Support for the preservation of the quality of adapted models**: related to the maintenance of the correctness and quality of adapted models. Regarding models correctness, these approaches can support semantic correctness (ensuring the correct behavior of the flow) and syntactic correctness (ensuring the correct flow structure) (LA ROSA, 2009). Regarding the process quality after adaptation, the approach should evaluate their suitability to the needs of the environment, the quality level of intermediate and final products generated and adherence to organizational goals.

Dynamic process adaptation is related to flexibility by deviation at runtime and deviation by change on the cases where processes structures are to be adapted while process instances are running. The decision making support involves the definition of strategies for implementing reasoning mechanisms to decide on possible adaptations. This research thesis proposes to treat adaptation decision making as an Artificial Intelligence task, thus next section presents the concepts used.

2.3. Automated Planning in Process adaptation

An approach to the dynamic process adaptation is to conceive it as an Artificial Intelligence (AI) planning task. As GHALLAB *et al.* (2004) affirm, “planning is the reasoning side of acting. It is an abstract, explicit deliberation process that chooses and organizes actions by anticipating their expected outcomes.” Planning algorithms search for plans that succeed not only for a given initial state but under potential circumstances, aiming at achieving, as best as possible, specified goals. This enables to relate many of the theoretical and computational advances in reasoning about actions to the task of adapting a process. Also, processes are seen as a classical planning environment because this thesis deals with known and formalized processes that are, fully observable, finite, static (changes happen only when agents act), deterministic and discrete (in time, action, objects and effects).

To demonstrate the correlation of planning to processes, it is possible to use, as an example, the Sussman Anomaly which is a classical “toy” problem in AI. In this problem, three blocks (labeled A, B, and C) rest on a table. The agent must stack the blocks such that A is atop B, which in turn is atop C. However, it may only move one block at a time. The problem starts with B on the table, C atop A, and A on the table as shown on Figure 2.4.

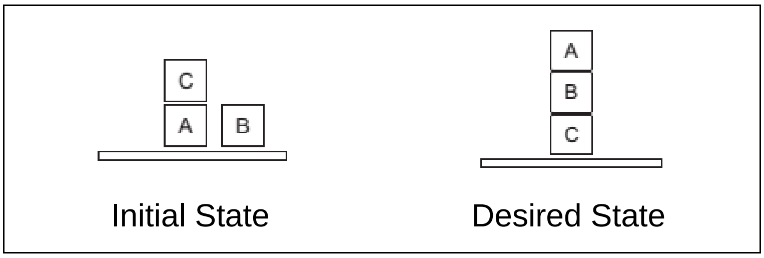

Figure 2.4 – Sussman Anomaly Problem

Besides the initial and final states, a planning problem must have a set of assumptions that describe the environment and represent the problem domain. The definition of a domain is basically described by the actions that can be performed. For blocks domain described above, two actions could be available: stack and unstack.

The sequence of actions: unstack C above A, stack B above C, and stack A above B is a solution for the problem, because it achieves the desired state. This sequence, or any other that meets the goal, is called a plan.

A Planner is a system that receives as input: the set of possible actions; the description of the initial state of the world; and the description of the desired goal, all of them codified in a formal description. Depending on the representation language it is also possible to describe: constraints among actions and parameters (data values); metrics to allow quantitative evaluation of plans (like optimization and metric-minimization/maximization); and preferences (soft-constraints that can be incorporated into the plan-metric, e.g., to maximize the number of satisfied preferences).

In many problem domains, a task can be accomplished by various sequences of actions (also known as plans). These plans can vary in quality: there can be many ways to solve a problem, but one generally prefers a way that is, e.g., cost-effective, quick and safe. In this cases the context that characterizes situations during process execution, provide insights for AI planners to take into account when producing a plan for a given problem.

So a process and its possible adaptations can also be considered a set of actions that may have constraints among them (e.g., action A must be performed before action B) and manipulate a set of data value aiming at achieving a desired goal according to a desired performance. We claim that there is a correspondence between the adaptation to a customized process instance and a (non-classical) Artificial Intelligence planning where the objective of the planning problem is specified as a form of control knowledge, such as a process control flow, together with a set of constraints to be optimized or enforced (de LEONI *et al.*, 2007).

So, managing (complex) process flexibility through a technological environment such as an automated planning problem aims to provide mechanisms for process managers and executors to face complex and changing circumstances that involve dealing with efficiency and efficacy requirements.

2.3.1. Planning representation languages and algorithms

The inputs to any planning algorithm are the descriptions of the domain and of the problem to be solved. Representation languages must be expressive for ease of representation and flexible for manipulation by algorithms.

In order to represent problem and domain information, rich representation models are needed, the majority of them is based on predicate logic as the case of PDDL (R-MORENO *et al.*, 2007). PDDL (Planning Domain Definition Language) is one of the most used languages for planning problems that started as a combination of STRIPS (Stanford Research Institute Problem Solver) and ADL (Action Description Languages) languages. It was initially developed for use in an International Planning Competition (IPC)[1] in 1998, allowing all competing planners to use the same input language, and

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

has been gradually but significantly extended and polished since that time. Currently, almost all new planners support some subset of PDDL.

> "*The adoption of a common formalism for describing planning domains fosters far greater reuse of research and allows more direct comparison of systems and approaches, and therefore supports faster progress in the field. A common formalism is a compromise between expressive power (in which development is strongly driven by potential applications) and the progress of basic research (which encourages development from well-understood foundations). The role of a common formalism as a communication medium for exchange demands that it is provided with a clear semantics*." (FOX and LONG, 2002).

In order to represent a planning problem in PDDL, two files are necessary: the domain files and the problem file (Figure 2.5).

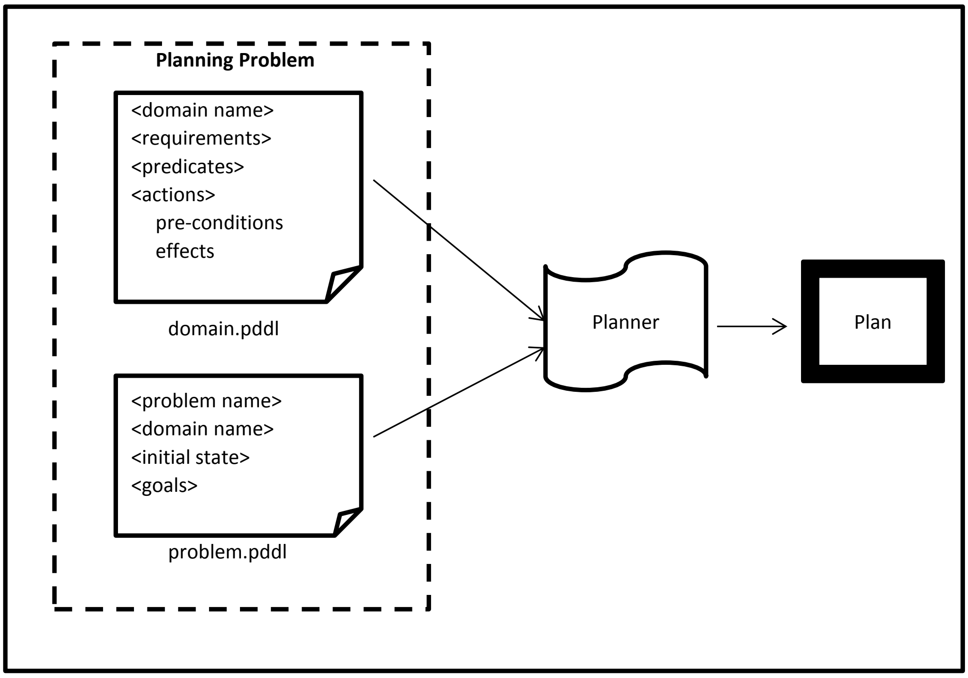

Figure 2.5 – Basic structure of a planning problem in PDDL

The files are exemplified through the Sussman Anomaly (the block domain) already described. In the domain file are specified, mainly: the domain name, language requirements, existing predicates and possible actions (Figure 2.6).

```
(define (domain Block)
(:requirements :strips :typing)
(:predicates (on  ?a - block ?b - block)
             (ontable  ?a – block)
             (clear ?b – block)
)
(:action stack
  :parameters (on  ?a - block ?b - block)
  :precondition (and (clear ?a) (ontable ( ?a) (clear ?b))
  :effect (and (not (clear ?b))
               (not (on table ?a))
               (on ?a ?b))
)
(:action unstack
  :parameters (on  ?a - block ?b - block)
  :precondition (and  (on ( ?a ?b) (clear ?a))
  :effect (and (clear ?b)
               (clear ?a)
               (on table ?a)
               (not (on ?a ?b)))
)
)
```

Figure 2.6 – Block World Domain file in PDDL

In the problem file, mainly the problem name, domain name, initial state and goals (Figure 2.7) are specified.

```
(define (problem SussmanAnomaly)
(:domain Block)
(:objects  A B C - block)
(:init (ontable  A)
       (ontable  B)
       (clear B)
       (clear C)
       (on C A)
)
(:goal (and (on A B)
            (on B C)
            (ontable C)
)
)
```

Figure 2.7 – Block World Problem file in PDDL

This thesis proposes, based on (GONZALEZ-FERRER *et al.*, 2009) and (LIASKOS *et al.*, 2010), that a BPM (Business Process Model) process structure and its goals, its ordering constraints, resources and the control flow rules can be translated into a PDDL knowledge representation language. Then, it would be possible to use a Planner that takes the domain and problem specifications as input and use it in order to obtain action plans for BPM process models.

The reasoning process is a knowledge and goal-driven process, guided by the procedural knowledge encoded in the domain. In the beginning, planning originally meant to achieve a set of desired goals by performing some set of the defined suitable tasks (a set of activities subject to order and temporal relations) given and initial state. Currently, planning algorithms extend beyond including constraints, optimality, preferences, etc. And for specific domains it goes on introducing Markov decisions processes, imperfect state information, game-theoretic equilibria and various others algorithms (LAVALLE, 2006). Each Planner constructs a plan and is considered as a planning algorithm.

Planning is foremost an exercise in controlling combinatorial explosion. Several different types of models exist, with the most complex featuring partial observability of the world states, nondeterministic transitions, temporal processes, and more. Heuristics are them classified accordingly to its complexity in classical (with deterministic and finite states, static and fully observable) and nonclassical planning (with nondeterministic and non-finite states, event-based and partial world observability).

Furthermore, one of the key difficulties encountered when attempting to devise an efficient domain independent planner is the wide variety of domains with which it could be presented; any simplifying assumptions or search guidance techniques employed need to be effective across a range of planning domains. This is in contrast to domain-specific planners, restricted to a single domain, which can be programmed with a wide range of hand-coded strategies and simplifying assumptions. In this thesis it has been tested and used only domain independent planners. The International Planning Competition proposes competitors to develop planners improving existing heuristic or proposing new ones and they may be stronger or not depending on the domain at hand. It is still a wide field of AI research.

In this thesis it has been used a temporal metric Planner called SAPA. SAPA is a domain-independent heuristic forward chaining planner that can handle durative actions (actions with temporal relations), metric resource constraints, and deadline goals (DO and KAMBHAMPATI, 2003). It implements PDDL version 2.1 and was chosen because of its relatively stability, time response and ease of use.

This thesis argues that dynamic process adaptation needs to be aware of context information that characterizes the situation that is demanding a process re-plan. The conceptualization of context, its manipulation and its relation with business process, as well as context-aware systems are discussed in the next chapter.

3. CONTEXT IN BUSINESS PROCESSES

This chapter discusses the definition of context and its relationship to business processes. Context and business process concepts are also discussed for dynamic process adaptation purposes and associated to a design theory for context-aware information systems used as a foundational conceptual base.

The goal of this chapter is not to present an in-depth description of definitions and techniques surrounding context-aware business process adaptation supported by information systems, but to discuss the fields of research used throughout the thesis, to allow a better understanding of the background and the relevance of context and information system when automating dynamic process adaptation in organizations.

3.1. Context

Context is an interdisciplinary topic and has a very broad interpretation in different domains (e.g., social anthropology, linguistics, philosophy, history and so on). Anthropologic, ethnographic, and other discipline´s interpretations about things and phenomena rely on a sense of context. As discussed by DILLEY (1999), social and cultural phenomena are interpreted within a reference, i.e., within a contextual perspective and interpretation. So, an object is set in context, when connected by relations to its relevant surroundings.

Among the several existing definitions over the term context (BAZIRE and BRÉZILLON, 2005), this thesis adopts the one proposed by BRÉZILLON (1999) which defines context as a complex description of the shared knowledge about physical conditions, social, historical and others in which actions and events occur. As SANTOS (2008) points out, "in a broad sense, context is anything that surrounds a situation, in a given moment, and that enables to identify what is and what is not relevant to interpret and understand that situation".

The importance of the context of a situation, which is the combination of circumstances (actions and events) happening at a given time (WORDNET, 2010), seems to be common sense among people. But, there is still no consensus on which knowledge can be considered as context information reflecting a series of studies that focus on different aspects and that mostly address only certain dimensions (NUNES *et al.*, 2009). These different notions show that we consider information as context depending on what we want to characterize.

Therefore, formalizing the context of a situation, providing meaning for it, raises important questions (DILLEY, 1999, ROSEMANN *et al.*, 2010, VIEIRA, 2011), such as:

What actually characterize a context? How context information is defined? Who is responsible for managing it? How does context impact the performance of organizational work? What information constitutes relevant context in organizational work processes? How to identify when a context is indeed happening, characterizing a given situation? How may context characterize the need for processes changes?

The interpretation of context in the real world is done differently for each person, even when the same information is involved. It happens because people interpret things, especially social and cultural phenomena, from its own internal reference (DILLEY, 1999). It is necessary to reach a common understanding of the semantics of context information and the implications for the organization arising from the combination between them.

These questions meet BRÉZILLON (1999), MCCARTHY (1993), KOKINOV (1999), SANTOS (2008) and ROSEMANN *et al.* (2008) observations whose general understanding denotes that:

i) An information is considered as context, depending on what it intends to contextualize (KLEMKE, 2000), i.e., the focus. So context is always related to a focus (another context, a task, a person, a thing, etc);
ii) Context is only considered relevant when it influences the behavior of people, systems and environment and/or is influenced by them. This influence can happen when context characterizes a deviation of the actions that are performed against the defined goals;
iii) Context is a complex concept with infinite dimension and consists of the association of relevant information, rules and propositions identified and captured in the environment;
iv) Not every context can be fully described because of its complexity, which demands the need for a simplification of the complex reality. However, this simplification can increase the degree of uncertainty about its occurrence;
v) Contexts identified in a given situation can be combined to form a common connection between them;
vi) Context is essentially dynamic.

According to these characteristics and the fact that there is a vast universe of information that can be characterized as a context, this thesis makes use of the model proposed by BRÉZILLON (2007) that addresses the question of context relevance according to its focus of attention (Figure 3.1). In this model, context is classified into: Contextual Knowledge (CK), External Knowledge (EK) and Proceduralized Context (PC).

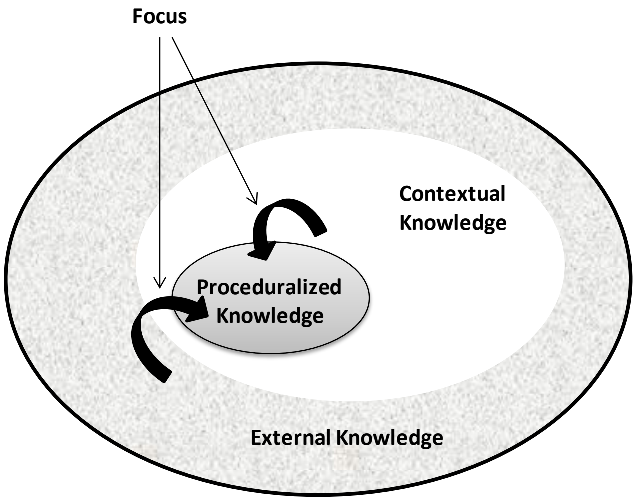

Figure 3.1 - Context classification according to the focus of attention (BRÉZILLON, 2007)

According to BRÉZILLON (1999, 2007) and BRÉZILLON and POMEROL (1999), a focus can be a step in the execution of a task or a decision, and it is what allows you to determine which Contextual Elements (CEs), i.e., data, should be instantiated and used to compose context information. From a focus, the context can be classified into CK or EK. CK is represented by the contextual information which is directly related to the focus. EK is represented by those who have no relationship with the focus. PC consists of the combination of CK and EK that are instantiated at a given time. This context is called Active Context that characterizes a situation within a given focus.

Furthermore, it will be used the distinction proposed by SANTOS (2008) between the terms: CE and Context. CE represents data, information or knowledge that characterizes something within a domain. A CE can be basic (fine-grained and typically represents a single data) or complex (inferred by combining more than one CEs) (WANG *et al.* 2004). For instance, the location of some equipment, a person's address, the temperature, etc. Context, on the other hand, represents the set of contextual elements values which have some kind of connection featuring a situation in relation to the given focus. Therefore, the identification of a specific context involves distinguishing what CEs characterize it. These CEs must be processed and represented in a format understandable and acceptable within the organization.

As an example (Figure 3.2), a contextual information related to a tour guide system, indicates if the weather is hot or cold where the tourist wants to go. However, the concepts of "cold" and "hot" are not inferred only collecting the environment's temperature. Other factors such as location, date, time and weather conditions, i.e., a specific set of contextual elements, should be taken into account to derive this information and should be represented in a clear, unified and unambiguous way for the system to understand what information influences the actions and decisions that are to be made.

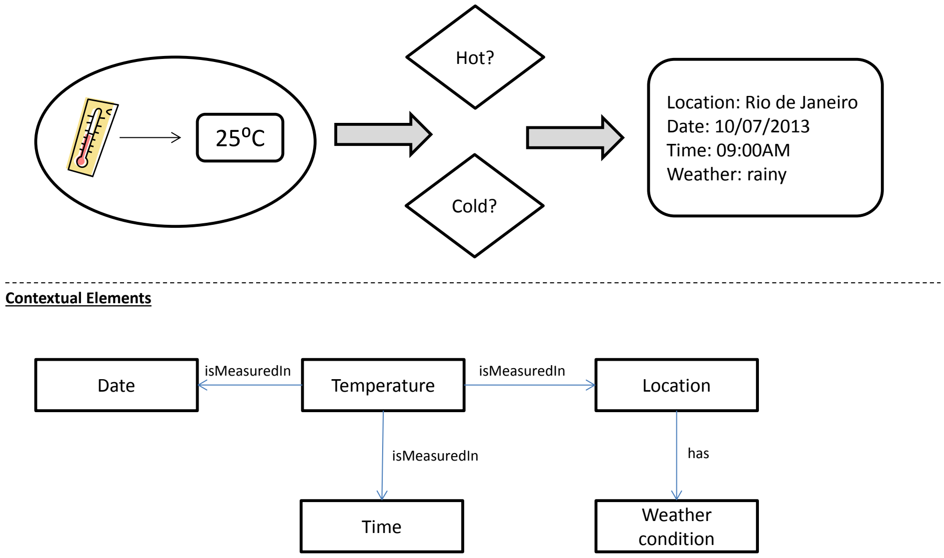

Figure 3.2 - Example of an interpretation of a set of correlated CEs

Based on these defined concepts, and understanding that in order to treat context it is necessary to have a focus of attention on which the influence and importance of contextual information are perceived, the PC is the context information that is actually relevant to characterize a particular activity (our focus of attention on this thesis) when the process is running and influences the identification of an adaptation process demand. So, before discussing the understanding of context in relation to business processes as a source to support dynamic process adaptation, it is discussed general requirements, challenges and approaches when considering the management of context in order to enhance the identification and treatment of adaptation demands.

3.1.1. Context Management

Context Management (CM), in general, involves the definition of models and systems to support the acquisition, handling, and maintenance of a repository of contextual information associated with artifacts. As a means of increasing knowledge about the work that is performed, CM is a difficult task to perform. To broaden its awareness it is necessary to clarify the contextual knowledge, representing it in a uniform way, organize it and make it accessible to everyone involved, providing a general and contextualized view of the facts (NUNES, 2007).

Among the design challenges of a context management system (CMS), regardless of its use, CHEN *et al.* (2004) and Santos (2008) stand out: (i) the characterization of CEs for use in a CMS and its representation in a semantic model; (ii) the identification of relevant CEs in the characterization of the situations; (iii) the acquisition of CEs from heterogeneous sources (e.g., physical sensors, databases, applications and agents); (iv) the processing (context reasoning) and interpretation of CEs acquired; (v) the dissemination and sharing (context sharing) of CEs between different applications; (vi) the evolution of context definitions (situations) according to previous performed actions and organizational goals.

In addition, other requirements must also be considered, such as, the quality of processed contextual information (ZIMMER, 2006), security, privacy, and performance of the system and issues related to uncertainty (RANGANATHAN *et al.*, 2004).

Based on those outlined challenges, the most important context management infrastructures in literature were analyzed and detailed in Appendix I. None of them were primarily designed to address dynamic processes adaptation, but dynamic adaptation of context-aware application in general. Context-aware systems are those able to adapt their operations to the current context without explicit intervention of the user (BALDAUF *et al.*, 2007). Namely, context awareness is a state where a device or a program is aware of the environment, i.e., it can recognize it and execute actions automatically, without the need for an explicit external demand (GATTI, 2009).

The first known approaches dealt mostly with location awareness, such as Intelligent Room, The Active Badge Location System and Cyberguide. Second Generation approaches (such as Context Toolkit (DEY *et al.*, 2001), Hydrogen (HOFER *et al.*, 2003), CASS (FAHY and CLARKE, 2004), Gaia (RANGANATHAN *et al.*, 2004), Cortex (DURAN-LIMON *et al.*, 2003) and SOCAM (GU *et al.*, 2005)) represented a breakthrough in terms of the establishment of a point-to-point architecture, the use of reusable software components and the use of context through an attribute/value tuple. The third generation approaches aimed at providing infrastructure to support context-sensitive in a diverse environment (such as ACAI (KHEDR, 2005) and CoBrA (CHEN *et al.*, 2004)), which makes use of agent-oriented techniques). The idea is to provide a less burden architecture that may evolve independently of it reasoning when considering the discover of new CEs, in different formats and levels of complexity and uncertainty, collected by different mechanisms.

Even considering more recent and domain-focused context-aware approaches (SILAPACHOTE *et al.*, 2013) (HEREDERO *et al.*, 2013) (SADIGHIAN *et al.*, 2014) (GRASSI *et al.*, 2014), the general theoretical architecture, proposed by (SCHMOHL, 2010), shown in Figure 3.3, still applies for most of the propositions. They studied several architectures (from all generations) in order to identify the common concepts and components.

In the Lexical Level context information (in this step, it is considered a CE) are acquired by sensors. It aims at keeping independent both of the context-aware system technology and other sensors. CEs are analyzed and combined at the Syntactical Level. At the Reasoning Level, basic context information is refined and organized. CEs are then fused into a reasonable and more sophisticated representation. The change detection happens at the Planning Level where system changes are planned. Finally, in the Application Level the changes executed through interactions with the users and the adaptive system itself.

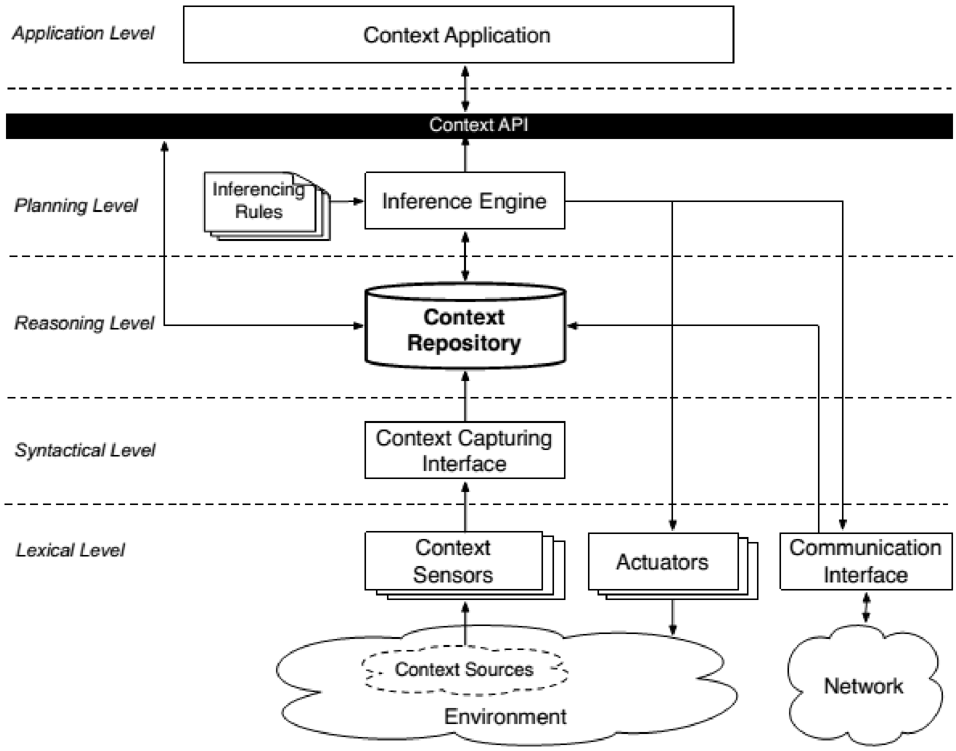

Figure 3.3 - General Architecture for context-aware systems (SCHMOHL, 2010)

The evolution of the approaches is mostly related to: (i) the separation of technologies for the acquisition from the processing of contextual elements, allowing greater independence and pro-activity in the capture of data in different formats and by different mechanisms; (ii) the semantic representation of context, allowing the increase of computational intelligence in handling the information and reasoning; and (iii) the establishment of mechanisms for storage, retrieval and learning.

The research on context-aware adaptation systems were not meant to be exhaustive. The approaches were analyzed, first to understand its concepts and to give insights on how to correlate them to concepts related to business process and dynamic process adaptation and, further, to identify their suitability and possible evolution in the treatment of dynamic process adaptation.

3.2. Context use in business processes

The motivation for the increasing importance in associating context to business processes is related to the fact that it provides a cause-effect relationship characterization between the demands for processes flexibility and the impacts on processes adaptation which is in line with the definition of ROSEMANN and RECKER (2006) and ROSEMANN *et al.* (2008, 2010) about context-aware processes, and how contextual information may influence the need for adjustments. Processes shall incorporate monitoring capabilities to observe the surrounding context information and their impact in process execution. They argue that the identification, documentation and analysis of contextual elements (which may lead to changes in processes) comprise the foundation for understanding the interrelationships between changes in the scenario of an organization and its processes. The authors propose to integrate context in process modeling, since context impacts the structure of the process model, and they defined a metamodel that considers the structure of a process, its goals and context.

SOFFER *et al.* (2010) propose an approach for learning and gradually improving business processes, considering three elements: process paths, context and goals. The authors argue that the success of a process instance can be affected not only by the way it is effectively executed, but also by environmental conditions, not controlled by the process. The learning approach is based on an experience foundation, including data from process instances such as the actual path, the results achieved, and context information that characterized it.

SAIDANI and NURCAN (2007) discuss the importance of context in the modeling of business processes and propose to include in the process modeling the description of the context execution. This approach is based on four steps: context elicitation, context categorization, context adaptation and measurement, and business process instantiation. They propose a taxonomy of the most common context information (location, time, resources and organization) to support the elicitation phase.

It is important to capture relationships between different workflow instances (practices) through their contexts for a better understanding of the commonalities and variability between them and how differences emerged. It is related with the well-known ambiguity between procedures versus practices (BRÉZILLON, 2007). People follow established procedures, but sometimes perform deviations in the normal flow, usually backed up by "good reasons".

In common, all these works consider the association of contextual knowledge to the process activities important in order to facilitate its reuse. According to ROSEMANN *et al.* (2008), "the early identification of context changes together with knowledge about what types of process changes are required leads to increased process flexibility, decreased reaction time and improved risk management".

So, the concept of context (BRÉZILLON, 1999) appears as a pointer to distinguish among the available information during process execution, those that are relevant in order to provide inputs for the analysis of the process instance adequacy to the current situation, addressing organizations goals and strategy in relation to the people who are collaboratively participating, the technology being used, the environmental aspects, risks, resources, etc. Through context analysis, it is possible to assess the moment when the necessary adjustment needs to occur to ensure the progress of the process instance.

So, in the next section, the formalization of context relationship with business process concepts within a specific domain is presented.

3.3. Mapping context and business process concepts for process adaptation purposes

MATTOS *et al.,* (2012) and MATTOS (2012) propose the representation of context in business processes based on conceptual models. The fundamental concept adopted here is: context is the set of CEs instantiated and combined (Situation) that are necessary to support an activity in a business process.

On the other hand, business process models tend to be rigid in format and are not able to easily encompass either foreseen or unforeseen variations in the environment in which they operate. It is due to, first, the difficulty to predict all the possible variations, and second the difficulty to manage if the modeler tries to include all the possible variations in the model. So, the approach here is to deal with relevant variations as “context” and address them adapting the process when they occur. In addition, the domain in which it is applied is constantly maintained through the establishment of specific concepts, data structure, functions, properties, rules and constraints.

A layered approach provides a conceptualization of the various aspects related to the context. Thus, it is possible to isolate the elements belonging to each layer and then establish their relationships. Moreover, the modular characteristic of this proposal should facilitate maintenance and evolution of the model, as shown in Figure 3.4.

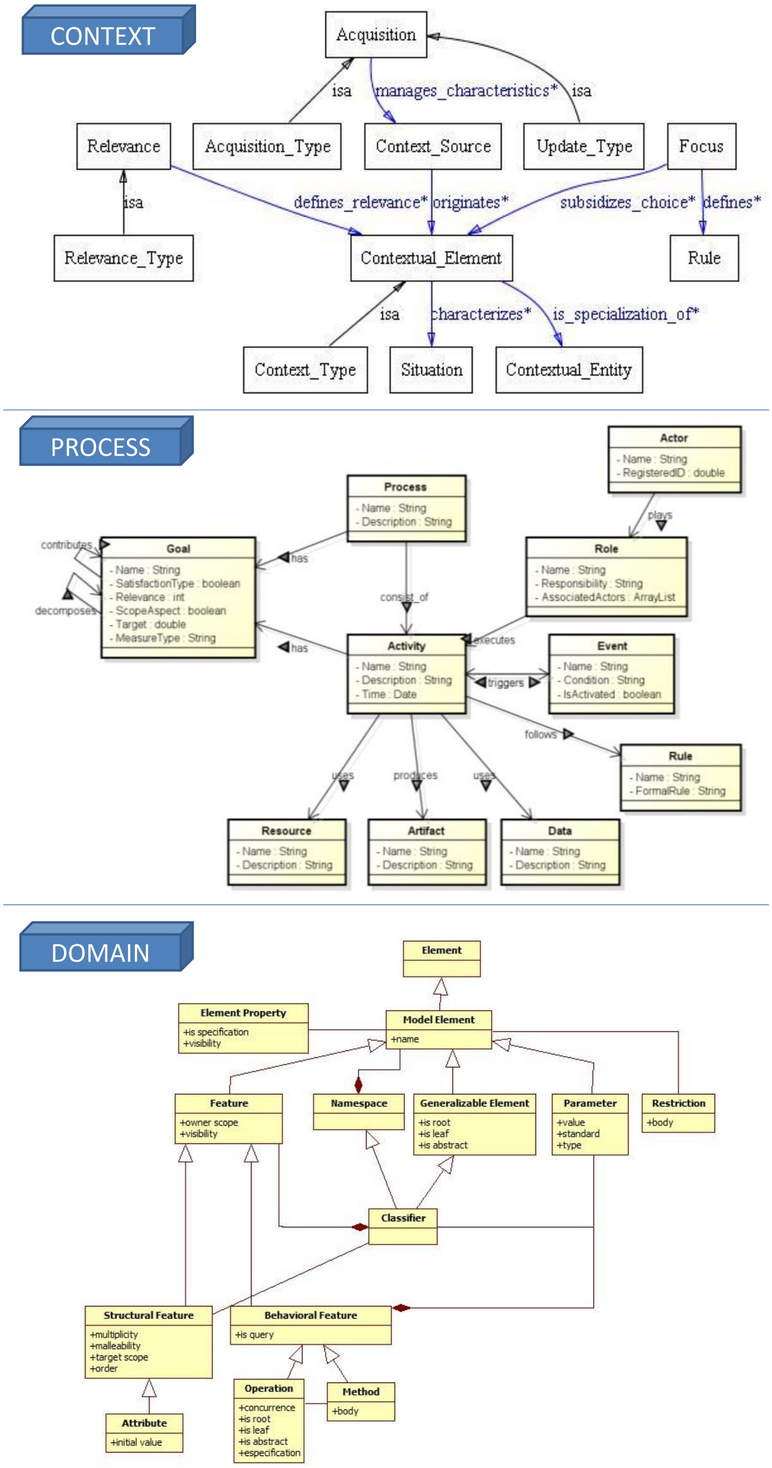

Figure 3.4 - Layered Metamodel for Context-Aware Business Processes

The Context Metamodel, in the first layer, comprises the concepts related to the context and their relationships which are fully described in Table 3.1. It was adapted from VIEIRA *et al.* (2011) so as to separate context concepts from business process concepts.

Table 3.1- Context Metamodel Concepts (Layer 1)

Concept	Definition
Contextual Entity	Represents entities (person, place, object, user, application) to be considered for the purpose of manipulating context information. It is characterized by at least one CE. It is an abstract concept. Attributes: name, type, description
Contextual Element (CE)	Represents a property used to characterize a contextual entity. It is the basic unit of the model, identified by a set of attributes and relationships associated to an entity. Attributes: name, description, value
Context Type	Represents the categorization of the CE according to the type of information it provides. Indicates when a CE is related to one of the questions defined by its attributes. Attributes: value
Context Source	Represents ways in which CEs instances can be derived from heterogeneous and external sources (physical sensors, desktops sensors, user-interface dialog, etc). Attributes: name, source type, source.
Acquisition	Represents ways of capturing CEs. It parameterizes the relationship between a CE and a context source. Attributes: Acquisition type, update frequency
Acquisition Type	Classifies the CE according to the forms of acquisition. Attributes: value
Update Type	Classifies the CE according to the value of update frequency. Attributes: value
Focus	Represents the organizations goals, task, step in the solution of a problem or a decision making, and serves as reference for the determination of which CEs are to be instantiated and used to define a Situation. Attributes: function, description, goal, is_activated
Rule	Represents a set of conditions and actions. A condition is characterized according to the values that a set (one or more) of CEs assume in a specific moment. Actions indicate a procedure to be executed when a condition is activated. Actions may be, as an example, to trigger a system action, to assign a new value to a CE, assign some new constraint, etc. Attributes: name, type, condition (set of CEs and associated values), action (procedures to be taken).
Relevance	Represents the level of importance of a CE in relation to the focus. It is characterized by a weight. Attributes: name, description, weight

Situation	Represents the set of CEs that characterizes the need for an adaptation. A situation may be perceived as the trend path that the process instance is following or may represent a condition that is already happening. Attributes: name, description, condition, is_activated

The second layer is the Business Process Metamodel, which defines the basic elements that should be used to describe a process, with the focus on the activity of the work process. The ontology proposed in (NUNES *et al.*, 2006) is used as a basis to specify the concepts a business process model should represent although other process conceptualizations can be used. Anyway, each concept in the business process metamodel is also considered a CE. The formalism proposed by MATTOS (2012) improves the original ontology by making all of the relevant concepts related to context explicit in a separate model (the first layer) and highlighting in the second layer a process metamodel. So, a PAIS that makes use of a business process modeling language, the concepts that are to be monitored must be identified and specified accordingly to be used by the Context Management Environment. The main classes that compose this metamodel, and that represent the minimal set of information that needs to be managed by PAIS in order to be able to treat dynamic process adaptation properly, are shown in Figure 3.5 and described in Table 3.2.

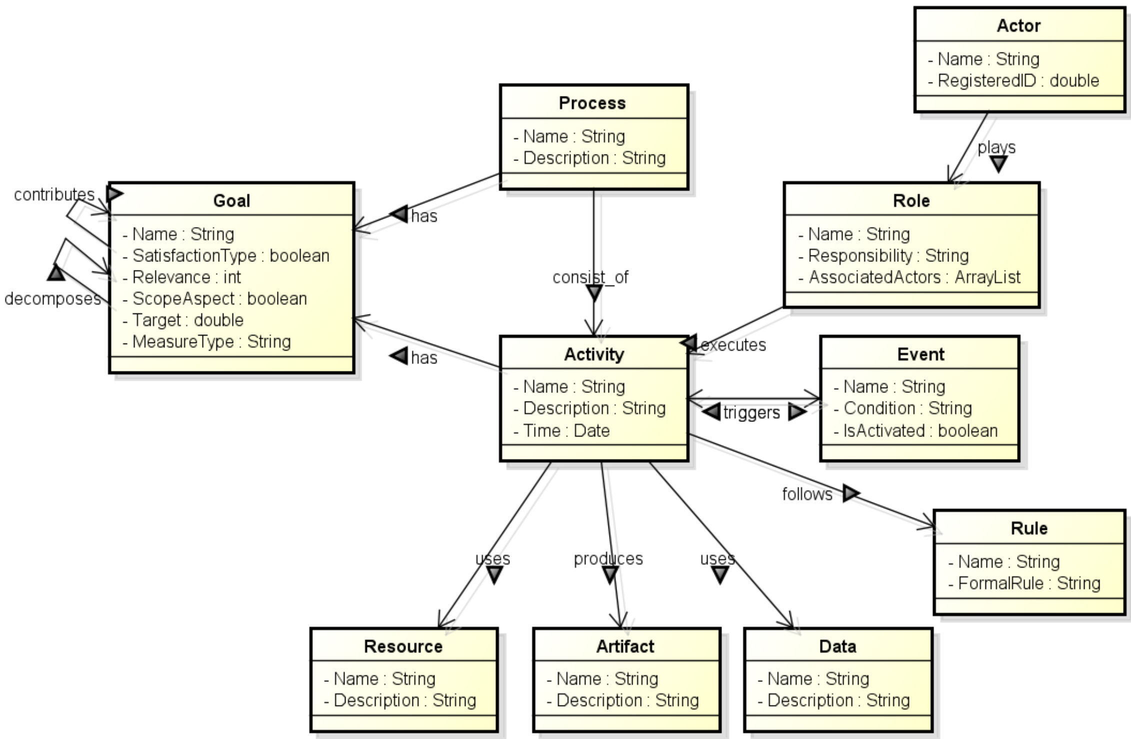

Figure 3.5 - Business Process Metamodel

Table 3.2 - Business Process Metamodel Concepts

Concept	Definition
Process	Represents a set of activities that aims to produce something targeting the achievement of specific goals. Attribute: name, description
Activity	Set of actions, pertained to a process, aimed at reaching one or more goals in a given time, which consumes and produces data and artifacts and requires actors to execute it. Attribute: name, description
Goal	The set of a desired state of affairs. Attribute: described next in this section
Actor	Represents professionals involved in the execution of an activity. They can be specialized in individuals, groups and non-humans actors. Attribute: name, registered id
Role	A function that is performed by one or more actors and which is assigned to each process activity. Roles have hierarchy among themselves and require some type of ability. Attribute: name, responsibility, associated actors
Artifact	Concrete product resulting from the execution of an activity that can serve as input to other activities. Attribute: name, description
Data	Information, internal or external, to the organization or process instance in execution. Attribute: name, description
Resource	Represents items used to support the execution of activities as computing platforms, equipment mechanical, materials needed, work environments and that have some restriction of use to be controlled. It may be specialized to specific subclasses application domain as, for example, application systems. Attribute: name, description
Rule	Represents information that defines or constrains some aspects of the business. Can be directly linked to the organization as a whole or can be linked to a specific domain of expertise. Its intention is to ensure business structure or influence its behavior. As an example, it may be internal constraints, such as efficiency standards and goals attendance or it may be external constraints such as laws and regulations. Attribute: name, formal rule
Event	Represents anything that happens during the course of a process instance and may cause (a trigger) an impact in the process instance execution. Attribute: name, condition, is activated

The third layer represents the Domain Metamodel, which is responsible for supporting the definition of the data structure, functions, relationships and constraints of the knowledge area considered. A Domain Metamodel is a high-level conceptual model that defines physical and abstract objects in a knowledge area. In other words, everything that influences a process (either internal or external data) should be understandable as part of this domain. The Domain Metamodel is represented as part of the UML Class Metamodel (UML, 2013), as shown in Figure 3.6. The concept Element is considered a CE (and the others its properties) and

Table *3.3* describes each one.

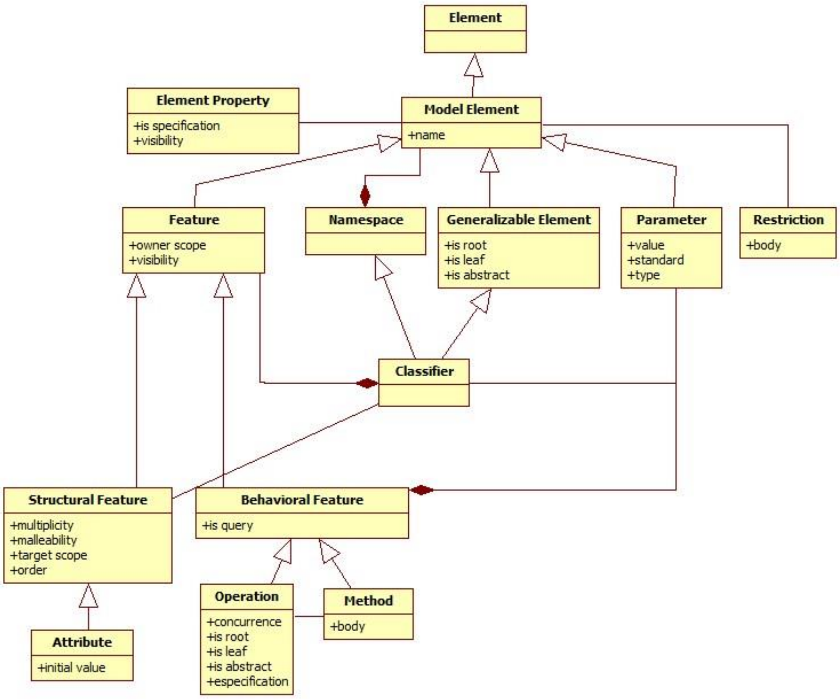

Figure 3.6 - Domain Metamodel

Table 3.3 – Domain Metamodel Concepts

Concept	Definition
Element	Base class for all elements that compose the UML metamodel. It is the atomic constituent of the model.
Model Element	Represents all business elements that are specified using UML.
Characteristic	Represents a possible classification of the Model_element. Defines a way to represent a particular domain element. It is a generalization of structural and behavioral features.
Restriction	Represents a possible classification of the Model_element. Defines a way to represent a particular domain element. Semantic condition or restriction expressed in text.
Attribute	Defines values that represent the state of an instance of a Classifier.

Operation	Behavioral aspect of a Classifier. Represents a function or procedure that may be applied to or by objects in a class.
Method	Behavioral aspect of a Classifier. Represents the implementation of an operation for a class.
Element Property	Sets the visibility of an element model contained in a Namespace.

As an example, the Domain Model presented in Figure 3.7 partially describes the Airspace Traffic Control (ATC) domain.

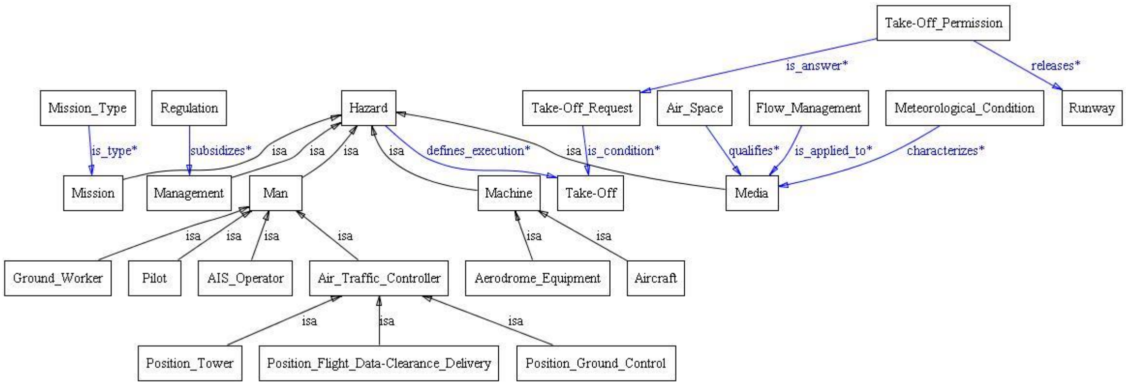

Figure 3.7 - ATC Domain Model

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 rules guarantees that a relationship exists between the models built from the metamodels.

- **Rule 1** (Formalization of the Relationship between CE and Situation):

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

  Given Dom (cei)= {di1, di2, ..., diMi}, where Mi=$|Dom(ce_i)|$, the set E is defined as the set of all contextual elements with their associated values:

  E= {ce1=d11, ..., ce1=d1M1, ce2=d21, ..., ce2=d2M2, ..., cen=dn1, ..., cen=dnMn}

  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. Note that 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 the purpose of 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.

The problem addressed by this thesis is related to the automation of dynamic process adaptation in a context-aware basis. The concepts related to context and business processes were identified and correlated. In order to propose how automation of dynamic process adaptation is to be done, context concepts, computationally speaking, are discussed, in context-aware information system design, so as to identify, theoretically, what statements for designing an adaptive system are relevant to support efficiently organizational work.

3.4. A design theory for Context-Aware Information Systems

In order to operationalize context and business processes concepts considering their automation in a PAIS, i.e., an environment technically supported, the theory-driven design proposed by (PLOESSER, 2013) was addressed as a conceptual foundational for Context-Aware Information Systems (CAIS).

PLOESSER (2013) observes that, although, the concept of "context" has received much attention in the reference fields of the Information Systems (IS) discipline, the measures that must be undertaken to arrive at systems that behave as context-aware are still unclear. The author argues that different assumptions and conceptualizations of context and systems, in turn, have led to different prescriptions regarding the construction of context-aware systems. The topic of context has received some consideration in research streams that are generally associated with IS, such as process modeling (BESSAI *et al.*, 2008; ROSEMANN and RECKER, 2006; SAIDANI and NURCAN, 2007), contextualization and improvement of business processes (RAMOS and SANTORO, 2010; ROSEMANN *et al.*, 2008), and context in PAIS (HALLERBACH *et al.*, 2009). While each contribution makes statements about specific design problems, they do not generalize to prescriptive guidelines for the design of context-aware IS. Therefore, an explicit understanding and study of the system context is instrumental in developing more effective systems and, in particular, systems that adapt to context changes.

Considering these issues, PLOESSER (2013) proposes a theory-driven design of CAIS as a set of prescriptive statements. Ploesser created guidelines for the design of CAIS starting with a set of meta-requirements based on the extensions of design propositions for work system theory (ALTER, 2009) and theory of adaptive systems (ACKOFF, 1971) towards CAIS. The meta-requirements describe the class of design problems addressed by information system design theory, which is a special kind of theory that explains artefacts as instances of a generalizable class of design problems and their resolution by a generalizable class of solutions (WALLS *et al.*, 1992). So Ploesser derived the set of generalizable meta-requirements for the class of CAIS into five meta-requirements (MR) a CAIS should address, as follows:

- MR-01: Increase process transparency by modelling all representation of work system variables and their interdependency.
  - It is related to the work **system** which represents processes, people, data and technology involved.
- MR-02: Increase context awareness by modelling all the relevant work system context variables and their possible values.
  - It is related to **context**-awareness in the work system.
- MR-03: Increase variability by specifying strategies for context behavioral adaptation of the work system.
  - It is related to process **adaptation**.
- MR-04: Decreases latency by specifying efficient and effective triggers to process adaptation, i.e., successfully match contextual situations with behavioral adaptation strategies.
  - It is related to adaptation **activation**.
- MR-05: Increases learning by improving response to context representation and adaptation strategies change and by considering new context.
  It is related to process **learning**.

In the next step, PLOESSER (2013) derived the meta-requirements into a set of meta-design features which describes de properties or features underlying a class of solutions to a given design problem as shown on Table 3.4. The meta-designed features helped the establishment of prescriptions a CAIS needs to implement in order to fully support dynamic adaptation of information systems.

Table 3.4 – Mapping CAIS Meta-Requirements to Meta-design features

MR	Meta-design feature	Problem Solution
MR-01	MD-01. Control perspective MD-02. Function perspective MD-03. Resource perspective MD-04. Data perspective MD-05. Output perspective	The description and manipulation of data from the output view, function view, control view, resource view and data view and their coordination must be done by a CAIS.
MR-02	MD-06. Immediate context layer MD-07. Internal context layer MD-08. External context layer MD-09. Environmental context layer	CAIS should capture context variables and their impact on other variables, the organization and the market.
MR-03	MD-10. Output adaptation strategies MD-11. Function adaptation strategies MD-12. Control adaptation	CAIS needs to have a definition of the strategy implementation. Adaptations may vary from: its reason (internal or external), the desired focus

MR	Meta-design feature	Problem Solution
	strategies MD-13. Resource adaptation strategies MD-14. Data adaptation strategies	of adaptation and the system work viewpoint. So, adaptations type may refer to: • Self-self adaptation strategies: Adaptation of the system to a system-internal change. • Self-other adaptation strategies: Adaptation of the environment to a system-internal change. • Other-self adaptation strategies: Adaptation of the system to an environmental change. • Other-other adaptation strategies: Adaptation of the environment to an environmental change. Furthermore, Ploesser defined 11 adaptations strategies that represent the set of capabilities that should be supported by a CAIS.
MR-04	MD-15. Response activation rules MD-16. Reaction activation rules MD-17. System act activation rules	CAIS must allow: • Manual, semi-automated and automated adaptations. • Context-driven activation of adaptation plans based on ECA rules.
MR-05	MD-18. Single-loop context learning MD-19. Double-loop context learning	A CAIS must have an ability to increase its efficiency under constant conditions. The learning strategies are: • Improving context representations: Modifies context information and theirs properties and interdependencies. • Improving adaptation strategies: Modifies context adaptation strategies in accordance with the difference between expected and obtained outcomes. • Transforming context representations: Transform context specification by identifying new context factors or deprecating old ones. Transforming adaptation strategies:

MR	Meta-design feature	Problem Solution
		Continuously innovating how a system adapts to the context.

Ploesser mapped the constructs in the extended work system model (WSM) proposed by ALTER (2009) to entities in an ER model that can be used to specify CAIS behavior as shown in Figure 3.8. The description of each concept can be found in (PLOESSER, 2013) and is used as a theoretical foundation further on this research work.

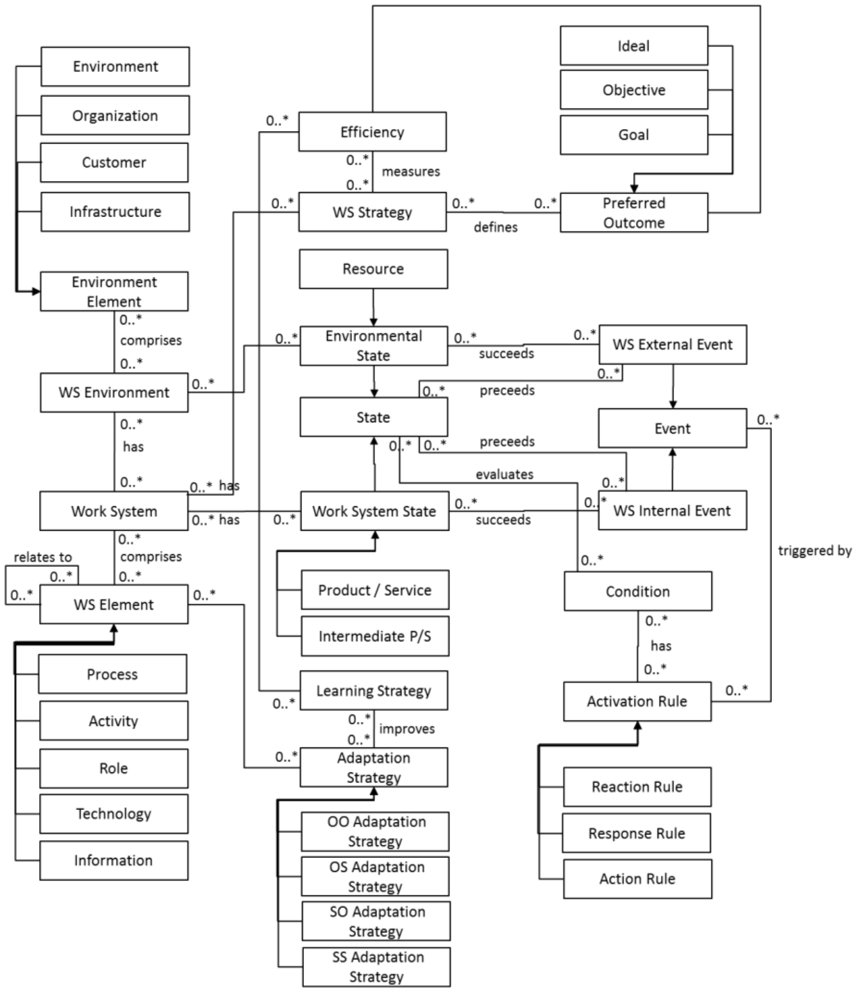

Figure 3.8 - Extended WSM Metamodel (with SSC Constructs) (PLOESSER, 2013)

The author has empirically validated his proposal through testable design propositions about the information system design theory (supported by GREGOR and JONES, 2007) although it has not been tested from the implementation point of view.

PLOESSER (2103) concludes his work, raising some important questions that are addressed is this thesis:

- Context information is an important factor in system design because it enables the rapid adaptation of work environment to context change. So it is important to think contextually speaking when designing any system that needs to be context-aware, including PAIS approaches, which are the type of information systems of interest in this research.
- Context indeed impacts on both technical and social components of information systems and may characterize the reduction of organization’s ability in meeting work objectives. It is important, therefore, to understand its concepts in relation to systems and its contribution to work efficiency and efficacy.
- Context change impacts both on information systems and its social component parts. System decisions in response to context that affect the technical system must be aligned with corresponding changes to the social system. It is important to notice when considering an adaptive system that is process-oriented. The nature of adaptation may vary and is not only concerned with the workflow but also with how interactions occur during a task execution.
- System changes must enable rapid adaption of information systems to context change so as to recover from a loss in performance. It is believed that the automation in recognizing the nature of adaptation and providing the necessary guidance in a dynamic environment is crucial when considering complex work that are to be aware of a lot of data that can potentially be used to reason over work´s performance.

MR-03 involves the definition of strategies for implementing context reasoning, which constitutes the kernel of this thesis. So, a critical analysis on related work about dynamic adaptation implemented by PAIS and AI approaches is presented in the next chapter.

4. RELATED WORK

This chapter presents PAIS approaches aimed at supporting, systematically and technologically, dynamic process adaptation. The goal was to identify and understand those approaches, and how they implement dynamic process adaptation. Next, it is discussed approaches that use Artificial Intelligence (AI) planning techniques as a mechanism for adaptations from the previous process plan in action. Those approaches are analyzed in relation to the four integrated aspects considered in Chapter 2. They are analyzed and requirements needed for their processing are discussed.

4.1. PAIS dynamic adaptation approaches

Among the PAIS proposals that deal with different types and levels of adaptation stand out: YAWL (AALST and HOFSTEDE, 2005), FLOWer (DUMAS *et al.*, 2005), Declare (PESIC *et al.*, 2007), ADEPT (REICHERT and DADAM, 2009) and AristaFlow (LANZ *et al.*, 2010). They were classified according to the four types of flexibility discussed by SCHONENBERG *et al.* (2008) and detailed in Chapter 2 (Section 2.1): flexibility by design time, flexibility by deviation at runtime, flexibility by under specification and flexibility through change.

YAWL[2] is a PAIS that supports the workflow language also named YAWL (Yet Another Workflow Language) based on workflow patterns[3]. 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. For each process component (worklet) that can be anticipated, it is possible to define an exception handling process (enabled through the use of ripple-down rules), which includes a number of exception handling primitives (for removing, suspending, continuing, completing, failing and restarting a work item, i.e., a task) and one or more compensatory processes in the form of worklets.

FLOWer, which evolved to Perceptive Workflow, as part of the Perceptive Platform[4], is a case-based PAIS used in industry that addresses flexible and knowledge intensive business processes. Case handling focuses on what can be done

[2] http://www.yawlfoundation.org/
[3] http://www.workflowpatterns.com/

instead of on what should be done. Due to these characteristics, it is considered a data-driven workflow system where the control-flow is not the focus, but instead, the products it generates. It allows adaptation at design time and by deviation at runtime controlled manually by the users.

Declare[5] is a declarative approach to business process modelling and execution, and focuses on two main things: tasks to be executed and constraints between tasks. It permits modelers to specify already known constraints, such as incompatibilities between two tasks or a required task if another one is chosen. It is mostly used for loosely-structured processes. It provides support to adaptation at design time, by deviation at runtime, by underspecification (late specification) and by change (allowing the changes in the process model be propagated to the running instances).

ADEPT is an adaptive workflow that has been successful in its application in different areas, particularly in health domain and disaster management. The ADEPT2 technology has been transferred into an industrial product and forms the technological base of the AristaFlow BPM Suite[6]. It provides adaptation at design time, by deviation at runtime and by underspecification (late specification), and by change.

According to SCHONENBERG *et al.* (2008), ADEPT (version 1.0), YAWL (version 8.2b), FLOWer (version 3.0) and Declare (version 1.0), none of them has a broad domain in attendance to flexibility in methods for dynamic adaptation. All of them, specifically, YAWL and AristaFlow, have been improved along the newest versions, providing a more stable workflow adaptation machine. A deeper analysis can be found on (WEBER *et al.*, 2009).

It was observed that a representation of processes to effectively support dynamic adaptation, providing greater flexibility, is still a challenge. Flexibility related to rules, roles, systems, information, resources, among others, is still an open research topic. In other words, dynamic process adaptation should involve not only the control flow, but also process elements, such as business rules, roles, artifacts (inputs and outputs), systems and other resources (Aalst and Hofstede, 2005). But dynamic process adaptation has been incorporated into PAIS recently and up to now it does not permit all types of flexibility.

Besides, related to the change in process instance model structure, PAIS approaches that deal with some level of flexibility already treat inconsistencies that arise when changing parts of a running process, therefore, a CMS should be aligned with it when suggesting or performing a process adaptation. Process adaptation may

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[4] http://www.perceptivesoftware.com/
[5] http://www.win.tue.nl/declare/
[6] http://www.aristaflow.com/ and http://www.aristaflow-forum.de/

still represent an additional risk to the integrity of systems, since errors can be masked or delayed and made more challenging its adherence to organizational reality.

In process adaptation, not only the circumstances that are occurring must be considered (SAIDANI and NURCAN, 2007), but also the understanding of how these conditions affect the process (XU and RAMESH, 2008). However, there is no efficient technology to support this yet (JAUFMAN and MÜNCH, 2005). In some situations, it is not even possible to know in advance how the process should behave. Flexibility should be provided on the fly, based on what is known about the organizational processes and domain.

Finally, although rule-based adaptations are (or should be) in line with organizational goals and desires, PAIS flexibility reasoning is not directly in tune with this perception of efficiency and efficacy in the analyzed proposals. The way the process itself is conducted is just as important for the organization as it is to complete and delivery its intended products.

In order to enhance PAIS abilities to dynamically adapt process instances, this thesis aims at improving context-awareness about the organizational environment in which a process instance is inserted so as to reason more autonomously and intelligently. In the next section automated planning techniques are discussed so as to act as the reasoning mechanism that considers the process in organizational context (transformed into domain and problem representations) as a whole to infer the expected outcomes of a sequence of tasks.

4.2. Planning-Based Approaches

The dynamic process adaptation problem can also be viewed as an AI planning approach (MARRELA *et al.*, 2012) by specifying activities as primitive and complex actions with preconditions and effects, the goals they must achieve and organizational desires. The AI planning task is to find a plan or a sequence of actions, based on an initial state, which achieves the defined goals and desires. And the goal of using AI automated planning in dynamic process adaptation is to allow the business processes to respond to new events, trying to satisfy as many specified goals and preferences as possible.

The AI community, in particular the planning and scheduling field, has applied successful techniques in different and complex domains like robotics, satellites or military. In these domains, there are activities that must be performed (planning) in a temporal perspective that consume or produce resources (scheduling). During execution, completion of activities, delays and other problems are detected to take the appropriate measures (rectify the situation, or in more drastic cases, a new plan) to satisfy the goals (R-MORENO *et al.*, 2007).

Recently, some approaches have been applied to process adaptation. MARRELA *et al.* (2012) proposes the use of PLANLETS associated to YAWL, which are self-contained YAWL specifications (worklets) with pre-conditions, desired effects and post-conditions that don´t make it necessary to explicitly define policies at design time. Planlets covers on automatic process flow adaptation at runtime, to handle exceptions that do not need any human interaction. It assumes dynamic adaptations management to be integrated in the PAIS. Although it makes use of planning techniques, the focus of this research is to find the worklet that best complies with the situation for the activity that is to be executed next. It does not reason over the entire process in a broader perspective to find out the best option for adaptation of the instance as this thesis argues.

A motivation for automated planning is very practical: planning is concerned with choosing and organizing actions based on changes in the state of a work system without the need to specifying and maintain adaptations rules. It is able to reason over the environment variables, possible actions, policies, constraints, goals and preferences that are activated in one specific moment. And this information is the one that a PAIS already deals without the burden of maintaining more rules and constraints.

4.3. Analysis and Challenges

The approaches were analyzed considering the dynamic process adaptation perspectives discussed on Section 2.2.1, as summarized on Table 4.1.

Table 4.1 - Analysis of the implementation of dynamic process adaptation perspective in the described approaches

Flexibility in time of adaptation	Perspective of adaptation	Decision making support	Support for the maintenance of the quality of adapted models
YAWL			
At design-time, by deviation, by underspecification and by change.	Works with control flow perspective.	Rule-based	Through the use of quality rules.
FLOWer			
At design-time and by deviation.	Works with control flow perspective.	Rule-based	Through the use of quality rules.
Declare			
At design-time, by deviation, by underspecification and by change.	Works with control flow perspective.	Rule-based	Through the use of quality rules.
ADEPT and AristaFlow			
At design-time, by deviation (manually by adding, removing and moving process steps, by underspecification and by change	Works with control flow perspective.	Rule-based	Through the use of quality rules.
PLANLETS			
By deviation (compensation process calling).	Works with control flow perspective supported by YAWL.	Planning techniques at activity level	Through the use of quality rules supported by YAWL.

By analyzing the presented approaches some issues that this thesis intends to address were identified:

- A variety of information, perspectives and reasoning dispersed among people and between people and systems was noticed, in which a series of circumstances are translated in work adaptation needs. However, there is not a clear direction on how to identify and deal with the relevant business aspects that influence process design and execution.

  This thesis makes use of context concepts related to business processes concepts that are, by nature, goal oriented, and proposes an operationalization of them in a planning domain and problem perspective.

- All the presented PAIS support decision making for dynamic process adaptation through the use of adaptation rules. It constitutes an increase in business process management efforts since adaptation rules are formed based on relevant information for organizations and already constitutes the representation of organizational specific domain of use. Nevertheless, it would be unfeasible to foresee all possible adaptation rules at design time and because of its dynamicity, they may vary frequently. So the reasoning over organizational domain representation and its current status and goals, decreases process management efforts while increases the adherence to organization's domain of knowledge.

  This thesis argues that it is possible to represent organizational domain and processes and reason over them in order to constantly evaluate process instance execution. It also defends that once domain changes, it is not required to reevaluate adaptation rules but to document the domain change, which is something organizations already do. Therefore, AI planning techniques help dynamic process adaptation to adaptively produce plans to support their decisions, as the result of a context-driven planning process, guided by the knowledge represented in the planning domain.
- After discussing context management approaches on Chapter 3 and considering it for process adaptation purposes, there is not a systematic support for capture, storage and reasoning of situations that arise while the execution of process instances is being performed, in order to identify adaptation needs addressing current organization's needs, and to create a body of knowledge about the organizations processes. And one of the first requirements for a worthwhile dynamic adaptation is to be automatic and proactive.

  Therefore, in order to leverage this challenge, this thesis proposes the development of a CMS (Context Management System) theoretical architecture for business process adaptation (to be coupled to a PAIS engine), that provides the following services: (1) assistance in the task being performed, for example, alert the user about actions that he/she must perform, or recommend existing resources related to the task; (2) perception of context, which refers to notifying the user of situations, people and interactions of his/her interest related to the running task, supporting the coordination of their own actions; (3) process adaptation or process behavior variation (in response to the occurrence of a situation), responding in a timely manner to changes in the environment and the actions of users; (4) presentation and dissemination of process adaptations to participants; (5) a continuous and proactive learning ability over the results of process instances; (6) other services such as the use of context to semantically enrich the knowledge manipulated in the process.

- AI planning is also an alternative to maintain adaptation rules which change and evolve over time. But most of the approaches rely on the fact that, when a change occurs, it is related to the problem definition and not on the domain definition (LEONI, 2009).

  In this thesis, it is claimed that domain (processes, components, constraints, rules, and policies) is always in constant evolution (domain change may even come from outside of the organization), and so forth, it may also be modified, demanding planners to reason over it, and re-plan process instances.

  Also, the analysis of situations that happen on a recurring basis may serve as input for process improvement, demanding changes in the process structure and the studied approaches are mostly not prepared for it. Structured processes are supposed to behave as a default procedure. So if an adaptation occurred from the original model, it is not to be considered just a deviation, but a situation that needs to be analyzed afterwards.

  PAIS are not systems that deal with a set of activities that may be performed in many ways, but with structured processes. In this scenario the process efficiency as a single strong business unit is to be considered when a situation occurs, i.e., a change in the domain (process, organizational business and demands, politics, etc.) needs to be considered in the process as a whole.

This thesis supports the argument that business processes should be aware of the context information. The more relevant information concerning the execution of the business process, the better we will be able to prevent an undesired situation to happen, and also the better we will be able to respond if a bad scenario actually occurs. So, in the next section, GCAdapt is proposed, a Context Management infrastructure to systematically treat the life-cycle for dynamic process adaptation and evolution based on context using AI planning during process decision reasoning.

5. GCADAPT: CONTEXT MANAGEMENT FOR ADAPTATION

This chapter presents the concepts related to context, process and CAIS are specialized and extended when needed, in order to operationalize it in the form of GCAdapt, a dynamic process adaptation architecture to support context-awareness in a PAIS approach.

In order to represent the specialized concepts and procedures, all diagrams that are related to the thesis were modeled using UML notation through the use of Astah (ASTAH, 2013). The business process, from the example scenario described in this chapter, was modeled using the software BizAgi Process Modeler (BizAgi)[7] with the Business Process Model Notation (BPMN)[8]. BPMN is a workflow based language that models business process based on flows of task and data and is in compliance with the concepts proposed on Chapter 3.

Sections 5.1 and 5.2 presents the conceptual model and rational for building GCAdapt. Section 5.3 describes the design of architecture modules. Finally, Section 5.4 presents some details of its implementation within a specific PAIS (YAWL) and the interface with the planner.

5.1. Operationalization of concepts and procedure

5.1.1. The operationalization of concepts

Based on the theory-driven design proposed by PLOESSER (2013) for CAIS and the Multilayer Context Metamodel proposed by MATTOS *et al.* (2012), a class diagram, depicted in Figure 5.1, relates the main concepts and relationships addressed in this thesis.

[7] http://www.bizagi.com/
[8] http://www.bpmn.org/

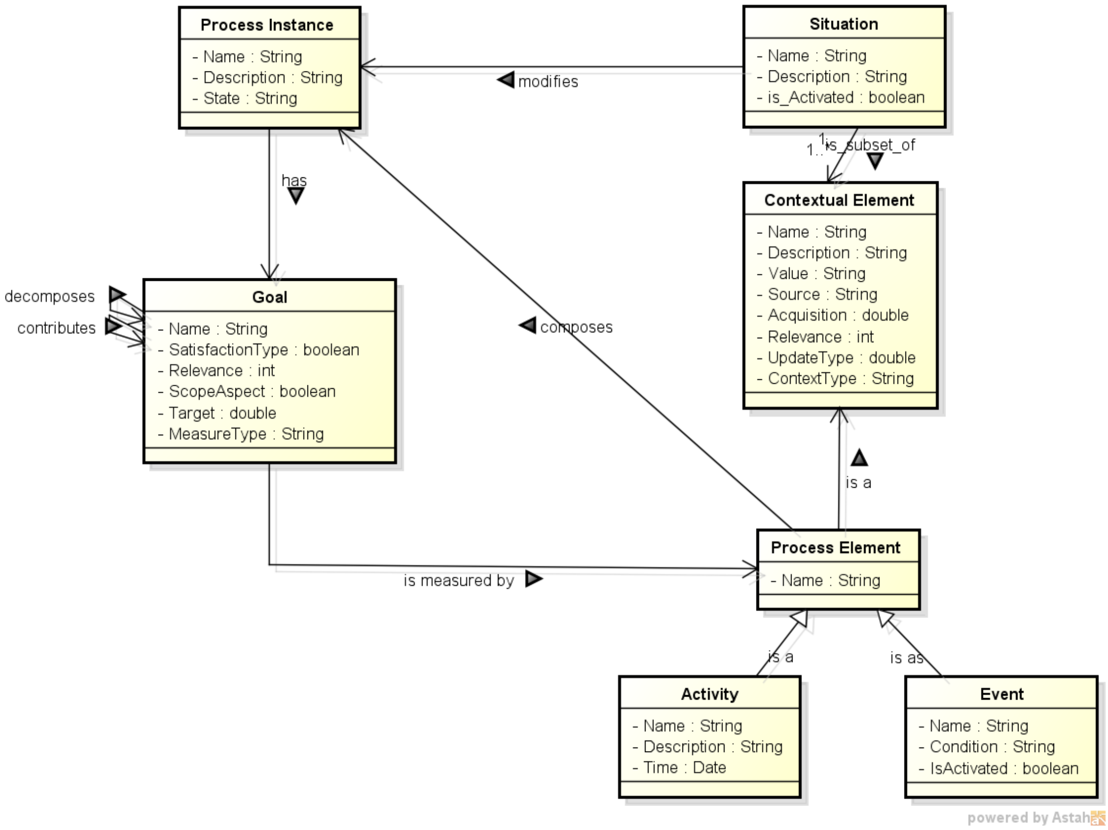


Figure 5.1 - Main Goal-Process-Context concepts correlated

A **Process Instance** represents one specific execution of a process and it has one or more **Goals** (from (PLOESSER, 2013)) to achieve. A Process Instance is composed of a number of **Process Elements** (from (MATTOS *et al.*, 2012)) which are all the concepts represented in the Business Process Metamodel (the concepts Activity and Event were represented in the figure). Each Process Element value (data value and resource status for example) can be a **Contextual Element** (from (MATTOS *et al.*, 2012)) (depending on its relevance to the process monitoring). A set of specific Contextual Element values (or range of values) constitutes a **Situation** (from (MATTOS *et al.*, 2012)) that marks the need to modify and re-plan the process instance in a specific time.

Then it was defined a set of prescriptive statements based on (PLOESSER, 2013) in order to derive GCAdapt. It is assumed that a PAIS is a special case of a CAIS, in which all the properties defined in (PLOESSER, 2013) are valid.

So an extension of Ploesser's work based on the analysis of the operationalization of the context-process concepts already discussed was made. Table 5.1 shows the requirements of the derived meta-requirements presented on Chapter 2 and their extensions in order to attend to our approach.

Table 5.1 - Mapping CAIS Design Theory meta-requirements to context-aware PAIS

MR	Properties for CAIS	Extended Properties for a context-aware PAIS approach
MR-01	Concerns to system transparency (system behaviour component) • Increase transparency by describing tasks performed by a system and their interdependencies • Increase transparency by describing technology used to convert inputs by system participants • Increase transparency by describing organization hierarchy, units, and roles relevant to a System • Increase transparency by describing the identity, availability, skill sets and relationships of people.	• Improve awareness of the relationship among processes and respective intended goals and desires.
MR-02	Concerns to Context awareness (system context component) • Increase awareness by describing variables in the immediate context and their impact on Work • Increase awareness by describing variables in the internal context and their impact on Work • Increase awareness by describing variables in the external context and their impact on Work • Increase awareness by describing variables in the environmental context and their impact on Work • Understand interrelationship of variables	No extension
MR-03	Concerns to System preparedness (Adaptation Strategy Component) • Increase preparedness by defining how tasks are modified in response to a change in context • Increase preparedness by defining how technology is modified in response to a change in context • Increase preparedness by defining how structure is modified in response to a change in context • Increase preparedness by defining	• Increase preparedness by defining how tasks, technology, structure and people are modified in response to a change in context. • Define strategy implementation.

MR	Properties for CAIS	Extended Properties for a context-aware PAIS approach
	how people are modified in response to a change in context	
MR-04	Concerns to System responsiveness • Increase responsiveness by defining rules and thresholds for activating strategies in situation (Context-driven activation of adaptation plans)	No extension
MR-05	Concerns to System learning • Increase relevance of adaptation plans by measuring discrepancy between plan and Outcome (Single-loop learning) • Increase relevance of adaptation plans by questioning the parameters that guide selection of plan (Double-loop learning)	No extension

Based on the meta-requirements, the next steps were:

1. The definition of meta-design features (which describes the properties or features underlying a class of solutions to a given design problem) helped us to analyze the concepts and theirs relations previously proposed.
2. The meta-requirements were used as a base to define the implementation of those requirements that a PAIS and the GCAdapt need to do to be able to support.
3. The adaptation strategies proposed by Ploesser, which represent the set of capabilities that should be supported by a CAIS, were addressed and extended to be supported by a PAIS and GCAdapt.

1. Definition of meta-design features

PLOESSER (2013) derived the meta-requirements into a set of features that solve the specified problems. Then he derived the meta-requirements to the representation of the concepts manipulated in the work system. Table 5.2 shows the differences in the current proposal in relation to the original. Ploesser's work was used as a basis to analyze de feasibility of the concepts defined and their correlations. Although his work is not exhaustive, we claim that his research provides a strong foundational basis to work on CAIS conceptual definitions and requirements.

The concepts manipulated in MR-01 are related to the Process Domain Metamodel, which are all Work System elements. But Ploesser does not define their independencies or explore the business process concepts necessary to a process-aware perspective. So another meta-design feature is proposed (MD-06 – Goal perspective) able to capture the events that occurred, the process instance characteristics, and the status (process elements values) to verify process goals. Ploesser defines the goal concept that is related to a preferred outcome defined by a Work System Strategy. In this thesis, Goal is the preferred outcome of the result of an activity and a process instance execution. A process represents the formalization in steps of an organizational strategy, so both concepts are correlated in the same way.

Regarding MR-02, Ploesser proposes the categorization of context into four layers according to ROSEMANN *et al.* (2008): immediate context, internal context, external context and environmental context. He also argues the model of context interdependencies. In this thesis, from the design point of view, contextual elements, no matter their category, are handled in the same way. Ploesser also defines that a Work System has a Work System Context and a Work System Environment and that the decomposition of its Work System elements represent the contextual data (a.k.a contextual element) from the Immediate Context layer (concerning the Work System) and the three other layers concerning Work System (intra and extra organization) Environments.

Related to MR-03, Ploesser proposes modification of the elements presented in the work system. In this thesis, also, all process elements known by the PAIS can be adapted (according to rules and constraints). According to Ploesser an event may trigger the adaptation (through an adaptation strategy that has a condition that activates a rule) of a CAIS modifying its state. In this thesis, Situation is treated not as an event, but as a sub-set of context variables that may trigger a change in the organizational domain and problem, and the need to re-plan the process. So adaptation strategies activation is different from that proposed by Ploesser. In this thesis, AI Automated Planning is used so as to reason over domain and problem changed by the Situation to select the best adaptation strategy to achieve intended goals.

Regarding MR-04, the meta-design features are related to act over the problem solution on the defined concepts. Once an adaptation is activated, PAIS must be able to recognize and execute it. Finally, MR-05 when dealing with the consequences of adaptations into the work that were done, inputs a need for GCAdapt to increase its efficiency in support context-awareness to a PAIS by implementing the learning strategies proposed by Ploesser.

Table 5.2 - Mapping CAIS Design Theory Meta-Design feature concepts to context-aware PAIS proposed concepts

MR	Meta-design Features (MD)	PAIS + GCAdapt
MR-01	**MD-01. Control perspective** **MD-02. Function perspective** **MD-03. Resource perspective** **MD-04. Data perspective** **MD-05. Output perspective**	GCAdapt must represent the description of the goals perspectives related to the perspectives proposed by Ploesser: **MD-06 – Goal perspective (goals, tasks, technology, structure, people)**
MR-02	**MD-07. Immediate context layer** **MD-08. Internal context layer** **MD-09. External context layer** **MD-10. Environmental context layer**	CE´s from any layer are to be operationalized in the same way (contextual data) by GCAdapt.
MR-03	**MD-11. Output adaptation strategies** **MD-12. Function adaptation strategies** **MD-13. Control adaptation strategies** **MD-14. Resource adaptation strategies** **MD-15. Data adaptation strategies**	The activation of adaptation strategies is proposed to be done through the use of AI automatic planning techniques adopted by GCAdapt.
MR-04	**MD-16. Response activation rules** **MD-17. Reaction activation rules** **MD-18. System act activation rules**	PAIS gets the adaptation strategy from the GCAdapt and executes it accordingly.
MR-05	**MD-19. Single-loop context learning** **MD-20. Double-loop context learning**	GCAdapt must implement learning strategies.

2. Definition of meta-design prescriptions

The meta-design features helped the definition of requirements that a CAIS should implement in order to fully support dynamic adaptation of information systems. Those definitions make explicit how a PAIS should work together with GCAdapt, as shown in Table 5.3.

First it is important to notice that in this approach, PAIS remains an independent environment. In the same way, GCAdapt is an independent system that might communicate not only with PAIS but also with the organizational environment (as Ploesser states, the work system and work system environment), and outside of it.

Table 5.3 - Mapping CAIS Meta-Design prescriptions to a context-aware PAIS

MD	Meta-design prescriptions	Operationalization prescriptions for a context-aware PAIS approach
MD-01 MD-02	The description and manipulation of data from the output view, function view, control view, resource view	In a PAIS all the data manipulated by the process need to be defined, and the rules and constraints for their use must

MD	Meta-design prescriptions	Operationalization prescriptions for a context-aware PAIS approach
MD-03 MD-04 MD-05	and data view and their coordination must be done by a CAIS.	be stated. PAIS must take care of the implementation of this associated meta-requirement. PAIS must be responsible for: • Allowing the modeling of processes (activities flow, roles, documents, data, etc); • Supporting the definition of process components, i.e., a set of self-contained workflow with associated constraints and selection rules in relation to the (standard) process. • Addressing dynamic flexibility in an automated extent.
MD-06	The description and manipulation of data from the goal perspective must be done by the GCAdapt.	A PAIS, by definition, is concerned with process execution. But goal should be defined and modelled. It can also be associated to the PAIS implementation but this is not a demand. In order to keep a PAIS straight to its proposed use, GCAdapt must be responsible for: • Allowing the definition and/or modeling of processes goals considering the properties and relations proposed; • Associate processes to goals considering the properties and relations proposed;
MD-07 MD-08 MD-09 MD-10	CAIS should capture context variables and their impact on other variables, the organization and the market.	GCAdapt is responsible for: • Maintaining the model of context variables (i.e., contextual elements) and theirs interdependencies; • Specifying and managing the context Repository containing de definition of contextual elements and Situations.
MD-11 MD-12 MD-13 MD-14 MD-15	CAIS needs to have a definition of the strategy implementation. Adaptations may vary from: it´s reason (internal or external), the desired focus of adaptation and the system work viewpoint. So, adaptations type may refer to:	Situation may characterize a change in the actual environment. So Situation rules are to be able to computationally specify these changes for GCAdapt to reason over this new environment, the process instance that is running and its demanding goals to be achieved.

MD	Meta-design prescriptions	Operationalization prescriptions for a context-aware PAIS approach
	• Self-self adaptation strategies: Adaptation of the system to a system-internal change. • Self-other adaptation strategies: Adaptation of the environment to a system-internal change. • Other-self adaptation strategies: Adaptation of the system to an environmental change. • Other-other adaptation strategies: Adaptation of the environment to an environmental change. Furthermore, Ploesser defined 11 adaptations strategies that represent the set of capabilities that should be supported by a CAIS.	So GCAdapt must be able to: • Select contextual elements elected from a Situation emergence. • Reason over adaptations in relation to process's goals based on the possible adaptations strategies. • Decide the adaptation to be implemented in the process instance. In relation to the adaptation type: • Self-self adaptation strategies: GCAdapt monitors, decides and sends to PAIS order to adapt the process instance. • Self-other adaptation strategies: GCAdapt monitors decide and may send to the environment (to a device or via communication) the order to adapt the respective environmental items. • Other-self adaptation strategies: GCAdapt monitors, decides and sends to PAIS order to adapt the process instance • Other-other adaptation strategies: GCAdapt monitors, decides and may send to the environment (to a device or via communication) the order to adapt the respective environmental items. PAIS should to be able to implement the 11 adaptation strategies in process instances to be fully adaptable. But GCAdapt must know what adaptation strategies a specific PAIS may support.
MD-16 MD-17 MD-18	CAIS must allow: • Manual, semi-automated and automated adaptations. • Context-driven activation of adaptation plans based on ECA rules.	GCAdapt may support automated and semi-automated adaptation and send the order to PAIS to implement or send the suggestion to the process manager to decide. PAIS is responsible for allowing manual adaptation.
MD-19	A CAIS must have the ability to increase its efficiency under	GCAdapt must implement learning

MD	Meta-design prescriptions	Operationalization prescriptions for a context-aware PAIS approach
MD-20	constant conditions. The learning strategies are: • Improving context representations: Modifies context information and theirs properties and interdependencies. • Improving adaptation strategies: Modifies context adaptation strategies in accordance with the difference between expected and obtained outcomes. • Transforming context representations: Transform context specification by identifying new context factors or deprecating old ones. • Transforming adaptation strategies: Continuously innovating how a system adapts to context.	strategies: • To improve the identification of modification on the actual context model. • To improve context rules over the environment. • To identify new contextual elements and deprecated ones and theirs interdependencies with the existing ones.

3. Definition of adaptation strategies

The eleven adaptation strategies proposed by PLOESSER (2013), which represent the set of capabilities that should be supported by a CAIS, were addressed and extended to be supported by a PAIS and GCAdapt. The strategies are summarized in Table 5.4.

Table 5.4 - Operationalization and extension of Adaptations Strategies

Adaptation strategy (Ploesser)	Operationalization by PAIS and GCAdapt
• The following strategies are related to the change in process control flow.	
(CAF-01) Perform function fragment: Perform a set of actions once or repeatedly in parallel to the normal course of action.	• GCAdapt reasons and decides the flows to be executed. • PAIS executes the selected independent control flows.
(CAF-02) Perform alternative fragment: Select one among a number of alternative courses of action.	• GCAdapt reasons and decides the fragments to be executed. • PAIS executes the changes in control flow.
(CAF-03) Skip function: Skip a particular function that is part of a	• GCAdapt reasons and decides to skip specific activities.

Adaptation strategy (Ploesser)	Operationalization by PAIS and GCAdapt
normal course of action.	• PAIS executes the changes in control flow
(CAF-04) Wait before performing function: Wait before performing a function that is part of the normal course of action.	• GCAdapt reasons and decides to suspend temporally the process instance. • PAIS executes the changes in control flow.
(CAF-05) Wait before completing function: Wait before completing a function that is part of the normal course of action.	• GCAdapt reasons and decides to pause the execution of an activity. • PAIS executes the changes in control flow.
	(CAF-06) Change process constraints and preferences: Change the prep and post constraints of activities. • GCAdapt reasons and decides the control flow among activities based on the changing constraints and preferences. • PAIS executes the changes in control flow.
• The following strategies are related to the change in process data and resource	
(CAR-01) Modify number of resources: Increase or decrease the number of available resources.	• GCAdapt reasons and decides the new number of resources to be used in a specific activity. • PAIS executes the change in the resource data quantity to be used in specific activities. • GCAdapt may inform resource to modify itself or the resource responsible for doing it.
(CAR-02) Modify type of resources: Modify the type of resources allocated to perform a function.	• GCAdapt reasons and decides the new type of resources to be used in a specific activity. • PAIS executes the change in the resource type to be used in specific activities. • GCAdapt may inform resource to modify itself or the resource responsible for doing it.
(CAD-01) Gather different data: Decrease amount of data captured by functions.	Gather different data may note decrease amount of data, instead it could spend the same effort and amount or even increase it. The adaptation is related to the manipulation of another type of data that the default one. • GCAdapt reasons and decides the type of data to be used in a specific activity. • PAIS executes the change in the gathering type of specific data in a specific activity.
(CAD-02) Gather data at a different time: Postpone the point in time at	• GCAdapt reasons and decides other activity where a specific data is to be

Adaptation strategy (Ploesser)	Operationalization by PAIS and GCAdapt
which data is captured by functions.	gathered. • PAIS executes the change in the gathering time of specific data from one activity to another.
• The following strategies are related to the review of process and organizational strategies.	
(CAO-01) Modify output quality: Increase or decrease the quality of outputs produced by functions.	• GCAdapt reasons and decides the change in the quality of the output data. • PAIS executes the change in the output quality.
(CAO-02) Modify output type: Modify the type of outputs produced by functions.	• GCAdapt reasons and decides the change of the type of the output data. • PAIS executes the change in the output type.
	(CAG-01) Redefine goals and preferences: Modify goal relevance and preferences, impact of organizational goals to process goals and activity (or activity fragments). • GCAdapt reasons and decides the process elements that need to be changed. • PAIS executes the change in the process instance.

Before proceeding to the specification of the GCAdapt architecture that implements all the proposed strategies, in the next subsection the procedures for a context-aware dynamic process adaptation are described.

5.2. The procedures

The proposal encompasses a system that supports a context management life-cycle for dynamic process adaptation. The context management life-cycle is an evolution of previous versions presented in (NUNES *et al.*, 2009, 2011a, 2011b, NUNES, 2007, 2011) and is composed by steps divided in two main phases: Design Time and Run Time (Figure 5.2). At design time, the domain infrastructure is elicited and configured. At runtime, the process is running and instances are monitored and adapted according to the defined context.

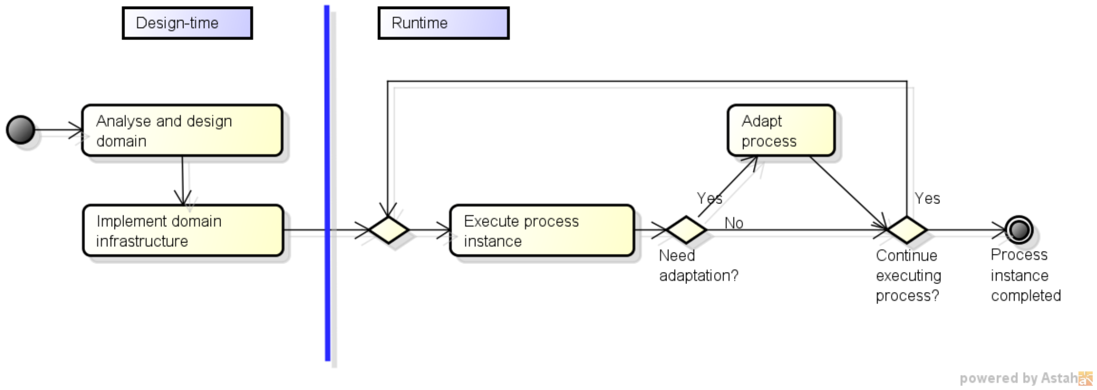


Figure 5.2 - Context Management life-cycle in process

Figure 5.3 presents the steps for the design-time, described in details as follows. It refers to the implementation of organization's context, domain and problem infrastructure.

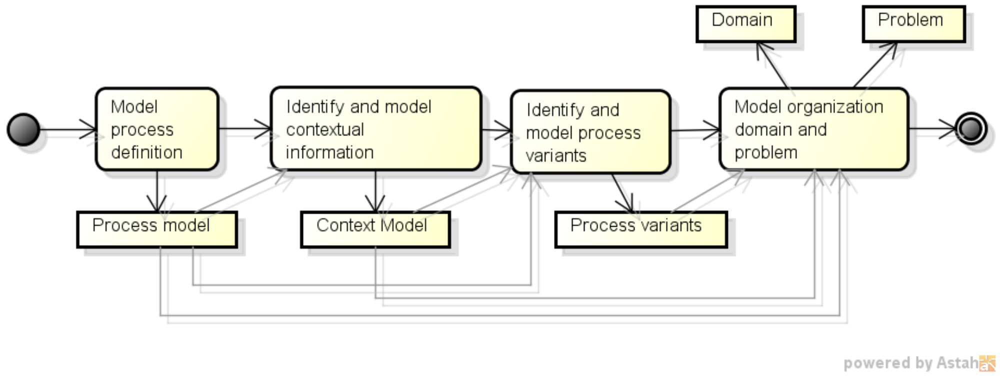


Figure 5.3 - Design-Time steps

Model process definition

The process definition (process model) in a PAIS aims to generate the control flow together with, the semantic relationships between the concepts used in the business processes and thus make possible the use of them for automation. Thus, process goals, policies and constraints are identified and modeled. Consequently, MD-01, MD-02, MD-03, MD-04 and MD-05 are dependent on the PAIS implementation. MD-06 is a feature that GCAdapt must implement.

As an example, suppose an Order Book process modeled in Figure 5.4. The process starts with a (set of) book request from a customer. The seller provides a quote and the customer places his/her order whose availability is checked by the Seller. The customer confirms order and decides payment type. If he/she chooses CC payment method, customer's CC information checked and if accepted customer pays for the items and the Seller delivers de items. If CC is not accepted, the Seller offers to the customer to pay in cash. Of he/she chooses this payment type the seller then delivers the items. Otherwise the purchase is cancelled.

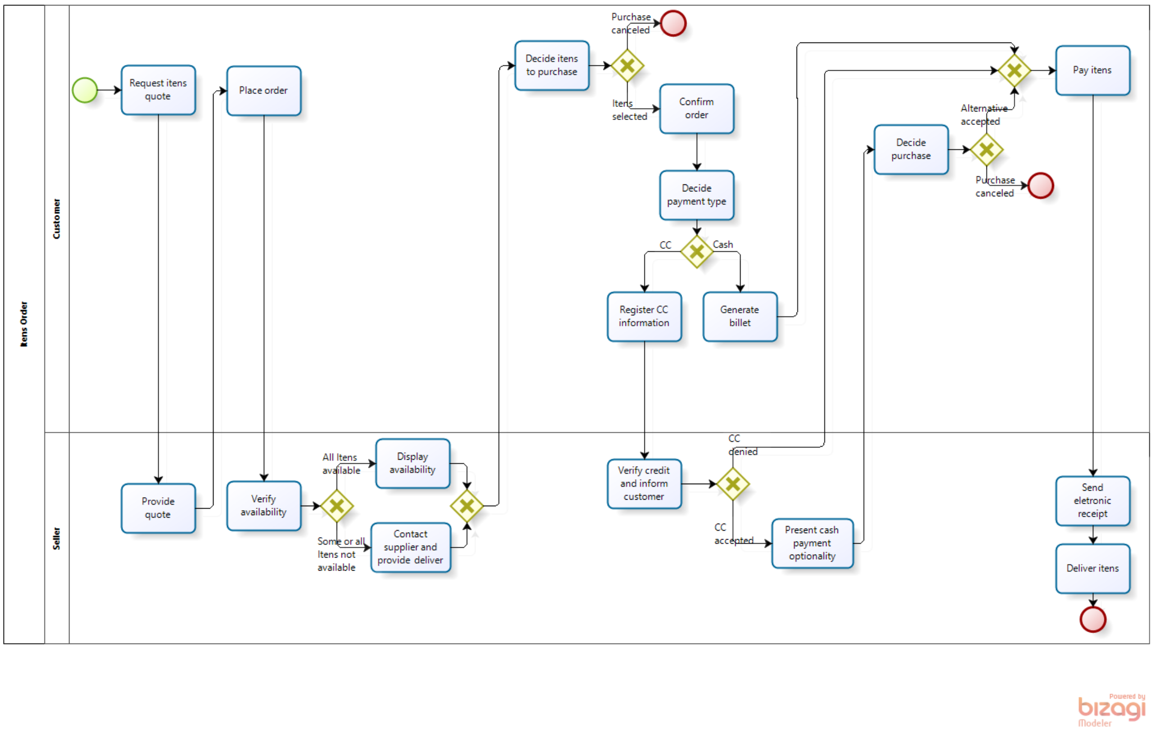


Figure 5.4 - Book Order process model

The goals were modeled using i* notation[9] (YU, 1997), which is a modeling language suitable for an early phase of system modeling in order to understand the problem domain. The i* makes use of notations in the NFR Framework, including softgoals, AND/OR decompositions, and contribution links. It includes tasks, (hard) goals, resources, and dependencies between actors (agents).

Goal models are effective in concisely capturing large numbers of alternative set of low-level tasks, operations, and configurations that can fulfill high-level organizational goals (MYLOPOULOS e CHUNG, 2001) (LIASKOS *et al.*, 2010):

- Goals that correspond to the tasks that must be accomplished (established as a constraint at design time) are represented as hard-goals.
- Goals that correspond to organizational strategies or desires are represented as soft-goals and offers levels of optionality.

The currently book store goals (shown in Figure 5.5 using the open-source requirements engineering tool OpenOME (OpenOME, 2011) (HORKOFF *et al.*, 2011)) are to minimize total costs and minimize delivery time so as to improve customer happiness. The policy that relates to this process establishes that “All premium clients have high priority while product delivery logistics is been planned”.

[9] http://www.cs.toronto.edu/km/istar/

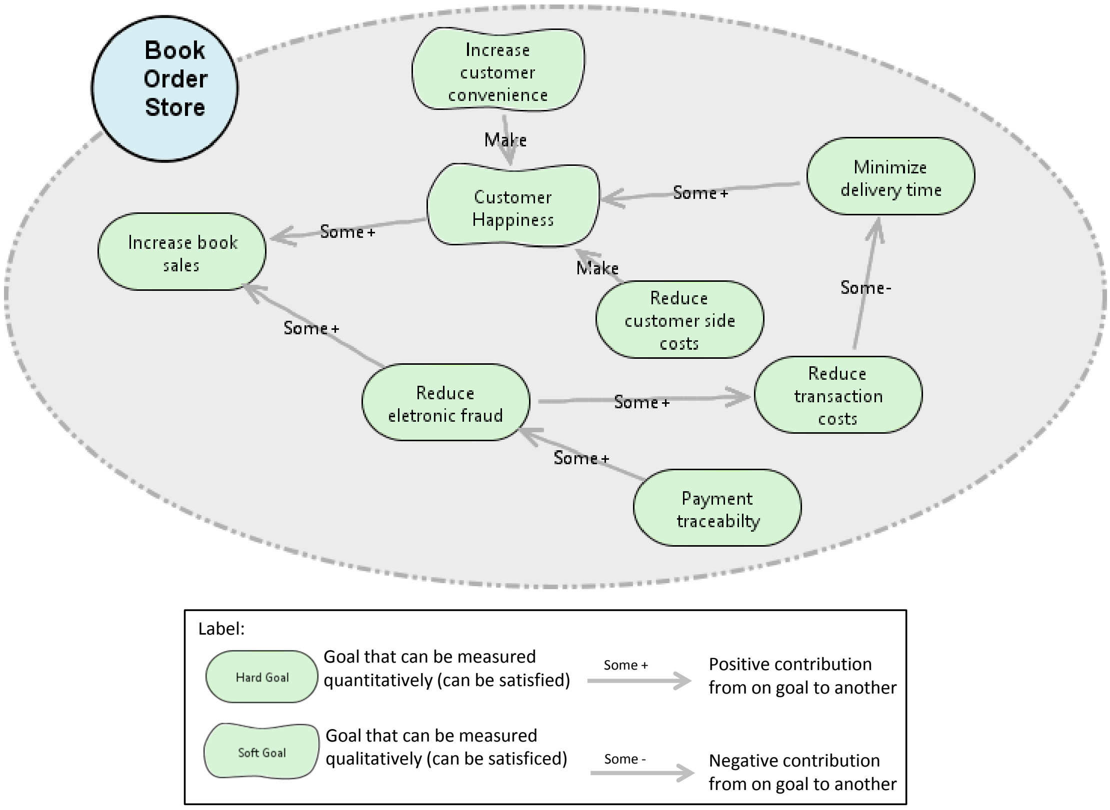


Figure 5.5 - Book Order goals

Identify and model contextual information

From the understanding of the concepts it is possible to identify contextual elements considered relevant to describe the actions that occur, while performing work activities, and characterize (initial) Situations. The element "context model" (structured accordingly to MATTOS *et al.* (2012)'s metamodel) provides an explicit representation of contextual knowledge that is being captured and is represented through the use of GCAdapt. The elicitation of context information defined by MD-07 (as for example, using the method proposed in (ANASTASSIU and SANTORO, 2013), MD-08, MD-09 and MD-10 are to be used to enrich context model.

As for the Book Order scenario, the partial process and context model elements, used in this scenario, are described in Figure 5.6, as shown.

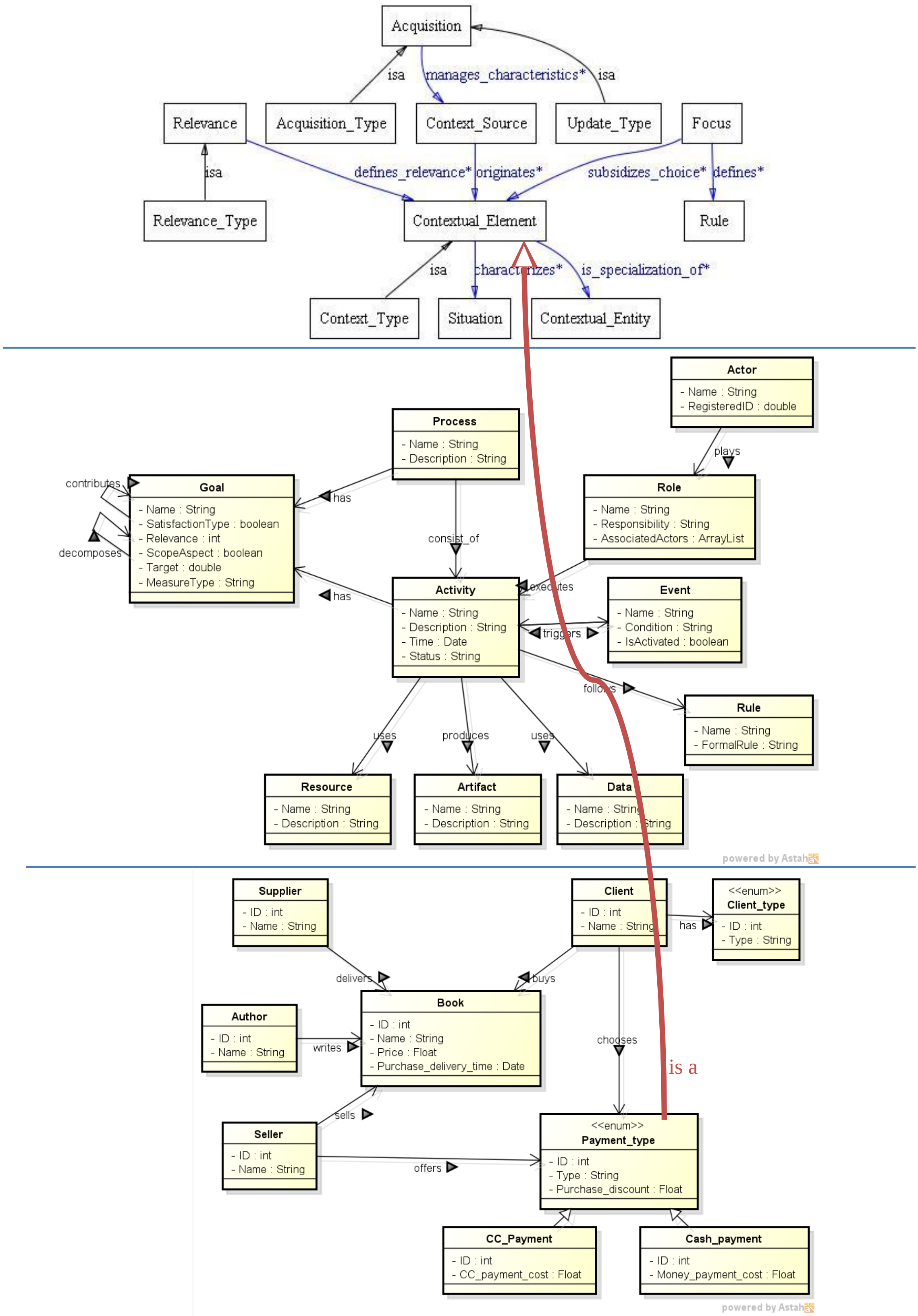


Figure 5.6 - Book Order “to-be” partial view of CEs from process and domain elements.

The Situations already known are elicited. As an example, focusing on the execution of “Decide payment type” activity (DecidePaymentType), if the client chooses to pay by credit card (Total_order = R$800,00) but the credit card company raised the costs (CC_cost_percentage) to 10% of the total order, then a situation S1 is characterized and the process needs to be replanned.

Situation S1 = {DecidePaymentType.Status = completed, CC_cost_percentage >= 10%, Total_order > R$600,00}

Identify and model process variants

Since the core process, goals and possible situations were defined, it is possible to identify what may vary and how. The outcome of this step are process variants, translated into a set of process components, modeled in a PAIS, with its own internal properties, constraints and conditions to get involved with the process definition. It is also related to MD-01, MD-02, MD-03, MD-04 and MD-05 and how a PAIS implements and relates variants for a process.

In the book order scenario, shown in Figure 5.7, a possible variant, in the control flow, activated by Situation S1, is to offer a discount to a specific client to pay in cash and let him decide.

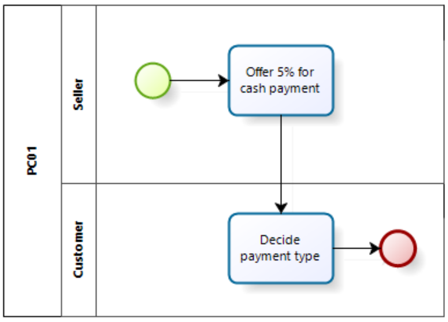


Figure 5.7 - Book Order process component (variant)

Model organization domain and problem

Process definition, process components and contextual information are the basis to construct domain and problem specifications that may be manipulated by GCAdapt, with the support of an AI Planner, so as to replan process instance when needed.

Part of the domain and problem PDDL files that represent Book Order process and Book Store domain are shown in Figure 5.8 and Figure 5.9.

```
(:predicates
    (completed ?a - activity)
    (notcompleted ?a - activity)
    (value ?x - parameter ?v - values)
)

(:functions
    (transactioncost)
)

(:durative-action Request_Itens_Quote
 :parameters ()
 :duration (= ?duration 10
 :condition (and (at start(notcompleted Requestitenssquote)) (at start(value InputCondition true)))
 :effect (and (at end(completed Requestitensquote)) (at end(increase (transactioncost) 4)))
)

(:durative-action  Provide_quote
 :parameters ()
 :duration (= ?duration 5)
 :condition (and (at start(notcompleted Providequote)) (at start(completed Requestitensquote)))
 :effect (at end(completed Providequote))
)

(:durative-action  Place_order
 :parameters ()
 :duration (= ?duration 6)
 :condition (and (at start(notcompleted Placeorder)) (at start(completed Providequote)))
 :effect (at end(completed Placeorder))
)
```

Figure 5.8 - Book Order domain representation

```
(define (problem BookOrder-p1)
(:domain BookOrder)

(:objects
   book7869 - book
   book4567 - book
)

(:init
     (notcompleted Requestbooksquote)
     (notcompleted Providequote)
     (notcompleted Placeorder)
     (notcompleted Payment)
     (notcompleted Verifyavailability)
     (notcompleted Contactsupplier)
     (notcompleted Providebookstoseller)
     (notcompleted Displayavailability)
     (notcompleted Sendprintedreceipt)
     (notcompleted Deliverbookstocostumer)
     (notcompleted Bookavailabilitycheck)

     (value PayType any)
     (value BookAvailability true)
     (value InputCondition true)
     (value OutputCondition false)

     (= (transactioncost) 0)
)

(:goal (and (value OutputCondition true) (completed Deliverbookstocostumer))
)

(:metric minimize (transactioncost))
)
```

Figure 5.9 - Book Order problem representation

With Domain and Problem implementation set, which involves building process architecture and context repository from the artifacts generated at design time in PAIS and GCAdapt, the process is ready to run and possibly be adapted at runtime.

Figure 5.10 presents the steps for runtime, described in details as follows. It describes process execution and adaptation.

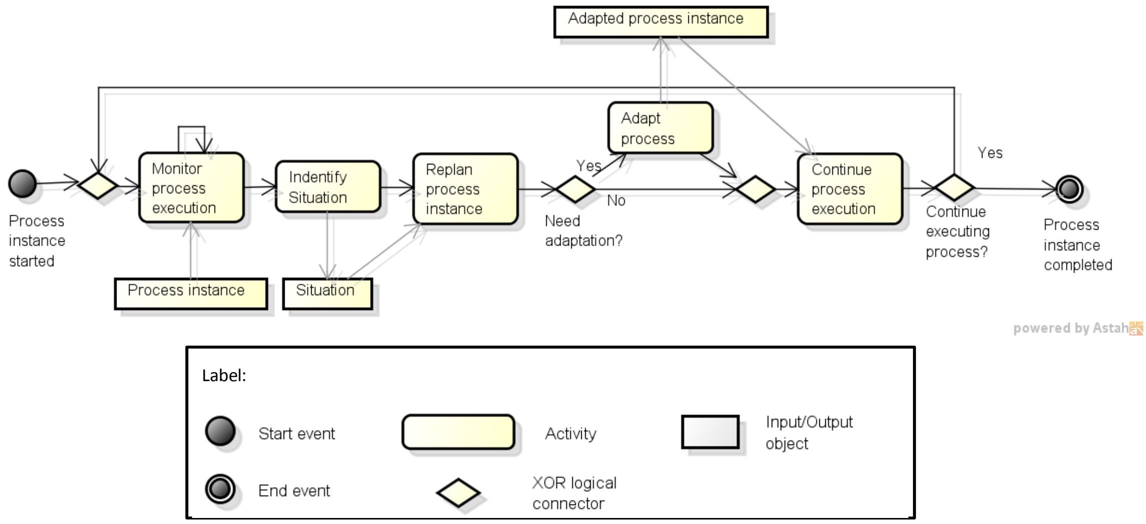


Figure 5.10 - RunTime steps

Monitor process execution

The monitoring of context occurs through the CEs capturing, which can be human or automatically identified by different types of sensors. So, while process instance is being executed, CE´s are being collected and analyzed.

In the example used, an instance of the Book Order process is been executed while client John is purchasing books at the store.

Identify Situation

Context identification occurs from the combination of values of contextual elements (CEs) captured during the execution of process instance activities that triggers process instance replanning.

In Book Order scenario, after the execution of “Decide payment type” activity if the client chooses to pay by credit card (Total_order = R$800,00) but the credit card company raised the costs to 10% of the total order, then a situation S1 is activated.

Replan process instance

Based on the occurrence of the Situation at hand, which may modify the domain and/or the problem through the identification of changes in resources, environmental conditions, policies, constraints, goals, etc., GCAdapt reasons over the new reality and decides for the best proceeding in order to make the process instance more effective. It is related to the implementation of features MD-11, MD-12, MD-13, MD-14 and MD-15.

In Book Order scenario, GCAdapt changes domain representation with the new values for the CE´s and call the Planner. The domain sets that if the cost for credit card payment is over 8% of the total order, then PC01 (shown in Figure 5.7) is activated, so as to try to decrease total costs.

So the new plan states as follows in Figure 5.11. Note that the process instance would be executed until completion, even if the adaptation was not implemented, but the adaptation allowed an increase in customer's satisfaction, and the seller's total purchase cost has decreased considerably.

So, when replanning process instance, GCAdapt tries to fulfill goals and satisfy preferences to its best achievement. It may find more than one possible adaptation, each of satisfying goals in different degrees.

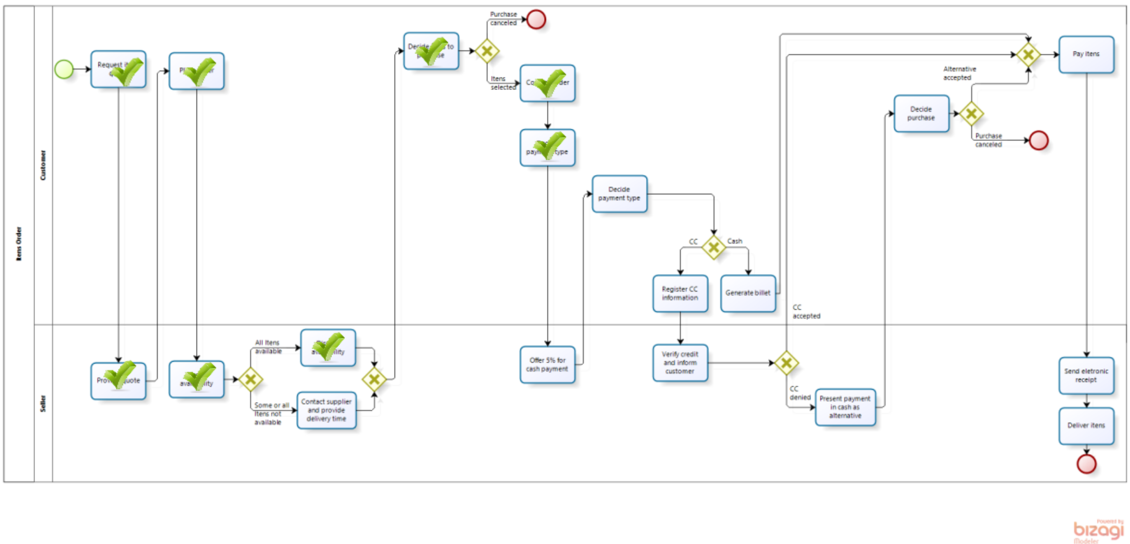


Figure 5.11 - Order Book process replanned

Adapt process

For each identified adaptation, GCAdapt may automatically decide and inform PAIS. The PAIS implements the adaptations accordingly. It is related to the implementation of features MD-16, MD-17 and MD-18.

In the Book Order process, GCAdapt informs PAIS to perform the adaptation for the process instance to act like the plan shown in Figure 5.11.

Continue process execution

Process instance continues its execution and Process execution monitor restarts. Besides, there are also steps, presented in Figure 5.12, that address context evolution considering the results of completed process instances and demands for change by the organization. They are related to the Meta-designs MD-19 and MD-20.

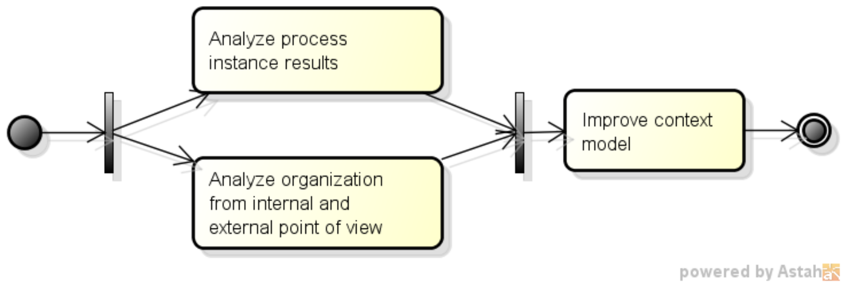


Figure 5.12 - Context Improvement procedure

Analyze process instance results

GCAdapt analyzes the results of processes executed in the PAIS in relation to the situations that happened; adaptations performed and achieved goals, so as to analyze its efficiency.

As an example for the Book Order process, the process manager may verify previous book orders and realize that even offering 5% of discount in cash payment, clients still decide to pay in credit card.

Analyze organization from internal and external point of view

Organization analyzes internal and external information considered relevant and that has some impact on organization’s processes and their interdependencies.

In the Book Store scenario organization may verify that purchases with values superior than R$ 600,00, may be awarded with a 15% discount when paying in cash and still provide a good profit for the organization.

Improve context model

GCAdapt improves context model based on the performed analyses. It is related to the identification, modification and removal of contextual elements and their interdependencies. It is also related to the identification, modification and removal of Situations definition.

In order to computationally support this context management life cycle, in the next section, we present GCAdapt, a dynamic process adaptation architecture, specifying how those requirements are implemented.

5.3. GCAdapt Architecture

GCAdapt is proposed in order to leverage the current BPM life-cycle aiming at supporting dynamic process adaptation through the use of intelligent planning techniques in a context-aware approach. In order to propose GCadapt within those characteristics, it was identified, also based on the CMS approaches studied on Chapter 3, that:

- A layered approach, as discussed in Chapter 3, isolates complexity and allows their treatment in an independent way.
- The centralization of context inference and reasoning, although becoming a bottleneck when dealing with an environment where there are many distributed systems, facilitates the management and reasoning of information.
- Context capture is to be separated from their reasoning/usage in order to enhance the extensibility of CE use capturing mechanisms and its reuse.
- Architectures for context management can be implemented in various ways, but the method and infrastructure (sensors, agents, etc.) used to capture contextual elements are important when defining the architectural style (BALDAUF *et al.*, 2007), because it will set the type and format of data and information in its raw state to be processed.
- It is important to note that, because explicit control is not required, the context capture, storage and processing mechanisms must execute in background so that the user and his/her main tasks are the focus and not the technical issues of context sensitivity (GATTI *et al.*, 2010).
- It is required to capture/acquire (low-level context information) contextual elements directly from the environment. In this sense, a challenge still in vogue is related to how to coordinate the various mechanisms for capturing and retrieving context in heterogeneous environments.
- It is necessary to provide a model of centralized CEs that can be shared across systems, equipment, agents and services that are in the work environment and that represents relevant information to the organization.
- The detection of the need for process adaptation and the decision on what is needed and when it should be performed must happen in a timely manner and become as sensitive as the adaptation of context-sensitive systems, given the strategic and organizational nature of business processes. Furthermore, it should be possible to adapt automatically when necessary.

CGAdapt, a Context Management architecture for dynamic process adaptation (Figure 5.13), was previously presented in (NUNES *et al.*, 2011a, 2011b and 2012). It provides a central server supporting the whole context management life cycle for dynamic process adaptation. The context reasoning engine is implemented separately from the running process through a PAIS approach. Thus PAIS becomes less rigid, more easily maintained, and only concerned with process implementation purposes. The architecture comprises independent services that provide abstractions necessary for the development of distributed intelligence, allows interactivity between capture mechanisms and implementation, having autonomous and proactive behavior.

The architecture has four main components: Aggregator, Mediator, Maintainer and Actuator. It interfaces with a variety of CEs and Context Rules, capturing and implementation mechanisms and PAIS.

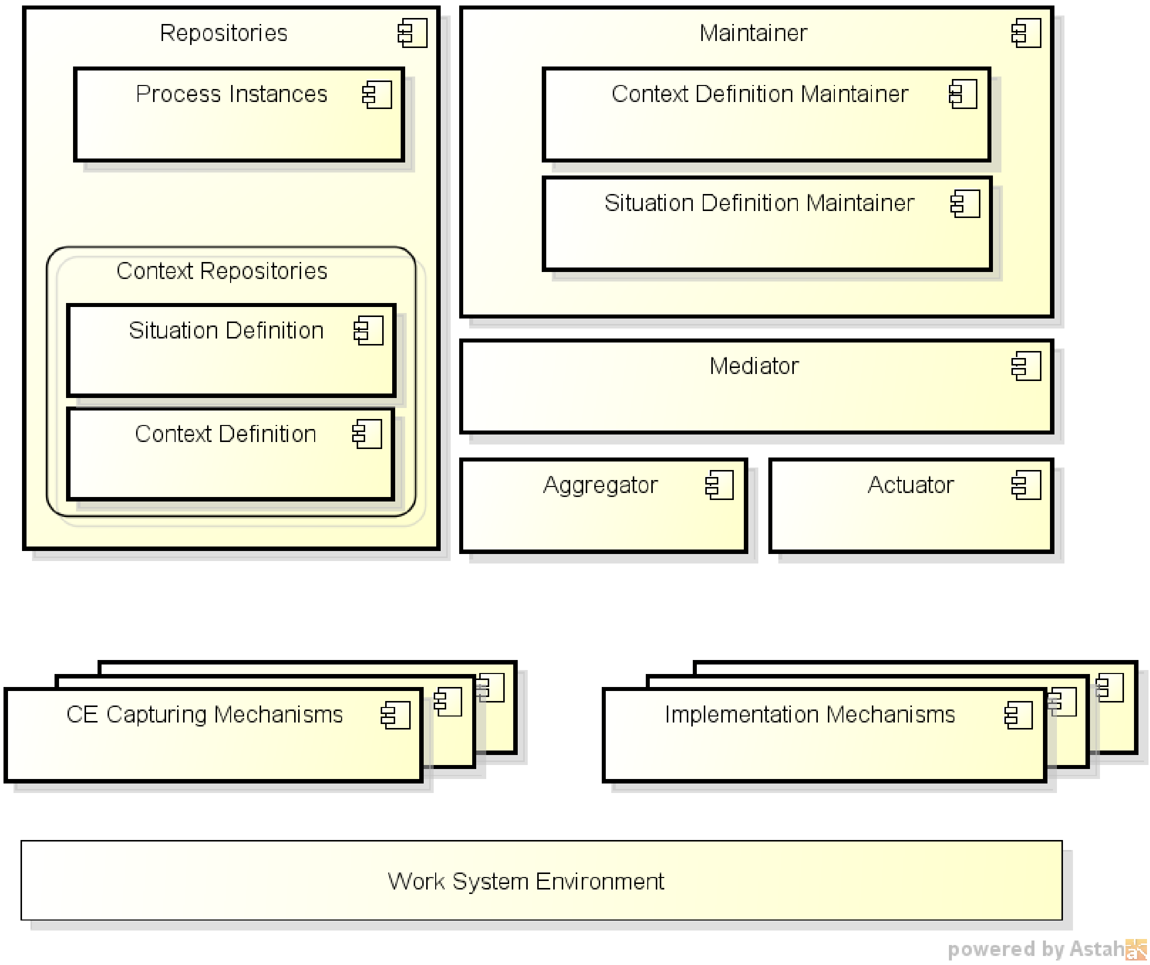


Figure 5.13 - GCAdapt - Context Management Architecture for dynamic process adaptation

5.3.1. Capture of CE

The capture of CEs is directly related to the way they are presented in the environment and how the activity is performed. Manual, semi or fully automatic, "CE Capturing Mechanisms” may capture CEs when they arise 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 or other application system). More information is available in the environment or is part of the result of an action, which requires mechanisms that automatically identify and capture them (NUNES *et al.*, 2009).

So, work environment is monitored by CE Capturing Mechanisms, which according to their specification, capture CEs in its original format. Once CEs are dynamic artifacts, GCAdapt allows the coupling of different mechanisms that are able to capture CEs in different formats and media. By separating how context is acquired from how it is used, applications can use contextual information without worrying about the details of a sensor (or agent or service) (any software or hardware component enabling to retrieve contextual information) and how to acquire context from it.

CE Capturing Mechanism may also transform raw data into data interpretable by GCAdapt. Thus, the capture comprehends the activities presented in Figure 5.14.

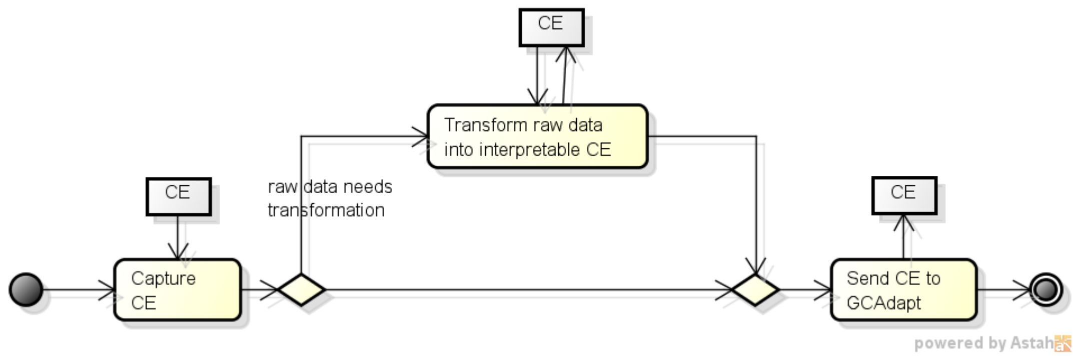


Figure 5.14 - Capturing Mechanisms Activity Diagram

In the Book Order process scenario, GCAdapt captures the value of the cost of payment if the current customer chooses to pay the items using credit card (value of CE CC_payment_cost).

5.3.2. Aggregator

Aggregation is responsible for the collection of one or more CEs that are logically related into a common repository. The Aggregator supports the activation of a Situation to an application, through the use of Situation Rules. It receives a collection of CEs, and verifies if a Situation is to be activated. Identified Situations during process instance execution are stored in the Log Repository for future process learning.

Thus, the Aggregator performs the activities presented in Figure 5.15.

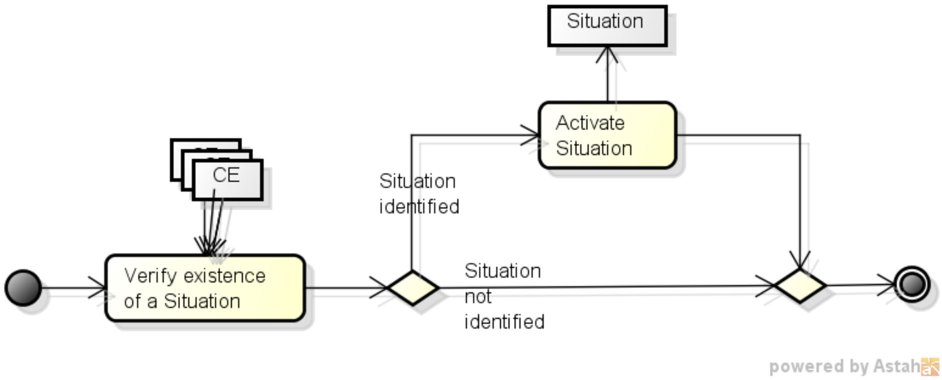


Figure 5.15 - Aggregator Activity Diagram

Aggregation can be seen as a middleware between the capturing mechanisms and the Mediator that does not have to be concerned on how to collect the different contextual elements and how to identify context, but on how to provide the interface with Mediator.

In the Book Order scenario, a Situation is activated when the cost of paying in cc (CC_cost_percentage) represents 10% over the total amount of the items the customer is purchasing and the total cost (Total_order) is above 600 reais.

Situation S1 = {DecidePaymentType.Status = completed, CC_cost_percentage = 10%, Total_order > 600}

5.3.3. Mediator

Mediator acts identifying adaptation needs when a Situation occurs. Its key features are: intelligent behavior and decision-making support skills. It is responsible for identifying possible adaptations during process instance execution, when they should be performed and the impact in relation to process and organizational goals. So, Mediator reasons over the situation activated that will not lead the process instance to a stable state (achieve its goal) or that will not lead the process instance into its best performance in order to decide which adaptation to be taken.

When a Situation is activated, it represents what has changed within the organizational work system (including process, systems, people, organization and outside data) through the use of ECA rule (KNOLMAYER *et al.*, 2000):

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

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

IF work system representation has changed THEN Replan process instance and adapt

In the contextualized work system representation, adaptation may be performed over one or more process elements managed by PAIS or in the environment accordingly to the available adaptation strategies.

Thus, the Mediator performs the activities presented in Figure 5.16.

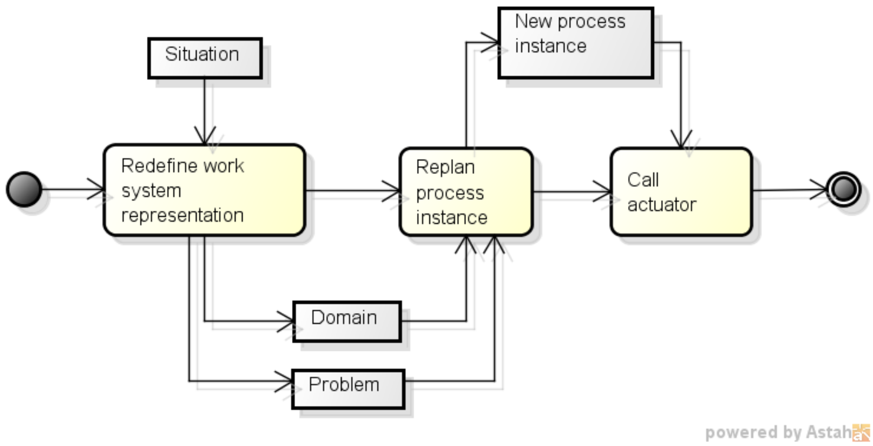


Figure 5.16 - Mediator Activity Diagram

In the Book Order scenario, the previous Situation is activated and the Book Store goal is to reduce total cost. So, when the process is replanned, an activity offering 5% discount for payment in cash is inserted in the process instance right after the customer has chosen to pay by credit card (Activity “Decide payment type”) and the customer can decide again if he chooses to continue paying by credit card or will change payment type.

5.3.4. Maintainer

Maintainer is responsible for managing Context and Situation definitions attained to current organization’s reality.

The Context Definition Maintainer is responsible for continuously maintaining context definitions updated to the current organization’s situation. It involves identifying context model evolution by adding / changing / deleting CEs and relationships among them. The implementation of context logic reasoning mechanism must be held separate from the running process through information systems and/or automation. Thus, the process implementation becomes less rigid and easier to be maintained and adapted.

The Situation Definition Maintainer is responsible for continuously maintaining (and storing in the Situation Definition Repository) Situation rules updated to current organization’s position.

The Context Repositories manage 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.

The evolution of the Situation and Context Rules can be enhanced by machine learning algorithms and mining techniques (REVOREDO, 2009), using the Process Instances Repository and Context Repositories, which are able to automatically extend the knowledge about the relevant domain and process CEs, as well as the definitions of Situations and Context Rules, based on structures that represent implicit information about domain objects (FRIEDMAN, 1997) (KRAMER, 1995) (DE RAEDT *et al.*, 2008). An approach, considering the presented architecture has been conducted by CARVALHO *et al.* (2013).

Thus, the Maintainer performs the activities presented in Figure 5.17.

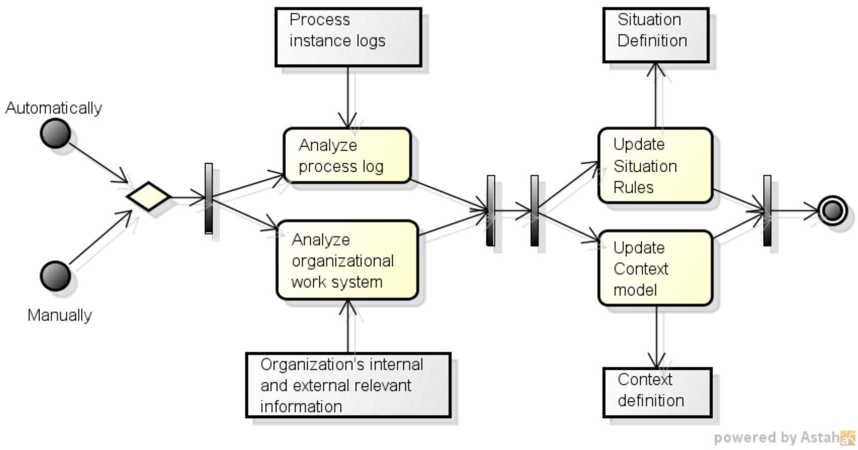


Figure 5.17 - Maintainer Activity Diagram

In the Book Order scenario, GCAdapt may verify that most of the customers (75%) that accept to pay in cash and be awarded with 5% discount has bought a total amount superior of R$ 800,00. The process manager receives this information and may change Situation S1 to {ActivityStatus ("Decide payment type") = completed, CC_cost_percentage = 10%, CC_payment_cost > 500} and the activation of 5% discount when CC_payment_cost > 500.

5.3.5. Actuator and Implementation Mechanisms

The Actuator receives the adaptation reasoned by the Mediator, and sends the appropriate commands to perform the necessary adaptations in the process 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 also may 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 are responsible for the interface between GCAdapt and PAIS to implement the necessary changes.

Thus, the Actuator performs the activities presented in Figure 5.18.

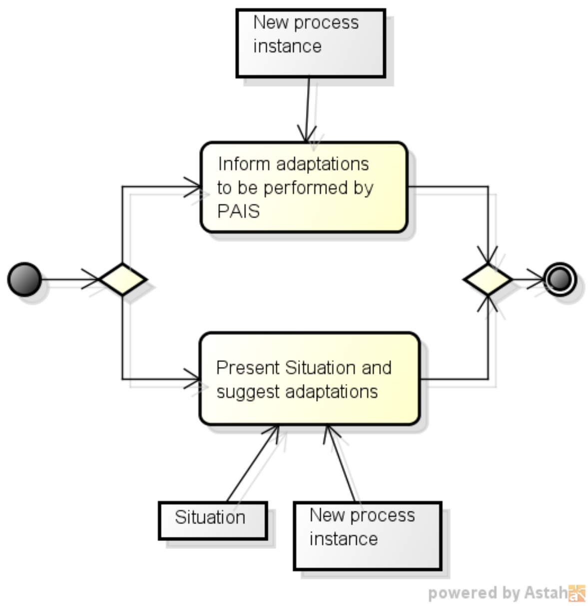


Figure 5.18 - Actuator Activity Diagram

In the Book Order scenario, the Actuator calls PAIS to insert two activities right after the customer has chosen to pay by credit card (Activity "Decide payment type"): "Offer 5% for cash payment" and "Decide payment type".

The reasoning and decision over a possible adaptation that aims to maintain process instance aligned with predefined goals is the core element of GCAdapt. Without a proper reasoning and decision, any of the modules will work effectively. So, the implementation made focus on the Mediator module. In the next chapter, the implementation mechanisms for the Mediator are described and an implementation using a chosen PAIS and Planner is presented.

6. MEDIATOR IMPLEMENTATION

Mediator module is the core of GCAdapt architecture. It is responsible for identifying an adaptation need at any moment during a process instance (the occurrence of a Situation), reasoning over the impact on process goals of possible solutions, and deciding the action to be performed (the re-planning of the instance). Therefore, it should interface with a Planner and with a PAIS. The general operation and requirements of Mediator was presented in Chapter 5, Section 5.2.3.

The implementation of the Mediator should provide a Planner with information to incrementally synthesize partial plans to adapt a process instance. Normally, planners treat plans in initial and final conditions but little or no information that helps to guide the planning process in between. The planner is expected to start up from a situation (an undesirable state) and move forward, supported by GCAdapt, specifically the Mediator. Besides, the implementation of the Mediator should provide a PAIS with adaptation decision skills based on the status of the process instance and current data received by it.

The technologies considered for this specific implementation were SAPA (planner) and YAWL (PAIS). SAPA was selected because of its achievements in the AIPS 2002[10][11] Planning Competition and because it was considered stable during the studies of a number of Planners. YAWL is a widely used PAIS by Academia and is implemented in a service-oriented way that already offers interfaces for developers to implement external services that communicate with the YAWL workflow engine. The implementation in YAWL and SAPA is aimed at carrying out an observational study focused on testing the approach and demonstrating a way of implementing it.

Section 6.1 describes the Mediator general behavior (including the interfaces with the planner and PAIS), and Section 6.2 details its architecture and coding considering the chosen technologies.

6.1. Mediator Behaviour

PAIS starts running based on a standard process (the process manually modeled), and adapts it at runtime, with the support of GCAdapt through the Mediator that uses automatic planning as a reasoner. Figure 6.1 presents the overall steps implemented from process design to process execution including possible dynamic process adaptation mechanisms. The steps are described as follows.

[10] http://ipc.icaps-conference.org/
[11] http://rakaposhi.eas.asu.edu/sapa.html/

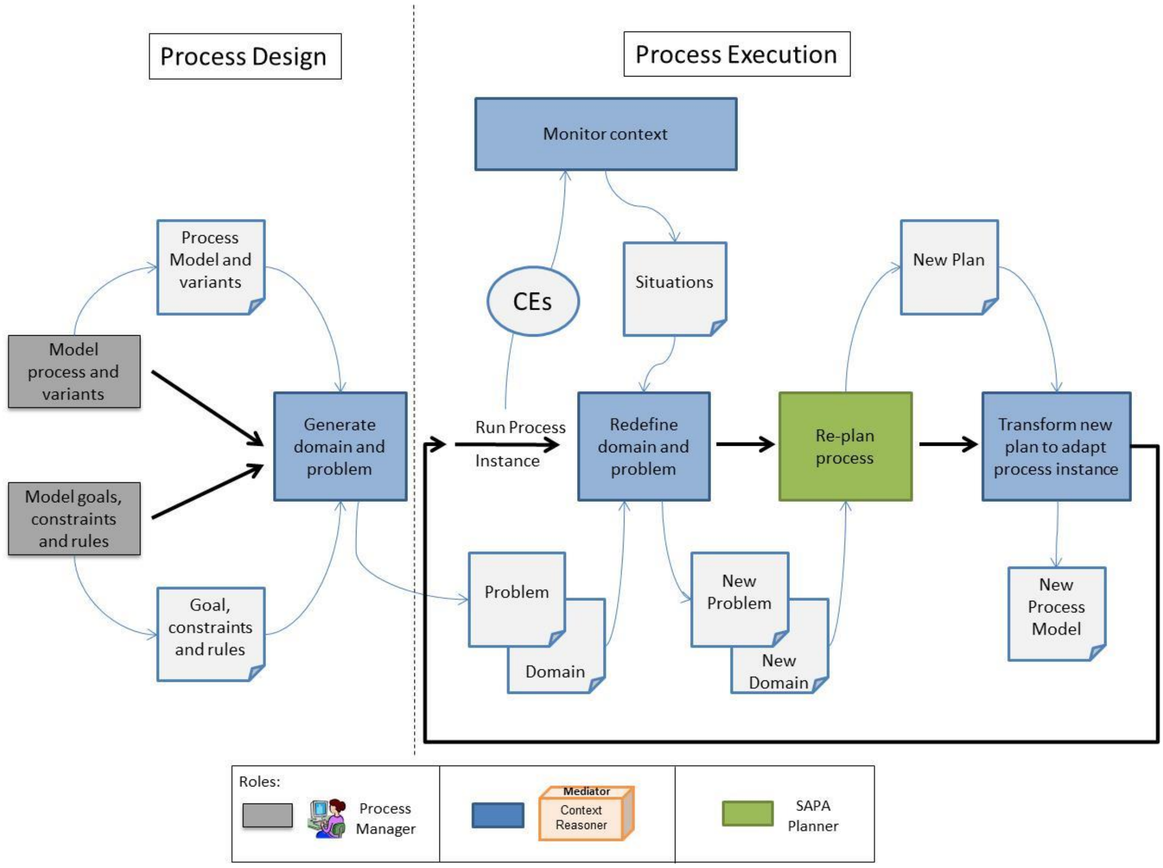


Figure 6.1 - Dynamic Process Adaptation from Process Design to Execution

Model process and variants: YAWL process modeler tool is used to model the process and all its already known variations.

Model goals, constraints and rules: Mediator receives the definition of goals, domain constraints and organizational rules. The rules transformation from YAWL process and worklet and organizational YAWL external definitions are presented in Appendix II and III.

Generate domain and problem: Mediator generates the Domain and Problem files (that are used as input for the planner), based on all the previous definitions. Since each PAIS uses its specific notations and represents its process components (i.e., variations) in different ways, it is proposed the representation of domain and model as XML files, so as to establish a standard for the Mediator to operate, independently of the PAIS process implementation. As an example, a partial view of the XML definition (gas production domain definition) is presented in Figure 6.2 and the complete transformation rules from XML to domain and problem PDDL files are described in

Appendix IV and Appendix V respectively. A partial view of the PDDL gas production domain is shown in Figure 6.3, as an example.

```xml
<processactions>
    <action name="Align_manual_valves" duration="1">
        <parameters />
        <conditiongroup>
            <condition type="at start" predicate="notcompleted">
                <variable>alignmanualvalves</variable>
            </condition>
            <condition type="at start" predicate="value">
                <variable>InputCondition</variable>
                <value>true</value>
            </condition>
        </conditiongroup>
        <effectgroup>
            <effect type="at end" predicate="completed">
                <variable>alignmanualvalves</variable>
            </effect>
        </effectgroup>
    </action>
    <action name="Open_remotely_alignment_valve_of_collector_well" duration="1">
        <parameters />
        <conditiongroup>
            <condition type="at start" predicate="notcompleted">
                <variable>openremotelyalignmentvalveofcollectorwell</variable>
            </condition>
            <condition type="at start" predicate="completed">
                <variable>alignmanualvalves</variable>
            </condition>
        </conditiongroup>
        <effectgroup>
            <effect type="at end" predicate="completed">
                <variable>openremotelyalignmentvalveofcollectorwell</variable>
            </effect>
        </effectgroup>
    </action>
    <action name="Open_shutdown_valve" duration="1">
        <parameters />
        <conditiongroup>
            <condition type="at start" predicate="notcompleted">
                <variable>openshutdownvalve</variable>
            </condition>
            <condition type="at start" predicate="value">
                <variable>AlignmentValveStatus</variable>
                <value>open</value>
            </condition>
        </conditiongroup>
        <conditiongroup operator="OR">
            <condition type="at start" predicate="completed">
                <variable>openremotelyalignmentvalveofcollectorwell</variable>
            </condition>
```

Figure 6.2 - Example: XML Partial view of a gas production domain.

```
(:durative-action Align_manual_valves
    :parameters ()
    :duration (= ?duration 1)
    :condition (and
        (at start (notcompleted alignmanualvalves))
        (at start (value InputCondition true))
    )
    :effect (and
        (at end (completed alignmanualvalves))
    )
)
(:durative-action Open_remotely_alignment_valve_of_collector_well
    :parameters ()
    :duration (= ?duration 1)
    :condition (and
        (at start (notcompleted openremotelyalignmentvalveofcollectorwell
        (at start (completed alignmanualvalves))
    )
    :effect (and
        (at end (completed openremotelyalignmentvalveofcollectorwell))
        (at end (completed alignmentValveStatusXORVerification))
    )
)
(:durative-action Open_shutdown_valve
    :parameters ()
    :duration (= ?duration 1)
    :condition (and
        (at start (notcompleted openshutdownvalve))
        (at start (value AlignmentValveStatus open))
        (at start (completed alignmentValveStatusXORVerification))
    )
    :effect (and
        (at end (completed openshutdownvalve))
    )
)
(:durative-action Open_locally_alignment_valve_collector_well
    :parameters ()
    :duration (= ?duration 1)
    :condition (and
        (at start (notcompleted openlocallyalignmentvalvecollectorwell))
        (at start (completed openremotelyalignmentvalveofcollectorwell))
        (at start (value AlignmentValveStatus closed))
    )
    :effect (and
        (at end (completed openlocallyalignmentvalvecollectorwell))
        (at end (value AlignmentValveStatus open))
        (at end (completed alignmentValveStatusXORVerification))
    )
)
```

Figure 6.3 - Example: PDDL Partial view of a gas production domain.

Monitor Context: Mediator receives CEs (Contextual Elements) manipulated by the PAIS. Every change in process data activates Mediator that in turn analyzes if it is necessary to change the Problem and Domain XML files.

Redefine Domain and Problem: Mediator redefines the Domain and Problem XML definitions based on the Situation and process status that are then transformed into new PDDL files.

Re-plan Process: SAPA reasons over the new Domain and Problem specifications to generate a new plan more suitable to the new perspective. A planner takes as input the domain and the problem (representing the change characterized by the Situation) and generates new plans that represent the process instance to be executed from this moment on. The first plan is always selected as the preferred one, but not necessarily the best.

Transform new plan to adapt process instance: Mediator translates the new plan into adaptation actions and calls Actuator to send them for PAIS to execute them.

6.2. Mediator Architecture and Implementation

Figure 6.4 shows the conceptual architecture that represents the interfaces among a PAIS and the GCAdapt-Mediator module and the other GCAdapt modules, as well as the GCAdapt-Mediator module and a Planner.

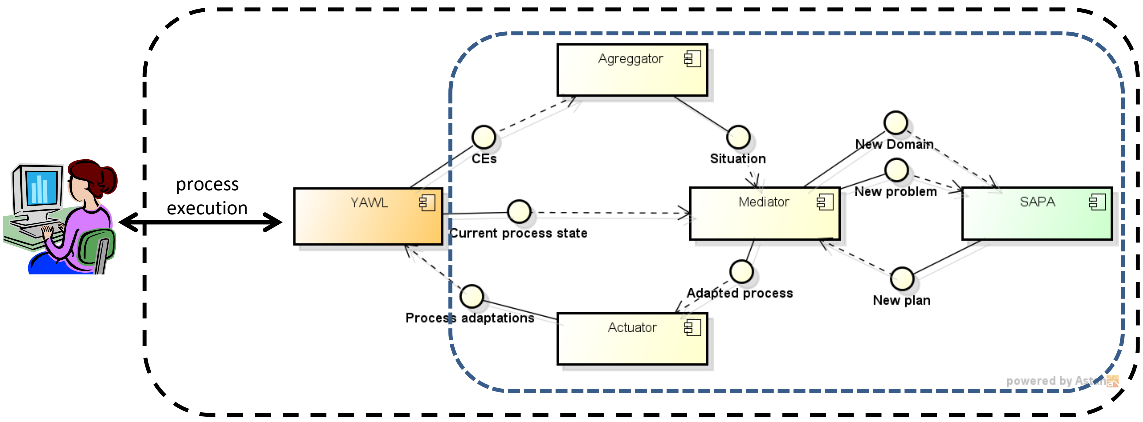


Figure 6.4 - General Architecture for the association between PAIS and the GCAdapt main modules

YAWL: Enacts the process based on the business process model (BPM) description, managing flow, resources and data.

Aggregator: Receives CEs from YAWL, processes Situations and sends the results to the Mediator.

Mediator: Changes the problem XML file based on the Situations and may change the domain XML file if the organization changes rules, goals, politics, constraints or variants. Then, the Mediator changes the domain and problem XML to PDDL files.

Mediator also receives a new Plan and call Actuator to inform the adaptations required for the process to the PAIS.

Planner: Receives as input the domain and problem PDDL files representing the situations that changed them and replans the process generating a new plan.

Actuator: Based on each adaptation informed by the Mediator in the new process instance, Actuator interfaces with YAWL to activate the process components that SAPA suggests in the new plan.

The implementation was built on top of YAWL PAIS[12]. YAWL is a BPM/Workflow system, based on a PetriNet language that handles complex data transformations, organizational resources and external Web Services.

The YAWL system provides support for flexibility and dynamic exception handling through the concept of worklets, which are self-contained processes associated to rules. It is possible to adapt a process through some primitives (for removing, suspending, continuing, completing, failing and restarting a workitem) and one or more compensatory processes in the form of YAWL processes (i.e., worklets, self-contained YAWL specifications executed as a replacement for a workitem or as compensatory processes). This approach directly provides for dynamic change and process evolution without having to resort to off-system intervention and/or system downtime.

Flexibility is supported by allowing a process designer to designate certain tasks to be substituted at runtime with a dynamically selected worklet. When a task is enabled, a choice may be made from the worklets repertoire (Figure 6.5) 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 is mapped back to the original task, which is then checked back into the engine, allowing the original process to continue.

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

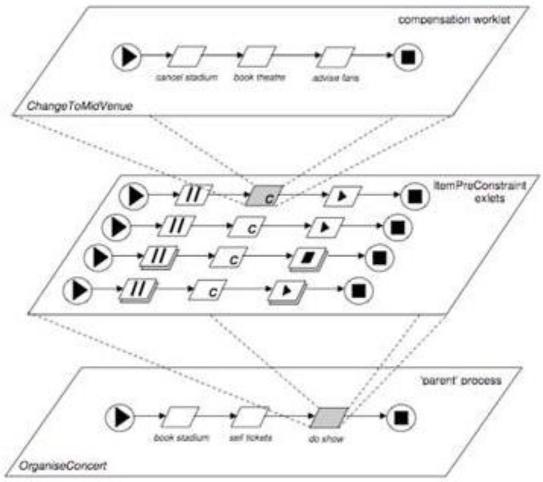


Figure 6.5 - Example of a process-exlet-worklet hierarchy (ADAMS, 2007)

The Planner adopted was SAPA[13] (TALAMADUPULA *et al*, 2010). It is a domain-independent heuristic forward chaining planner that can handle durative actions, metric resource constraints and deadline goals. It is developed using JAVA Technology, and handles PDDL 2.1, Level 3 which was the highest level used in the Third International Planning Competition (IPC3)[14].

GCAdapt was implemented in Java. The Mediator implementation includes:

1. The routines to parser the domain and problem XML files defined from PAIS process, variants definitions, organizational goals, politics and constraints, to PDDL files.
2. The interface with the SAPA Planner.
3. The changes in the output file so as to represent the new plan.
4. The interface with YAWL worklet methods so as to run the available adaptation actions.

In order to make possible the whole cycle of adaptation to occur, Aggregator and Actuator were also partially implemented together with Mediator, as a unique service, to work with the processes used in the observational study (Chapter 7), CEs and adaptations required.

In particular, we assumed the tasks of a YAWL process and each worklet specification to be considered as planning actions.

[13] http://rakaposhi.eas.asu.edu/sapa.html/
[14] http://ipc.icaps-conference.org/

So taken YAWL's exception handling framework as a starting point, one contribution of this work is the construction of Mediator as a YAWL service that interfaces with preconceived interface port X available by YAWL architecture, before the execution of each activity, to reason over process instance in execution and domain goals and constraints without the need to establish (and maintain) rules that define adaptations based on variable statements.

Figure 6.6 shows the Mediator Service interface with YAWL architecture. Interface X has been designed to allow the Engine to notify Custom Services of certain milestone events during the execution of a process instance providing services the ability to dynamically check for, capture and handle process exceptions.

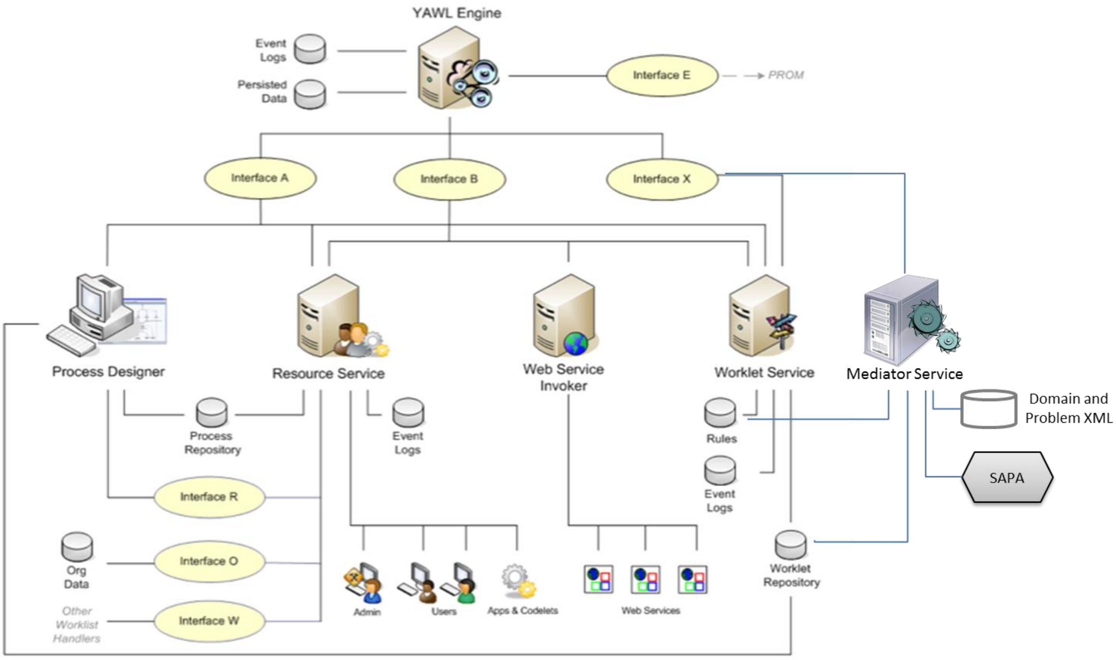


Figure 6.6 - Interaction of YAWL Architecture to Mediator.

The integration of Mediator to YAWL was done based on the Worklet Service implementation. The conditions and worklets execution rules were defined through customized functions. So five new functions were developed and used as conditions expressions in rule nodes (through the class RdrConditionFunctions) and, together with Mediator (a standalone application) track process instance execution and trigger the selected compensatory processes.

startMediator

This function is responsible for the creation of a Mediator instance that will keep track of the process instance execution. A CasePreConstraint rule was created for the default process (Figure 6.7). A CasePreConstraint is a case-level pre-constraint rule that is checked when each case (i.e., instance) begins.

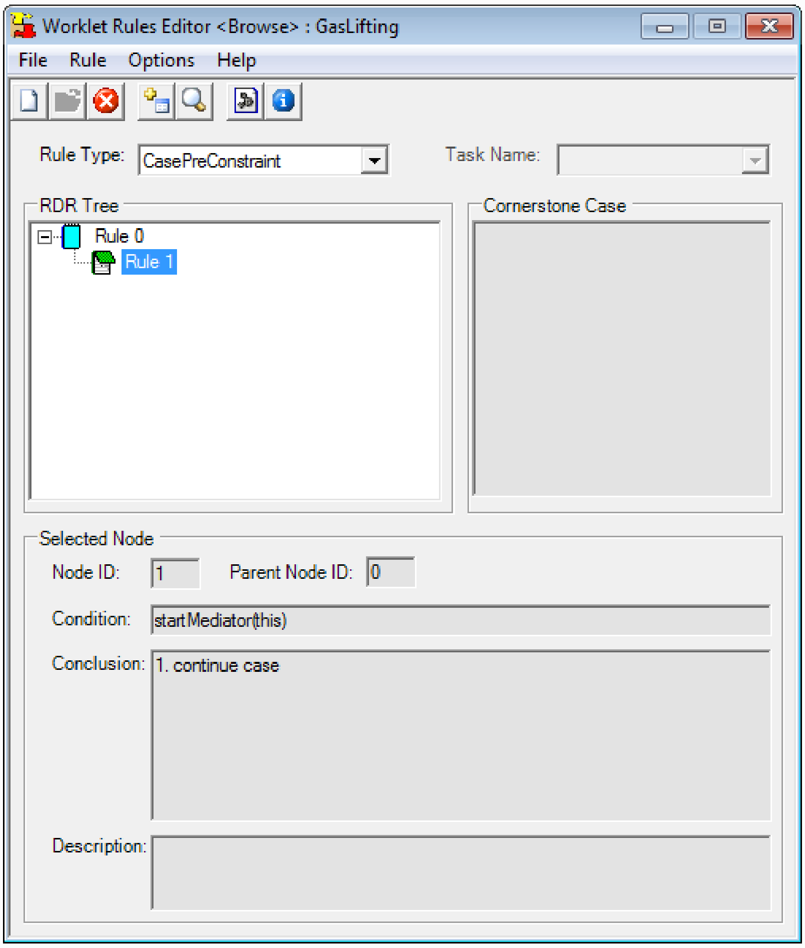


Figure 6.7 - CasePreConstraint rule for startMediator function

updateMediatorState

This function is responsible for the update of the Mediator state accordingly to the process instance execution. It is through this function that the XML problem file is updated, setting the activities that already executed and new variable values updated by the executor during default process activities execution. It always returns false, so the rule conclusion is not executed, because in fact it aims only at gathering information. An ItemPreConstraint rule was created for each activity in the default process (Figure 6.8). An ItemPreConstraint is an item-level pre-constraint rule that is checked when each workitem in a case becomes enabled (i.e., ready to be checked out).

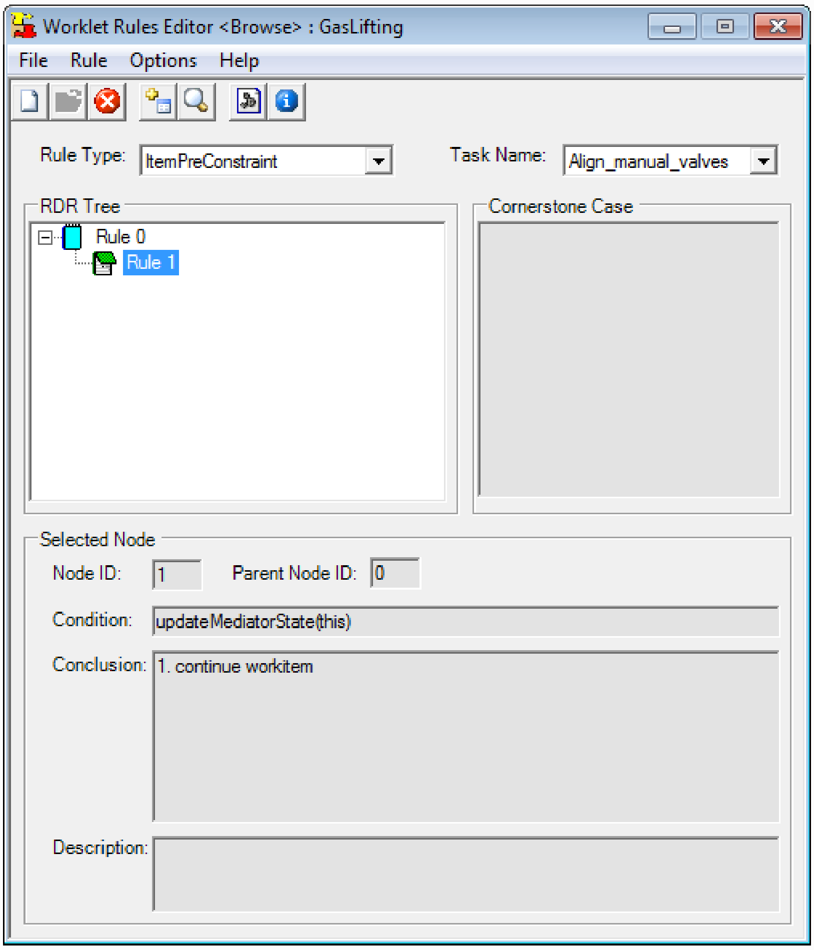


Figure 6.8 - ItemPreConstraint rule for updateMediatorState function

executeMediator

This function is responsible for executing Mediator planning, verifying if a specific compensatory process was activated to be executed while process running. In Figure 6.9, it is verified if compensatory process PC01 must be executed. If it returns true, conclusion is executed (the process instance is paused, a PC01 instance is started and after that the execution process instance continues its default execution). An ItemPreConstraint rule was created for each activity in the default process where the compensatory process might be called before its default execution.

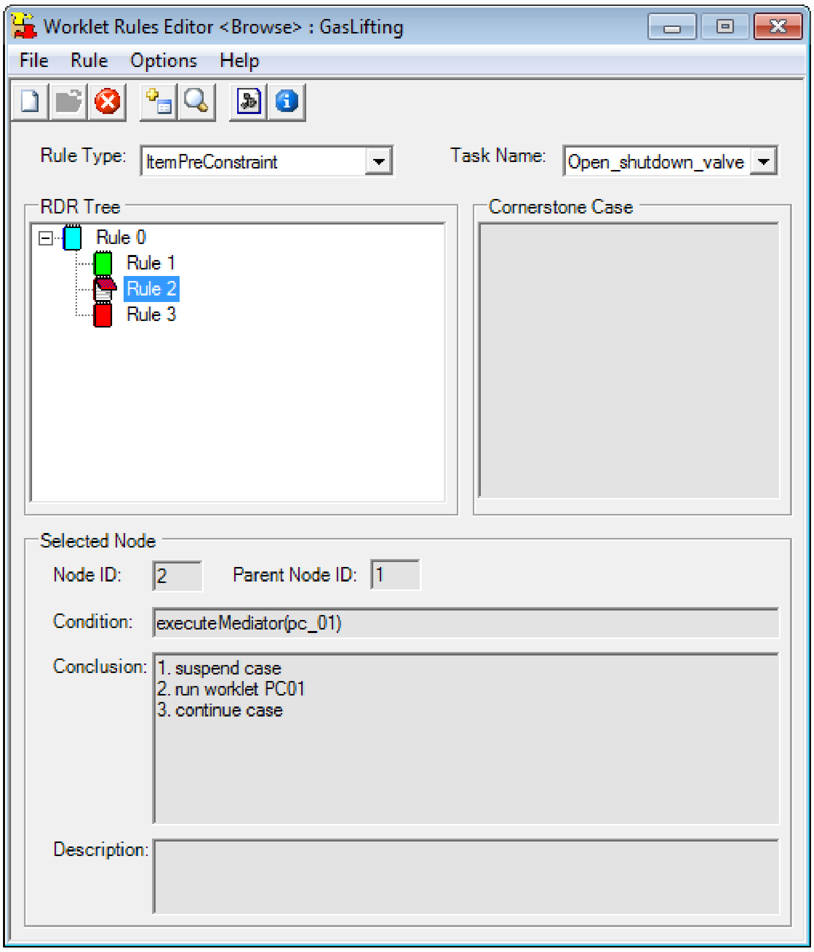


Figure 6.9 - ItemPreConstraint rule for executeMediator function

updateMediatorStateWorkletAttributes

This function is responsible for the update of Mediator state accordingly to variables change in the compensatory process in execution. It is through this function that the Problem XML file is updated, setting the activities that were executed and the variable values updated by the executor during compensatory process activities execution. An ItemPostConstraint rule was created for each activity in the compensatory processes (Figure 6.10). An ItemPostConstraint is an item-level post-constraint rule that is checked when each workitem moves to a completed status.

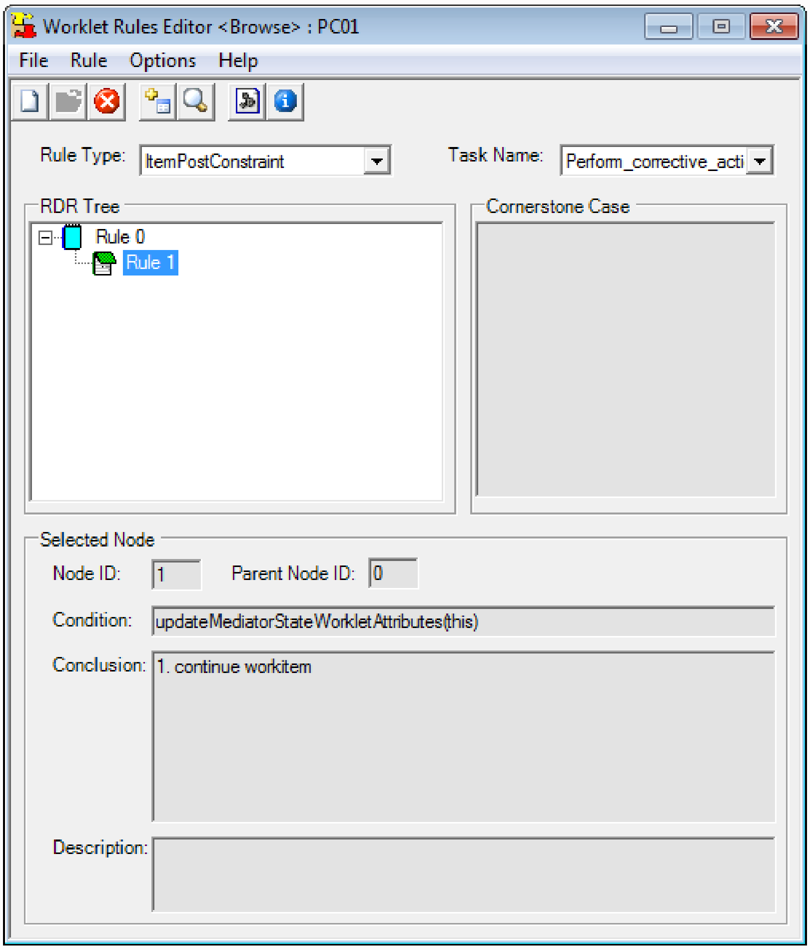


Figure 6.10 - CasePostConstraint rule for updateMediatorStateWorkletAttributes function

updateMediatorStateFinalizeWorklet

This function is responsible for the update of Mediator state according to the process compensatory execution end. It is through this function that the problem XML file is updated, setting the completion of the compensatory process. A CasePostConstraint rule was created for each compensatory process (Figure 6.11). A CasePostConstraint is a case-level post constraint rule that is checked when a case completes.

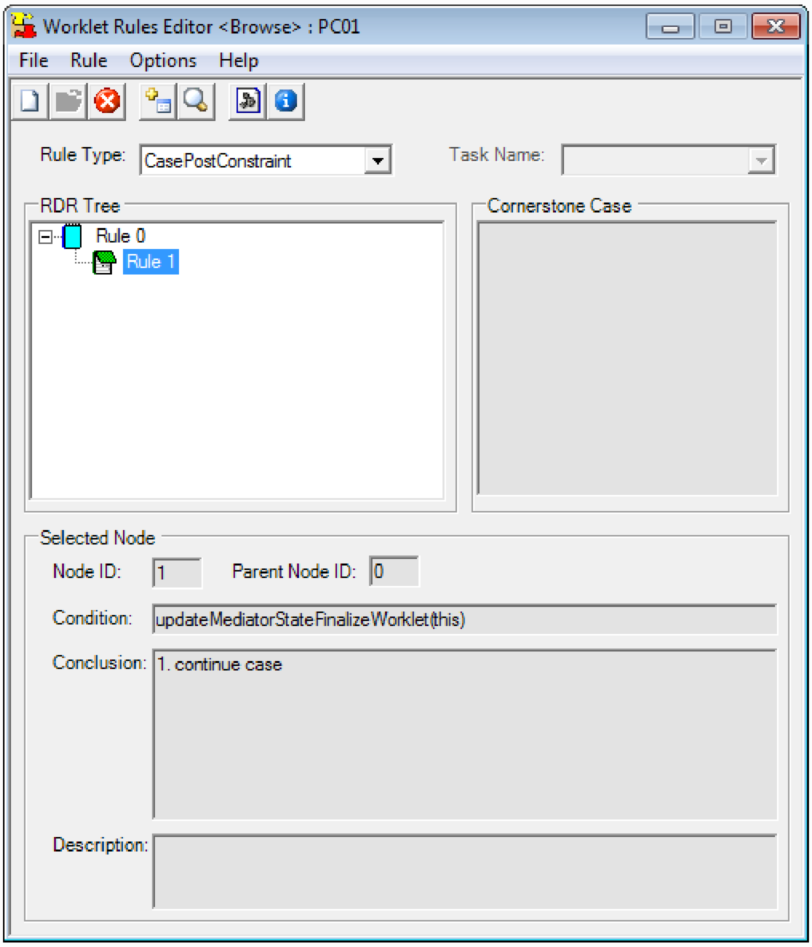


Figure 6.11 - CasePostConstraint rule for updateMediatorStateFinalizeWorklet function

YAWL interfaces with external services through XML over http, and all the XML rules to invoke the functions developed for the Mediator Service could have been created automatically since there is a clear standard construction. But because of the ease of use, and experimentation purposes, the Worklet Rules Editor was used and the rules were manually created.

So, worklets are created as usual, and Mediator Service receives information updated from process instance execution, modifies domain and problem XMLs files, transform them into PDDL files and call SAPA to re-plan it. Mediator enables worklets based on the new plan generated.

As mentioned, Mediator was developed based on Worklet Service class and methods that interface with YAWL process execution activities in order to receive and propagate data. It is hosted on Tomcat web server that already hosts YAWL environment by default. Figure 6.12 shows Mediator implementation classes and methods.

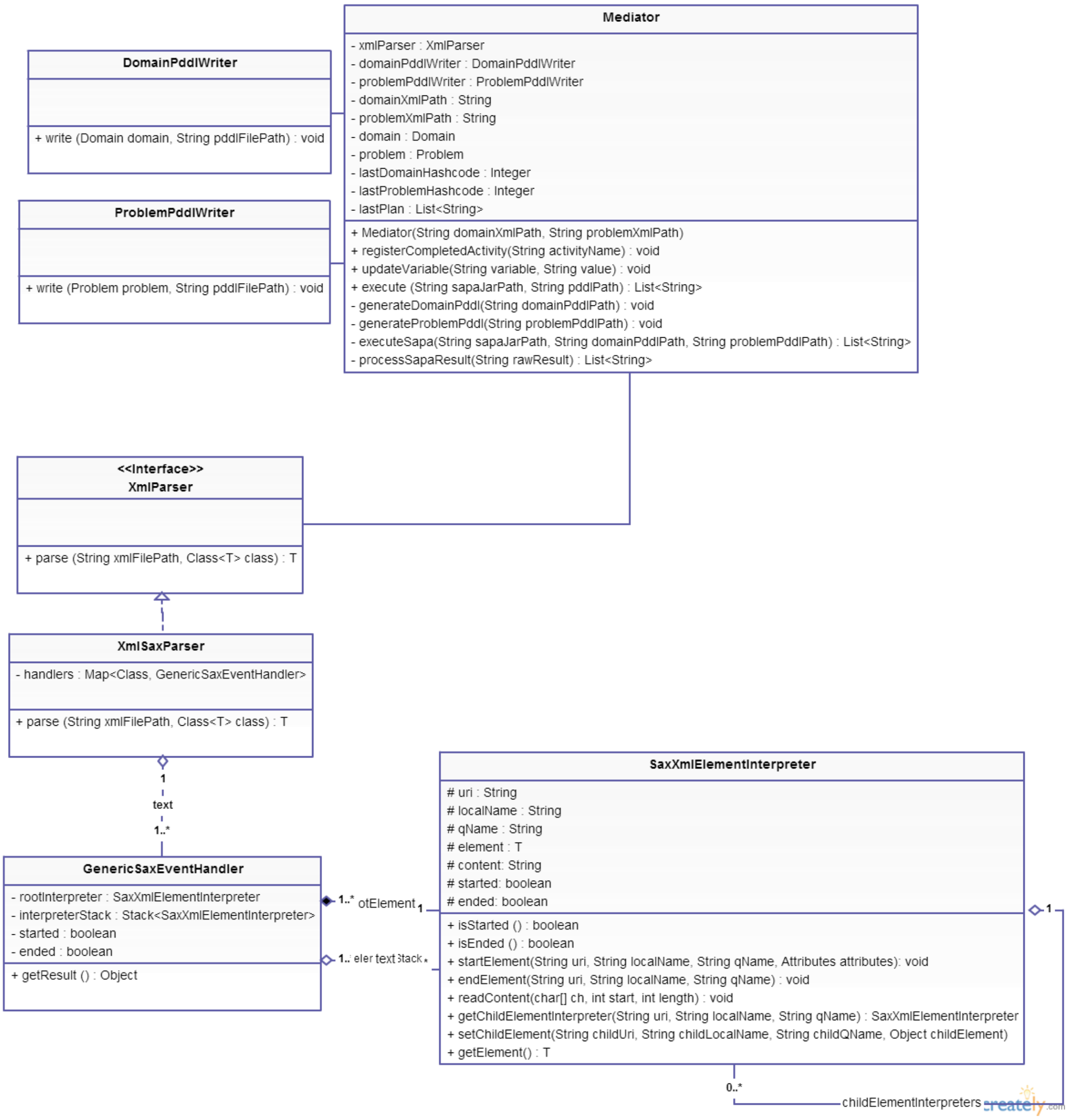


Figure 6.12 - Mediator Entity-relationship diagram

- XML Parser class contains the parse Interface method responsible for the XML reading.
- XMLSaxParser class implements parser based on SAX API. For each existing domain and problem XML file, a GenericSaxEventHandler is created.
- GenericSaxEventHandler is responsible for listening SAX events when reading XML files. It is based on org.xml.sax.helpers.DefaultHandler. Each XML file must have a specific implmentation. It returns the result of XML interpretation, i.e., the object that contains XML data.
- SaxXmlElementInterpreter is responsible for the interpretation of XML elements. For each XML element there is a specific implementation. Each interpreter is

composed by the child's elements interpreter so as to represent the XML tree structure.

- The DomainPddlWriter and the ProblemPddlWriter are responsible for writing PDDL domain and problem definitions, respectively, from the object that represents each of them.
- Mediator is the main program class responsible to track process instances and generate execution plans.
    - It receives domain and problem XML archive paths (Mediator(String domainXmlPath, String problemXmlPath)).
    - It updates problem XML when activities and compensatory processes are executed (registerCompletedActivity(String activityName)) and variable values are changed (updateVariable(String variable, String value)).
    - It executes the planning based on the current process status (represented in the problem XML), generating domain and problem PDDL files (generateDomainPddl (String domainPddlPath) and generateProblemPddl (String problemPddlPath)), executes SAPA Planner (executeSapa(String sapaJarPath, String domainPddlPath, String problemPddlPath)) providing those files as input and returns the generated plan as a list of activities (processSapaResult(String rawResult)).

An implementation of GCadapt Mediator, together with Aggregator and Actuator (in a minor participation) was described in this chapter in order to put in practice the main ideas of GCAdapt architecture proposed in Chapter 5. The mechanisms used to interface Mediator Service with the YAWL engine were presented and the Mediator operation was described through the classes and methods that were implemented. In the next chapter, this implementation will be used to support the evaluation of GCAdapt approach.

7. OBSERVATIONAL STUDY

This chapter presents the evaluation of the solution in two different domains: (i) gas lifting process from an oil and gas production macroprocess of an Oil and Gas Company in Brazil; and (ii) Aircraft takeoff of the Galeão Airport in Rio de Janeiro, Brazil.

7.1. Evaluation Plan

Purpose and Scope

The main goal of this observational study is to evaluate if Mediator is able to manage deviations from pathway during execution, adapting these pathways in a way that is adherent to goals, business rules and constraints.

This goal is detailed according to the structure proposed by WOHLIN *et al.* (1999):

Analyze	the dynamic process adaptation using an implementation of the GCAdapt Mediator integrated into YAWL.
For the purpose of	Characterize
Regarding	Feasibility and effectiveness of adaptation for the adapted process
From the viewpoint of	Researcher and the Domain Expert
In the context of	Two real processes from different domains (gas lifting and aircraft takeoff)

Study Description

The conditions under which the observational study was executed are:

- The study was conducted using two business process models in different domains, possible variants (process components), CEs and situations that were elicited and validated with domain experts that work for the respective organizations. Both processes run on large scale, with many instances running simultaneously.
    - Gas lifting process: The process was modeled within a large Exploration and Production Oil & Gas Company. Contextual elements and situations were identified and validated with the modeling analysts.
    - Aircraft Takeoff process: The process was modeled within the largest International Airport in Rio de Janeiro. The process was elicited and validated by two air traffic controllers and process components, CEs and situations were identified and validated with a domain expert that works in the Airspace Traffic Control (ATC).

- Processes were modeled using BPMN notation attending each organization BPM methodology. Afterwards they were converted to the YAWL notation based on Petrinets.
- Situations were also identified with specialists in the domain and the process.
- In order to simulate possible Situations, CEs values were generated randomly using a tool developed within the research group within a research dissertation (CARVALHO *et al.*, 2013).
- Thereafter, Situations were presented to other specialists (different from the previous ones) so as to be evaluated by them.
- Finally, the thesis proposal and solution was presented to the specialists and they were asked about the benefits of the solution.

Variables and Research Questions

The observational study aims at answering the questions formulated as follows. For each question, the variables to be analyzed are described.

a. **Dependent Variables:** They were defined accordingly to the proposed goals and the questions to be responded by the study

Question 1: Was the Mediator able to adapt the process correctly?

This question aims to determine if it is possible to generate adapted processes using the proposed approach (GCAdapt + SAPA + YAWL). The results obtained from the analysis of this issue allow evaluating the applicability of the approach to adapt processes that continue to run properly.

To examine this question, the following variable will be used: Degree of correctness of the adapted process.

This variable will be evaluated through the analysis of the performed adaptations and observation of consistency maintenance of the process (according to business rules and constraints defined on the domain modeling).

The following hypothesis was analyzed:

H01: The business process models produced by the approach are not correct in respect to its syntax.

If the null hypothesis can be rejected with relatively high confidence, it is then possible to formulate alternative hypotheses.

Ha1: The business process models produced by the approach are correct in respect to its syntax.

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

This question seeks to evaluate if the adapted process may have a better performance than the standard one would have.

To examine this question, the following variable will be used: Degree of performance of the instances adapted.

This variable will be evaluated through answers given by specialists to hypothetical situations and the analysis against the adaptations performed by the proposed implementation.

The following hypotheses were analyzed:

H02: The business process models produced by the approach do not have a better performance when compared to the standard process.

If the null hypothesis can be rejected with relatively high confidence, it is then possible to formulate alternative hypotheses.

Ha2: The business process models produced by the approach have a better performance when compared the standard process

Question 3: Is the process representation (process and process components definitions) within the proposed approach more efficient than the conventional one with all the elements within the diagram?

This question seeks to evaluate if the process models structure is considered more efficient compared to traditional approaches (used in these organizations) that consider, for example, the use of XOR verifications in the process model itself and adaptations (when PAIS allows) based on IF-THEN (or ECA) rules. It aims at analyzing the utility and feasibility of ideas behind GCAdapt.

To examine this question, the following variables will be used: a) Degree of user satisfaction with the domain representation; (b) Degree of user satisfaction with the proposed approach.

These variables will be evaluated through the application of a questionnaire to specialists to collect their impressions.

The following hypotheses were analyzed:

H03: The approach behind GCAdapt does not have benefits when compared to the standard approach.

If the null hypothesis can be rejected with relatively high confidence, it is then possible to formulate alternative hypotheses.

Ha3: The approach behind GCAdapt has benefits when compared to the standard approach.

Question 4: Considering the adaptation to a context change, do the models produced by the approach require less time to be adapted in comparison to the manual analysis?

To examine this question, the following variable will be used: Total time.

This variable will be evaluated through the application of hypothetical situations and the answers given by the specialists on the time spent by them to recognize and act on it.

The following hypotheses were analyzed:

H04: The reasoning time, over business process instances, spent by the approach do not consume less time when compared to the standard process.

If the null hypothesis can be rejected with relatively high confidence, it is then possible to formulate alternative hypotheses.

Ha4: The reasoning time, over business process model instances, spent by the approach consumes less time when compared to the standard process.

b. **Independent Variables:** In this study the independent variables considered are related to: (i) the specialists who validated process models, components, contextual elements and situations; and (ii) the chosen domain and process models.

Specialists: Experience in the domain; Level of knowledge of the chosen processes.

Domain and process: Size of the process; Complexity of the process; Process relevance; Domain relevance.

Regarding the specialists, the ones interviewed work directly in the process, not being possible to increase control over the level of experience and knowledge.

The variables of produced artifacts seek to characterize the domain and processes used in the observational study. The intention is to observe whether the approach is applicable to any domain and processes, size and complexity or has a limited acting.

Validity of the study

The identified threats to the observational study validity are:

- Internal validity
  - In order to not influence the simulation of situations, they will be generated randomly. It will not be possible to confirm that all combinations of values of the monitored CEs in each process have already been part of a real scenario of execution. However this exemption is important so that the study is not biased.
  - The identification of possible Situations was partial and it is not possible to confirm if information is correct. But even if it is not being totally right or being a simplified version of reality, it is still considered by the interviewed experts an occurrence that may happen.
  - Another threat to validity is that when choosing YAWL as PAIS and SAPA as Planner, the approach is limited to: (i) the level of flexibility in adaptation supported by YAWL and; (ii) the richness of PDDL notation supported and reasoning algorithm implemented by SAPA.
- External Validity
  - Although completely different domains have been chosen, it is not possible to say that the observational study is exhaustive. Further studies with a larger number of processes and in different domains have to be performed.
- Construct validity
  - Since the participants were chosen for convenience, it is possible that their behaviors were based on assumptions about the expected results from the studies and they could be biased towards the researcher’s intentions. But, a random selection of participants was not possible since it required participants with knowledge and experience about the domains and processes.
  - Another threat to validity is that situations were created with the participation of the researcher and validated by the participants. Although participants elicited possible situations before any explanation on the research was done, it was not a product exclusively elaborated by the organizations.
- Conclusion validity
  - The main threat to the conclusion validity in this observational study is related to the independent variables, not being ideal from the analysis of adherence viewpoint to the processes goals because more experts from different roles that act on the processes are needed. Therefore, this study presents a limitation related to the results, which will be considered only as evidence.

7.2. Gas Lifting Observational Study

Scenario Description

Today, oil and gas are produced in almost every part of the world, from 100 small barrels-a-day in private wells, to more than 4000 barrels-a-day wells. They may be produced in shallow 20 meter deep reservoirs up to 3000 meter deep wells in more than 2000 meters of water. Despite this range, many parts of the process are quite similar in principle.

Petroleum is mostly recovered through well drilling. The drilling comes after the studies of structural geology, sedimentary basin analysis, reservoir characterization (mainly in terms of the porosity and permeability of geologic reservoir structures). It is refined and separated, into a large number of consumer products, from gasoline (petrol) and kerosene to asphalt and chemical reagents used to make plastics and pharmaceuticals.

One of the production processes is Gas Lifting. It is the term used in the oil and gas industry to designate the process through which liquids (oil and water) and gas, produced by a reservoir, are vertically transported from the bottom of the well to the wellhead, on the surface, overcoming the force of gravity.

For the lifting to occur naturally it is necessary that the reservoir pressure is sufficient to overcome the weight of fluid column, causing the well to flow. In this case, the process is called natural lifting and the well is named “flow well”.

The modeling of the lifting process described above is based on a process modeling project performed in a Brazilian company in the oil and gas industry. Production fields are grouped into Business Organizational Units, which are managed as if they were small companies. Professionals working in each field often need to travel long distances to interact with each other and with the central office staff in order to discuss and solve technical problems, exchange experience and define best practices. Although professionals in the company use collaboration tools and information systems, they do not fully benefit from sharing knowledge, experience and solutions.

The lifting process (as shown in Figure 7.1) starts with activities to verify and set the equipment used to control the gas lifting. Then all equipment is started and the gas collection is monitored by the operators. Some of the monitored variables are collected manually and some are monitored via central terminal.

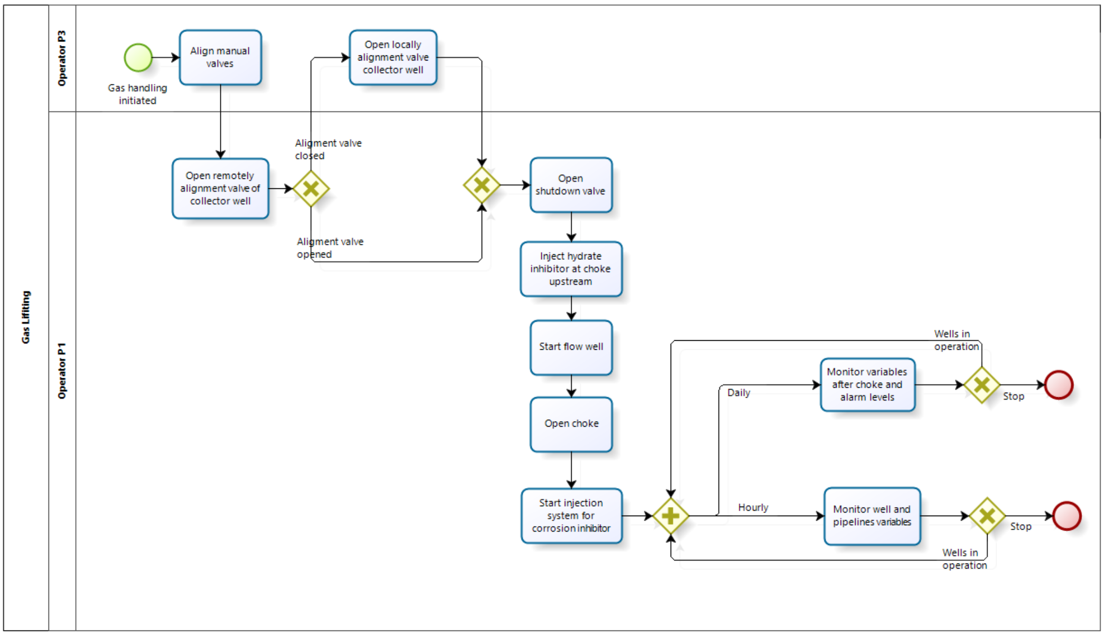


Figure 7.1 - Gas Lifting Process Model

Goal Definition

- Decrease production losses due to unpredicted stops.
  - It involves, not only, treating Situations that may affect the process instance in execution but also preventing them to happen in the following instances, since this is a process that keeps running continuously in a cyclical planning and stops programmatically only for mandatory operation maintenance actions.

Contextual Elements

The domain model considered in this scenario is presented in Figure 7.2.

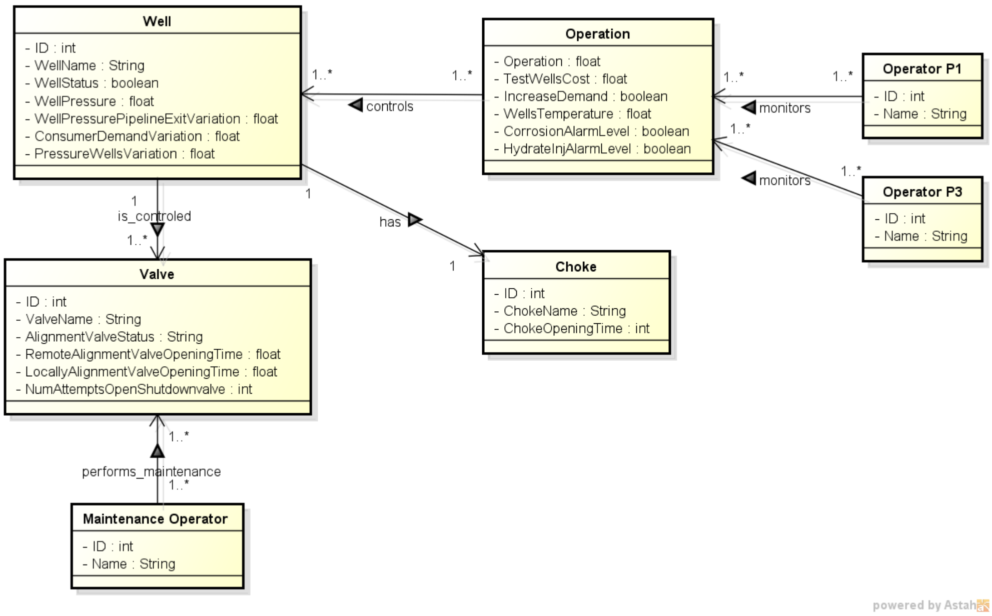


Figure 7.2 - Gas Lifting Process domain model

Situations

Fourteen Situations that may happen during Gas Lifting process execution were identified. Situations 1 and 2 are described above. All 14 Situations are presented in Appendix VI.

Situation 1 - Problem in remotely opening collector well alignment valve: After the execution of activity “Open remotely alignment valve of collector well” a situation is triggered indicating that there is a difficulty (RemoteAlignmentValveOpeningTime) in remotely opening the collector well alignment valve (AlignmentValveStatus).

S01 = {openremotelyalignmentvalveofcollectorwell.status = completed,
AlignmentValveStatus = open,
RemoteAlignmentValveOpeningTime >= 5 min}

Situation 2 - Problem in locally opening collector well alignment valve: After the execution of activity “Open locally alignment valve collector well” a situation is triggered indicating that there is a difficulty (LocallyAlignmentValveOpeningTime) in locally opening the collector well alignment valve (AlignmentValveStatus), although the valve has been opened.

S02 = {openlocallyalignmentvalvecollectorwell = completed,
AlignmentValveStatus = open,
LocallyAlignmentValveOpeningTime >= 5 min}

Situations were analyzed and as a result, a total of 15 process components (YAWL worklets) were identified. Process component PC_06 is shown in Figure 7.3 as a BPMN model and in Figure 7.4 as a YAWL model. All the process components can be seen in Appendix VII.

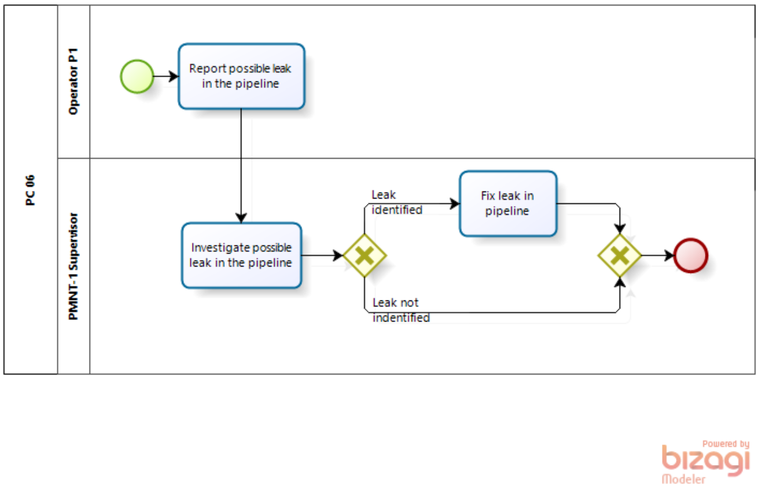


Figure 7.3 - Gas Lifting Process – BPMN designed Process Component PC_06.

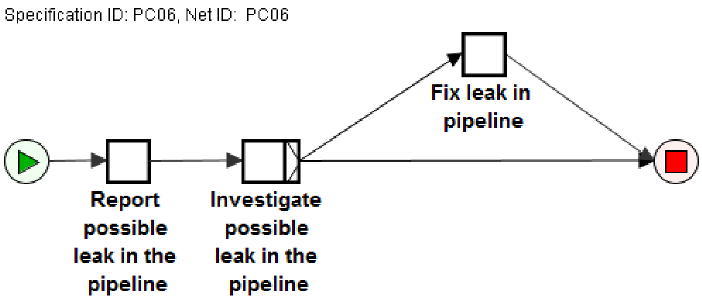


Figure 7.4 - Gas Lifting Process – YAWL designed Process Component PC_06.

Implementation and Analysis

The implementation and result analysis are structured according to the variables and questions previously presented.

Independent variables: In relation to the specialists, the lifting process is considered a main process by the organization because it is an important part of the oil & gas production. In production fields, onshore and offshore, the lifting, separation and transport processes are the ones towards most of the operators' work and efforts are directed. These are considered complex and big sized processes whose workflow changes among unit operations.

Dependent variables:

Question 1: Was the Mediator able to adapt the process correctly?

Some Situations were randomly simulated so as to analyze the adapted process. In order to do this, five process instances (described in Appendix VIII) were generated, and through each adaptation the new process structure was analyzed.

In test #1, as an example, when activity “Open locally alignment valve collector well” is executed, the following variables were set (AlignmentValveStatus = open, LocallyAlignmentValveOpeningTime = 6). Situation S02 was activated and PC_02 activated to be executed. PC_02 instance was activated in YAWL engine, as show in Figure 7.5.

The service log (Figure 7.6 - Gas Lifting Process – Test #1 – Problem update in prompt command logFigure 7.6 and Figure 7.7) shows that right after the execution of the “Open locally alignment valve collector well”, before the execution of the next activity (“Open shutdown valve”), process variables are updated (Figure 7.6) and the planning process is initiated (see – “* Iniciando planejamento do processo”). SAPA is executed and searches for a solution (Figure 7.7). PC_02 is enacted in the new plan.

All five tests worked as planned. Worklets were enacted as soon as they appear in the plan, considering that all of them were supposed to be executed right after situations that are supposed to trigger them were activated.

One of the things not addressed in this implementation was the fact that if the worklet is not executed and the process continues running (i.e, process variable values that activated a specific situation remain the same) another instance of the same worklet is activated. There was no treatment in order to realize that an instance to deal with the situation has already been executed, but the implementation of this verification is possible to be implemented as long as the waiting time to invoke enacted worklets only at specific moments of time of process execution.

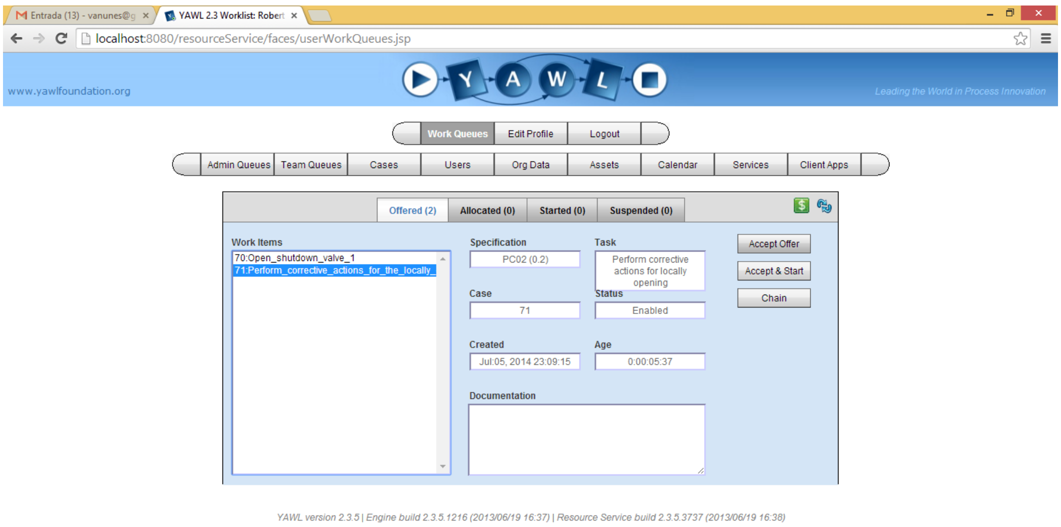


Figure 7.5 - Gas Lifting Process – Test #1.

```
Tomcat
-     checkout successful: 70:Open_locally_alignment_valve_collector_well_1
- HANDLE CHECK WORKITEM CONSTRAINT EVENT
- Checking pre-constraints for workitem: 70:Open_shutdown_valve_1
********* Atividade: Open_shutdown_valve
<GasLifting>
  <IncreaseDemand>false</IncreaseDemand>
  <Operation>100</Operation>
  <AlignmentValveStatus>open</AlignmentValveStatus>
  <NumAttemptsOpenShutdownValveStatus>true</NumAttemptsOpenShutdownValveStatus>
  <ChokeOpeningTime>1</ChokeOpeningTime>
  <WellPressurePipelineExitVariation>0</WellPressurePipelineExitVariation>
  <ConsumerDemandVariation>0</ConsumerDemandVariation>
  <LocallyAlignmentValveOpeningTimeStatus>false</LocallyAlignmentValveOpeningTim
eStatus>
  <WellStatus>true</WellStatus>
  <HydrateInjAlarmLevel>false</HydrateInjAlarmLevel>
  <NumAttemptsOpenShutdownvalve>0</NumAttemptsOpenShutdownvalve>
  <RemoteAlignmentValveOpeningTime>2</RemoteAlignmentValveOpeningTime>
  <WellPressureStatus>true</WellPressureStatus>
  <WellsTemperatureStatus>true</WellsTemperatureStatus>
  <TestWellsCost>1</TestWellsCost>
  <LocallyAlignmentValveOpeningTime>6</LocallyAlignmentValveOpeningTime>
  <ConsumerDemandVariationStatus>true</ConsumerDemandVariationStatus>
  <WellPressure>80</WellPressure>
  <CorrosionAlarmLevel>false</CorrosionAlarmLevel>
  <RemoteAlignmentValveOpeningTimeStatus>true</RemoteAlignmentValveOpeningTimeSt
atus>
  <PressureWellsVariation>0</PressureWellsVariation>
  <WellPressurePipelineExitVariationStatus>true</WellPressurePipelineExitVariati
onStatus>
  <ChokeOpeningTimeStatus>true</ChokeOpeningTimeStatus>
  <PressureWellsVariationStatus>true</PressureWellsVariationStatus>
  <WellsTemperature>0</WellsTemperature>
</GasLifting>
- HANDLE ENABLED WORKITEM EVENT
*  Iniciando planejamento do processo.
- Connection to engine is active
- Received workitem for worklet substitution: 70:Open_shutdown_valve_1
-     specId = GasLifting - version 0.13
- Rule set does not contain rules for task: Open_shutdown_valve OR No rule set f
ound for specId: GasLifting - version 0.13
* Iniciando execuÞÒo do Sapa
- Workitem returned to Engine: 70:Open_shutdown_valve_1
;; parsed domain: gaslifiting
;; parsed problem: gaslifiting-p1
;;GROUNDING GOALS
;; Goal: (completed monitor_variables_after_choke_and_alarm_levels) 46 Deadline:
 Infinity hard RewardC: 0.0 Penalty: 0.0
;; Goal: (completed monitor_well_and_pipelines_variables) 47 Deadline: Infinity
hard RewardC: 0.0 Penalty: 0.0
;; Goal: (value locallyalignmentvalveopeningtimestatus true) 50 Deadline: Infini
ty hard RewardC: 0.0 Penalty: 0.0
;;Reachable: Fluents: 12 Propositions: 61 Actions: 20
;;Dynamic: Fluents: 3 Propositions: 20 Actions: 11
;;Parsing & grounding: 64 milliseconds.
;; grounded first orders
;;SELECTED GOALS: [50, 46, 47]
```

Figure 7.6 - Gas Lifting Process – Test #1 – Problem update in prompt command log

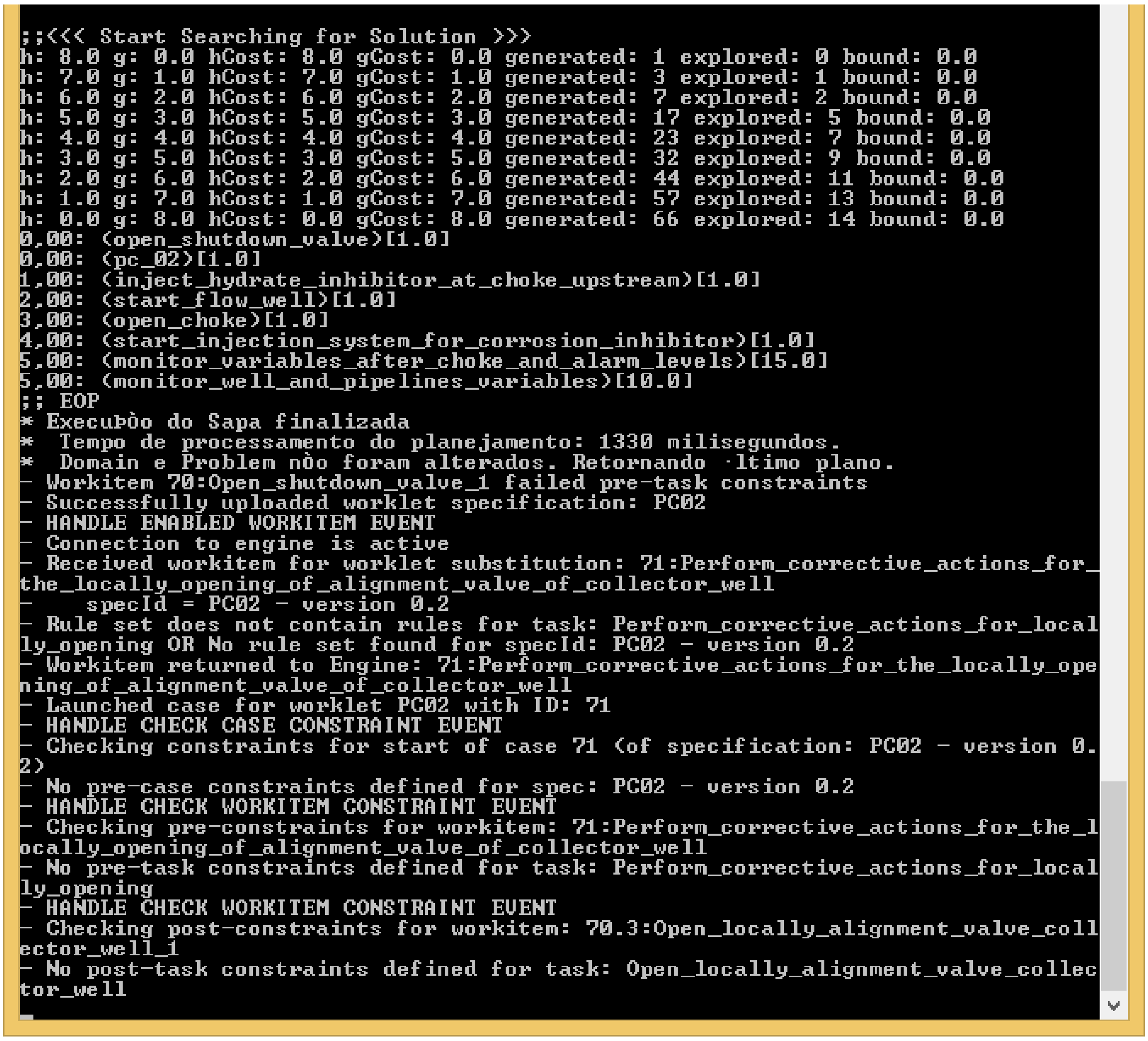


Figure 7.7 - Gas Lifting Process – Test #1 – Re-plan in prompt command log.

The interview was conducted with the process modelers responsible for the process elicitation and modeling. It was not possible to interview the specialists (process executors) because they were not available to continue the study. Therefore it was possible to evaluate questions 2, 3 and 4 by process modelers' viewpoint. Anyway some remarks were done based on group discussions.

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

Considering the modeler analysis's viewpoint, the situations were identified based on the oil & gas production process pattern that usually considers 4 main processes: Start engine, Maintain engine, Stop engine and Stop engine in emergency. The Situations and Process Components were extracted from the Maintain engine process. So the Situations (set of CEs values) that end up in enacting activities to be performed are in compliance with the original model that was validated by the specialists. Therefore, the level of complexity of process was perceived as high, as well as the degree of satisfaction with the proposed approach, because it was considered closer to the real scenario of execution. The level of complexity in the evolution of the process models was not able to be evaluated, because it is directly related to the machinery and technology used in the lifting process which was not the object of interest during the process modeling project (that was independent of this research thesis).

Question 3: Is the process representation (process and process components definitions) within the proposed approach more efficient than the conventional one with all the elements within the diagram?

After process elicitation and internal discussions between the modelers in charge of the process model, it was considered that Maintain engine is a very complex process responsible for the monitoring of a great number of variables that does not necessarily occur in the same flow sequence. Depending on the value of a variable, it is necessary for the operator to monitor another one that does not come straight in the flow sequence. The model exists mostly for the operator to use as a guide and as documentation. So, in order to be more effective, the representation of the process as default and the dismemberment of Maintain process into independent group of actions for each verification would represent more realistically what, indeed, happens in reality.

The use of systems to collect and prompt oil and gas information from production field is a reality, and based on observations during process elicitation, the use of a system that suggests actions based on Situations is feasible, although it was not possible to discuss about the automatic implementation of adaptations.

Question 4: Considering the adaptation to a context change, do the models produced by the approach require less time to be adapted in comparison with the manual analysis?

The total time to reason and act on situations simulated (described in Appendix VIII) for Question 1 were calculated (Table 7.1). Since it is mainly a manual process where the operator automatically receives some information and others are gathered by visually analyzing the valves and equipment, the reasoning time was considered feasible because it is much less than the time spent only to reunite the values and manually reason over them. An operator that gathers information on the field transmit it by radio (or other voice communication) to the central operation that analyzes and reacts to them, but still it demands a delay that exceeds the time presented in this study.

Table 7.1 - Gas Lifting Process – Mediator adaptation reasoning time evaluation

	Activities were Situations were activated	Situations	Time (milliseconds)
1	A	-	-
	B	S02 - PC02	1742
	C	S04 - PC04	1731
	D	S05 - PC05	1865
	E	S09 - PC10	1816
	F	-	-
2	A	-	-
	B	S02 - PC02	1376
	C	-	-
	D	-	-
	E	-	-
	F	S12 - PC13 S14 - PC15	1840
3	A	S01 - PC01	1894
	B	-	-
	C	S04 - PC04	1295
	D	-	-
	E	-	-
	F	S11 - PC12	1248
4	A	S01 - PC01	1240
	B	-	-
	C	S04 - PC04	1237
	D	-	-
	E	S06 - PC06	1959
	F	S12 - PC13	1672
5	A	S01 - PC01	1271
	B	-	-
	C	S03 - PC03	1803
	D	-	-
	E	-	-
	F	S12 - PC13 S14 - PC15	1441

"*If the relationship between intelligence and computation is taken seriously, then intelligence cannot be explained by intractable theories because no intelligent creature has the time to perform intractable computations. Nor can intractable theories provide any guarantees about the performance of* *engineered systems. Presumably, robots don't have the time to perform intractable computations either.*" (BYLANDER, 1991)

In general, as discussed by BYLANDER (1991), the computational complexity from propositional STRIP planning, to determine if a given planning instance has any solutions, is PSPACE-complete. A decision problem is PSPACE-complete if it can be solved using an amount of time that is polynomial in relation to the input length. COBHAM (1965) states that polynomial time is a synonym for "tractable", "feasible", "efficient", or "fast". And the running time is upper bounded by a polynomial expression in the size of the input for the algorithm, i.e., T(n) = O(nk) for some constant k.

Based on this, the performance of SAPA Planner (DO and KAMBHAMPATI, 2003) was already tested using complex domain and problems as Zeno Travel (PENBERTHY and WELD, 1994). This domain has actions to embark and disembark passengers onto aircraft that can fly at two alternative speeds between locations. In the metric variant the planes consume fuel at different rates according to the speed of travel (two alternatives) and distances between locations vary. Problem instances require plans to minimize some linear combination of time and fuel use. The results show that most of the problems are solved within 500 seconds.

Since, in this research, PDDL domain represents activities with precedence rules among them, the plan variants are considered when associated to the number of resources manipulated. So complexity is mostly subject to the objects that should be manipulated in the problem instance (number of resources). In this observational study, it was possible to presume the amount of medium time when considering complex problems in this type of domain representation, but it is possible to assure that this value is much less than 500 seconds, considering that the presented domains and problem approaches cost less than 2 seconds to be reasoned.

Summarizing, Table 7.2 shows the four discussed questions, analyzed variables and results.

Table 7.2 - Gas Lifting Process – Summarized questions, variables and results

Qc	Variable	Results
1	Model correctness	• All situations were reproduced correctly. • All models were considered correct accordingly to YAWL quality model checking.
2	Process performance	• Variations extracted from validated models. • Evidence that adapted instances are positive.
3	User satisfaction	• Process and variations considered more adherent to reality. • Simplicity and compliance.

4	Reasoning time	• T < 2 sec
		• PSPACE-Complete problem
		  • Precedence relations among actions
		  • Evidence: T << 8 min

7.3. Aircraft take-off Observational Study

Scenario Description

The Airspace Traffic Control (ATC) scenario was chosen due to its remarkable relevance, as well as its highly dynamic nature, and because it presents a number of factors that could possibly interfere with the process execution. ATC is a service provided by controllers on the ground 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 to fly in accordance with the operating characteristics of aircraft and traffic conditions at any given time. Controllers may provide guidance regarding the route, altitude and/or speed proposed by the aircraft operator for a particular flight; pilots must comply with the instructions and authorizations received.

In many countries, ATC services are provided throughout the length of an airspace, and these services are used by private, military and commercial aircraft companies. The airspaces where the controller sends authorizations are called controlled airspaces, as opposed to uncontrolled airspaces, where aircraft pilots are responsible for their own safety and navigation. Depending on the type of flight and the class of airspace, the air traffic controller provides instructions that pilots must follow or merely assist pilots operating in certain airspace. In addition to being dedicated to passenger safety, ATC aims to speed up aircraft deployment, preventing delays and reducing operating costs for users.

Based on interviews with experts conducted during the modeling process, the Aircraft Takeoff process was modelled in the case study described in (MATTOS *et al.*, 2012) because of its importance to aviation, with thousands of instances being performed daily. The model developed is based on the Business Process Metamodel. Both the domain and process models were built with the help of specialists through interviews. The following professionals were interviewed: two air traffic controllers, who are the heads of the airport control tower at Galeão Airport in Rio de Janeiro, Brazil, each with over thirty years of experience, an airline pilot with twenty-nine years of experience and more than 2500 flight hours. Furthermore, the process applies to aerodromes that have a control tower, which constitutes a significant portion of flights conducted in Brazilian airspace. The flow of activities in the Aircraft Takeoff process is depicted in Figure 7.8.

The takeoff process starts with the filling and submission of flight plan. Then flight plan is analyzed, authorized and ground procedures are performed so as the aircraft is put in position and takes-off.

A sample of real data regarding instances of the Aircraft Take-off Process was used to help define some of the situations. Data were extracted from daily reports released by the Center for Management of Air Navigation (CGNA). The CGNA centralizes information regarding the operational components of the infrastructure needed to manage the use of airspace in Brazil. By managing this information, CGNA is able to 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 term. 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 provide a rich amount of information to be handled, which allowed exploring the contextual elements and define situations. The reports were analyzed corresponding to a period of six months, from June to December of 2011. CEs, Situations and process worklets where modeled with the help of a professional who works at the Brazilian Airspace Control System supporting it through the use of the specialized systems.

Goal Definition

- Guarantee passengers and aerodrome safety
  - That is the main goal of commercial aviation, which is to keep passengers and staff safety in all flight stages.
- Optimize ground time
  - It involves reducing ground time (preventing delays) and operational costs in a co-related cost benefit.

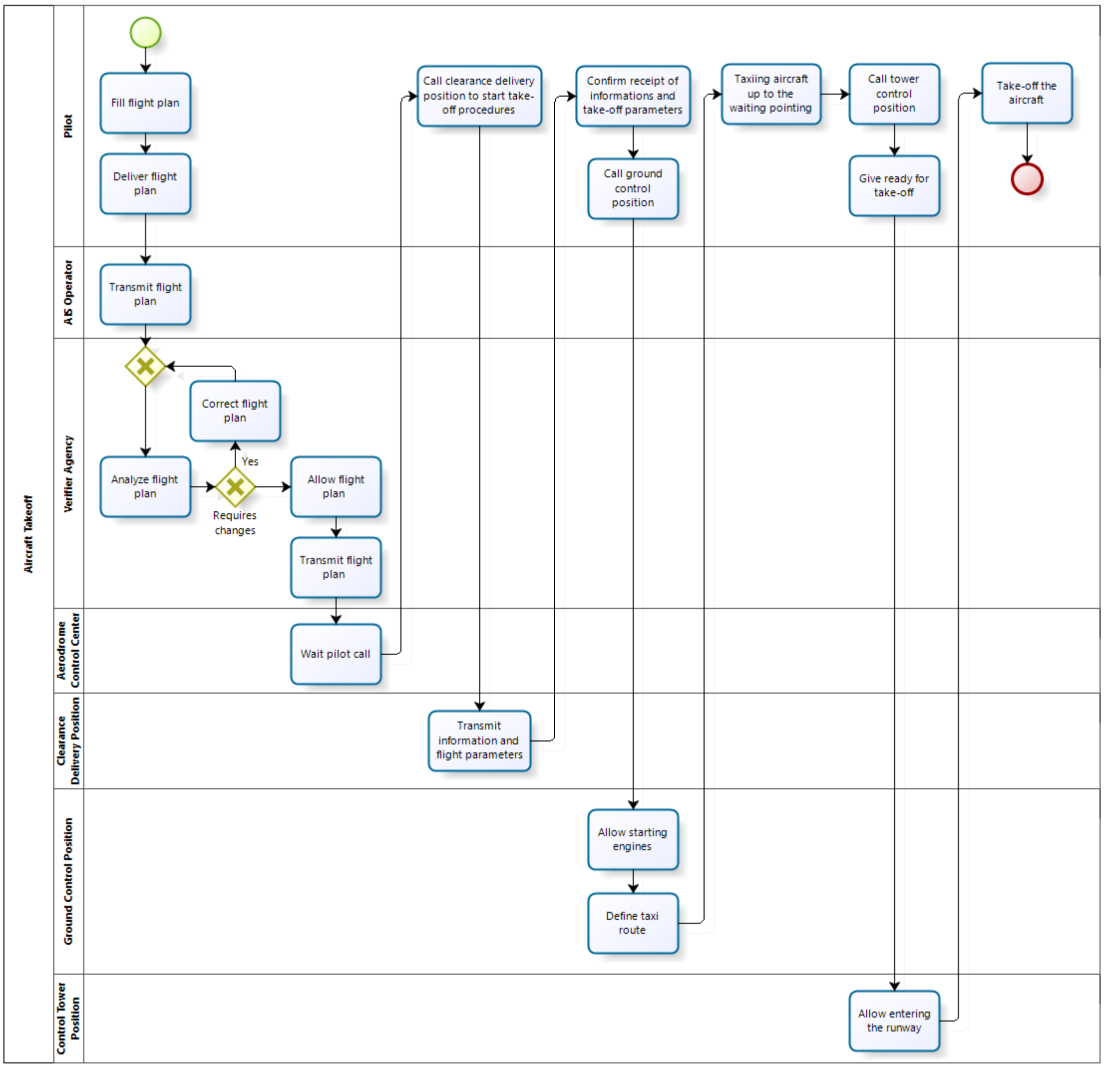


Figure 7.8 - Aircraft Takeoff process model

Contextual Elements

The domain model considered in this process scenario is presented in Figure 7.9.

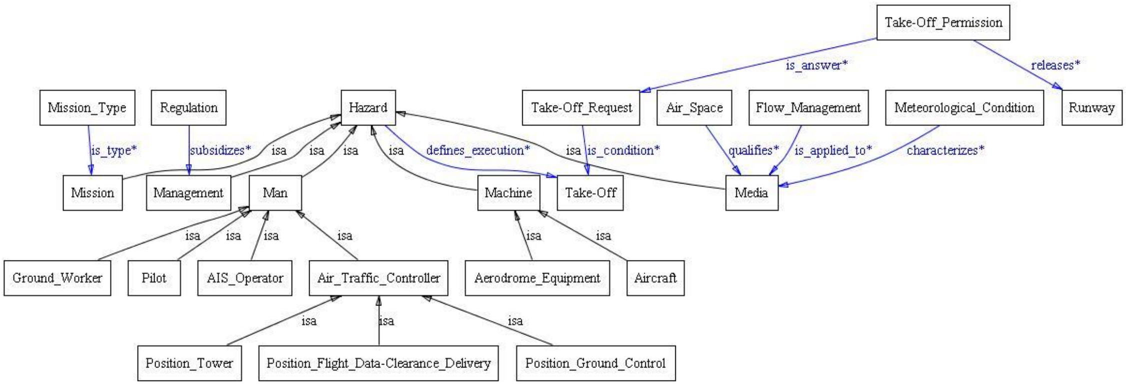


Figure 7.9 - Aircraft take-off Process domain model (MATTOS *et al.*, 2012)

Situations

Nine Situations that may happen during aircraft take-off process execution were identified. Situations 1 and 4 are described in the following. All nine Situations are presented in Appendix IX.

Situation 1 – 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.

S01 = { fillflightplan.status = completed,
RainfallLevelDestination = high,
MeteorologicalStatus = unfavorable}

Situation 4 – Wind direction change: After the execution of activity "Taxiing aircraft up to the waiting point" a situation is triggered indicating that wind conditions and direction have changed.

S04 = {definetaxiroute.status = completed,
WindDirection = opposite}

As a result, Situations were analyzed and a total of 7 process components (YAWL worklets) were identified. Process component PC_04 is shown in Figure 7.10 as a BPMN model and in Figure 7.11 as a YAWL model. All the process components can be seen in Appendix X.

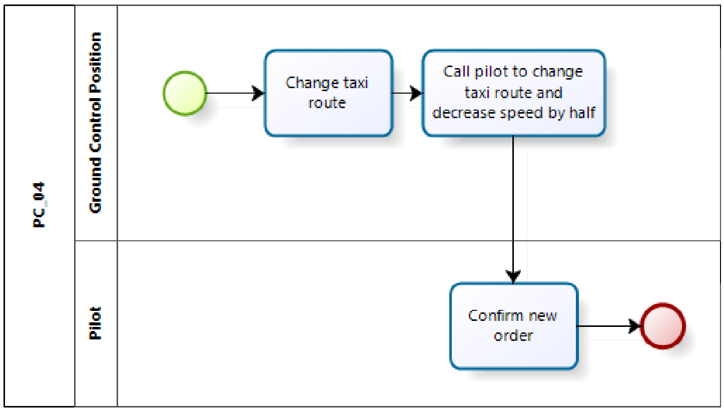


Figure 7.10 - Aircraft take-off Process – BPMN designed Process Component PC_04.

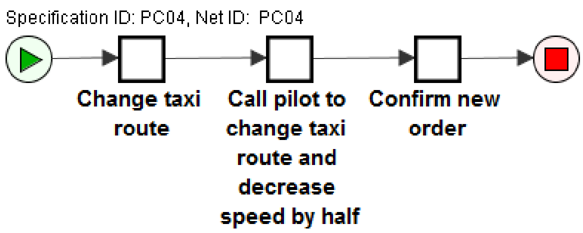


Figure 7.11 - Aircraft take-off Process – YAWL designed Process Component PC_04.

Implementation and Analysis

The implementation and result analysis are structured accordingly to the variables and Questions discussed previously.

Independent variables: In relation to the specialists, the aircraft take-off process is one of the most important processes because it is responsible for most of the delay when considering the total flight attendance time. It is considered complex because of the amount of "things" (e.g., CEs) that might happen, characterizing situations that demand some decision in relation to the default procedure.

Dependent variables:

Question 1: Was the Mediator able to adapt the process correctly?

Some Situations were simulated randomly so as to analyze the adapted process. In order to do this, five process instances (described in Appendix XI) were created, and through each adaptation the new process structure was analyzed.

In test #1, right before "Transmit flight plan" is to be executed, the variable 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 7.12 (process instances 75 – default process and 76 – PC_07).

The service log shows that right before the execution of “Transmit flight plan”, the problem file is updated with the process variables (Figure 7.13) and the planning process is initiated (see – “* Iniciando planejamento do processo”) (Figure 7.14). SAPA is executed and searches for a solution. The new plan for the process is presented and the first activity (transmit_flight_plan) is passing the calling of worklet PC_07 as a condition.

All 5 tests worked as planned. Worklets were enacted as soon as they appear in the plan, considering that all of them were supposed to be executed right after situations that trigger them were activated. The limitations in implementation presented in the previous study also apply in this one.

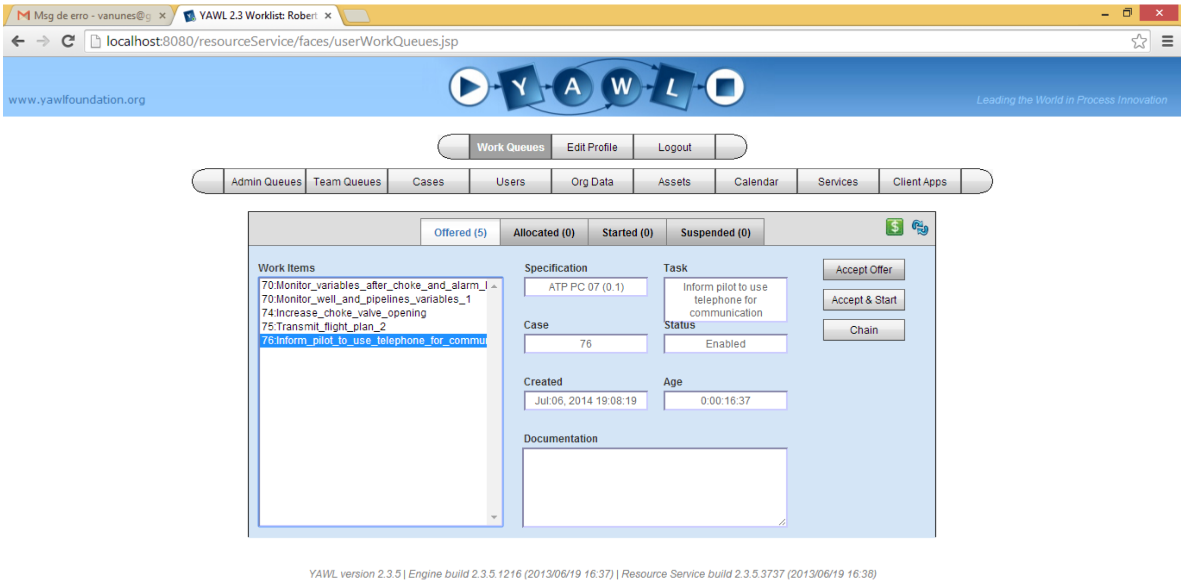


Figure 7.12 - Aircraft take-off Process – Test #1

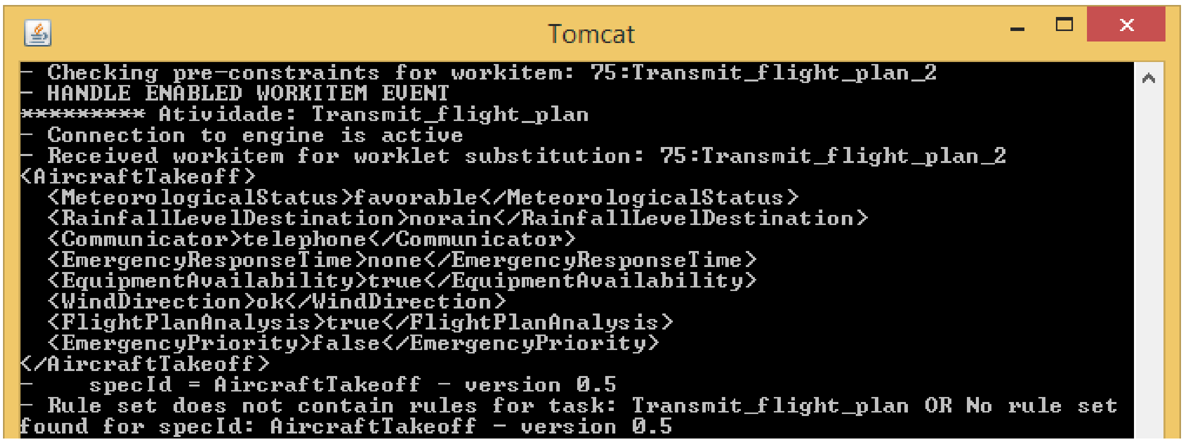


Figure 7.13 - Aircraft take-off Process – Test #1 – Problem update in prompt command log

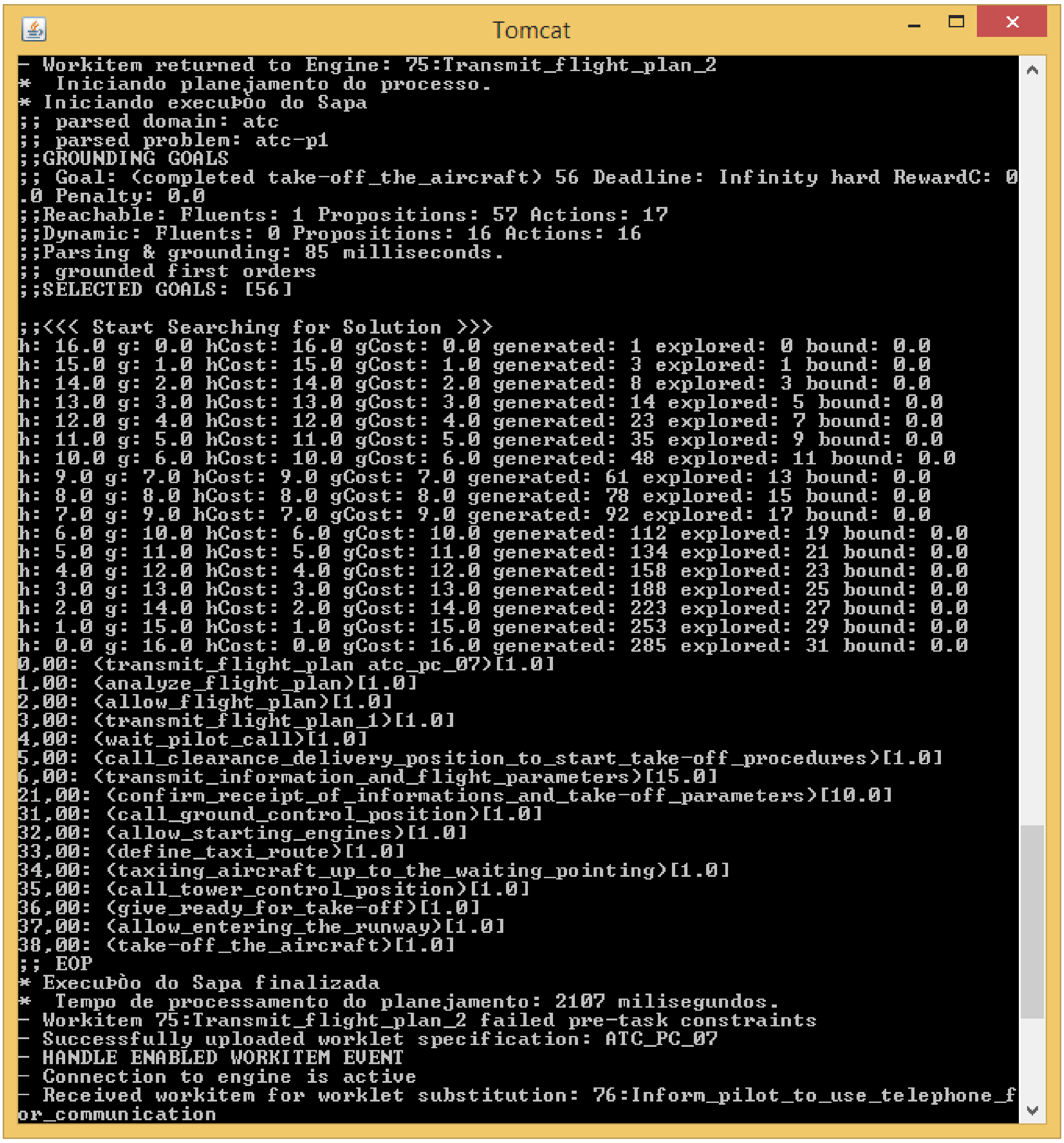


Figure 7.14 - Aircraft take-off Process – Test #1 – Re-plan in prompt command log

An interview with four domain specialists (pilots) was conducted in order to evaluate questions 2, 3 and 4. The questionnaire template is presented in Appendix XII and the interviews with them are reported in Appendix XIII. The questions were related to: (i) the perception about the time relevance for the hypothetical Situations; (ii) the possible actions they would choose for the hypothetical Situations; and (iii) their opinion about the approach as a whole.

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

The specialists were presented to nine Situations (related to the Situations described in Appendix IX) and possible actions to react on them to choose. Their choices are detailed in Table 7.3 (a full description of the choices answered by the pilots is described in Appendix XIII. It was based on the questions presented in Appendix XII).

Table 7.3 - Aircraft Takeoff Process – Questionnaire Group 1 answers

S	Activated actions	Actions Chosen by P1	Actions Chosen by P2	Actions Chosen by P3	Actions Chosen by P4	Correlated answers
S1	c	b, c, e	b, c, d	c	c	4
S2	c	b	b, d	b	e	0
S3	c	c	a	a	a	1
S4	c	c	c	c	e	3
S5	b	b, c	b, c	b	b, d	4
S6	c	a, c	c	b	c	3
S7	b	b	b, c	b	c	3
S8	c	d	c, e, f	c	f	2
S9	c	c	b, d	b	c	2

In general the specialists choose as one of the possible reactions the worklet that was previously modeled (Appendix X). The exception was in Situations 2 and 3, but it has to do with an overall aspect described by all of them related to the fact that the number of “factors” (e.g., CEs) that are significant to decide what to do when something different from the default procedure are innumerous. Although, when presented with the action chosen by the Mediator, in relation to the CEs at hand, they all agreed that this could be an action to be taken. 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 wouldn´t be a reason to change flight plan and they would proceed normally.

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

Pilot P3 observed that in order to understand the research thesis conducted, the situations were correctly elicited, and the adaptations apply. But he stated that realistically speaking, decisions are done based on an even more complex combination of information. Pilot P2 also commented on the fact that not all the possible “events” (e.g, situations) can be modeled in advance, as was also mentioned by pilot P1, even though the problems that arise by the combination of all CE´s are known. In order words, P1 thinks that all the problems may be known and modeled but not all the possible combinations of information 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 that is only responsible for working on the analysis and learning from those reports). The pilots’ opinions meet the researcher’s requirements for a context management mechanism for process adaptations purposes (as discussed in Chapter 5). Learning from previous process executions is indeed primordial for maintaining and improving the quality of the reasoning mechanism.

So, during the interviews it was explained that the GCAdapt architecture approach aims at learning from the take-off procedures executions already performed so as 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.

So, from the pilots’ viewpoint, it is feasible to perform computational reasoning based on the monitoring of contextual information. Although they mentioned that because they deal with people´s lives in a very complex environment, “this system” needs to have a very high level of confidence.

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 in proper moments of time so as not to influence the pilot in taking decisions about things that are not relevant at a certain time. 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 becoming, increasingly, a system and knowledge management other than “only command flight operations”.

Question 3: Is the process representation (process and process components definitions) within the proposed approach more efficient than the conventional one with all the elements within the diagram?

In the study, from the pilots' viewpoint, the number of variables (ECs) and combinations of values are numerous and result in different situations that can lead to different reactions. So, questions related to the approach (procedure execution and awareness of contextual information, reasoning and learning) where made. They were asked to assign a score from 1 to 5 (1 – strongly disagree, 2- partially disagree, 3 – impartial, 4 – partially agree, 5 – strongly agree) to the benefits of using a system capable of using computational intelligence to help taking actions during unexpected situations. Answers are summarized in Table 7.4 (a full description of the choices answered by the pilots is described in Appendix XIII. It was based on the questions presented in Appendix XII).

Table 7.4 - Aircraft Takeoff Process – Questionnaire Group 2 – question 10 answers

Benefits	P1	P2	P3	P4
Decrease in time perception of unexpected events	4	4	5	5
Dissemination of information to all participants of the take-off 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 take-off over actions related to unexpected events and the outcome of the take-off procedure in order to improve computational reasoning.	5	5	5	5

All the pilots foresee potential when they were presented with the research approach and mechanisms. The disagreement from Pilot P1 in relation to benefits in disseminating information among the process executors comes from the fact that as all four pilots are militaries, but P1 has recently gone to commercial flight, and because of companies' political and commercial interests, some decisions are not in the hands of the pilot as in military aviation. So, in his point of view, being aware of information that he has no managerial power can bring a sense of frustration.

Question 4: Considering the adaptation to a context change, do the models produced by the approach require less time to be adapted in comparison with the manual analysis?

The total time to reason and act on situations simulated (described in Appendix XI) for Question 4 were calculated (Table 7.5).

Table 7.5 - Aircraft Takeoff Process – Mediator adaptation time reasoning evaluation

I	**Activities were Situations were activated**	**Situations**	**Time (milliseconds)**
1	A	S09 - PC07	1408
	B	S01 - PC01	1403
	C	-	1456
	D	S02 - PC08	1179
	E	S02 - PC08	1309
	F	S01 - PC01	1686
	G	S07 - PC05	1129
	H	S04 - PC02	1446
	I	S04 - PC02 S07 - PC05 S02 - PC08	1657
	J	S07 - PC05	1607
	K	S02 - PC08	1675
	L	S04 - PC02 S02 - PC08	1708
2	A	-	1364
	B	-	1269
	C	S02 - PC08	1766
	D	S02 - PC08	1404
	E	S01 - PC01	1642
	F	-	1368
	G	-	1383
	H	S02 - PC08	1735
	I	S01 - PC02 S02 - PC08 S03 - PC05	1727
	J	S04 - PC02 S03 - PC05	1506
	K	S03 - PC05	1876
	L	S03 - PC05	1450
3	A	-	1497
	B	S03 - PC09	1799
	C	S02 - PC08	1289
	D	-	1683
	E	-	1412

	F	S03 - PC06	1931
	G	-	1692
	H	S08 - PC02 S06 - PC04	1214
	I	S07 - PC05	1483
	J	S02 - PC08	1399
	K	S04 - PC02	1517
	L	S04 - PC02 S03 - PC05 S02 - PC08	1573
4	A	-	1654
	B	S02 - PC08	1601
	C	S01 - PC01	1436
	D	-	1252
	E	S08 - PC06	1314
	F	-	1074
	G	S02 - PC08 S03 - PC05	1402
	H	S02 - PC08 S03 - PC05	1123
	I	S01 - PC01	1035
	J	S04 - PC02 S03 - PC05	1017
	K	S04 - PC02 S03 - PC05 S02 - PC08	1181
	L	S04 - PC02 S03 - PC09	1224
5	A	-	1239
	B	S03 - PC09	1239
	C	S01 - PC01	1176
	D	S01 - PC01	1300
	E	-	1119
	F	S02 - PC08	1271
	G	S02 - PC08	1094
	H	S04 - PC02	1138
	I	S02 - PC08	1083
	J	S04 - PC02 S03 - PC05	1023
	K	S04 - PC02	962
	L	S04 - PC02 S03 - PC05	1149

The Aircraft take-off process, although being smaller in terms of number of the worklets defined, evidenced to be more complex because of the intrinsic relation of CEs manipulated in the observational study. Even though, the time processing still remained the same, which strengthens the discussion in the previous study, on the increase of time in relation to the increase of domain complexity.

Also, discussing time to be aware and react to the Situations presented in the questionnaire, the four pilots responded that things are currently done in a fast or median time (Table 7.6), but the faster the better. Pilot P4 responded median because two main factors: He runs an aircraft with not updated technology to provide information automatically and the situations presented were not considered by him as of high risk, so sometimes they happen with a little delay that does not impact his work in military aviation.

Table 7.6 - Aircraft Takeoff Process – Questionnaire Group 1 – Reaction time question do Situations

	P1	P2	P3	P4
S1	a	A	b	b
S2	a, b	A	b	b
S3	a	A	a	b
S4	b	A	a	b
S5	a	A	a	b
S6	a	A	a	b
S7	a	A	a	b
S8	a	A	a	b
S9	a	A	a	b

Lable: a – fast, b – median, c- high

Summarizing, Table 7.2 shows the four discussed questions, analyzed variables and results.

Table 7.7 - Gas Lifting Process – Summarized questions, variables and results

Qc	Variable	Results
1	Model correctness	• All situations were reproduced correctly. • All models were considered correct accordingly to YAWL quality model checking.

2	Process performance	• Answers adherent to situations presented.
		  • 9 situations (7 adherents).
		  • Many more factors may impact in decision making

3	User satisfaction	• Evidence that the approach was considered useful in supporting the accomplishment of the thesis goals.

4	Reasoning time	• T < 2 sec
		• Reaction time considered fast when T < 5 min
		• PSPACE-Complete problem
		  • Precedence relations among actions
		  • Evidence: T << 8 min

7.4. Hypotheses Analysis

Question 1

Based on the tests performed during implementation and during the formal tests, a possible rejection of the null hypothesis H01 was observed. It is possible to conclude that this specific prototype implementation correctly activated the adaptations and the processes were executed to completion without errors.

Question 2

Based on the analysis of the gas lifting modeling project and the discussion with the interviewed specialists on the aircraft take-off observational study, although it became clear that a more detailed elicitation of relevant contextual information and possible adaptations need to be done in order to use the approach in a real scenario, a possibility, also confirmed by the interviewed specialists, for the rejection of the null hypothesis H02 was observed. It is possible to obtain evidence that the approach is feasible.

Question 3

Based on the discussion with the interviewed specialists on the aircraft take-off observational study, the specialist 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 procedure is under a high risk management orientation, pilots cannot lose focus of the main tasks in order to safely taking-off aircrafts.

Although it was not possible to interview operators for the GasLifting Study, the 8 year experience of the modelers team in eliciting oil and gas production processes allowed to discuss over the benefits of introducing this approach, since it was possible to observe an increase in the automation of analysis of the variables that affect oil and gas production.

Based on those impressions, a possibility for the rejection of the null hypothesis H03 was observed. The GCAdapt approach may bring more benefits not only in the interpretation of standard processes and possible adaptations but also in the reaction to unexpected situations.

Question 4

Based on the tests performed during implementation and during the formal tests, and correlating it to the discussion on the increase in domain and problem complexity, a possibility for the rejection of the null hypothesis H04 was observed. It is possible to conclude that this specific prototype implementation reasons over possible adaptations in a reasonable time that could enhance the chances of the process to keep aligned to its goals.

Therefore, this research observational study has shown the feasibility of the approach by discussing its deployment on top of YAWL PAIS and SAPA Planner and by showing some tests based on two real process scenarios.

8. CONCLUSION

8.1. Summary of Dissertation

This thesis proposed a solution for dynamic process adaptation materialized in the GCAdapt architecture. The motivation for this thesis research was that nowadays, business processes have become a crucial part of many organizations, playing an important role in the way they operate. These processes are often supported by PAIS and the successful execution of each process instance depends on an amount of factors, viewed as context information, that demands adjustments and is hard to situate, monitor and reason for adaptation purposes.

So GCAdapt represents the architecture of a computational solution for dynamic process adaptation addressing the management of context. It serves as a basis to: maintain the suitability of a process instance according to organizations and people's needs/goals; discover new situations that demand new process behavior not previously defined; and understand how context affects process.

Each module of CGAdapt has been detailed through a UML Activity Diagram so as to specify how they should work. The Mediator module is the core of the proposed architecture since it is the module that infers the need for an adaptation and establishes an interaction with an Artificial Intelligence planner that should re-plan the process.

This thesis considers process reasoning as knowledge and goal-driven mechanism guided by procedural rules, business rules, constraints, resource availability and characterization and desires. The modeling of business processes as an Artificial Intelligence planning task, through its representation as domain and problem files, has been proposed in order to understand and reason on formal relations between context and processes in a goal oriented view so as to assist in the identification of efficient adaptations for this purpose.

Based on observational studies, it was possible to collect evidence about the feasibility of the solution since the outcomes from the execution of the inferences and tasks of the planner resulted in coherent processes, as well as its instance could achieve the desired goals, as the analysis of experts' interviews showed. In the Gas Lifting process, as an example in Situation 03, contextual elements' values are not critical but may prevent the gas lifting process from its maximum expected quantity of gas per hour lifted from the well, and increase the risk of some incident that may cause the process to stop abruptly. The faster the action on the situation, the higher the chances that data returns to normal values are. For instance, considering that a group of wells is connected by one reservatory, the increase in the variation of pressure among the wells may cause loss of circulation or invasion in the well by other unexpected fluids which may limit production or may cause equipment in the surface to stop.

8.2. Main Contributions

The contributions are summarized as follows:

Implications for research

The research integrated and established an operationalization of the concepts related to context, business process and goals. It was discussed and grounded, not only on the discussion among other research dissertations correlated to this thesis research, but also on a foundational theory over the concepts related to CAIS (Context-Aware Information System). It formed the basis for evolvement considering specific domains.

Second, the architecture, which was thought to be developed through independent services that provide abstractions necessary for the development of distributed intelligence, allows interactivity between capture mechanisms and implementation, having autonomous and proactive behavior.

It also allowed, so far, other researches in the group to run focused but independently. ANASTASSIU and SANTORO (2013) proposed a method for identification of relevant context information (internal to the organizational) in business process which is the basis to establish an effective information infrastructure for process dynamic adaptation that is aware of context that characterize situations properly. Complementary, RAMOS *et al.*, (2013) proposed a method for the identification of relevant context information external to the organization that characterizes process instances situations. MATTOS *et al.*, (2012, 2014) proposed the representation of context of a business process activity in a given domain through conceptual models structured in layers in order to broaden the perception of the relation among context, business process and domain concepts. During these three master dissertation developments, the research group discussed and substantiated the relevance of context-awareness in business processes and grounded the discussed concepts to further be used to operationalize this thesis research.

Further on, CARVALHO *et al.*, (2013) proposed an approach for the Situation Definition Maintainer (Chapter 5, Figure 5.17) that presents a computational engine that infers the need to update situations and adaptation rules, suggesting changes to them.

The thesis also proposed the representation of business processes as an Artificial Intelligence planning task, which not only may lead to more effective outcomes, but also makes not necessary the establishment of static adaptation rules. Conceiving business processes and its intended achievements as dynamic domain and problem representations, allows the reasoning over process based on the available organizational and domain information that have already been monitored (or at least documented on a regular basis) without the need to create adaptation rules based on them, maintain and evolve every time organization or external demands require.

Implications for practice

Regarding the applicability, although YAWL limits process flexibility due to its implementation aspects, it was possible to observe the feasibility of the solution in demanding YAWL adaptations on time and effectively. A main contribution related to this aspect was the actual implementation of a service coupled to YAWL engine system that is able to reason using a Planner and automatically produce results to autonomously implement in the YAWL process instance.

By first proposing a general view of the implementation, it is possible to follow the prescriptions (translated in a set of design features a context-aware PAIS must consider) in order to implement the solution using different PAIS and Planners.

Finally, the specification and construction of two real process scenarios may serve for future evaluations of this and other researches in the group.

8.2.1. Publication Results

Some of the results of this research were registered in the following publications:

- MATTOS, T., SANTORO, F.M., REVOREDO, K., NUNES, V.T., 2014, "A Formal Representation for Context-Aware Business Processes", Computers in Industry Journal, v.65, pp.1193-1214.
- CARVALHO, J.S., SANTORO, F.M., REVOREDO, K., NUNES, V.T., 2013, "Learning context to adapt business processes", 2013 IEEE 17th International Conference on Computer Supported Cooperative Work in Design (CSCWD), pp.229-234, Whistler, Canada.
- CARVALHO, J.E.S., SANTORO, F. M., REVOREDO, K., NUNES, V.T., 2013, Aprendendo Contexto para Adaptar Processo. In: Simpósio Brasileiro de Sistemas de Informação. Anais do Simpósio Brasileiro de Sistemas de Informação. Porto

Alegre: Sociedade Brasileira de Computação, 2013. v. 1, pp. 613, João Pessoa PB, Brasil.

- NUNES, V.T., WERNER, C.M.L., SANTORO, F.M., 2012, “Mediating process adaptation through a goal-oriented context-aware approach”, In: Computer Supported Cooperative Work in Design (CSCWD), 2012 IEEE 16th International Conference on, pp. 160-167, Wuhan.
- MATTOS, T.C., SANTORO, F.M., REVOREDO, K., NUNES, V.T., 2012, "Formalizing the situation of a business process activity," 2012 IEEE 16th International Conference on Computer Supported Cooperative Work in Design (CSCWD), pp.128,134, Wuhan, China.
- MATTOS, T., SANTORO, F.M., REVOREDO, K., NUNES, V.T., 2012, “Formalizando Contexto em Processos de Negócio. In: Simpósio Brasileiro de Sistemas de Informação”. São Paulo. Anais do Simpósio Brasileiro de Sistemas de Informação. Porto Alegre : Sociedade Brasileira de Computação.
- NUNES, V.T., WERNER, C.M.L., SANTORO, F.M., 2011, "Dynamic process adaptation: A context-aware approach". CSCWD 2011 - 15th International Conference on Computer Supported Cooperative Work in Design, pp. 97-104, Lausanne, Switzerland.
- NUNES, V.T., SANTORO, F.M., BRÉZILLON, P., WERNER, C.M.L., 2011, "Contextualizing dynamic process adaptation". 7th International Workshop on Modeling and Reasoning in Context - 7th International and Interdisciplinary Conference on Modeling and Using (CONTEXT’11), Karlsruhe, Germany.
- NUNES, V.T., 2011, “Dynamic Process Adaptation: A context-aware approach”, PHD Symposium of the 9th International Conference on Business Process Management Available in: http://bpm2011.isima.fr/.
- NUNES, V.T., MAGDALENO, A.M., WERNER, C.M.L., 2010, “Modelagem de contexto sobre o domínio de processos de desenvolvimento de software”, Relatório Técnico ES-734/10, COPPE/UFRJ. Disponível em: http://www.cos.ufrj.br.
- NUNES, V.T., WERNER, C.M.L., SANTORO, F.M., 2010, "Context-based Process Line", ICEIS 2010 - 12th International Conference on Enterprise Information Systems, p. 277-282, Funchal, Madeira, Portugal.
- GATTI, L., SANTORO, F.M., NUNES, V.T., 2010, "An agent-based architecture for knowledge management in context-aware business processes". 14th International Conference on Computer Supported Cooperative Work in Design (CSCWD), pp. 318-323, Shanghai, China.

The following paper was submitted and was under revision until completion of the thesis writing:

- NUNES, V.T., SANTORO, F.M., WERNER, C.M.L., 2014, "Dynamic Process Adaptation: Planning in a Context-Aware Approach", Computers in Industry Journal, Url: http://ees.elsevier.com/comind/.

8.3. Boundaries

Limitations in literature review

Literature was selected among the field of business process, CAIS and PAIS fields of research. So, in this respect, the literature review was selective. As context and processes are interdisciplinary topics, a broader search covering other fields of research could enhance the conceptualization foundation and domain expressiveness. However, this thesis rely on the fact that the research group related to this thesis and the research approaches helped considerably to ensure an adequate definition, relation and operationalization among context and business processes concepts.

Limitations in practice

The approach implementation using YAWL and SAPA Planner presented some limitations imposed by these applications. Although YAWL is one of the most used PAIS in academia (also used by some organizations[15]), it treats flexibility in a specific away as discussed in Chapters 2 and 6. So Mediator was implemented following the definitions and limitations imposed by YAWL architecture and business process execution and adaptation implementation, which is supposed to happen with any PAIS that would be chosen to test the operationalization of this proposed approach.

SAPA Planner has some limitations regarding the richness of PDDL representation. As it implements PDDL 2.1 partially, some constructs were not able to be used like "or", "when", verification of number in problem goals and preferences. But it was not possible to make use of a Planner that implements PDDL 3.1 (latest version) due to implementation issues (as unidentified bugs as an example) even though using SAPA it was possible to observe the feasibility of the proposal.

A system to control organizational information outside of the process was not implemented. So, if a goal, business rule or any other process element changes, it needs to be done altering domain and/or problem XML files. An user-friendly system would be necessary to deal with those information.

[15] For more information go to: http://www.yawlfoundation.org/

Limitations in the observational study

In addition to the aforementioned threats presented in Chapter 7 in the evaluation plan, the study using the implementation didn't deal with the timing aspect that is related to the appropriate time to present situations and to enable adaptations, which is a concern mentioned by the pilots interviewed for the Aircraft take-off study. As risk management is very critical in the studied domains, adaptations were enabled immediately when identified.

In relation to the selected PAIS and Planner, other implementations would be important in order to evaluate PAIS and GCAdapt usability rather than only feasibility.

8.4. Future perspectives

There is a number of future research works related to this thesis that influence each other and may derivate different research paths:

- The discussion on how the context level of uncertainty and relevance should be addressed in dynamic process adaptation as well as the consideration of how a contextual element value evolves in a period of time (tendency).
- The discussion on how goals relevance and personal goals (i.e., stakeholder's context and desires viewpoint) should be addressed in dynamic process adaptation.
- Implementation and integration of other GCAdapt modules. For each of them, methods and technologies that might be dependent or not on a specific domain have to be investigated.
- Implementation of a graphical interface so as to visually provide stakeholders context perception while process running. Context representation for user visualization and manipulation purposes represents a thorough study that is related to how people deal with context information and the timing concern since it might represent information overload in some domains.
- Implementation of an application to deal (receive and manipulate) with organizational and strategic information. Context information that may be used to characterize some impact in process execution is related not only to information directly manipulated in the instances. So a study on how to manipulate and represent information that impacts on the organization as a whole and consequently in its processes is required and an approach that integrates to GCAdapt is needed in order to manipulate and reason over those kinds of contextual information.
- Selection of other more sophisticated Planners and/or algorithms to experiment process representation with greater details and more realistic.

- The view of business processes as HTN (Hierarchical Task Network) knowledge representation language, may help to represent some BPM structures. PDDL alone is not able to represent as AND relations for instance.
- The adoption of PDDL 3.1 may also enrich business process and goals specification as it extends PDDL 2 to support the specification of preferences and hard constraints over state properties of a trajectory. These preferences form the building blocks for definition of a PDDL 3 metric function that defines the quality of a plan (GEREVINI and LONG, 2005, GEREVINI *et al.*, 2009).

  When dealing with goals and specific contexts, the field of preference-based planning is a form of automated planning and scheduling that focuses on producing plans that additionally satisfy as many user-specified preferences as possible. These are called preference-based Planners. Unfortunately, due to implementation issues, it was not possible to use the ones existing in the literature.

- Implementation of a multiple process perspective in order to treat the impact of processes in the same domain.
- Treat processes as partially observable domain in non-deterministic and non-finite environments, i.e., treat dynamic process adaptation as non-classical planning problem.
- Treat in more depth questions related to time constraints, cost models, utility models and indecidability.
- Evaluation in different domains so as to evaluate the generalization of the approach.
- To consider the implementation of a PAIS engine that enables flexibility at each process element (it is related to the investigation and implementation of all the operationalization proposed in Table 5.4, since only CAF-01 and CAF-04 where used in the two observational studies). It would permit adaptation at any process granularity level, as argued by the research.
- Invest on AI Planner specification and implementation to consider the use of structured process and the specific characteristic it presents, so as to represent it more properly using PDDL and implement reasoning algorithms that best match this scenario.

In summary, this thesis began with the formulation of a problem in a wide aspect, followed by the literature that supported the propositions made, and the solution provided by the architecture that encompass context management for dynamic process adaptation purposes, named GCAdapt, and the focus on its core engine, named Mediator, responsible for the reasoning and decision making process.

One important point to be highlighted is that, being context the basis of the proposal, and by nature dynamic itself, the architecture was proposed to be proactive in learning based on previous process instances execution in relation to the performance achieved and also provided with manual mechanisms for domain specialists to improve themselves.

Even though the observational studies showed the validity of the research and feasibility of the proposal, many questions remain and this researcher sees future research, even beyond the ones briefly listed above, as a continual and long work in progress theme.

REFERENCES

AALST, W.M.P., 2009, “Process-Aware Information Systems: Design, Enactment, and Analysis”, *Wiley Encyclopedia of Computer Science and Engineering*, pp. 2221–2233.

AALST, W.M.P., JABLONSKI, S., 2000, "Dealing with workflow change: identification of issues and solutions", *International Journal of Computer Systems, Science, and Engineering*, v. 15, n. 5, pp. 267-276.

AALST, W.M.P., HOFSTEDE, A.H.M.T., 2005, "YAWL: Yet Another Workflow Language", *Journal of Information Systems*, v. 30, pp. 245-275.

ACKOFF, R.L., 1971, “Towards a System of Systems Concepts”, *Management Science Journal*, v. 17, pp.661–671.

ADAMS, M.J., 2007, *Facilitating Dynamic Flexibility and Exception Handling for Workflows*, PhD Thesis, Queensland University of Technology, Brisbane, Australia.

ALTER, S., 2009, “Metamodel for Understanding, Analyzing, and Designing Sociotechnical Systems”, *Proceedings of JAIS Theory Development Workshop*, v. 9, pp. 1–47.

ANASTASSIU, M., SANTORO, F.M., 2013, “A method for identification of relevant context in business process”, *1st International Workshop on Context for Business Process Management* (CBPM 2013 – CONTEXT-2013), Annecy.

ASTAH, 2013, Astah Community version 6.7, Available in: < http://astah.net/ > Acessed in: 18/11/2013.

BALDAUF, M., DUSTDAR, S., ROSENBERG, F., 2007, "A survey on context-aware systems", *International Journal of Ad Hoc and Ubiquitous Computing*, v. 2, pp. 263-277.

BAZIRE, M., BRÉZILLON, P., 2005, “Understanding Context Before Using It: Modeling and Using Context”, *Proceedings of the 5th international conference on Modeling and Using Context* (Context’05), pp. 29-40, Paris, France.

BESSAI, K., CLAUDEPIRRE, B., SAIDANI, O., 2008, “Context-aware Business Process Evaluation and Redesign”, *Proceedings of the 9th Workshop on Business Process Modeling Development and and Support*, In: International Conference on Advanced Information Systems, Montpellier, France.

BIDER, I., 2005, "Masking flexibility behind rigidity: Notes on how much flexibility people are willing to cope with". *Proceedings of the CAiSE’05 Workshops, Workshop on Business Process Modeling, Development and Support*, pp. 7-18, Porto, Portugal.

DURAN-LIMON, H. A., BLAIR, G.S., FRIDAY, A., et al., 2003, *Context-aware middleware for pervasive and Ad-Hoc environments*, Computing Department, Lancaster University, v. 26031, pp. 1-9, Bailrigg Lancaster, UK.

BRÉZILLON, P., 2007, “Context modeling: Task model and model of practices”, In: Kokinov *et al.* (Eds.), *Proceedings of the 6th international conference on Modeling and Using Context (Context’06)*, Springer Verlag, pp. 122-135, Denmark.

BRÉZILLON, P., 1999, “Context in problem solving: a survey”, *The Knowledge Engineering Review Journal*, vol. 14, pp. 47-80.

BREZILLON, P., POMEROL, J., 1999, "Contextual knowledge sharing and cooperation in intelligent assistant systems", *Le Travail Humain - Journal on Human Factors*, v. 62, n. 3, pp. 223-246.

BYLANDER, T., 1991, “Complexity results for planning”, *Proceedings of the Twelfth International Joint Conference on Artificial Intelligence*, Sydney, pp. 274-279.

CARVALHO, J.S., SANTORO, F.M, REVOREDO, K., NUNES, V.T., 2013 “Learning context to adapt business processes”, *2013 IEEE 17th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*, Whistler, v.1. pp. 229-234.

CHEN, H., FININ, T., JOSHI, A., 2004, "Semantic Web in the context broker architecture", *Proceedings of the Second IEEE Annual Conference on Pervasive Computing and Communications*, Orlando, Florida, pp. 277- 286.

COBHAM, A., 1965, "The intrinsic computational difficulty of functions", *Proceedings of the Logic, Methodology, and Philosophy of Science II*, North Holland.

DE LEONI, M., MECELLA, M., DE GIACOMO, G., 2007, “Highly dynamic adaptation in process management systems through execution monitoring”, *Proceedings of the 5th international conference on Business process management (BPM'07)*, Berlin, Heidelberg, pp. 182-197.

DE RAEDT, L., KERSTING, K., KIMMING, A., REVOREDO, K., TOIVONEN, H., 2008, “Compressing probabilistic Prolog programs”, *Machine Learning Journal*, v.70, pp.151-168.

DEY, A., ABOWD, G., SALBER, D., 2001, "A Conceptual Framework and a Toolkit for Supporting the Rapid Prototyping of Context-Aware Applications", *Human-Computer Interaction*, v. 16, n. 2, pp. 97-166.

DILLEY, R. M., 2002, “The problem of context in social and cultural anthropology”, *Language and Communication*, v. 22, n. 4, pp. 437-456.

DO, M.B., KAMBHAMPATI, S., 2003, “Sapa: A Multi-objective Metric Temporal Planner”, *Journal of Artificial Intelligence Research*, v.20, i. 1, pp.155-194.

DUMAS, M., AALST, W.M.P., HOFSTEDE, A.H.M.T., 2005, *Process Aware Information Systems: Bridging People and Software Through Process Technology*, 1o ed, Wiley-Interscience.

DUMAS, M., LA ROSA, M., MENDLING, J., REIJERS, H.A., 2013, *Fundamentals of Business Process Management*, Springer-Verlag Berlin Heidelberg.

FAHY, P., CLARKE, S., 2004, "CASS - Middleware for Mobile Context-Aware Applications", *Workshop on Context Awareness - MobiSys*, Boston, Massachusetts, v. 3, p. 304–308.

FERNANDES, A, CIARLINI, A.E.M., FURTADO, A.L., HINCHEY, M.G., CASANOVA, M.A., BREITMAN, K.K, 2007, “Adding flexibility to workflows through incremental planning”, *Innovations in Systems and Software Engineering*, v. 3, i. 4, pp. 291-302.

FOX, M., LONG, D., 2002, "PDDL+: Modeling continuous time dependent effects". *Proceedings of the 3rd International NASA Workshop on Planning and Scheduling for Space*.

FRIEDMAN, N., 1997, "Learning Belief Networks in the Presence of Missing Values and Hidden Variables", *Proceedings of the Fourteenth International Conference on Machine Learning*, p. 125-133.

GATTI, L., SANTORO, F.M., NUNES, V.T., 2010, "An agent-based architecture for knowledge management in context-aware business processes". *14th International Conference on Computer Supported Cooperative Work in Design, 2010 (CSCWD 2010)*, pp. 318-323, Shanghai, China.

GEREVINI, A., HASLUM, P., LONG, D., SAETTI, A., DIMOPOULOS, Y., 2009, “Deterministic planning in the fifth international planning competition: PDDL3 and experimental evaluation of the planners”, *Artificial Intelligence*, v. 173, pp.619–668.

GEREVINI, A., LONG, D., 2005, *Plan constraints and preferences for PDDL3*, Technical Report 2005-08-07, Department of Electronics for Automation, University of Brescia, Brescia, Italy.

GHALLAB, M., NAU, D., TRAVERSO, P., 2004, *Automated Planning: Theory and Practice*, Morgan Kaufmann Publishers Inc., Elsevier, San Francisco, CA, USA, ISBN: 1-55860-856-7.

GONZALEZ-FERRER, A., FERNANDEZ-OLIVARES, J., CASTILLO, L., 2009, “JABBAH: A Java Application Framework for the Translation Between Business Process Models and HTN”, *Proceedings of 3rd International Competition on Knowledge Engineering for Planning and Scheduling*, pp. 28–37, Thesaloniki.

GRASSI, D., BOUHTOUCH, A., CABRI, G., 2014, “Inbooki: Context-Aware Adaptive E-Books”, *Context-Aware Systems and Applications, Lecture Notes of the Institute for*

Computer Sciences, Social Informatics and Telecommunications Engineering, v.128, pp. 57-66.

GREGOR, S., JONES, D., 2007, “The Anatomy of a Design Theory”, *Journal of the Association for Information Systems*, v.8, pp.312–335.

GU, T., PUNG, H., ZHANG, D., 2005, "A service-oriented middleware for building context-aware services", *Journal of Network and Computer Applications*, v. 28, n. 1 (jan.), pp. 1-18.

HALLERBACH, A., BAUER, T., REICHERT, M, 2009. “Guaranteeing Soundness of Configurable Process Variants in Provop”, *In: Proceedings of The 11th IEEE Conference on Commerce and Enterprise Computing*, pp.98-105, Vienna, Austria.

HEREDERO, G., PENMETSA, H., AGRAWAL, V., SHASTRI, L., 2013, “Activity Context-Aware System Architecture for Intelligent Natural Speech Based Interfaces”, *In Activity Context-aware System Architectures Workshop, Twenty-Seventh AAAI Conference on Artificial Intelligence*, Bellevue, Washington, pp. 21-35.

HEVNER, A., CHATTERJEE, S., 2010, *Design Research in Information Systems: Theory and Practice*, Springer.

HEVNER, A, MARCH, S, PARK, J, 2004, "Design Science in Information Systems Research", *Management Information Systems Quarterly*, v. 28, n. 1, pp. 75-105.

HOFER, T., SCHWINGER, W., PICHLER, M., 2003, "Context-Awareness on Mobile Devices - the Hydrogen Approach", *Proceedings of the 36th Annual Hawaii International Conference on System Sciences (HICSS'03)*, v. 9, pp. 292.1, Washington, DC, USA.

HORKOFF, J., YU, Y., YU, E.S.K., 2011, “OpenOME: An Open-source Goal and Agent-Oriented Model Drawing and Analysis Tool”, *5th International i* Workshop (iStar11 Tool Fair Demos)*, pp.154-156, Trento, Italy.

JABLONSKI, S., AAALST, W.M.P., 2000, "Dealing with workflow change: identification of issues and solutions", *International Journal of Computer Systems Science and Engineering*, v. 15, n. 5, pp. 267-276.

JAUFMAN, O., MUNCH, J., 2005, "Acquisition of a Project-Specific Process", *Proceedings of the 6th International Conference on Product Focused Software Process Improvement*, pp. 328-342, Oulu, Finland.

KHEDR, M., 2005, "ACAI: agent-based context-aware infrastructure for spontaneous applications", *Journal of Network and Computer Applications*, v. 28, n. 1, pp. 19-44.

KLEMKE, R., 2000, "Context Framework - an Open Approach to Enhance Organisational Memory Systems with Context Modelling Techniques", *Proceedings of* *the Third International Conference on Practical Aspects of Knowledge Management* (*PAKM 2000*), Basel, Switzerland.

KNOLMAYER, G., ENDL, R., PFAHRER, M., 2000, “Modeling Processes and Workflows by Business Rules”, *In Business Process Management, Models, Techniques, and Empirical Studies*, Springer-Verlag, London, UK, pp.16-29.

KOKINOV, B.N., 1999, "Dynamics and Automaticity of Context: A Cognitive Modeling Approach", *2th International and Interdisciplinary Conference on Modeling and Using Context*, pp.200-213, Italy.

KRAMER, S., 1995, *Predicate Invention: A Comprehensive View Technical*, Report OFAI-TR-95-32, Available at: <http://citeseer.ist.psu.edu/viewdoc/summary?doi=10.1.1.45.4258>.

KUENG, P., KAWALEK, P., 1997, “Goal-based business process models: creation and evaluation”, *Business Process Management Journal*, v. 3, n. 1, pp. 17-38.

KUMAR, K., NARASIPURAM, M.M., 2006, "Defining requirements for business process flexibility". *Proceedings of the CAiSE’06 Workshops - Workshop on Business Process Modeling, Development, and Support (BPMDS’06)*, pp. 137–148, Luxembourg.

LA ROSA, M., 2009, *Managing variability in process-aware information systems*, PhD Thesis, Queensland University of Technology, Australia, 2009 Available at: http://eprints.qut.edu.au/20531/. Acessed in: 4 Dec 2010.

LANZ, A., KREHER, U., REICHERT, M., 2010, "Enabling Process Support for Advanced Applications with the AristaFlow BPM Suite", *Proceedings of the Business Process Management Demonstration TrackBusiness*, Hoboken, New Jersey, USA.

LAVALLE, S. M., 2006, *Planning Algorithms*, Cambridge University Press, University of Illinois.

LEONI, M., 2009, “Adaptive process management in highly dynamic and pervasive scenarios”, *Proceedings Fourth European Young Researchers Workshop on Service Oriented Computing*, pp. 83-97, Pisa, Italy.

LIASKOS, S., MCILRAITH, S.A., SOHRABI, S., MYLOPOULOS, J., 2010, “Integrating Preferences into Goal Models for Requirements Engineering”, *18th IEEE International Requirements Engineering Conference (RE)*, pp.135-144, Sydney, Australia.

MARRELLA, A., RUSSO, A., MECELLA, M., 2012, “Planlets: Automatically Recovering Dynamic Processes in YAWL”, *OTM Conferences 2012 - On the Move to Meaningful Internet Systems, Lecture Notes in Computer Science*, v.7565, pp. 268-286.

MATTOS, T., SANTORO, F.M., REVOREDO, K., NUNES, V.T., 2014, “A Formal Representation for Context-Aware Business Processes”, *Computers in Industry*

Journal, Url: http://ees.elsevier.com/comind/. (to be published)

MATTOS, T.C., 2012, *Caracterização de Situações em Processos de Negócio Sensíveis a Contexto*, M.Sc Thesis, Federal University of the State of Rio de Janeiro.

MATTOS, T.C., SANTORO, F.M., REVOREDO, K., NUNES, V.T., 2012, "Formalizing the situation of a business process activity," *2012 IEEE 16th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*, pp.128,134, Wuhan, China.

MCCARTHY, J., 1993, "Notes on formalizing context". *Proceedings of the 13th international joint conference on Artifical intelligence*, pp. 555–560, Chambery, France.

MEJIA BERNAL, J, FALCARIN, P., MORISIO, M., 2010, "Dynamic context-aware business process: a rule-based approach supported by pattern identification", *Proceedings of the 2010 ACM Symposium on Applied Computing (SAC '10)*, pp. 470-474, Sierre, Switzerland.

MILLAN-MILLÁN, G., FDEZ-OLIVARES, J., SÁNCHEZ-GARZÓN, I., PRIOR, D., CASTILLO, L., 2013, "Knowledge-Driven Adaptive Execution of Care Pathways Based on Continuous Planning Techniques", *International Conference on Business Process Management 2012 Joint Workshop, ProHealth 2012/KR4HC 2012*, Tallin, Estonia, v.7738, pp. 42-55.

MYLOPOULOS, J., CHUNG, L., 2001, "Exploring alternatives during requirements analysis", *IEEE Software*, v.18, pp.92-96.

NUNES, V.T.; WERNER, C.M.L.; SANTORO, F.M., 2012, "Mediating process adaptation through a goal-oriented context-aware approach", *2012 IEEE 16th International Conference on Computer Supported Cooperative Work in Design (CSCWD 2012)*, pp. 160-167 Wuhan, China.

NUNES, V.T., (2011), "Dynamic Process Adaptation: A context-aware approach", *PHD Symposium of the 9th International Conference on Business Process Management*, Clermont-Ferrand, France.

NUNES, V.T., WERNER, C.L.M., SANTORO, F.M., BRÉZILLON, P., 2011a, "Contextualizing dynamic process adaptation". *7th International Workshop on Modeling and Reasoning in Context - 7th International and Interdisciplinary Conference on Modeling and Using (CONTEXT'11)*, Karlsruhe, Germany, pp. 71-82.

NUNES, V.T.; WERNER, C.M.L.; SANTORO, F.M., 2011b, "Dynamic process adaptation: A context-aware approach," *2011 IEEE 15th International Conference on Computer Supported Cooperative Work in Design (CSCWD 2011)*, Lausanne, Switzerland, pp.97-104.

NUNES, V.T., SANTORO, F.M., BORGES, M.R., 2009, “A context-based model for Knowledge Management embodied in work processes”, *Journal of Information Sciences*, v.179, n.15, pp. 2538-2554.

NUNES, V.T., 2007, *Um Modelo de Suporte à Gestão de Conhecimento Baseado em Contexto*, Dissertação de M.Sc, NCE/UFRJ, Universidade Federal do Rio de Janeiro.

NUNES, V.T, SANTORO, F.M., BORGES, M.R.., 2006, "Context in Knowledge-Intensive Collaborative Work", *10th International Conference on Computer Supported Cooperative Work in Design (CSCWD 2006)*, pp.1-6, Nanjing, China.

OPENOME, (2011), Available at: <https://se.cs.toronto.edu/trac/ome>, Accessed in: 03/11/2013.

PENBERTHY, S., WELD, D., 1994, “Temporal planning with continuous change”, *Proceedings of the 12th National Conference on Artificial Intelligence*, pp. 1010 – 1015.

PESIC, M., SCHONENBERG, H., AALST, W.M.P., 2007, "DECLARE: Full Support for Loosely-Structured Processes". *Proceedings of the 11th IEEE International Enterprise Distributed Object Computing Conference*, pp. 287–300, Washington, DC, USA.

PLOESSER, K., 2013, *A Design Theory for Context-Aware Information Systems*, PhD thesis, Queensland University of Technology.

RAMOS, E., SANTORO, F., BAIAO, F.A., 2013, “Thinking Out of the Box: Discovering the Relevance of External Context to Business Processes”, *Knowledge Discovery, Knowledge Engineering and Knowledge Management*, v. 348, pp. 455-470, Springer Berlin Heidelberg.

RAMOS, E., SANTORO, F., 2010, “Process Improvement Based on External Knowledge Context”, *Proceedings of the 21th Australasian Conference on Information Systems*, 01-03 Dec 2010, Brisbane, Australia.

RANGANATHAN, A, MUHTADI, J.A., CAMPBELL, R.H., 2004, "Reasoning about Uncertain Contexts in Pervasive Computing Environments", *IEEE Pervasive Computing*, v. 3, n. 2, pp. 62–70.

REGEV, G., BIDER I., WEGMANN, A., 2007, "Defining business process flexibility with the help of invariants", *Software Process: Improvement and Practice*, v. 12, n. 1, pp. 65-79.

REICHERT, M., DADAM, P., 2009, "Enabling Adaptive Process-aware Information Systems with ADEPT2", *Handbook of Research on Business Process Modeling*, Hershey, New York: Information Science Reference, pp. 173–203.

REICHERT, M., WEBER, B., 2012, *Enabling Flexibility in Process-Aware Information Systems - Challenges, Methods, Technologies*, Springer, ISBN: 978-3-642-30408-8, pp. I-XVIII, 1-515.

REVOREDO, K., 2009, *Revisão de Teorias Relacionais Probabilísticas através de Exemplos com Invenção de Predicados*, PHD Thesis, COPPE, Universidade Federal do Rio de Janeiro.

ROSEMANN, M., RECKER, J., FLENDER, C., 2010, "Designing Context-Aware Business Processes", *Systems Analysis and Design: People, Processes and Projects*, M.E. Sharpe Inc., pp. 51-73.

ROSEMANN, M., RECKER, J., FLENDER, C., 2008, "Contextualisation of business processes", *International Journal of Business Process Integration and Management*, v.3, n.1, pp.47-60.

ROSEMANN, M., RECKER, J. C., 2006, "Context-aware Process Design: Exploring the Extrinsic Drivers for Process Flexibility", Available at: http://eprints.qut.edu.au/4638/, Acessed in: 30 Jan 2011

R-MORENO, M.D., BORRAJO, D., CESTA, A., ODDI, A., 2007, "Integrating planning and scheduling in workflow domains", *Expert Systems with Applications*, v. 33, i. 2, pp.389-406.

SADIGHIAN, A., FERNANDEZ, J.M., LEMAY, A., ZARGAR, A.T., 2014, "ONTIDS: A Highly Flexible Context-Aware and Ontology-Based Alert Correlation Framework", *Foundations and Practice of Security, Lecture Notes in Computer Science*, pp. 161-177.

SAIDANI, O., u, S., 2007, "Towards Context Aware Business Process Modelling", *Proceeding of the 8th Workshop on Business Process Modeling, Development, and Support (BPMDS 2007)*, *Held in conjunction with CAiSE'07*, Trondheim, Norway.

SANTOS, V.V., 2008, *CEManTIKA: A Domain-Independent Framework for Designing Context-Sensitive Systems*, Phd Thesis, Universidade Federal de Pernambuco – UFPE.

SCHONENBERG, H., MANS, R., RUSSEL, N., 2008, "Process Flexibility: A Survey of Contemporary Approaches", *Advances in Enterprise Engineering I,* Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 16-30.

SCHMOHL, R., 2010, *The contextual map: detecting and exploiting affinity between contextual information in context-aware mobile environments*, Phd Thesis, Institut für Informatik, Technischen Universität München.

SILAPACHOTE, P., SRISUPHAB, A., SATIANRAPAPONG, R., KAEWPIJIT, W., Waragulsiriwan, N., 2013, "A context-aware system for navigation and information dissemination on android devices," *2013 IEEE Region 10 Conference (TENCON 2013)*, pp.1-25.

SNOWDON, R.A., WARBOYS, B.C., HOLL, C, 2007, "On the architecture and form of flexible process support", *Software Process Improvement and Practice*, v. 12, n. 1, pp. 21-34.

SOFFER, P., GHATTAS, J., PELEG, M., 2010, "A Goal-Based Approach for Learning in Business Processes", *International Perspectives on Information Systems Engineering*, Berlin, Springer Berlin Heidelberg, pp. 239-256.

SHARP, A., MCDERMOTT, P., 2001, *Workflow Modeling: Tools for Process Improvement and Application Development*, 1 ed., Artech House Publishers.

TALAMADUPULA, K.; BENTON, J.; KAMBHAMPATI, S.; SCHERMERHORN, P.; SCHEUTZ, M., 2010, “Planning for Human-Robot Teaming in Open Worlds”, *ACM Transactions on Intelligent Systems and Technology (TIST)*, v.1, pp.1-14.

VIEIRA, V., TEDESCO, P., SALGADO, A.C., 2011, “Designing context-sensitive systems: An integrated approach”, *Expert Systems with Applications*, v. 38, i. 2, pp. 1119-1138.

WALLS, J.G., WIDMEYER, G.R., SAWY, EL.O.A., 1992, “Building an Information System Design Theory for Vigilant EIS”, *Information Systems Research*, v.3, pp. 36–59.

WANG, X.H., ZHANG, D.Q., GU, T., 2004, "Ontology based context modeling and reasoning using OWL", *Proceedings of the Second IEEE Annual Conference on Pervasive Computing and Communications Workshops*, pp. 18-22, Orlando, Florida.

WEBER, B., SADIQ, S., REICHERT, M., 2009, "Beyond rigidity – dynamic process lifecycle support", *Computer Science - Research and Development*, v. 23, pp. 47-65.

WESKE, M., 2007, *Business Process Management: Concepts, Languages, Architectures*, 1 ed. Springer.

WOHLIN, C.; RUNESON, P.; HÖST, M., 1999, *Experimentation in Software Engineering: An Introduction*, 1st ed. Springer.

WORDNET, 2010, “WordNet. WordNet - A lexical database for English”, Available at: <http://wordnetweb.princeton.edu/perl/webwn>, Acessed in: 10 set 2011.

YU, E., 1997, “Towards Modelling and Reasoning Support for Early-Phase Requirements Engineering”, *3rd IEEE International Symposium on Requirements Engineering (RE)*, pp. 226-235.

XU, P., RAMESH, B., 2008, "Using Process Tailoring to Manage Software Development Challenges", *IEEE IT Professional*, v. 10, pp. 39-45.

ZIMMER, T., 2006, "Qoc: Quality of context - improving the performance of context-aware applications", *Advances in Pervasive Computing*, v.207, pp.209-214, Dublin.

APPENDIX I

Appendix 1 presents the analysis regarding to context management approaches discussed in Chapter 3.

Approach	***CoBrA (3° generation)***
Goal	Developed to support pervasive and context-sensitive systems in smart spaces by integrating agents, services, and devices that exploit context information. Intelligent spaces: physical spaces (rooms, vehicles, offices) populated with intelligent systems that provide pervasive computing services to users.
Architecture	Centralized architecture (a type of server) based on agents (broker-centric agent) for supporting context-sensitive systems in smart environments. Agents: May be applications hosted on mobile devices, services provided by devices in a room (projection services, light controller) and web services that provide presence for people, places and things in the physical world (such as services to track people and things).
GC Model	Networked service / middleware / context-server
CEs identification	Does not address this issue. Provides an ontology for pervasive systems.
CEs representation	Maintains a centralized context model shared by agents, services and devices. Used in the representation, unification and reasoning. Adopts two OWL ontologies: - SOUPA (Standard Ontology for the Ubiquitous and Pervasive Applications): It is an ontology to support the representation of important concepts for ubiquitous and pervasive systems. - CoBrA-Ont: It is an ontology for meetings in smart environments.
CEs capturing mechanisms	Use of sensors (service agents). Makes use of FIPA platform and design pattern (Proxy pattern) where FIPA agents can be developed to perform communication via bluetooth or SOAP. Thus it is possible to capture data from different devices having different communication interfaces
CEs processing in order to identify complex information	Provides the following mechanisms: - A module to identify context (contextual elements of greater complexity) from contextual elements captured in the environment and to identify and address inconsistencies that may arise through the use of logic-based rules: Jena (used to make inferences in OWL), and Jess

	Prolog (used to interpret context through specific domain rules) and Theorist (Prolog meta-interpreter for default and abductive reasoning - used to treat inconsistencies). - A knowledge base module: To store context information in a Jena ontology within a MySQL database. - Privacy management module: through the reasoner Racer.
Disseminating and sharing information	Centralized storage in the broker and available to all agents in accordance with privacy rules set by users.
Context reasoning for system adaptation	Uses logical inference (Jena and Jess) to identify necessary actions to systems depending on the environmental context (time and place).
Context definitions and rules of inference treatment	Does not address this issue.

Approach	***A-CoBrA (3° gen)***
Goal	CoBrA agent-based architecture to support context-sensitive systems in the management of knowledge work processes based on the context of these activities
Architecture	The same as CoBrA
GC Model	Networked service / middleware / context-server
CEs identification	Does not address this issue. Provides an ontology for activities.
CEs representation	OWL Adopts context ontology context focusing on activities proposed pro NUNES (2009)
CEs capturing mechanisms	The same as CoBrA
CEs processing in order to identify complex information	The CoBrA broker was refactored and specialized to associate the capture of context to a running activity. Thus activity context reasoner module performs inferences, using the same technologies used in CoBrA, more specifically JENA, to retrieve useful information that has been handled in a similar context in the same activity.
Disseminating and sharing information	The same as CoBrA
Context reasoning for system adaptation	The same as CoBrA, but focusing on providing information.

Context definitions and rules of inference treatment	Does not address this issue.

Approach	**SOCAM - Service Oriented Context Aware Middleware (3° gen)**
Goal	SOCAM (Service-Oriented Context-Aware Middleware) is a middleware for building context-sensitive mobile services.
Architecture	Distributed architecture (client / server) with centralized server. Provides support for acquiring, discovering, interpreting and access context. Uses a central server called "Context Interpreter" that collects contextual data from different providers and offers users processed information.
GC Model	Networked service / middleware / context-server
CEs identification	Does not address this issue.
CEs representation	Ontologies (OWL) on two levels: It has a level corresponding to a generic ontology with general concepts of pervasive systems and a second level where ontologies from different domains can be coupled in order to reduce the processing complexity.
CEs capturing mechanisms	Context providers such as physical sensors, computer services, etc..
CEs processing in order to identify complex information	Context reasoning mechanism (Ontology Reasoning) based on first order logic, which collects contextual data from different providers and offers customers processed information. There is also the possibility of adding other reasoning mechanisms to diversify the capacity for a specific case. There is also the context interpreter which is responsible for interacting with the context sources and contextual database to provide information for mobile services and service for its service location. Moreover, it deals with context identification in two ways: context that is captured directly from the environment; and context that is identified (through reasoning) from the combination of different contexts. It deals with inconsistency between context information through classification of contexts (sensed, defined or deducted) and dependency relations that allows to incorporate to the reasoning the use of probabilities and Bayesian networks in uncertain contexts.
Disseminating and sharing information	Centralized storage of generic and domain ontologies.
Context reasoning	Uses communication via RMI with context-sensitive systems and

for system adaptation	makes use of rules in the systems to determine behavior and making services context-aware.
Context definitions and rules of inference treatment	Does not address this issue.

Approach	**Context Toolkit (2° gen)**
Goal	Support the development of context-sensitive systems
Architecture	Distributed architecture, developed in Java, where each widget, aggregator, discoverer and interpreter are implemented as separate processes. Assuming independent language mechanisms were used, some of these elements have been developed, as well as applications in C + +, Python, Visual Basic, etc..
GC Model	Distributed architecture but with a central device responsible for discovering widgets, aggregators and interpreters available.
CEs identification	Does not address this issue.
CEs representation	Attribute-value tuples
CEs capturing mechanisms	Context widgets
CEs processing in order to identify complex information	Aggregation and interpretation of context. There is an element called aggregator, which is similar to the widget functionality to allow the context acquired to be subscribed, stored and searched. However they differ in scope. A widget represents the context of a particular sensor, while the aggregator is responsible for the entire context of an entity (person, place or object). The latter acquires the context of existing widgets, increasing the degree of separation between the acquisition of the context and its use.
Disseminating and sharing information	Encapsulated in Aggregators (software components) that provide applications with access to the context information that is logically related to each other.
Context reasoning for system adaptation	Uses services (analogous to widgets) responsible for controlling and changing the information in the environment.
Context definitions and rules of inference treatment	Does not address this issue.

Approach	**CASS - Context-awareness sub-structure (2° gen)**
Goal	Middleware developed to support context-sensitive system on mobile

	devices.
Architecture	A centralized middleware approach that contains 5 elements: Interpreter, Context Retriever, Rule Engine, Sensor Listener and a database.
GC Model	Networked service / middleware / context-server
CEs identification	Does not address this issue.
CEs representation	Ontological model stored in relational database.
CEs capturing mechanisms	Sensors distributed over several computers.
CEs processing in order to identify complex information	The Sensor Listener monitors new data arriving via sensors and stores them in the database. The Context Retriever is responsible for retrieving the stored contextual data. The two of them can make use of the interpreter. The Rule Engine is the inference engine that that identifies the context of the highest level through the knowledge base (database context).
Disseminating and sharing information	Centralized storage via database and wirelessly communication with Sensors and LocationFinder. The database, known as Context Knowledge Base, also stores inference rules and domain knowledge to create higher-level context.
Context reasoning for system adaptation	Through the interpreter, the inference engine query the knowledge base to find similar contexts and solutions assigned using the forward-chaining technique.
Context definitions and rules of inference treatment	Does not address this issue.

Approach	***Hydrogen (2° gen)***
Goal	Extensible framework that supports context sensitivity on mobile devices
Architecture	Three-tier architecture (Adapter, Manager and Application) all located in each of the mobile devices used. Allows devices to exchange context next to each other without centralization.
GC Model	Distributed architecture with centralized storage.
CEs identification	Does not address this issue. There is a basic object-oriented framework that can be extended to accommodate other types of context
CEs representation	Context model object-oriented with a superclass called ContextObject from which the model can be extended.

CEs capturing mechanisms	Adapters (software components) for various types of context.
CEs processing in order to identify complex information	Interpretation and aggregation of raw data only.
Disseminating and sharing information	As the hydrogen approach, it is characterized by peer-to-peer network of mobile devices, it offers no possibility of persistent storage, it only stores the current context and shares with other devices using Bluetooth and WLAN.
Context reasoning for system adaptation	Uses a context server (in the Management layer) responsible for storing all the context information about the current device's environment and share this information with other devices. But each application is responsible for making decisions about what information is collected
Context definitions and rules of inference treatment	Does not address this issue.

Approach	***Cortex (2° gen)***
Goal	Context oriented middleware that aims to support the development of context-sensitive systems in a mobile environment. Depends on the use of specific services built for environments where wireless network
Architecture	Based on Sentient Object Model. Sentient Objects - They are encapsulated entities that consist of three main parts: a capture sensor, a context hierarchy and a mechanism of inference. These special entities are able to consume and produce events. They are objects that receive events as inputs, process them and generate other events as output, i.e., they are autonomous objects able to sense the environment and act proactively making decisions and performing actions.
GC Model	Networked service / middleware / context-server
CEs identification	Does not address this issue.
CEs representation	Information is encapsulated in Sentient Objects and structured hierarchically.
CEs capturing mechanisms	Through special entities called sentient objects that are able to perceive events that happen and identify existing context.
CEs processing in order to identify complex information	Aggregation in this case is obtained by the hierarchical composition of sentient objects, generating context-sensitive compounds objects, grouping two or more objects. As an example of composition, consider a car including a number of

	controls (engine, transmission, brakes, etc). Each of these controls can be represented by a sentient object. However, the car as a whole may also be represented by a compound sentient object, which includes the set of controls as well as the rest of the car machinery. Sentient objects have a logic control that performs the mechanism of decision making.
Disseminating and sharing information	There is a context database with information from the past, present and future prediction based on the history of the stored context. Makes use of STEAM event service to provide communication between the components of the architecture.
Context reasoning for system adaptation	Because only one context can exist at a given time, the Sentient Object containing the enabled context has inference rules engines developed in CLIPS that perform the reasoning.
Context definitions and rules of inference treatment	Does not address this issue.

Approach	***Gaia (2° gen)***
Goal	Agent based infrastructure that aims to provide mobile services in a centralized manner.
Architecture	Centralized Architecture. Use extended MVC.
GC Model	Networked service / middleware / context-server
CEs identification	Does not address this issue.
CEs representation	Quaternary predicates (DAML + OIL) as Context (<Context type>, <Subject>, <Relater>, <Object>)
CEs capturing mechanisms	Context providers are services.
CEs processing in order to identify complex information	Context-service module (first order logic). The context objects of higher level are constructed by performing first order logical operations, as quantification, implication, conjunction, disjunction and predicate negation. This architecture is derived from the Context Toolkit. This system can determine higher-level contexts from raw data using interpretation and aggregation.
Disseminating and sharing information	Centralized database for persistent storage.
Context reasoning for system adaptation	Client applications request context information from lower and higher level to make decisions

Context definitions and rules of inference treatment	Does not address this issue.

Approach	***ACAI - Agent-Based Context-aware Infrastructure (3° gen)***
Goal	Infrastructure that allows to collect, process, and disseminate context information to multi-agent context-sensitive applications,
Architecture	Layered architecture, each layer containing modules responsible for different tasks (Application, Services and Perception).
GC Model	Networked service / middleware / context-server
CEs identification	Does not address this issue.
CEs representation	Use of OWL ontologies
CEs capturing mechanisms	The perception layer is responsible for the detection, capture and acquisition of context information via sensors and agents. Context agent suppliers encapsulate the context sensors sources and capture the raw information that is interpreted and provided to other agents in a format that can be understood.
CEs processing in order to identify complex information	In the service layer, the "Context Inference" module identifies complex context that are not available directly in the perception layer. Developed in Jade using Protege OWL ontology for manipulation.
Disseminating and sharing information	Context can be stored, queried and accessed. Through the application layer, it provides the interface between the users of mobile devices and applications and functionality from the ACAI context service.
Context reasoning for system adaptation	Decide relevant infomation to be presented. Uses logic reasoning, fuzzy logic and semantic representation of rules to deduce new contexts and decide actions.
Context definitions and rules of inference treatment	Does not address this issue.

Approach	***Context Management Framework (3° gen)***
Goal	Infrastructure that allows the recognition of context in real time treating uncertainties, changing information and providing context for event-based applications.
Architecture	Layered architecture with centralized server based on blackboard.
GC Model	Networked service / middleware / context-server
CEs identification	Does not address this issue.
CEs representation	Uses RDF.

CEs capturing mechanisms	Resource servers that collect raw data through various sources.
CEs processing in order to identify complex information	Context recognition service: uses context atoms as input and returns to the Context Manager a single object of highest level. It also treat inconsistencies through Bayesian networks.
Disseminating and sharing information	Uses a centralized server that stores data and provides information to client applications.
Context reasoning for system adaptation	Client applications require to context service that when a specific context changes, they are to be informed. Each application is responsible for making decisions for itself.
Context definitions and rules of inference treatment	Does not address this issue.

APPENDIX II

Transformation rules from YAWL to XML– Domain

Tag domain

YAWL	XML
<decomposition id="[domainname]" isRootNet="true" xsi:type="NetFactsType"> Ex.: <decomposition id="GasLifiting" isRootNet="true" xsi:type="NetFactsType">	<domain ="[domainname]"> ... </domain>

Tag constants

YAWL	XML
For type “activity”: <processControlElements> <task id=”[name1]”> <task id=”[name2]”> … <task id=”[namen]”> </processControlElements> Ex.: <task id="Align_manual_valves"> <name>Align_manual_valves</name> <flowsInto> <nextElementRef id=" Align_manual_valves " /> </flowsInto> <join code="xor" />	<constants> <constant type="[typename1]"> <name>[name1]</name> <name>[name2]</name> ... <name>[namen]</name> </constant> ... <constant type="[typenamen]"> <name>[name1]</name> <name>[name2]</name> ... <name>[namen]</name> </constant> </constants>

<split code="and" /> <resourcing> … </resourcing> <decomposesTo id="Align_manual_valves" /> </task> For type “parameters”: <localVariable> <name>[name1]</name> </localVariable> <localVariable> <name>[name2]</name> </localVariable> … <localVariable> <name>[namen]</name> </localVariable> Ex.: <localVariable> <index>2</index> <name>AlignmentValveStatusStatus</name> <type>boolean</type> <namespace>http://www.w3.org/2001/XMLSchema</namespace> <initialValue /> </localVariable>	

Tag functions

YAWL	**XML**
All YAWL local variables whose type is integer or float are to be considered	<functions>

as functions. <localVariable> <name>[functioname1]</name> </localVariable> … <localVariable> <name>[functionamen]</name> </localVariable> Ex.: <localVariable> <index>2</index> <name>AlignmentValveOpeningTime</name> <type>float</type> <namespace>http://www.w3.org/2001/XMLSchema</namespace> <initialValue /> </localVariable>	<function name="[functioname1]"> <variable type="[variabletype1.1]">[variable1.1]</variable> ... <variable type="[variabletype1.n]">[variable1.n]</variable> </function> ... <function name="[functionamen]"> <variable type="[variabletypen.1]">[variablen.1]</variable> ... <variable type="[variabletypen.n]">[variablen.n]</variable> </function> </functions>

Tag action

YAWL	XML
PROCESS <task id="[actionname]"> <!-- Conditions --> <!-- Condition 1: The action was not completed --> <!-- conditiontype=“at start” predicatename=”notcompleted” --> <task id="[conditionvariable1]"> <!-- Condition 2: The previous action was completed --> <!-- conditiontype=“at start” predicatename=”completed” --> <nextElementRef id="[conditionvariable2]" /> <!—This must be the tag of the previous action --> <!-- Condition 3 … n : Any other parameter verification that may come from YAWL or other organizational sources --> <!-- conditiontype=“at start” predicatename=”value” --> <!—If it is a verification of a XOR, take the structure of the previous action that is responsible for the decision--> <flowsInto> <nextElementRef id="[actioname]" /> <predicate ordering="0">/[processname]/[conditionvariable3]/text() = '[conditionvalue3]'</predicate> </flowsInto> <!-- or --> <!-- conditiontype=“at start” operator=”[=, <, <=, >, >=]” function=”[functionname2]”--> <!-- Effects -->	<processactions> <action name="[actionname]" duration="[timeduration]"> <parameters /> <conditiongroup> <!-- Operator default: AND --> <condition type="[conditiontype1]" predicate="[predicatename1]"> <variable>[conditionvariable1]</variable> <value>[conditionvalue1]</value> </condition> <condition type="[conditiontype2]" predicate="[predicatename2]"> <variable>[conditionvariable2]</variable> <value>[conditionvalue2]</value> </condition> <conditiongroup operator="OR"> <conditioncomparison type=”[conditiontype3]” operator="[operator1]" function="[functionname1]"> <value>[conditionvalue3]</value> </conditioncomparison > <conditioncomparison type=”[conditiontype4]” operator="[operator2]" function="[functionname2]"> <value>[conditionvalue4]</value> </conditioncomparison> </conditiongroup> </conditiongroup> <effectgroup> <!-- Operator default: AND --> <effect type="[effecttype1]" predicate="[predicatename1]"> <variable>[effectvariable1]</variable> <value>[effectvalue1]</value> </effect> <effect type="[effecttype2]" predicate="[predicatename2]">

```
  <"—Effect 1: The action is completed after execution -->
  <!-- conditiontype="at end" predicatename="completed" -->
  <task id="[conditionvariable1]">

  <!-- Effect 3 … n : Any other parameter value after action execution that may come from YAWL or other organizational sources -->
  <!-- conditiontype="at end" predicatename="value" -->

  <!—If it is a verification of a XOR -->
  <flowsInto>
    <nextElementRef id="[actioname]" />
    <predicate ordering="0">/[processname]/[ effectvariable3]/text() = '[effectvalue3]'</predicate>
  </flowsInto>

  <!--If it is the manipulation with numbers -->
</task>

WORKLETS
<!—For each worklet, only its activation and calling are represented -->
<decomposition id="[actionname]" isRootNet="true" xsi:type="NetFactsType">

Ex.:
<decomposition id="PC_01" isRootNet="true" xsi:type="NetFactsType">
<!— Each condition are to be manually inserted since it comes from organizational strategy -->
```

```
      <variable>[effectvariable2]</variable>
      <value>[effectvalue2]</value>
    </effect>
    <effectgroup operator="OR">
      <effect type="[effecttype3]" predicate="[predicatename3]">
        <variable>[effectvariable3]</variable>
        <value>[effectvalue3]</value>
      </effect>
      <effectfunction type="[effecttype4]" action="[effectaction1]">
        <function name="[functionname1]">
          <variable>[functionvariable1]</variable>
          <variable>[functionvariable2]</variable>
        </function>
        <value>[effectvalue4]</value>
      </effectfunction>
    </effectgroup>
  </effectgroup>
</action>
...
</processactions>
<processvariants>
 <!—Same rules as process actions -->
</processvariants>
```

APPENDIX III

Transformation rules from YAWL to XML – Problem

Tag problem

YAWL	XML
<decomposition id="[domainname]" isRootNet="true" xsi:type="NetFactsType">	<problem name="[problemname]" domain="[domainname]"> ... </problem>

Tag objects

YAWL	XML
It comes from the organization strategy. Represents the number of resources Ex.: How many operator P1 existis.	<objects> <object type="[objecttype1]"> <name>[object1.1]</name> <name>[object1.2]</name> ... <name>[object1.n]</name> </object> ... <object type="[objecttypen]"> <name>[objectn.1]</name> <name>[objectn.2]</name> ... <name>[objectn.n]</name> </object> </objects>

Tag initialize

YAWL	XML
<!—Start tasks as notcompleted --> <processControlElements> <task id="[name1]"> <!-- without the _ as separators and lower case --> <task id="[name2]"> <!-- without the _ as separators and lower case --> … <task id="[namen]"> <!-- without the _ as separators and lower case--> </processControlElements> For parameters (predicate = value): <localVariable> <name>[object1]</name> <initialValue>[value1]</initialValue> </localVariable> <localVariable> <name>[object2]</name> <initialValue>[value2]</initialValue> </localVariable> … <localVariable> <name>[objectn]</name> <initialValue>[valuen]</initialValue> </localVariable> For function: It comes from the organization strategy	<initialize> <init predicate="[predicate1]"> <object>[object1]</object> <value>[value1]</value> </init> ... <init predicate="[predicaten]"> <object>[objectn]</object> <value>[valuen]</value> </init> ... <initfunction function="[function1]"> <object>[object1.1]</object> <object>[object1.2]</object> <value>[value1]</value> </initfunction> ... <initfunction function="[functionn]"> <object>[objectn.1]</object> <object>[objectn.2]</object> <value>[valuen]</value> </initfunction> </initialize>

Tag goal

YAWL	XML
Process: It needs to have predicate completed, constants related to tasks which: <flowsInto> <nextElementRef id="OutputCondition" /> <isDefaultFlow /> </flowsInto> All other goals and desires must come from the organization strategy.	<goal> <predicate name="[predicate1]"> <object>[object1]</object> <value>[value1]</value> </predicate> ... <predicate name="[predicaten]"> <object>[objectn]</object> <value>[valuen]</value> </predicate> </goal>

Tag metric

YAWL	XML
It comes from the organization strategy.	<metric> <action>[action]</action> <object>[object]<object> </metric>

APPENDIX IV

Transformation rules from XML to PDDL – Domain

Tag domain

XML	PDDL
<domain ="domainname"> ... </domain>	(define (domain BookOrder) ...)

Tag requirements

XML	PDDL
<requirements> <requirement>[requirement1]</requirement> <requirement>[requirement1]</requirement> ... <requirement>[requirementn]</requirement> </requirements>	(:requirements :[requirement1] : [requirement2] ... :[requirementn])

Tag types

XML	PDDL
<types> <type>[type1]</type> <type>[type2]</type> ... <type>[type3]</type> </types>	(:types [type1] [type2] ... [typen])

Tag constants

XML	PDDL
<constants> <constant type="[typename1]"> <name>[name1]</name> <name>[name2]</name> ... <name>[namen]</name> </constant> ... <constant type="[typenamen]"> <name>[name1]</name> <name>[name2]</name> ... <name>[namen]</name> </constant> </constants>	(:constants [name1] [name2] ... [namen] – [typename1] [name1] [name2] ... [namen] – [typename2] ... [name1] [name2] ... [namen] – [typenamen])

Tag predicates

XML	PDDL
<predicates> <predicate name="[predicatename1]"> <variable type="[variabletype1.1]">[variable1.1]</variable> ... <variable type="[variabletype1.n]">[variable1.n]</variable> </predicate> ... <predicate name="[predicatenamen]"> <variable	(:predicates ([predicatename1] ?[variable1.1] – [variabletype1.1] ... ?[variable1.n] – [variabletype1.n]) ... ([predicatenamen] ?[variablen.1] – [variabletypen.1] ... ?[variablen.n] – [variabletypen.n]))

type="[variabletypen.1]">[variablen.1]</variable> ... <variable type="[variabletypen.n]">[variablen.n]</variable> </predicate> </predicates>	

Tag functions

XML	PDDL
<functions> <functione name="[functioname1]"> <variable type="[variabletype1.1]">[variable1.1]</variable> ... <variable type="[variabletype1.n]">[variable1.n]</variable> </function> ... <function name="[functionamen]"> <variable type="[variabletypen.1]">[variablen.1]</variable> ... <variable type="[variabletypen.n]">[variablen.n]</variable> </function> </functions>	(:functions ([functionname1] ?[variable.11] - [variabletype1.1] ... ?[variable1.n] - [variabletype1.n]) ... ([functionnamen] ?[variablen.1] - [variabletypen.1] ... ?[variablen.n] - [variabletypen.n]))

Tag action

XML	PDDL
<action name="[actionname]" duration="[timeduration]"> <parameters> <obj>obj1</obj> <obj>obj2</obj> … <obj>objn</obj> </parameters> <conditiongroup> <!-- Operator default: AND --> <condition type="[conditiontype1]" predicate="[predicatename1]"> <variable>[conditionvariable1]</variable> <value>[conditionvalue1]</value> </condition> <condition type="[conditiontype2]" predicate="[predicatename2]"> <variable>[conditionvariable2]</variable> <value>[conditionvalue2]</value> </condition> <conditiongroup operator="OR"> <conditioncomparison type=”[conditiontype3]” operator="[operator1]" function="[functionname1]"> <value>[conditionvalue3]</value> </conditioncomparison > <conditioncomparison type=”[conditiontype4]” operator="[operator2]" function="[functionname2]"> <value>[conditionvalue4]</value> </conditioncomparison> </conditiongroup> </conditiongroup> <effectgroup> <!-- Operator default: AND --> <effect type="[effecttype1]"	(:durative-action [actionname] :parameters (?obj1 ?obj2 … ?objn) :duration (= ?duration [timeduration]) :condition ((and ([conditiontype1] ([predicatename1] [conditionvariable1] [conditionvalue1])) ... ([conditiontype2] ([predicatename2] [conditionvariable2] [conditionvalue2])) (or ([conditiontype3] ([operator1] ([functionname1]) [conditionvalue3])) ... ([conditiontype4] ([operator2] ([functionname2]) [conditionvalue4]))))) :effect ((and ([effecttype1] ([predicatename1] [effectvariable1] [effectvalue1])) ... ([effecttype2] ([predicatename2] [effectvariable2] [effectvalue2])) (or ([effecttype3] ([predicatename3] [effectvariable3] [effectvalue3])) ... ([effecttype4] ([effectaction1] ([functionname1] [functionvariable1] [functionvariable2]) [effectvalue4])))))

predicate="[predicatename1]"> <variable>[effectvariable1]</variable> <value>[effectvalue1]</value> </effect> <effect type="[effecttype2]" predicate="[predicatename2]"> <variable>[effectvariable2]</variable> <value>[effectvalue2]</value> </effect> <effectgroup operator="OR"> <effect type="[effecttype3]" predicate="[predicatename3]"> <variable>[effectvariable3]</variable> <value>[effectvalue3]</value> </effect> <effectfunction type="[effecttype4]" action="[effectaction1]"> <function name=”[functionname1]”> <variable>[functionvariable1]</variable> <variable>[functionvariable2]</variable> </function> <value>[effectvalue4]</value> </effectfunction> </effectgroup> </effectgroup> </action>	)

APPENDIX V

Transformation rules from XML to PDDL – Problem

Tag problem

XML	PDDL
<problem name="[problemname]" domain="[domainname]"> ... </problem>	(define (problem [problemname]) (:domain [domainname]) ...)

Tag objects

XML	PDDL
<objects> <object type="[objecttype1]"> <name>[object1.1]</name> <name>[object1.2]</name> ... <name>[object1.n]</name> </object> ... <object type="[objecttypen]"> <name>[objectn.1]</name> <name>[objectn.2]</name> ... <name>[objectn.n]</name> </object> </objects>	(:objects [object1.1] [object1.2] ... [object1.n] – [objecttype1] [object2.1] [object2.2] ... [object2.n] – [objecttype2] ... [objectn.1] [objectn.2] ... [objectn.n] – [objecttypen])

Tag initialize

XML	PDDL
<initialize> <init predicate="[predicate1]"> <object>[object1]</object> <value>[value1]</value> </init> ... <init predicate="[predicaten]"> <object>[objectn]</object> <value>[valuen]</value> </init> ... <initfunction function="[function1]"> <object>[object1.1]</object> <object>[object1.2]</object> <value>[value1]</value> </initfunction> ... <initfunction function="[functionn]"> <object>[objectn.1]</object> <object>[objectn.2]</object> <value>[valuen]</value> </initfunction> </initialize>	(:init ([predicate1] [object1] [value1]) ... ([predicaten] [objectn] [valuen]) ... (= ([function1] [object1.1] [object1.2]) [value1]) ... (= ([functionn] [objectn.1] [objectn.2]) [valuen]))

Tag goal

XML	PDDL
<goal> <predicate name="[predicate1]"> <object>[object1]</object> <value>[value1]</value> </predicate> ... <predicate name="[predicaten]"> <object>[objectn]</object> <value>[valuen]</value> </predicate> </goal>	(:goal (and ([predicate1] [object1] [value1]) ... ([predicaten] [objectn] [valuen])))

Tag metric

XML	PDDL
<metric> <action>[action]</action> <object>[object]<object> </metric>	(:metric [action] ([object]))

APPENDIX VI

Gas Lifting Process – Situations

Situation 1: Immediately after the execution of activity "Open remotely alignment valve of collector well" a situation is triggered indicating that there is a difficulty (RemoteAlignmentValveOpeningTime) in remotely open the collector well alignment valve (AlignmentValveStatus). S01 = {openremotelyalignmentvalveofcollectorwell.status = completed, AlignmentValveStatus = open, RemoteAlignmentValveOpeningTime >= 5 min}
Situation 2: Immediately after the execution of activity "Open locally alignment valve collector well" a situation is triggered indicating that there is a difficulty (LocallyAlignmentValveOpeningTime) in locally open the collector well alignment valve (AlignmentValveStatus), although the valve has being opened. S02 = {openlocallyalignmentvalvecollectorwell.status = completed, AlignmentValveStatus = open, LocallyAlignmentValveOpeningTime >= 5 min}
Situation 3: Immediately after the execution of activity "Open shutdown valve" a situation is triggered indicating that it was necessary 2 attempts to open the shutdown valve (NumAttemptsOpenShutdownValve). S03 = {openshutdownvalve.status = completed, NumAttemptsOpenShutdownValve = 2}
Situation 4: Immediately after the execution of activity "Open shutdown valve" a situation is triggered indicating that it was necessary more than 2 attempts to open the shutdown valve (NumAttemptsOpenShutdownValve). S04 = {openshutdownvalve.status = completed, NumAttemptsOpenShutdownValve > 2}
Situation 5: Immediately after the execution of activity "Open choke" a situation is triggered indicating that the well pressure (WellPressure) is under 70% and the choke opening (ChokeOpeningTime) was done less than 30 minutes. S05 = {openchoke.status = completed, WellPressure < 70%, ChokeOpeningTime < 30 min}
Situation 6: Immediately after the execution of activity "Monitor well and pipelines variables" a situation is triggered indicating that the well pressure at the pipeline exit (WellPressurePipelineExitVariation) has a variation greater than 5 kgf/cm2, the variation in consumer demand (ConsumerDemandVariation) is less than 10% and the variation of pressure in all wells (PressureWellsVariation) is under 10%. S06 = {monitorwellandpipelinesvariables.status = completed, WellPressurePipelineExitVariation >= 5 kgf/cm2, ConsumerDemandVariation <= 10%,

PressureWellsVariation <= 10%}

Situation 7: Immediately after the execution of activity “Monitor well and pipelines variables” a situation is triggered indicating that the well pressure at the pipeline exit (WellPressurePipelineExitVariation) has a variation greater than 5 kgf/cm2, the variation in consumer demand (ConsumerDemandVariation) is less than 10%, the variation of pressure in all wells (PressureWellsVariation) is greater than 10%, the costs of testing wells (TestWellsCost) increased by 15% and the risk of a stop (Operation) is not high since the operation proceeds on a regular basis.

S07 = {monitorwellandpipelinesvariables.status = completed,

WellPressurePipelineExitVariation >= 5 kgf/cm2,

ConsumerDemandVariation <= 10%,

PressureWellsVariation > 10%,

TestWellsCost >= 15%,

Operation = 100%}

Situation 8: Immediately after the execution of activity “Monitor well and pipelines variables” a situation is triggered indicating that the well pressure at the pipeline exit (WellPressurePipelineExitVariation) has a variation greater than 5 kgf/cm2, the variation in consumer demand (ConsumerDemandVariation) is less than 10%, the variation of pressure in all wells (PressureWellsVariation) is greater than 10%, the costs of testing wells (TestWellsCost) increased by 15% and the risk of a stop (Operation) is not high since the operation proceeds on a regular basis.

S08 = {monitorwellandpipelinesvariables.status = completed,

WellPressurePipelineExitVariation >= 5 kgf/cm2,

ConsumerDemandVariation <= 10%,

PressureWellsVariation > 10%,

TestWellsCost >= 15%,

Operation <= 60%}

Situation 9: Immediately after the execution of activity “Monitor well and pipelines variables” a situation is triggered indicating that the well pressure at the pipeline exit (WellPressurePipelineExitVariation) has a variation greater than 5 kgf/cm2, the variation in consumer demand (ConsumerDemandVariation) is greater than 10% and there is an increase to the demand for gas (IncreaseDemand).

S09 = {monitorwellandpipelinesvariables.status = completed,

WellPressurePipelineExitVariation >= 5 kgf/cm2,

ConsumerDemandVariation >= 10%,

IncreaseDemand = true}

Situation 10: Immediately after the execution of activity “Monitor well and pipelines variables” a situation is triggered indicating that the well pressure at the pipeline exit (WellPressurePipelineExitVariation) has a variation greater than 5 kgf/cm2, the variation in consumer demand (ConsumerDemandVariation) is greater than 10% and there is no increase to the demand for gas (IncreaseDemand).

S10 = {monitorwellandpipelinesvariables.status = completed,

WellPressurePipelineExitVariation >= 5 kgf/cm2,

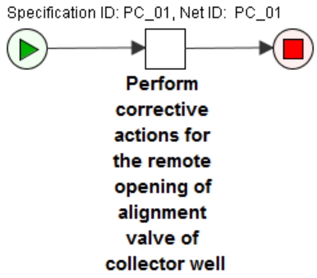
ConsumerDemandVariation >= 10%,

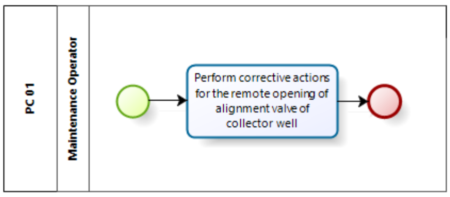
IncreaseDemand = false}
Situation 11: Immediately after the execution of activity “Monitor variables after choke and alarm levels” a situation is triggered indicating that the temperature in all wells (WellsTemperature) is greater than 10% and below 20% the average. S11 = { monitorvariablesafterchokeandalarmlevels.status = completed, WellsTemperature > 10% and <= 20%}
Situation 12: Immediately after the execution of activity “Monitor variables after choke and alarm levels” a situation is triggered indicating that the temperature in all wells (WellsTemperature) is greater than 20% the average. S12 = { monitorvariablesafterchokeandalarmlevels.status = completed, WellsTemperature > 20%}
Situation 13: Immediately after the execution of activity “Monitor variables after choke and alarm levels” a situation is triggered indicating that the corrosion alarm level (CorrosionAlarmLevel) was shot (low level). S13 = { monitorvariablesafterchokeandalarmlevels.status = completed, CorrosionAlarmLevel = true}
Situation 14: Immediately after the execution of activity “Monitor variables after choke and alarm levels” a situation is triggered indicating that the corrosion alarm level (HydrateInjAlarmLevel) was shot (low level). S13 = { monitorvariablesafterchokeandalarmlevels.status= completed, HydrateInjAlarmLevel = true}

APPENDIX VII

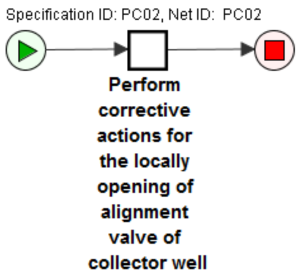
Gas Lifting Process – Worklets (YAWL and BPMN specification)

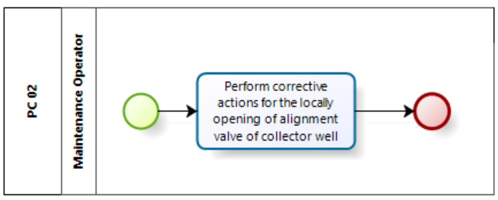
PC_01 – Activated by S01 (CAF-01)



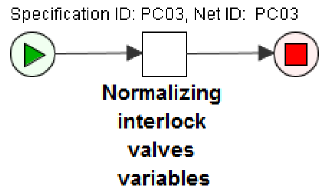


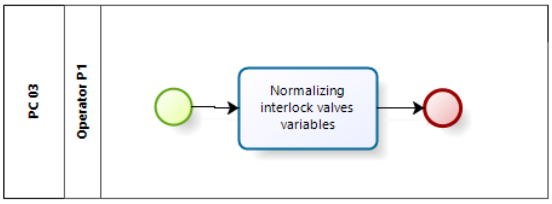
PC_02 – Activated by S02 (CAF-01)



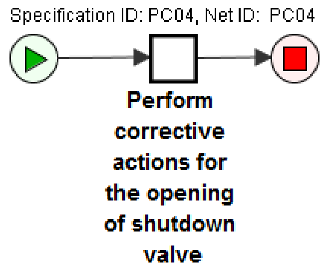


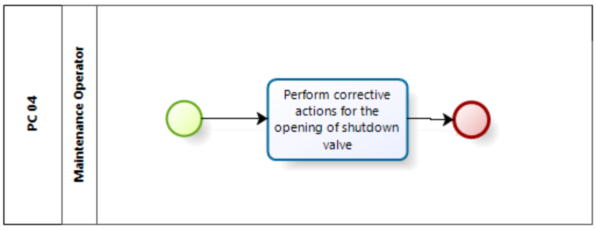
PC_03 – Activated by S03 (CAF-05)



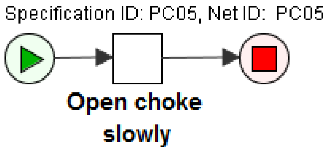


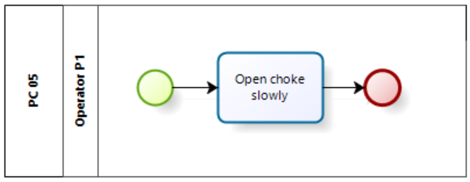
PC_04 – Activated by S04 (CAF-05)



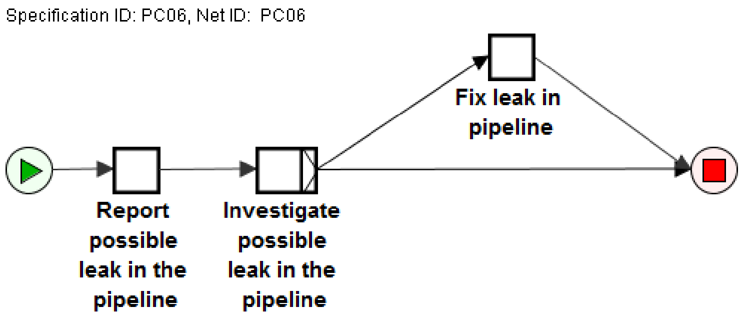


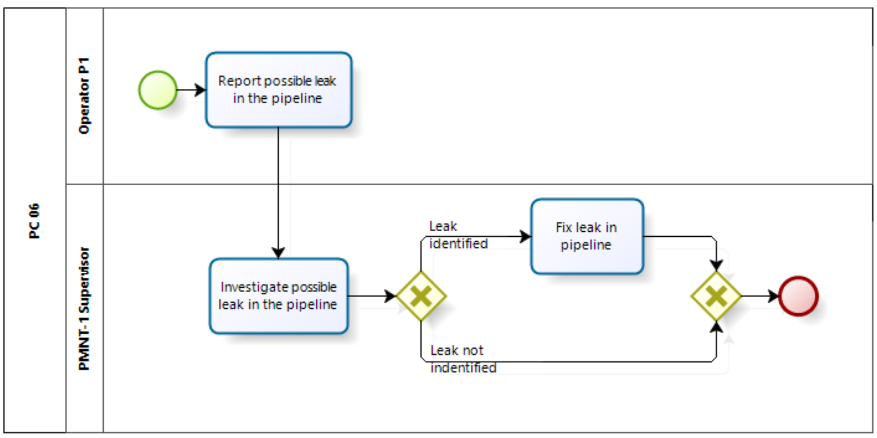
PC_05 – Activated by S05 (CAF-05)



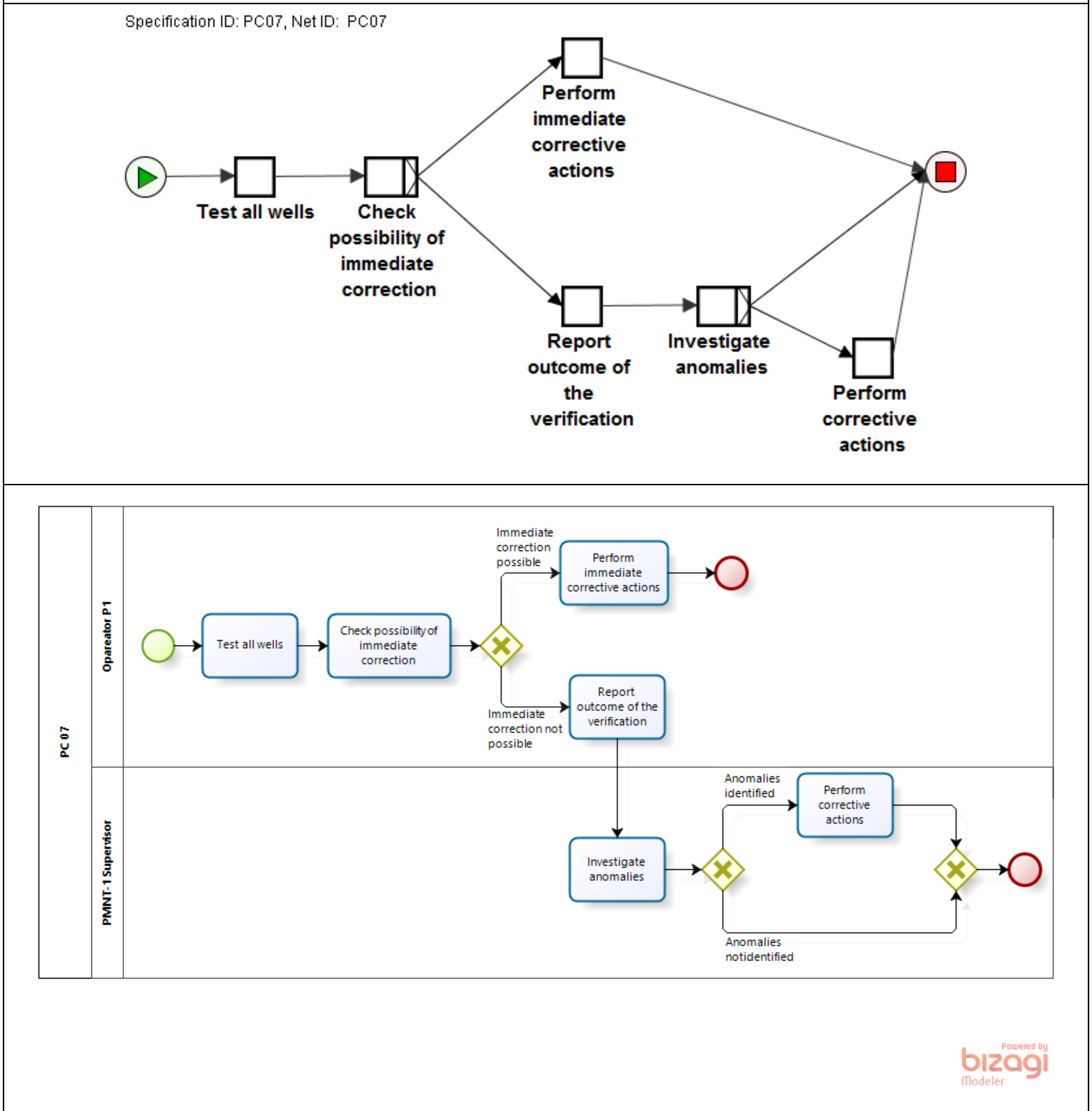


PC_06 – Activated by S06 (CAF-01)

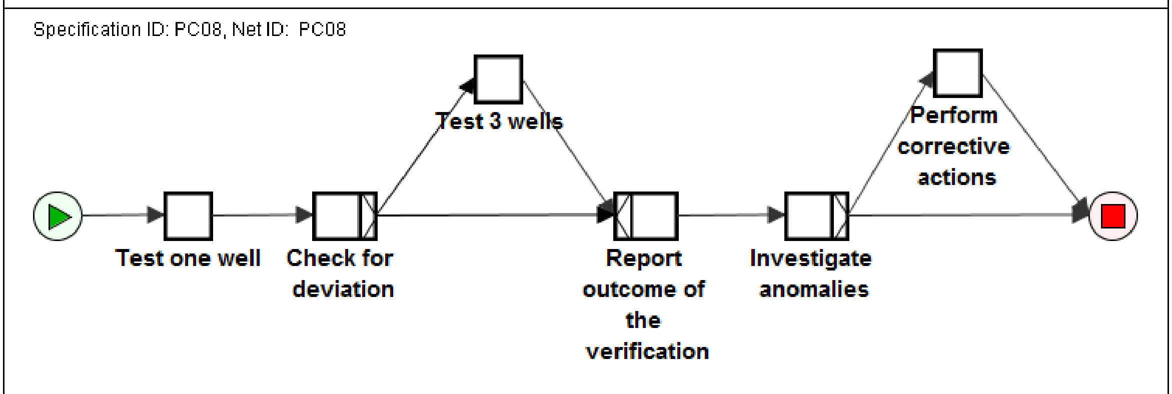


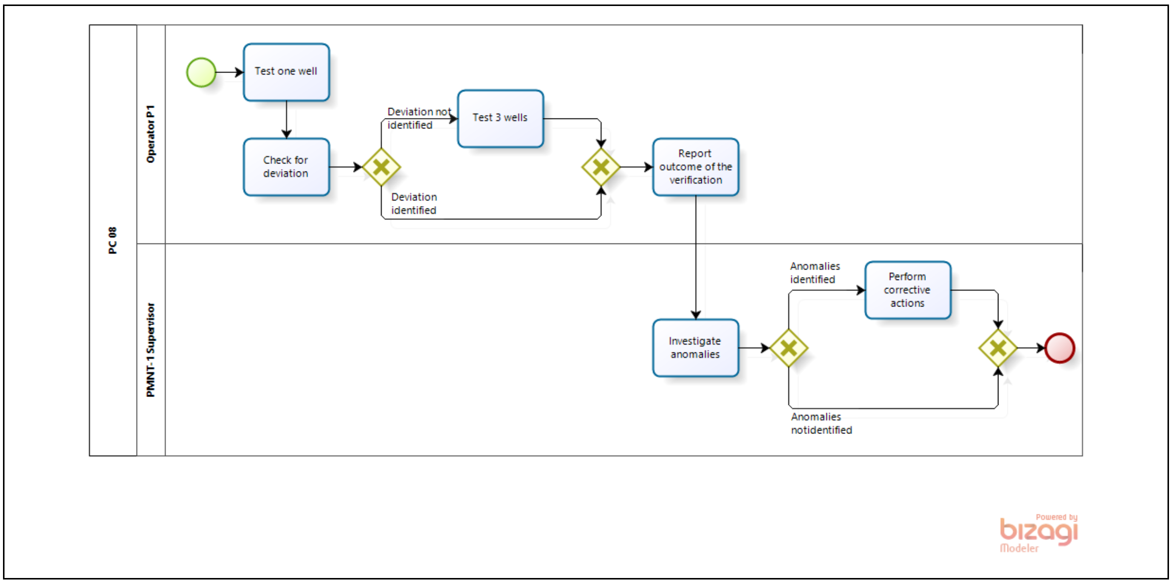


PC_07 – Activated by S06 (CAF-05)

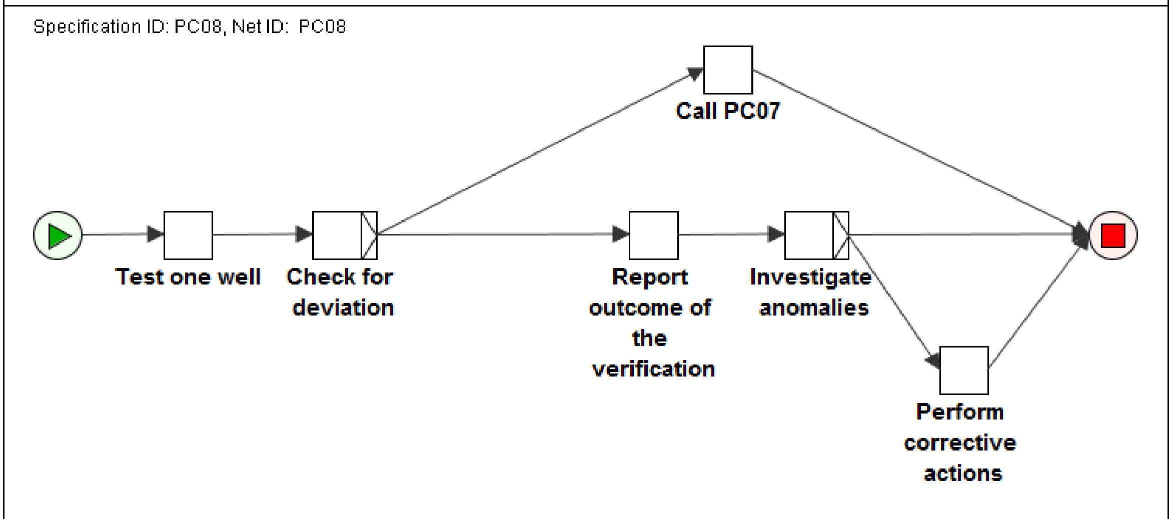


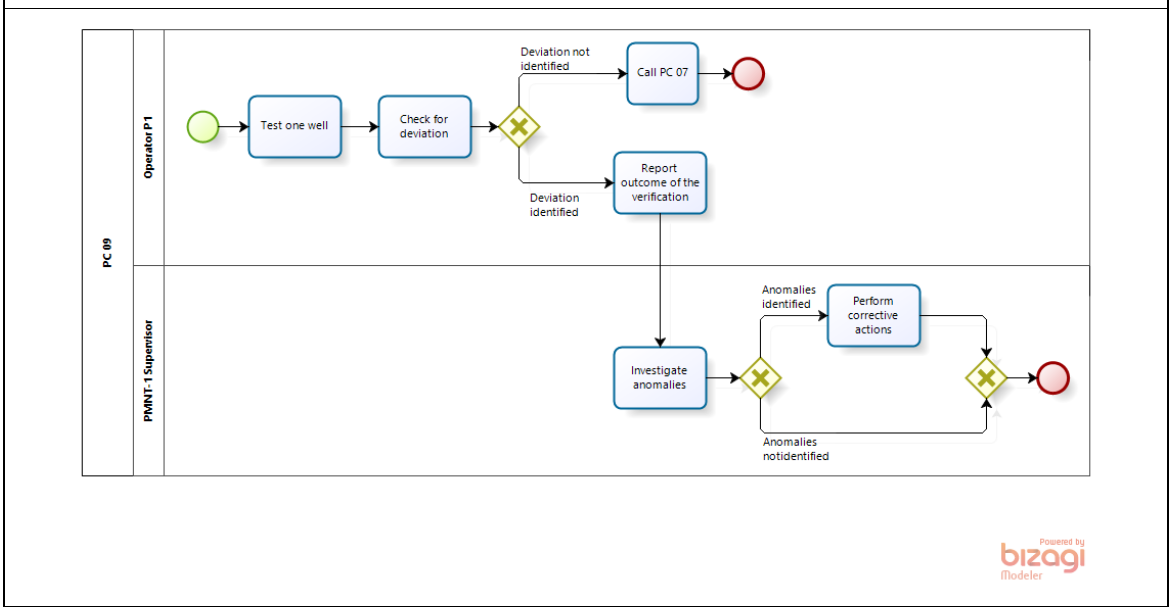
PC_08 – Activated by S07 (CAF-01)



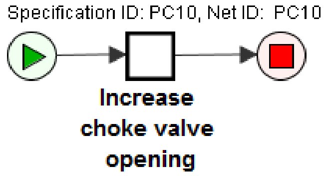


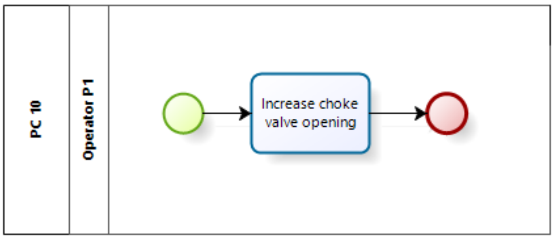
PC_09 – Activated by S08 (CAF-01)



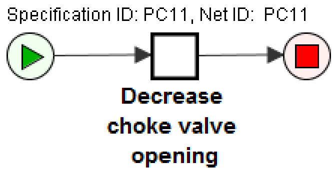


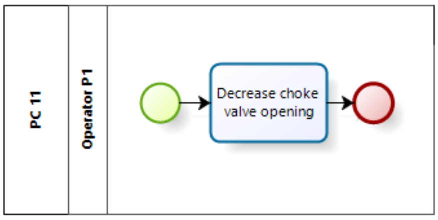
PC_10 – Activated by S09 (CAF-01)



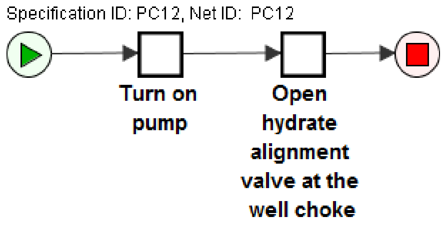


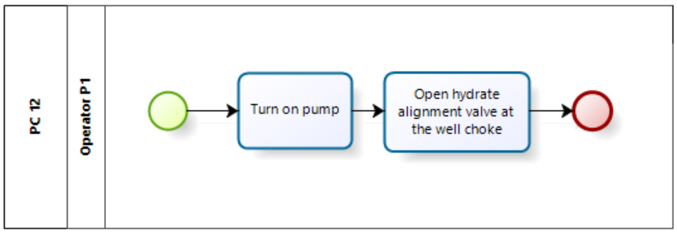
PC_11 – Activated by S10 (CAF-01)



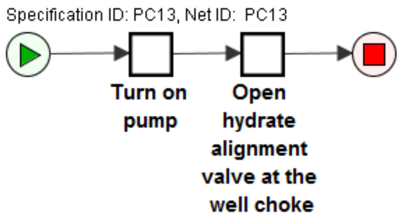


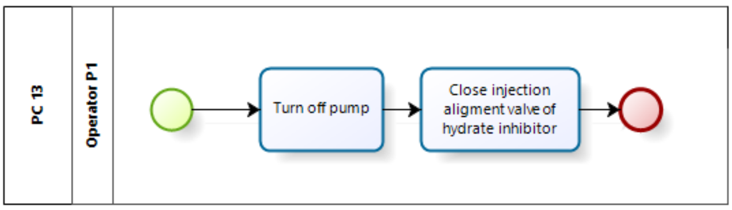
PC_12 – Activated by S11 (CAF-01)



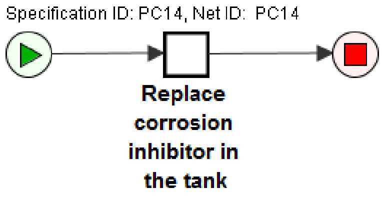


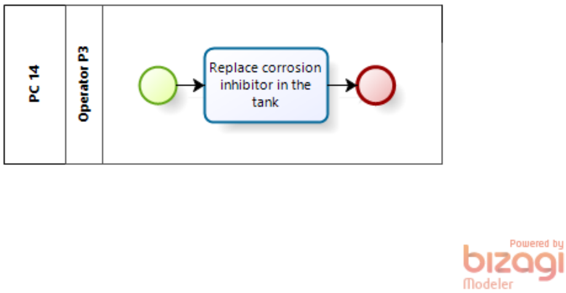
PC_13 – Activated by S12 (CAF-01)



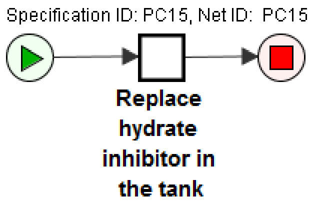


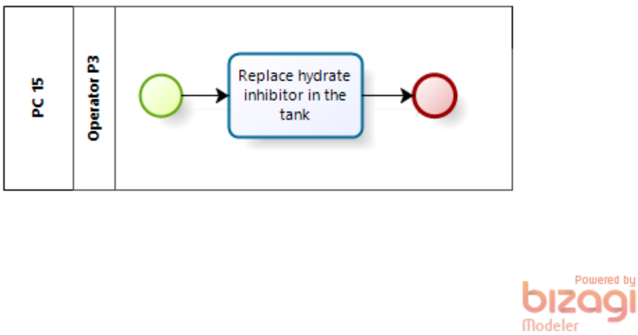
PC_14 – Activated by S13 (CAF-01)





PC_15 – Activated by S14 (CAF-01)





APPENDIX VIII

Gas Lifting Process – Process Instances (Simulation of occurrence of CEs values).

It was defined at most 5 possible values for each CE:

- Collector well alignment valve (AlignmentValveStatus)
    - open
    - closed
- Remote Alignment valve opening time (RemoteAlignmentValveOpeningTime)
    - lessthan3 (0 < t < 3)
    - equalgreaterthan3lessthan5 (3 < = t < 5)
    - equalgreaterthan5lessthen7 (5 <= t < 7)
    - equalgreaterthan7lessthen9 (7 <= t < 9)
    - equalgreaterthan7 (t >= 9)
- Locally Alignment valve opening time (LocallyAlignmentValveOpeningTime)
    - lessthan3 (0 < t < 3)
    - equalgreaterthan3lessthan5 (3 < = t < 5)
    - equalgreaterthan5lessthen7 (5 <= t < 7)
    - equalgreaterthan7lessthen9 (7 <= t < 9)
    - equalgreaterthan7 (t >= 9)
- Number of attempts at opening (NumAttemptsOpenShutdownvalve)
    - 1
    - 2
    - 3
    - 4
    - equalgreaterthan5 (n >= 5)
- Well Presure (WellPressure)
    - lessthan30% (0 < p < 30)
    - equalgreaterthan30lessthan50 (30 <= p < 50)
    - equalgreaterthan50lessthan70 (50 <= p < 70)
    - equalgreaterthan70lessthan90 (70 < = p < 90)
    - equalgreaterthan90lessthan100 (90 < = p < 100)
- Execution Activity Time (ChokeOpeningTime)
    - lessthan10 (0 < t < 10)
    - equalgreaterthan10lessthan20 (10 <= t < 20)
    - equalgreaterthan20lessthan30 (20 < = t < 30)
    - equalgreaterthan30lessthan40 (30 <= t < 40)
    - equalgreaterthan40 (t >= 40)
- Variation in well pressure at the pipeline exit (WellPressurePipelineExitVariation)
    - lessthan2 (0 < p < 2)
    - equalgreaterthan2lessthan4 (2 <= p < 4)
    - equalgreaterthan5lessthan7 (5 <= p < 7)
    - equalgreaterthan7lessthan9 (7 <= p < 9)
    - equalgreaterthan9 (p >= 9)
- Variation in consumer demand (ConsumerDemandVariation)

    - equallessthan4 (0 < d <= 4)
    - greaterthan4equallessthan7 (4< d <= 7)
    - greaterthan7equallessthan10 (7 < d <= 10)
    - greaterthan10equallessthan13 (10 < d <= 13)
    - greaterthan13 (d > 13)
- Variation of pressure in all wells (PressureWellsVariation)
    - equallessthan4 (0 < d <= 4)
    - greaterthan4equallessthan7 (4< d <= 7)
    - greaterthan7equallessthan10 (7 < d <= 10)
    - greaterthan10equallessthan13 (10 < d <= 13)
    - greaterthan13 (d > 13)
- Cost of test in wells (TestWellsCost)
    - lessthan7 (0 < c < 7)
    - equalgreaterthan7lessthan15 (7 <= c < 15)
    - equalgreaterthan15lessthan22 (15 <= c < 22)
    - equalgreaterthan22lessthan23 (22 <= c < 23)
    - equalgreaterthan23 (c >= 23)
- Operation (Operation)
    - equallessthan20 (0 < p <= 20)
    - greaterthan20equallessthan40 (20 < p <= 40)
    - greaterthan40equallessthan60 (40 < p <= 60)
    - greaterthan60equallessthan80 (60 < p <= 80)
    - greaterthan80equallessthan100 (80 < p <= 100)
- Increase in Demand (IncreaseDemand)
    - true
    - false
- Wells Temperature (WellsTemperature) > 10 and <= 20%
    - equallessthan5 (0 < p <= 5)
    - greaterthan5equallessthan10 (5 < p <= 10)
    - greaterthan10equallessthan20 (10 < p <= 20)
    - greaterthan20equallessthan30 (20 < p <= 30)
    - greaterthan30equallessthan40 (30 < p <= 40)
- Corrosion alarm level (CorrosionAlarmLevel)
    - true
    - false
- Hydrate injection alarm level (HydrateInjAlarmLevel)
    - true
    - false

The table below presents Process Instances and respective CEs values generated randomly.

Label:

A	Open remotely alignment valve of collector well
B	Open locally alignment valve collector well
C	Open shutdown valve
D	Open choke

E	Monitor well and pipelines variables
F	Monitor variables after choke and alarm levels

Process Instances

I	Situation	Situation
1	1, A, AlignmentValveStatus_closed, RemoteAlignmentValveOpeningTime_lessthan3	-
	1, B, AlignmentValveStatus_open, LocallyAlignmentValveOpeningTime_equalgreaterthan5lessthan7	S2
	1, C, NumAttemptsOpenShutdownvalve_3	S4
	1, D, WellPressure_equalgreaterthan30lessthan50, ChokeOpeningTime_lessthan10	S5
	1, E, WellPressurePipelineExitVariation_equalgreaterthan7lessthan9, ConsumerDemandVariation_greaterthan13, PressureWellsVariation_greaterthan7equallessthan10, TestWellsCost_equalgreaterthan15lessthan22, Operation_greaterthan40equallessthan60, IncreaseDemand_true	S9
	1, F, WellsTemperature_greaterthan5equallessthan10, CorrosionAlarmLevel_false, HydrateInjAlarmLevel_false	-
2	2, A, AlignmentValveStatus_closed, RemoteAlignmentValveOpeningTime_equalgreaterthan3lessthan5	-
	2, B, AlignmentValveStatus_open, LocallyAlignmentValveOpeningTime_equalgreaterthan7lessthen9	S2
	2, C, NumAttemptsOpenShutdownvalve_1	-
	2, D, WellPressure_equalgreaterthan30lessthan50, ChokeOpeningTime_equalgreaterthan40	-
	2, E, WellPressurePipelineExitVariation_lessthan2, ConsumerDemandVariation_greaterthan10equallessthan13, PressureWellsVariation_greaterthan10equallessthan13, TestWellsCost_equalgreaterthan23, Operation_greaterthan40equallessthan60, IncreaseDemand_true	-
	2, F, WellsTemperature_greaterthan30equallessthan40, CorrosionAlarmLevel_false, HydrateInjAlarmLevel_true	S12, S14
3	3, A, AlignmentValveStatus_open, RemoteAlignmentValveOpeningTime_equalgreaterthan5lessthen7	S1
	3, C, NumAttemptsOpenShutdownvalve_3	S4
	3, D, WellPressure_equalgreaterthan70lessthan90, ChokeOpeningTime_equalgreaterthan10lessthan20	-
	3, E, WellPressurePipelineExitVariation_equalgreaterthan5lessthan7, ConsumerDemandVariation_equallessthan4, PressureWellsVariation_greaterthan13, TestWellsCost_equalgreaterthan22lessthan23, Operation_greaterthan40equallessthan60, IncreaseDemand_true	-
	3, F, WellsTemperature_greaterthan10equallessthan20, CorrosionAlarmLevel_false, HydrateInjAlarmLevel_false	S11

4	4, A, AlignmentValveStatus_open, RemoteAlignmentValveOpeningTime_equalgreaterthan7lessthen9	S1
	4, C, NumAttemptsOpenShutdownvalve_equalgreaterthan5	S4
	4, D, WellPressure_equalgreaterthan30lessthan50, ChokeOpeningTime_equalgreaterthan40	-
	4, E, WellPressurePipelineExitVariation_equalgreaterthan5lessthan7, ConsumerDemandVariation_greaterthan4equallessthan7, PressureWellsVariation_equallessthan4, TestWellsCost_equalgreaterthan23, Operation_greaterthan60equallessthan80, IncreaseDemand_true	S6
	4, F, WellsTemperature_greaterthan30equallessthan40, CorrosionAlarmLevel_false, HydrateInjAlarmLevel_false	S12
5	5, A, AlignmentValveStatus_open, RemoteAlignmentValveOpeningTime_equalgreaterthan7lessthen9	S1
	5, C, NumAttemptsOpenShutdownvalve_2	S3
	5, D, WellPressure_equalgreaterthan50lessthan70, ChokeOpeningTime_equalgreaterthan20lessthan30	-
	5, E, WellPressurePipelineExitVariation_lessthan2, ConsumerDemandVariation_greaterthan10equallessthan13, PressureWellsVariation_greaterthan4equallessthan7, TestWellsCost_lessthan7, Operation_equallessthan20, IncreaseDemand_true	-
	5, F, WellsTemperature_greaterthan30equallessthan40, CorrosionAlarmLevel_false, HydrateInjAlarmLevel_true	S12, S14

APPENDIX IX

Aircraft Take-off Process – Situations

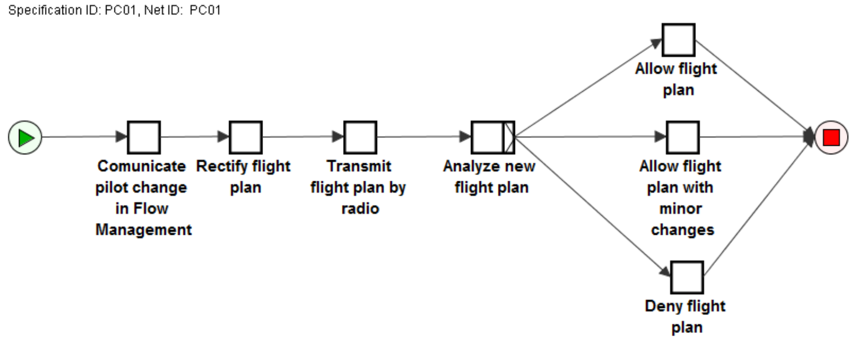
Situation 1: After the execution of activity “Allow flight plan” a situation is triggered indicating that a situation related to management flow is occurring. S01 = {fillflightplan.status = completed, RainfallLevelDestination = high, MeteorologicalStatus = unfavorable}
Situation 2: After the execution of activity “Allow flight plan” a situation is triggered indicating that a situation related to management flow is occurring. S02 = {fillflightplan.status = completed, RainfallLevelDestination = high / very high, EquipmentAvailability = false}
Situation 3: After the execution of activity “Allow flight plan” a situation is triggered indicating that a situation related to management flow is occurring. S03 = {fillflightplan.status = completed, RainfallLevelDestination = norain, MeteorologicalStatus = unfavorable}
Situation 4: After the execution of activity “Taxiing aircraft up to the waiting point” a situation is triggered indicating that wind conditions and direction has changed. S04 = {definetaxiroute.status = completed, WindDirection = opposite}
Situation 5: Before the execution of activity “Taxiing aircraft up to the waiting point” a situation is triggered indicating that an unplanned priority (medical, military or political) has occurred. S05 = {definetaxiroute.status = at start, EmergencyPriority = true, EmergencyResponseTime = medium}
Situation 6: Before or during the execution of activity “Taxiing aircraft up to the waiting point” a situation is triggered indicating that an unplanned priority (medical, military or political) has occurred. S06 = {definetaxiroute.status = at start/completed, EmergencyPriority = true, EmergencyResponseTime = fast}
Situation 7: After the execution of activity “Taxiing aircraft up to the waiting point” a situation is triggered indicating that an unplanned priority (medical, military or political) has occurred. S07 = {definetaxiroute.status = at start/completed, EmergencyPriority = true}
Situation 8: Before the execution of activity “Allow Starting Engines” a situation is triggered indicating that an unplanned priority (medical, military or political) has occurred. S08 = {allowstartingengines.status = at start, EmergencyPriority = true,

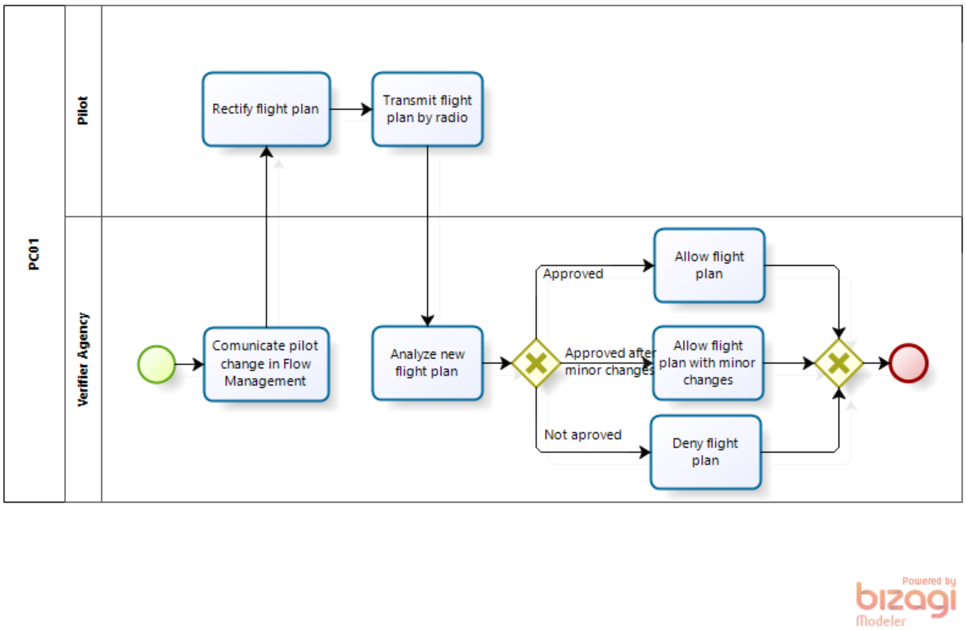
EmergencyResponseTime = medium/low}
Situation 9: Before the execution of activity “Transmit flight plan” a situation is triggered indicating that an unplanned priority (medical, military or political) has occurred. S09 = {transmitflightplan.status = at start, uhf = false, telephone = true}

APPENDIX X

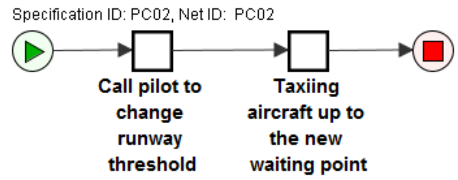
Aircraft Take-off Process – Worklets

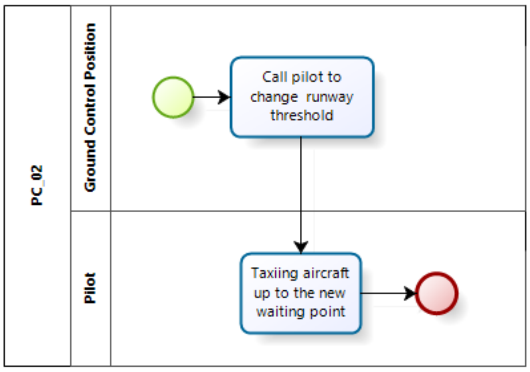
PC_01, PC_08, PC_09 – Activated by S01, S02, S03 (CAF-01)



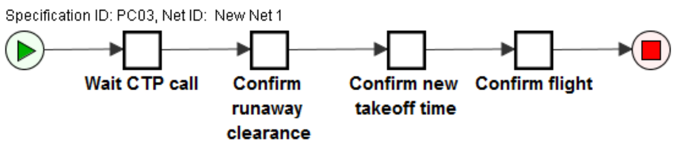


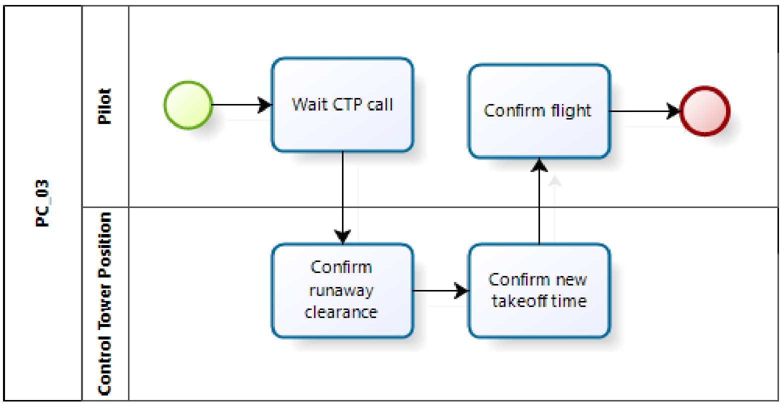
PC_02– Activated by S04 (CAF-05)



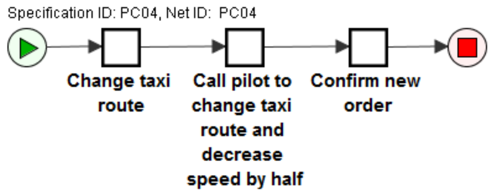


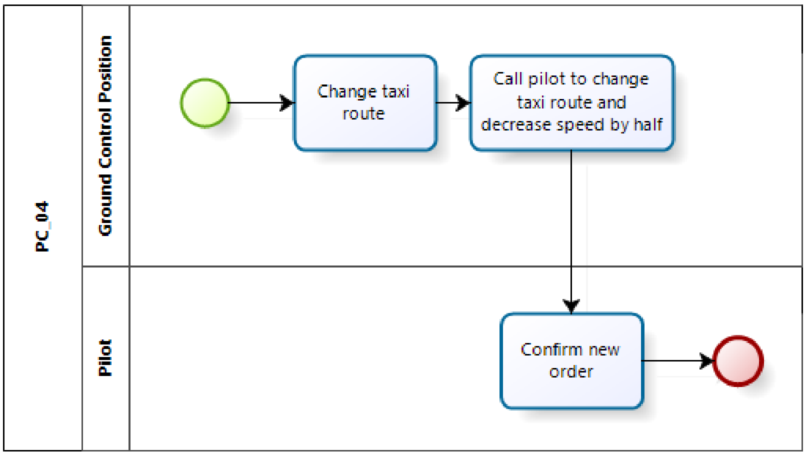
PC_03– Activated by S05 (CAF-05)



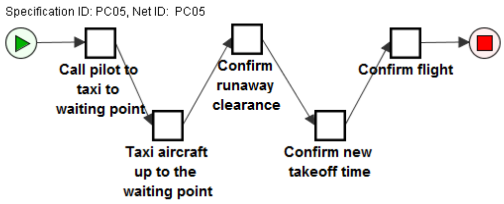


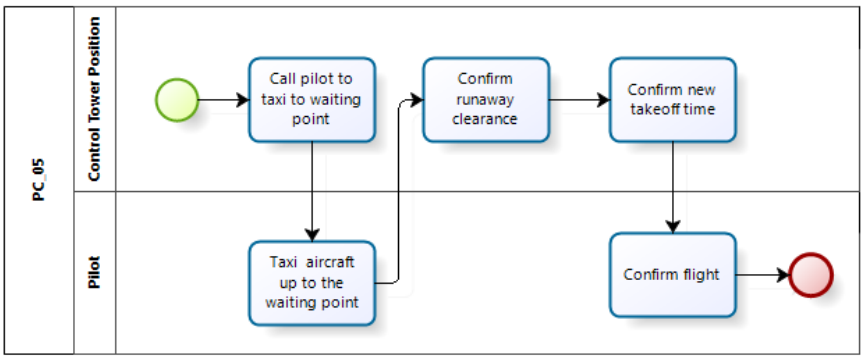
PC_04– Activated by S06 (CAF-05)



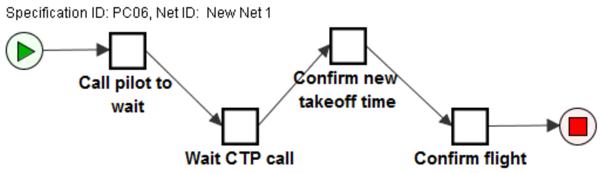


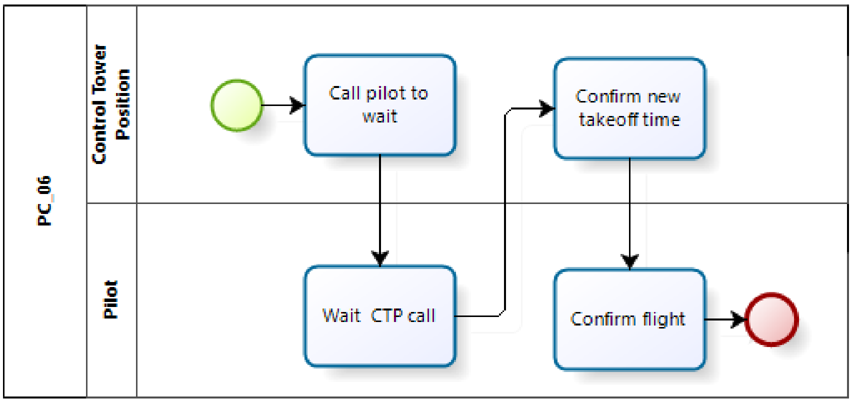
PC_05 – Activated by S07 (CAF-05)



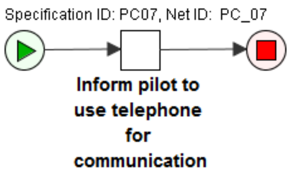


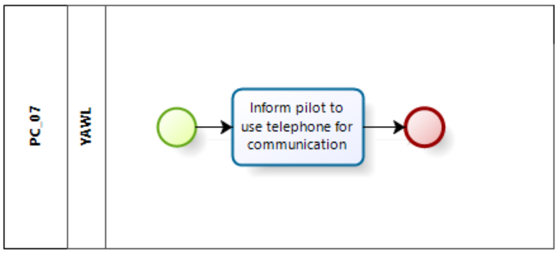
PC_06 – Activated by S08 (CAF-05)





PC_07 – Activated by S09 (CAF-01)





APPENDIX XI

Aircraft Take-off Process – Process Instances (Simulation of occurrence of CEs values).

It was definition at most 5 possible values for each CE:

- Rainfall level at destination (RainfallLevelDestination)
  - norain
  - low
  - medium
  - high
  - veryhigh
- Meteorological status (MeteorologicalStatus)
  - favorable
  - unfavorable
- Equipment Availability (EquipmentAvailability)
  - true
  - false
- Wind direction (WindDirection)
  - ok
  - opposite
- Emergency Priority (EmergencyPriority)
  - true
  - false
- Emergency Response time (EmergencyResponseTime)
  - verylow
  - low
  - medium
  - high
  - veryhigh
- CommunicationEquipment
  - uhf
  - telephone

The table below presents Process Instances and respective CEs values generated randomly.

Lable:

A	Deliver flight plan
B	Allow flight plan
C	Wait pilot call
D	Call clearance delivery position to start take-off procedures
E	Confirm receipt of information and take-off parameters
F	Call ground control position
G	Allow starting engines
H	Define taxi route
I	Taxiing aircraft up to the waiting pointing

J	Call tower control position
K	Give ready for take-off
L	Allow entering the runway

Process Instances

I	Situation	Situations
1	1, A, CommunicationEquipment_telefone	S09 - PC07
	1, B, RainfallLevelDestination_high, MeteorologicalStatus_unfavorable, EquipmentAvailability_true	S01 - PC01
	1, C, RainfallLevelDestination_veryhigh, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_true, EmergencyResponseTime_veryhigh	-
	1, D, RainfallLevelDestination_low, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_false, EmergencyResponseTime_veryhigh	S02 - PC08
	1, E, RainfallLevelDestination_low, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_false, EmergencyResponseTime_verylow	S02 - PC08
	1, F, RainfallLevelDestination_high, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_true, EmergencyResponseTime_high	S01 - PC01
	1, G, RainfallLevelDestination_norain, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_true, EmergencyResponseTime_high	S07 - PC05
	1, H, RainfallLevelDestination_high, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_true, EmergencyResponseTime_high, WindDirection_opposite	S04 - PC02
	1, I, RainfallLevelDestination_low, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_true, EmergencyResponseTime_verylow, WindDirection_opposite	S04 - PC02 S07 - PC05 S02 - PC08
	1, J, RainfallLevelDestination_low, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_false, WindDirection_ok	S07 - PC05
	1, K, RainfallLevelDestination_high, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_false, WindDirection_ok	S02 - PC08
	1, L, RainfallLevelDestination_low, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_false, WindDirection_opposite	S04 - PC02 S02 - PC08
2	2, A, CommunicationEquipment_uhf	-
	2, B, RainfallLevelDestination_veryhigh, MeteorologicalStatus_favorable, EquipmentAvailability_true	-
	2, C, RainfallLevelDestination_veryhigh, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_true, EmergencyResponseTime_high	S02 - PC08
	2, D, RainfallLevelDestination_veryhigh,	S02 - PC08

	MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_false, EmergencyResponseTime_veryhigh	
	2, E, RainfallLevelDestination_high, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_false, EmergencyResponseTime_high	S01 - PC01
	2, F, RainfallLevelDestination_low, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_false, EmergencyResponseTime_low	-
	2, G, RainfallLevelDestination_medium, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_false, EmergencyResponseTime_low	-
	2, H, RainfallLevelDestination_medium, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_false, EmergencyResponseTime_high, WindDirection_ok	S02 - PC08
	2, I, RainfallLevelDestination_veryhigh, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_true, EmergencyResponseTime_veryhigh, WindDirection_opposite	S01 - PC02 S02 - PC08 S03 - PC05
	2, J, RainfallLevelDestination_high, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_true, WindDirection_opposite	S04 - PC02 S03 - PC05
	2, K, RainfallLevelDestination_veryhigh, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_true, WindDirection_ok	S03 - PC-05
	2, L, RainfallLevelDestination_norain, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_true, WindDirection_ok	S03 - PC-05
3	3, A, CommunicationEquipment_uhf	-
	3, B, RainfallLevelDestination_norain, MeteorologicalStatus_unfavorable, EquipmentAvailability_true	S03 - PC09
	3, C, RainfallLevelDestination_low, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_false, EmergencyResponseTime_veryhigh	S02 - PC08
	3, D, RainfallLevelDestination_high, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_false, EmergencyResponseTime_verylow	-
	3, E, RainfallLevelDestination_medium, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_false, EmergencyResponseTime_medium	-
	3, F, RainfallLevelDestination_medium, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_true, EmergencyResponseTime_medium	S03 - PC-06
	3, G, RainfallLevelDestination_medium, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_true, EmergencyResponseTime_veryhigh	-
	3, H, RainfallLevelDestination_low, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_true,	S08 - PC02 S06 - PC04

	EmergencyResponseTime_fast, WindDirection_opposite	
	3, I, RainfallLevelDestination_high, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_true, EmergencyResponseTime_medium, WindDirection_ok	S07 - PC05
	3, J, RainfallLevelDestination_veryhigh, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_false, WindDirection_ok	S02 - PC08
	3, K, RainfallLevelDestination_norain, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_false, WindDirection_opposite	S04 - PC02
	3, L, RainfallLevelDestination_veryhigh, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_true, WindDirection_opposite	S04 - PC02 S03 - PC05 S02 - PC08
4	4, A, CommunicationEquipment_uhf	-
	4, B, RainfallLevelDestination_veryhigh, MeteorologicalStatus_favorable, EquipmentAvailability_false	S02 - PC08
	4, C, RainfallLevelDestination_high, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_true, EmergencyResponseTime_verylow	S01 - PC01
	4, D, RainfallLevelDestination_norain, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_false, EmergencyResponseTime_verylow	-
	4, E, RainfallLevelDestination_medium, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_true, EmergencyResponseTime_medium	S08 - PC06
	4, F, RainfallLevelDestination_medium, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_true, EmergencyResponseTime_high	-
	4, G, RainfallLevelDestination_veryhigh, MeteorologicalStatus_favorable, EquipmentAvailability_false, EmergencyPriority_true, EmergencyResponseTime_low	S02 - PC08 S03 - PC05
	4, H, RainfallLevelDestination_low, MeteorologicalStatus_favorable, EquipmentAvailability_false, EmergencyPriority_true, EmergencyResponseTime_veryhigh, WindDirection_ok	S02 - PC08 S03 - PC05
	4, I, RainfallLevelDestination_high, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_false, EmergencyResponseTime_veryhigh, WindDirection_ok	S01 - PC01
	4, J, RainfallLevelDestination_norain, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_true, WindDirection_opposite	S04 - PC02 S03 - PC05
	4, K, RainfallLevelDestination_medium, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_true, WindDirection_opposite	S04 - PC02 S03 - PC05 S02 - PC08
	4, L, RainfallLevelDestination_norain, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_false, WindDirection_opposite	S04 - PC02 S03 - PC09
5	5, A, CommunicationEquipment_uhf	-

	5, B, RainfallLevelDestination_norain, MeteorologicalStatus_unfavorable, EquipmentAvailability_true	S03 - PC09
	5, C, RainfallLevelDestination_high, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_false, EmergencyResponseTime_veryhigh	S01 - PC01
	5, D, RainfallLevelDestination_high, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_false, EmergencyResponseTime_medium	S01 - PC01
	5, E, RainfallLevelDestination_veryhigh, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_false, EmergencyResponseTime_low	-
	5, F, RainfallLevelDestination_low, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_false, EmergencyResponseTime_medium	S02 - PC08
	5, G, RainfallLevelDestination_high, MeteorologicalStatus_favorable, EquipmentAvailability_false, EmergencyPriority_false, EmergencyResponseTime_low	S02 - PC08
	5, H, RainfallLevelDestination_veryhigh, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_false, EmergencyResponseTime_medium, WindDirection_opposite	S04 - PC02
	5, I, RainfallLevelDestination_norain, MeteorologicalStatus_unfavorable, EquipmentAvailability_false, EmergencyPriority_false, EmergencyResponseTime_low, WindDirection_ok	S02 - PC08
	5, J, RainfallLevelDestination_high, MeteorologicalStatus_unfavorable, EquipmentAvailability_true, EmergencyPriority_true, WindDirection_opposite	S04 - PC02 S03 - PC05
	5, K, RainfallLevelDestination_veryhigh, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_false, WindDirection_opposite	S04 - PC02
	5, L, RainfallLevelDestination_high, MeteorologicalStatus_favorable, EquipmentAvailability_true, EmergencyPriority_true, WindDirection_opposite	S04 - PC02 S03 - PC05

APPENDIX XII

Interview template for Aircraft takeoff observational study

Contexto da pesquisa

Este trabalho de pesquisa tem como objetivo trabalhar com adaptação dinâmica de processos.

Para entender este contexto vamos usar o próprio domínio de aviação como exemplo, utilizando o processo de decolagem de aeronaves que foi levantado junto a dois controladores de voo que trabalham no Aeroporto do Galeão. Esta é a visão dos controladores entrevistados e podem existir algumas diferenças em relação a sua visão, mas o processo serve como um exemplo de parte da realidade que acontece nos procedimentos para decolagem.

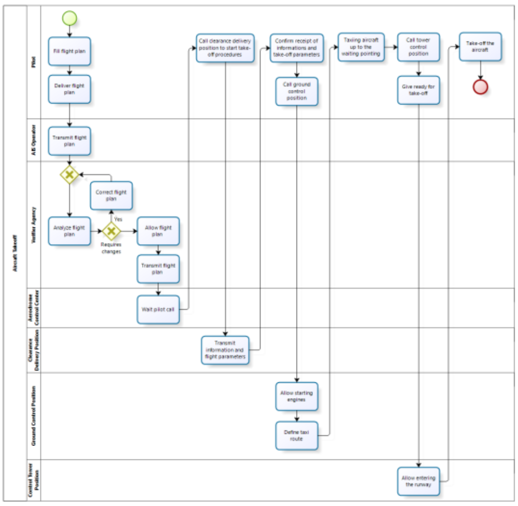
Este processo modelado trata do procedimento padrão a ser executado. Ou seja, ele não contempla possíveis variações ou o acontecimento de eventos inesperados que podem requerer a tomada de ações não previstas.

É disto que trata a pesquisa que venho desenvolvendo. Como apoiar as pessoas no raciocínio em relação a diversos eventos não previstos?

Imagina que as decolagens de aeronaves, apesar de seguirem um procedimento padrão, são únicas entre si. Isso quer dizer que os valores das variáveis que são observadas durante o procedimento de decolagem (informações do plano de voo, informações do aeroporto, informação de gerenciamento de fluxo, informações sobre condições meteorológicas, etc...) nunca são exatamente os mesmos.

Esta pesquisa propõe um software (com uma sistemática baseada em inteligência artificial) que seja capaz de receber todas essas informações que acontecem durante o procedimento de decolagem e fosse capaz de raciocinar sobre eventos inesperados.

Porém os questionamentos abaixo estão voltados para entender: (i) Se de fato o tempo de reação é uma questão importante; (ii) Se o raciocínio (para as situações apresentadas) seria semelhante a decisão manual; e (iii) Qual sua opinião sobre os procedimentos nos quais trabalha, como eles poderiam ser melhorados no sentido de estar preparado para eventualidades e se uma solução que implemente as ideias de pesquisa propostas são factíveis e trariam benefícios.



Grupo 1

Suponha eventos não previstos que possam acontecer durante os procedimentos para decolagem de uma aeronave.
Para cada pergunta, caso julgue necessário ou interessante cite observações em relação ao acontecimento dessa situação e o que você acha que poderia ser melhorado para otimizar o processo de decolagem e o voo em si.

Situação 1

1. Evento: Após a autorização do plano de vôo, ocorre uma mudança meteorológica desfavorável indicando que a incidência de chuva no destino é de grande volume.

   Do seu ponto de vista, a reação a essa informação, que pode impactar nos procedimentos de decolagem, é:
   a) Rápida (ocorre bem antes da decolagem)
   b) Mediana (ocorre próximo a decolagem ou logo após)
   c) Demorada (ocorre após a decolagem)
2. Que ação (ou ações) normalmente é tomada?
   a) Nenhuma ação é tomada.
   b) O voo tem sua hora de decolagem atrasada.
   c) O plano de voo é revisto para considerar possibilidades como alteração da rota.
   d) O voo é cancelado.
   e) Outra ação é tomada (neste caso, especificar a ação).

Situação 2

3. Evento: Após a autorização do plano de vôo, ocorre uma indisponibilidade de algum equipamento.

   Do seu ponto de vista, a reação a essa informação, que pode impactar nos procedimentos de decolagem, é:
   a) Rápida (ocorre bem antes da decolagem)
   b) Mediana (ocorre próximo a decolagem ou logo após)
   c) Demorada (ocorre após a decolagem)
4. Que ação (ou ações) normalmente é tomada?
   a) Nenhuma ação é tomada.
   b) O voo tem sua hora de decolagem atrasada.
   c) O plano de voo é revisto para considerar possibilidades como alteração da rota.
   d) O voo é cancelado.
   e) Outra ação é tomada (neste caso, especificar a ação).

Situação 3

5. Evento: Após a autorização do plano de vôo, ocorre uma mudança meteorológica favorável indicando que a incidência de chuva no destino, que era de grande volume, diminui e continua em ritmo de diminuição.

   Do seu ponto de vista, a reação a essa informação, que pode impactar nos procedimentos de decolagem, é:
   a) Rápida (ocorre bem antes da decolagem)
   b) Mediana (ocorre próximo a decolagem ou logo após)
   c) Demorada (ocorre após a decolagem)

6. Que ação (ou ações) normalmente é tomada?
    a) Nenhuma ação é tomada.
    b) O voo tem sua hora de decolagem atrasada.
    c) O plano de voo é revisto para considerar possibilidades como alteração da rota.
    d) O voo é cancelado.
    e) Outra ação é tomada (neste caso, especificar a ação).

Situação 4

7. Evento: Antes ou durante o taxiamento na pista o vento mudou de direção.

   Do seu ponto de vista, a reação a essa informação, que pode impactar nos procedimentos de decolagem, é:
    a) Rápida (ocorre antes de já ter percorrido grande parte do percurso de taxiamento)
    b) Mediana (ocorre próximo ao ponto de partida)
    c) Demorada (ocorre quando o avião já está pronto para decolar)
8. Que ação (ou ações) normalmente é tomada?
    a) Nenhuma ação é tomada.
    b) O voo tem sua hora de decolagem atrasada.
    c) Você recebe uma informação para alterar a cabeceira da pista e/ou alterar de pista.
    d) O voo é cancelado.
    e) Outra ação é tomada (neste caso, especificar a ação).

Situação 5

9. Evento: Antes ou durante o taxiamento na pista ocorre uma emergência médica/militar/política considerada de atendimento médio a demorado.

   Do seu ponto de vista, a reação a essa informação, que pode impactar nos procedimentos de decolagem, é:
    a) Rápida (ocorre bem antes da decolagem)
    b) Mediana (ocorre próximo a decolagem ou logo após)
    c) Demorada (ocorre após a decolagem)
10. Que ação (ou ações) normalmente é tomada?
    a) Nenhuma ação é tomada.
    b) O voo tem sua hora de decolagem atrasada.
    c) Você recebe uma informação para taxiar por uma rota maior afim de liberar o ponto de parada.
    d) O voo é cancelado.
    e) Outra ação é tomada (neste caso, especificar a ação).

Situação 6

11. Evento: Antes ou durante o taxiamento na pista ocorre uma emergência médica/militar/política considerada de rápido atendimento.

    Do seu ponto de vista, a reação a essa informação, que pode impactar nos procedimentos de decolagem, é:
    a) Rápida (ocorre bem antes da decolagem)
    b) Mediana (ocorre próximo a decolagem ou logo após)

c) Demorada (ocorre após a decolagem)

12. Que ação (ou ações) normalmente é tomada?
    a) Nenhuma ação é tomada.
    b) O voo tem sua hora de decolagem atrasada.
    c) Você recebe uma informação para taxiar por uma rota maior a fim de liberar o ponto de parada.
    d) O voo é cancelado.
    e) Outra ação é tomada (neste caso, especificar a ação).

Situação 7

13. Evento: Após o taxiamento na pista, quando você já está da posição de decolagem, ocorre uma emergência médica/militar/política.

    Do seu ponto de vista, a reação a essa informação, que pode impactar nos procedimentos de decolagem, é:
    a) Rápida (ocorre bem antes da decolagem)
    b) Mediana (ocorre próximo a decolagem ou logo após)
    c) Demorada (ocorre após a decolagem)
14. Que ação (ou ações) normalmente é tomada?
    a) Nenhuma ação é tomada.
    b) Você recebe uma informação para taxiar para um ponto de espera e recebe nova hora de decolagem.
    c) O voo é cancelado.
    d) Outra ação é tomada (neste caso, especificar a ação).

Situação 8

15. Evento: Antes de ligar as turbinas do avião ocorre uma emergência médica/militar/política considerada de atendimento médio a demorado.

    Do seu ponto de vista, a reação a essa informação, que pode impactar nos procedimentos de decolagem, é:
    a) Rápida (ocorre bem antes da decolagem)
    b) Mediana (ocorre próximo a decolagem ou logo após)
    c) Demorada (ocorre após a decolagem)
16. Que ação (ou ações) normalmente é tomada?
    a) Nenhuma ação é tomada.
    b) As turbinas são ligadas e aeronave aguarda novo comando.
    c) Você recebe uma informação para não ligar as turbinas e aguardar novo comando.
    d) Você recebe uma informação para ligar as turbinas e taxiar por uma rota maior a fim de liberar o ponto de parada.
    e) O voo é cancelado.
    f) Outra ação é tomada (neste caso, especificar a ação).

Situação 9

17. Evento: Antes de transmitir o plano de voo ocorre um problema no comunicador padrão.

    Do seu ponto de vista, a reação a essa informação, que pode impactar nos procedimentos de decolagem, é:

a) Rápida (ocorre bem antes da decolagem)
b) Mediana (ocorre próximo a decolagem ou logo após)
c) Demorada (ocorre após a decolagem)

18. Que ação (ou ações) normalmente é tomada?
    a) Nenhuma ação é tomada.
    b) Você aguarda a solução para o comunicador padrão.
    c) Você seleciona outro meio de comunicação (como telefone) para transmitir o plano de voo.
    d) O voo é atrasado.
    e) Outra ação é tomada (neste caso, especificar a ação).

Grupo 2 – Responda as perguntas abaixo

1. A quanto tempo você se trabalha nesta função?
2. Quais são as metas que você, na sua função, visa garantir?
3. Na sua visão, quando eventos não previstos acontecem, como as decisões de alteração no procedimento padrão de decolagem são tomadas?
4. Que critério(s) você utiliza para definir se um evento que está acontecendo é relevante e pode impactar (de forma positiva ou negativa) no procedimento de decolagem?
5. Existem mecanismos computacionais que apoiem a tomar decisões de ações de alteração no procedimento padrão de decolagem?
6. De acordo com sua opinião seria possível levantar todos os eventos fora do previsto (fora do procedimento normal padrão) que podem acontecer durante os procedimentos de decolagem?
7. Você tem acesso a todas as informações que demandam alterações (não decididas por você) no procedimento de decolagem?
8. Você vê benefícios em ter acesso às informações e eventos que podem impactar nos procedimentos de decolagem no momento em que eles estão acontecendo? Você acha que isso poderia agilizar e melhorar a reação a eventos ruins?
9. Você vê benefícios em ter apoio de um sistema capaz de utilizar inteligência computacional para raciocinar recebendo esses eventos fora do previsto e sugerir ações que ajudem a otimizar o procedimento de decolagem?
10. Atribua uma nota de 1 a 5 (1 para discordo totalmente e 5 para concordo totalmente) para os benefícios de se utilizar um sistema capaz de utilizar inteligência computacional para ajudar a tomar ações durante eventos não inesperados:
    1 – Discordo totalmente
    2 – Discordo parcialmente
    3 – Não discordo nem concordo
    4 – Concordo parcialmente
    5 – Concordo totalmente

Benefícios	Nota
Diminuição no tempo de percepção do evento inesperado	
Disseminação da informação para todos os participantes do procedimento de decolagem	
Tomada de decisão e sugestão de ações para reagir aos eventos	

inesperados	
Manutenção da documentação do processo padrão, simples, de fácil entendimento e organizando em representações diferentes ações (atividades) a serem tomadas dependendo da ocorrência de eventos não esperados durante o procedimento padrão	
Aprendizado baseado em decolagens anteriores, sobre ações tomadas em relação aos eventos inesperados e o resultado do procedimento de decolagem como forma de melhorar o raciocínio computacional	

Este espaço é reservado para você listar outros benefícios que enxerga ou listar mecanismos ou ações que você acha que poderiam melhorar o procedimento de decolagem.

11. Você vê alguma desvantagem no uso de uma abordagem computacional neste sentido?

APPENDIX XIII

Pilots reports from interview questionnaire.

Group 1

S: Situation (R – Reaction time, A- action to be taken)

Situation 1		
	R / A	Observations
P1	a	Se eu tivesse acesso a essa informação antes da aprovação do plano de voo, dependo de informações como o destino (pois se sabe quais é o padrão médio de chuva que ocorre – se perduram ou não e também os centros meteorológicos (o centro meteorológico de Brasilia – CMV - Centro Meteorológico de Vigilância - é o maior que existe) que trabalham com probabilidades de acontecimento, continuidade e volume de chuva) e do tempo de voo, da importância do voo ir pra lá ou não, as condições do aeródromo de receber uma aeronave nas condições (em relação aos auxílios a navegação aérea (quais as probabilidades daquele auxílio dar pane – cuja probabilidade é calculada em função do que já aconteceu no passado)). A tomada de decisão teria que ser feita o mais rápido possível, porque tem que prever combustível e porque pode acabar impactando no tempo não só da decolagem, mas do voo também.
	b, c, e	Dependendo do objetivo ele toma uma decisão, não só das variáveis. Por exemplo, um voo comercial do RJ pra Porto Alegre, se está chovendo muito, eu posso descer em Florianópolis, mas teria um custo alto de desembarque, pagamento de tempo em solo, taxi e hotéis, então vai ser melhor atrasar o voo. No caso de uma missão militar o objetivo é estar o mais próximo do destino, então o voo é realizado até Florianópolis ou ponto mais próximo possível.
P2	a	-
	b, c, d	-
P3	b	Deve-se leva em consideração a segunda alternativa e, por isso, a reação não precisa ser tão rápida assim.
	c	Mas deve-se leva em consideração que existe um número de variáveis muito maior que se leva em consideração para tomar esta decisão.
P4	b	-
	c	-

Situation 2		
	R / A	Observations
P1	a, b	A aeronave já decola com pelo menos duas alternativas, a segunda é sempre a opcional. Depende do objetivo do voo. Mas a resposta a esse evento, seria bom se fosse rápido, mas

		mediano já ajudaria muito
	b, d	-
P2	a	-
	b, d	-
P3	b	-
	b	Dependendo do tipo de equipamento consulta os manuais para saber se vai decolar ou não ou já toma a ação direta. Tem alguns aviões que já tem uma automação da verificação dos equipamentos, mas ainda é manual. Com relação aos equipamentos principais já existe um sistema que alerta quando um equipamento principal está com problema.
P4	b	-
	e	-

Situation 3		
	R / A	Observations
P1	a	Dá pra adequar durante o voo. Mas o que acontece é que a maioria das aeronaves não tem acesso a informação, então já o avião já decolou provavelmente nada será realizado. Mas o ideal é ser realizado o mais rápido possível
	c	Se o avião já decolou provavelmente nenhuma ação é tomada. Mas quanto mais rápido for tomada, pode-se alterar o plano de voo. Mas tudo vai depender de uma série de outras variáveis, algumas já comentadas.
P2	a	-
	a	O voo prossegue normalmente.
P3	a	-
	a	-
P4	b	-
	a	Em função da autoridade que está sendo transportada, mesmo que a possibilidade de chuva seja melhor, ele consulta a autoridade.

Situation 4		
	R / A	Observations
P1	b	-
	c	No caso, por exemplo, se só existir uma pista e o gráfico do avião informa que ele não pode decolar com aquela componente de calda, o voo pode ser até cancelado.
P2	a	-
	c	-
P3	a	-
	c	-

P4	b	-
	e	A depender da influencia do vento a decisão de saída ou pista serão alterados.

Situation 5		
	R / A	Observations
P1	a	-
	b, c	Depende de quão demorado
P2	a	-
	b, c	-
P3	a	-
	b	-
P4	b	-
	b, d	-

Situation 6		
	R / A	Observations
P1	a	-
	a, c	Se for menos de 5 minutos não preciso fazer nada. Mantenho meu plano. Se for maior um pouco posso taxiar por uma rota maior a fim de liberar o ponto de parada.
P2	a	-
	c	-
P3	a	-
	b	Depende da gravidade mesmo. Se for médica, por exemplo, eles abortam imediatamente. Param por complete.
P4	b	-
	c	-

Situation 7		
	R / A	Observations
P1	a	-
	b	Tem que dar prioridade para a emergência.
P2	a	-
	b, c	-
P3	a	-
	c	Dependendo do que for, continua, senão as vezes pode cancelar mesmo. Tudo dependen do nível da emergência
P4	b	-

	b	Se for uma emergência simples então só reposiciona.

Situation 8		
	R / A	Observations
P1	a	-
	d	É preferível taxiar por um ponto maior e garantir a decolagem do que ficar parado esperando o que vai acontecer, pois geralmente isso acaba impactando em taxiamento demorado de qualquer forma (pois as filas de taxiamento e partida são formadas por ordem de pedido). Depende do horário também, se for as 17hrs é melhor taxiar. Se for de madrugada, é melhor nem ligar as turbinas e aguardar já que são menos voos. As maiores pistas de taxiamento são Galeão, Brasilia e Guarulhos.
P2	a	-
	c, e	O voo pode ser atrasado também.
P3	a	-
	f	Solicitado novo horário para acionamento.
P4	b	-
	c	-

Situation 9		
	R / A	Observations
P1	a	O piloto tem que passar o plano de voo pelo menos 45 minutos antes da decolagem. Se ele chega no aeroporto atrasado e quer passar o plano as 07:00 para um voo as 08:00 e tem algum problema de comunicação, ele pode não conseguir fazer o voo na hora que deseja. No caso de voos comerciais que tem horários fixos e são realizados com periodicidade definida, existem centros só pra receber o plano de voo e existem os repetidores de planos, que já são pré-aprovados para ter velocidade no processo, mas daí isso é feito com bastante antecedência.
	c	Tem outras opções de contingência que são selecionadas hoje em dia em função da escolha do piloto (passar pela internet, usa diversos telefones, vai pessoalmente a sala de controle de tráfego, etc).
P2	a	-
	b, d	-
P3	a	-
	c	-
P4	b	-
	b	Normalmente passa com muito tempo de antecedência, por isso essa resposta.

Group 2

Question 1	
P1	14 anos (piloto comercial)
P2	19 anos (piloto militar)
P3	17 anos (piloto militar)
P4	17 anos (piloto militar)

Question 2	
P1	Segurança e Efetividade (ser eficaz e eficiente)
P2	Segurança, profissionalismo e eficiência.
P3	Segurança de voo e bem atendimento aos passageiros.
P4	Segurança de voo e estrito cumprimento de regras.

Question 3	
P1	O piloto em solo não tem autonomia para decidir, o que às vezes causa um desconforto, pois quem decide é o controlador. O controlador tem a visão completa de informações que o piloto não tem. Com relação ao plano de voo, a decisão tomada é conjunta, pois leva em consideração informações relacionada às condições do avião, como nível de combustível por exemplo. Até antes do plano de voo o piloto tem maior poder de decisão, mas após isso, o piloto ou o controlador sugerem alterações no plano e decidem em conjunto.
P2	São baseadas nas implicações para a decolagem e na avaliação dos riscos atinentes. As variáveis são analisadas em grupo, com toda a tripulação, e o comandante toma a decisão que julgar ser a mais acertada.
P3	Levando em consideração o tipo de imprevisto é tomada uma decisão em conjunto. Com anuência do segundo piloto e mecânico em voo.
P4	Levando em consideração o tipo de imprevisto a ser considerado, a decisão será tomada depois da decolagem.

Question 4	
P1	Tudo que o piloto julgar que pode alterar o perfil de voo e que está relacionado basicamente a algum aspecto de segurança e capacidade do equipamento.
P2	Critérios relacionados à segurança de voo.
P3	Critérios principais são segurança e as informações que a aeronave está passando.
P4	Geralmente as possíveis ocorrências são preestabelecidas

Question 5	
P1	Não que eu saiba. Tem o manual e o piloto sabe de cor. Ele pode consultar o manual para ajudar a tomar decisões.
P2	Sim. Nas aeronaves mais modernas, alguns sistemas podem ser úteis

	quando fornecem parâmetros para a tomada de decisões.
P3	O avião que eu voo, dependendo do momento que der a pane, ele segura a informação e depois da decolagem ele dá o alarme. Porque o piloto poderia abortar a decolagem por causa de uma pane no radio que é uma bobagem, então o sistema avisa depois pra não te desconcentrar.
P4	O sistema apresenta as informações e panes e apresenta através de um nível de alerta (Warning, Caution, Advisory). O próprio avião classifica os níveis das panes para alertar ao piloto. E apresenta em momento apropriado para o piloto não perder tempo com informações não relevantes em momentos críticos como o procedimento de decolagem.

Question 6	
P1	Seria difícil mapear todas as causas desses procedimentos fora do normal. Por exemplo, um problema que é o encurtamento de pista, pode ser causado por vários fatores como um animal na pista, apagamento parcial das luzes da pista, etc... Se você trabalha a partir do reconhecimento dos impactos acho que seria possível mapear grande parte dos problemas, mas o que pode gerá-los (as causas) são inúmeros para se fazer isso manualmente. Também acho que seria possível mapear os impactos a partir dos logs manuais que já foram gerados.
P2	Não, mas muitos podem ser previamente conhecidos.
P3	É possível sim levantar em treinar ostensivamente em simulação de voo.
P4	Pode se estabelecer o levantamento com base no histórico de ocorrências. Todas as situações são registradas em relatórios de voo e incidentes/acidentes.

Question 7	
P1	O piloto não tem informação sobre informações de fluxo de tráfego aéreo. Ele não sabe se vai demorar muito ou pouco tempo para decolar, se a rota está congestionada ou não, se o aeroporto de destino está congestionado ou não. Tanto que as cias aéreas estão usando mecanismo de reservas de slots por tempo definido.
P2	Na maioria das vezes, sim.
P3	Sim. Porque o avião que eu piloto tem uma automação mais moderna. Outros pilotos voam com aviões com automação que não permitem ter acesso a todas as informações relevantes.
P4	Não. Depende do tipo de informação ele não tem acesso diretamente. Depende de outras pessoas.

Question 8	
P1	O piloto não tem muito que fazer. Como ele não tem muita gerência sobre vários eventos, ele pode ficar na verdade insatisfeito com decisões que ele é obrigado a obedecer. Para a pessoa que é um usuário não faz diferença ele saber o motivo de

	uma decisão. Não acho que isso seria um benefício
P2	Sim. Melhora muito.
P3	Sim. E quanto maior o numero de informação você tiver melhor e mais precisa será sua tomada de decisão.
P4	Sim. A medida que o piloto possui mais informações sua consciência situacional amplia e isso contribui para sua tomada de decisão.

Question 9	
P1	Sim. E está caminhando pra isso. O sistema “Sagitárius” já trás diversos benefícios para o controlador de voo prevendo facilidades para gerenciar melhor algumas informações sobre aeronaves, suas capacidades e o espaço aéreo para ter uma fluidez melhor do espaço aéreo.
P2	Sem dúvida, já que, muitas vezes, a subjetividade da tomada de decisão, pode levar a uma decisão incorreta.
P3	Sim. Entretanto a ação final deve ser tomada pelos tripulantes. E dependendo do momento o sistema talvez nem seja eficaz, pq como eu acho que o piloto é que tem tomar a decisão, se ele recebe uma sugestão e ainda tem que raciocinar em cima dela, talvez demore muito.
P4	Sim.

Question 10	
P1	4, 1, 5, 5, 5 A partir do momento que você tenta quantizar (cientificar) e qualificar o processo, você pode obter resultados que você não esperaria que fossem daquela forma.
P2	4, 3, 5, 4, 5 Creio que o maior benefício, seria o de evitar o julgamento incorreto do piloto, quando se depara com uma situação inesperada.
P3	5, 5, 5, 5, 5 Cada Organização militar tem uma Seção de investigação para estudar e discutir os problemas que ocorrem em voos. E isso às vezes é disseminado pela FAB inteira através do CENIPA que centraliza este trabalho. Na aviação civil também existe um órgão que apóia no recebimento, análise e aprendizagem de incidentes e acidentes que possam ter acontecido. Mas o CENIPA atende tanto os militares quanto os civis. Além disso, a tendência para automação é cada vez maior. Mas o gerenciamento de risco ainda cabe à tripulação. Hoje em dia o piloto é mais um gerente do sistema do que um piloto.
P4	5, 5, 5, 5, 5 Todo auxilio computacional para conscientização situacional deve merecer incentivo de é pesquisa, mas deve-se ter sempre em mente que a decisão final é do piloto.

Question 11	
P1	O exagero no uso, principalmente no começo. Tem que testar muito e não

	ter uma dependência exagerada antes de ter uma confiabilidade no sistema
P2	Creio que o maior benefício, seria o de evitar o julgamento incorreto do piloto, quando se depara com uma situação inesperada.
P3	Evitar de o homem evitar ser escravo da automação.
P4	A maior dependência de sistema, quando o foco deveria ser na capacitação de recursos.