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ABSTRACT

In System and Software Engineering development, unforeseen changes occurring during process enactment are almost inevitable but often poorly managed due to a lack of efficient mechanisms for spontaneously handling these run time changes. We proposed a change aware process management system that allows process actors reporting emergent changes, analyzing possible impacts, and notifying people affected by the changes. To this end, we integrated a *Change Management Component* with a *Process Management System*. The *Process Management System* monitors process enactment and uses the run time process information to construct a *Process dependency graph* (*PDG*) representing the dependencies among the elements of running processes. The *Change Management Component* captures change requests sent asynchronously, then reasons the PDG to determine impacted elements. Our PDG reflects the information of process instances and therefore can uncover the intra process or inter processes dependencies that are invisible on process models. We implemented a prototype named CAPE based on the platform jBPM and the graph database Neo4j.

KEY WORDS: change impact analysis; Process Management System; process enactment

1. INTRODUCTION

Nowadays, changes in System and Software Engineering (SSE) projects are almost inevitable due to evolving requirements, resources, and technologies. Changes occurring in a running task can affect, in a chaining fashion, other tasks either inside one organization or among different organizations. Badly managed changes can lead to unwanted reworks and cause projects to fall behind schedule and go over budget. Applying a holistic, structured approach to manage changes is then crucial to avoid adding extra cost and risk to both the project and organizational levels.

As pointed out in [1], the complexity of the product, in terms of the number of components and the relationships between them, is a major source of change management problems. In general, the development of a system involves multi-teams, multi-disciplines, and can be realized on multi-sites. Consequently, facing a change, a single person can rarely have a detailed overview of all the system's components, such that he would be able to assess the impact and inform the concerned actors. Having a partial view on the development process, often, process actors do not know how their work relates to other tasks and have difficulties, even impossibility, in identifying the right person to communicate with for quickly resolving a problem. Lack of information on task

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connections can lead to unnecessary repetition or inconsistent results, which in turn will require rework or changes in other tasks. Insufficient communication usually discourages process actors to report all the changes they made or obliges them to follow hierarchical channels for propagating a change, where it can be delayed or misinterpreted.

Most modern SSE processes are extremely complex and inherently uncertain. These characteristics make managing SSE processes especially challenging. On the one hand, it is hard to finely describe SSE processes in order to exactly reflect the process execution in reality. Changes emerging at run-time are not predictable and therefore not integrated into process models. On the other hand, it is hard to develop an effective *Process Management System* (PMS) to automatically coordinate SSE processes that require low-level operational, flexible, and collaborative workflows [2]. In this context, although each organization does have a certain change management process, it is often poorly applied and relies on humans to propagate changes, especially emergent changes. Change management in SSE is thus a critical issue that is far from being mastered [3].

To facilitate run-time change management in SSE development, we aim at a *change aware process environment*, which provides an overall control on the development along with mechanisms for (1) *capturing changes* occurring in the development environment and (2) *analyzing change impacts* and *informing affected process actors*, all in a timely and systematical manner. We do not have the ambition to propose a complete solution for change management. We are primarily interested in the change notification issue. Change implementation is out of the scope of the presented work. Our objective is to provide an effective assistance for coordinating process actors in order to keep their work products consistent. Thus, we propose a flexible enactment of the SSE process to deal with changes made on the work products of the SSE process. Such changes are not described in the process model. So, if actors follow strictly the process model, they cannot handle the changes. We provide a certain flexibility on instantiation and execution of tasks in order to allow integrating the run-time changes in the actual process. But we do not handle changes made on the process model itself, that is, the process structure is supposed to be intact during its execution.

This paper extends our previous work [4] to enable more collaborative patterns, especially those concerning multiple instances tasks. We also enhanced the functionalities of our environment to support both emergent and initiated changes to respectively correct or evolve the process's work products. The remaining part of the paper presents our solution to obtain the objectives mentioned earlier and is organized as follows. Section 2 gives a brief description of our approach based on a motivating example. Section 3 presents the *process dependency graph* (*PDG*), an abstract graph describing the links between running processes and providing us with a global structure to analyze the impact of a change. Our idea is using PDG inside a process environment to enable change notification and analysis at run-time. We describe in Section 4 the architecture of our *change aware process environment* and report in Section 5 the experiments carried out by using our prototype CAPE. Some related works are discussed in Section 6, and Section 7 concludes our paper.

2. APPROACH

In this section, first, we describe, through an example inspired from a real process of our industrial partners, a typical situation of changes in process enactment and point out some synchronization problems if the change is not well managed. Finally, we present our approach to tackle this issue.

2.1. Motivating example

In [3], the authors classified change processes existing inside companies into two types: *official* and *unofficial*. An *official change process* is a macro-level process defining formal protocols to be respected to handle changes concerning to a company or a product. Normally at this level, the change process is rather well defined and conducted. An *unofficial change process* happens generally inside technical processes, during the pre-certification phases, as *backwards patching/debugging redesign* processes where developers attempted to fix a problem quickly during the development. This type of process is often informal or semi-formal and poorly managed due to the lack of coordination among developers. In this work, we focus on the problem of change management in the context of an unofficial change process.

Figure 1 shows a portion of a system engineering process simplified from the V-model. This example describes the system development phase containing two technical processes as *System Development* process (Figure 1a) and *Verification* & *Validation* process (Figure 1c). In our example, these two processes are performed respectively by *System Team* and *Test Team*. The *System Team* defines five roles as *Analyst*, *Designer*, *Test Designer*, *Developer*, and *Integrator*; the *Test Team* has only one role as *Tester*.

In the *System Development* process, the activity *Design System* produces two work products: *System Architectural Model*, which specifies the high-level design of the system, and *Test Strategy*, which describes several functionalities of the system to be tested later by the *Test Team*. From the *System Architectural Model*, the activity *Specify Component Requirements* generates the requirements for each component of the system. These requirements are aggregated in the work product *Component Requirements*. For each component requirement, the *Component Development* sub-process (Figure 1b) is realized to design the *Component Design Model* and then implement the final component. As the development of different components can be realized concurrently and independently, the sub-process *Component Development* is modeled as a multi-instance task. The number of instances of the sub-process is determined at run-time by the number of elements in the work product *Component Requirements*.

In parallel, the *Test Strategy* is analyzed in the activity *Specify Test Requirements* to produce the *Test Specifications* for each functionality to be tested. In a test specification, the system under test is represented by a list of *Component Design Models* of the components implementing the tested functionality. The test specifications are combined into the work product *Test Specifications*.

The *Test Team* starts to work in parallel with the *System Development Team* when the *Test Specifications* are defined. For each element in the *Test Specifications* set, an instance of the *Verification* & *Validation* (V&V) process is created. The *Tester* analyzes the test specification to get the *Test Objectives*, the list of *Component Design Models* of the system under test, and the *Environment Specification* needed for preparing the *Test Bench* that will be used for executing the test.

These two general processes can be used for various development projects, thus, may be adapted to a specific context of a given project as illustrated in the following scenario.

Scenario Δ

We examine the $project_1$ whose *Specify Component Requirements* task and *Specify Test Requirements* task are carried out. Thus, the components to be developed and the tests to be executed are known. The main information about the $project_1$ are presented in Table I.

We suppose that at that moment, the company has two other projects, $project_2$ and $project_3$, which are waiting to use the test bench tb_1 for their V&V processes denoted as $P_{2.1.vv}$ and $P_{3.1.vv}$.[1]

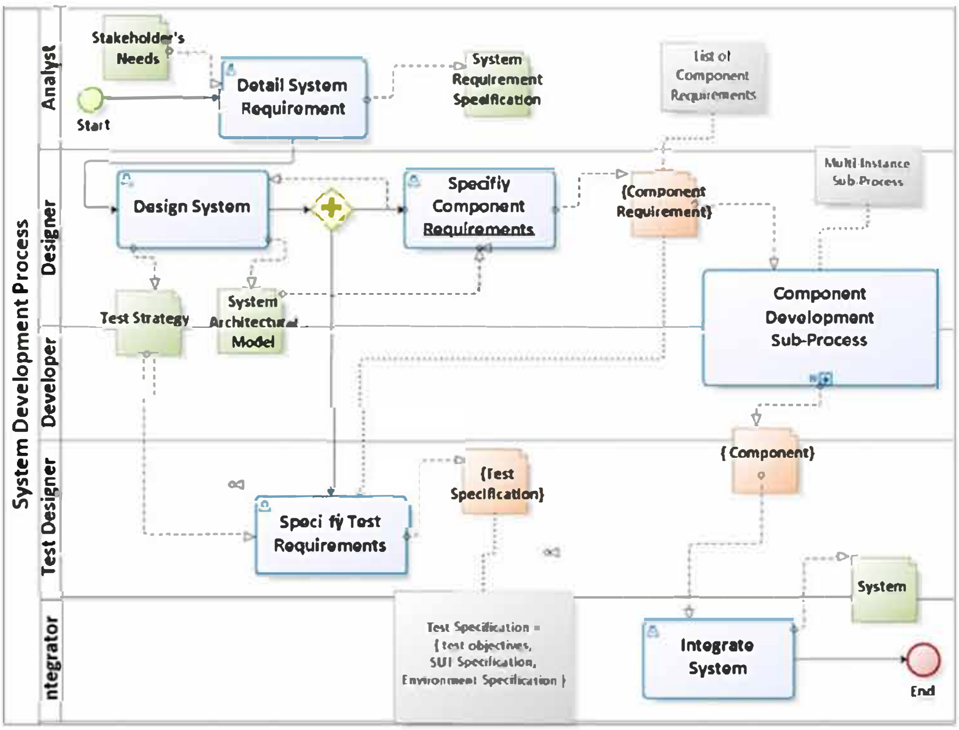
Change We consider one of the most common unofficial change situation that frequently occurs during system development:

In the $project_1$, when carrying out the *Implement Component* task to build the component C_1, the developer d_1 faces a problem in the *Component Design Model* CDM_1. To continue and finish his implementation, d_1 wants to modify CDM_1, which is out of his responsibility. If the change was controlled, d_1 had to inform the designer des_1 of the problem and then wait for a new version of CDM_1. However, in reality, in a loosely controlled development environment, d_1 may change directly CDM_1 without reporting the change because (1) he cannot wait and (2) he does not know the concerned people to notify them of the change.

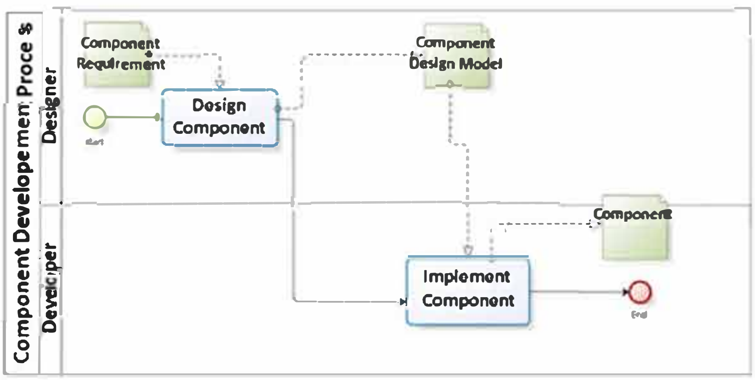
In this example, the possible impacts of the change on CDM_1 initiated by d_1 are

- *Impacts inside* $project_1$: any change in CDM_1 will immediately affect the process instance $P_{1.vv}$ performed by tester t_1 who is preparing the test environment for the functionality F_1 that is based

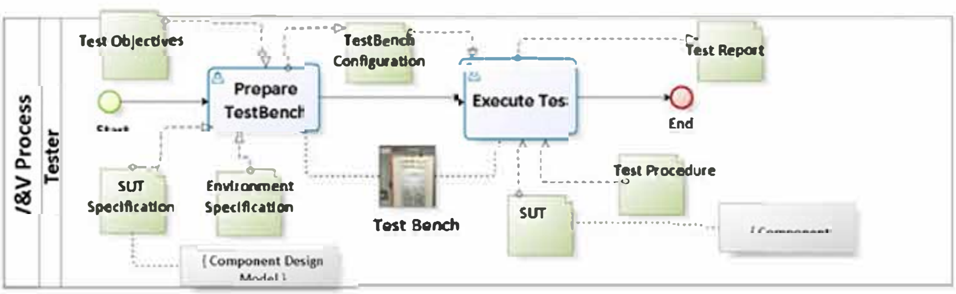
[1] $P_{i.j.vv}$ represents the instance j of process V & V belongs to the project i



(a) **System Development Process**



(b) **Component Development Sub-process**



(c) **Verification & Validation Process**

Figure 1. Processes of a System Development phase. (a) System Development Process. (b) Component Development Sub process. (c) Verification & Validation Process.

on CDM_1 and CDM_2. Changing CDM_1 without notifying t_1 may lead to an incompatible test environment tb_1, which is obsolete and not corresponding to the real component C_1 developed by d_1.

Table I. Information of Project 1.

Human resources	Analyst = a_1, Designer = des_1, des_2, des_3, Test Designer = td_1, Developer = d_1, d_2, d_3, Integrator = i_1, Tester = t_1, t_2
Non human resources	Test Bench = $\{tb_1, tb_2\}$
Components	$\{C_1, C_2, C_3\}$
Test objectives	Functionality F_1 on C_1, C_2 Functionality F_2 on C_2, C_3
System development processes	Number of instances = 1, $P_{1.1.sd}$ Number of sub process instances = 3
Verification & Validation processes	Number of instances = 2, Test objectives = F_1, F_2 $P_{1.1.vv}$ for F_1 and $P_{1.2.vv}$ for F_2

Such a change, however, will not impact the work of the integrator i_1 who is waiting for the implementation of C_1. This change will not impact neither the work of the tester t_2 who is preparing the test environment for the functionality F_2 based on CDM_2 and CDM_3. This change may require reworks of the designer des_1 to insure the consistency between the work product *Component Requirement* CR_1 and the *Component Design Model* CDM_1.

- *Impacts on other projects*: the change on CDM_1 in $project_1$ leads to reworking of the tester t_1 to prepare the new version of configuration for the test bench tb_1. Consequently, t_1 may have to keep tb_1. for a longer period. Because tb_1. is also required in the V&V process instances $P_{2.1.vv}$ of $project_2$ and $P_{3.1.vv}$ of $project_3$, the change in $project_1$ can have significant impact on $project_2$ and $project_3$. The impact concerning shared resources requires often stressful and costly planning adjustment for the whole company.

The aforementioned impacts cannot be deduced from the process models as information arises only at run-time, such as the list of components, the state of tasks, the shared resources, and so on. By performing the analysis at the model level, we can deduce just some coarse impacts of change. For example, we can say that a change on the work product type *Component Design Model* will impact the activities *Prepare Test Bench* and *Execute Test*. But if these activities have many concurrent task instances performed by different testers, we cannot say exactly who and which task instances are affected. Moreover, at the model level, we cannot know the inter-process impacts via shared resources.

We are interested in this unofficial change and motivated by development environments where changes are handled manually and communication between concerned actors is free and *ad hoc*. In such environments, the poor coordination can lead to unawareness of changes and therefore to possible reworking. We aim to develop a mechanism that helps coordinating better the process actors and therefore managing changes more efficiently. As observed, in order to thoroughly assess change impacts, managing and analyzing changes should be done at instance level (run-time). In the next section, we present our solution to achieve this objective.

2.2. *Proposal*

In this paper, we seek to remedy the problem of unnoticed changes in order to permit concerned people to anticipate and respond to changes so that they can avoid obsolete works. The ultimate goal of our work is providing a *change aware process environment* being reactive to change requests but proactive to change implementations with the following functionalities:

- *Capturing in a centralized and continuous way all change requests sent asynchronously by various process actors*: This functionality requires consolidating process management mechanism and change management mechanism. On the one hand, a PMS is needed to monitor process actors' activities. On the other hand, a *Change Management Component* is needed to allow process actors reporting changes and analyzing the impact of their change on the whole system.
- *Analyzing the potential impacts when a change happens and notifying process actors affected by the change*: To enable analyzing the impacts of change among process elements in a timely and systematically manner, we need to integrate the process management mechanism and the query mechanism on the run-time process data. The result of this consolidation is the *PDG* that

represents dependencies existing among all process elements of the system at run-time and therefore provides process actors with information of the whole development environment what they cannot know from their local viewpoint.

We emphasize the use of run-time process information in order to establish a global view on the state of all elements inside the development environment. As pointed out in the example in Section 2.1, while some of the dependencies existing among elements inside one process instance can be easily extracted at build-time from the process model, there are other dependencies that only emerge at run-time. It is especially the case of dependencies among different instances of a multi-instance task or multi-instance sub-process. It is also the case of dependencies via shared resources among different running processes. In contrast to most of the existing works that have concentrated on the dependencies at process model level [5, 6], our PDG describes dependencies at run-time in the process instance-level, thus allowing a more thorough change impact analysis. For an efficient storing and querying of run-time process data, the PDG is implemented in a graph database. When a change request is made, PDG provides a sound and effective basis to traverse intra-process instance and inter-process instances to derive the affected elements.

3. PROCESS DEPENDENCY GRAPH

This section presents the *PDG*, which is our solution to represent a global view about the system at run-time.

3.1. Process information

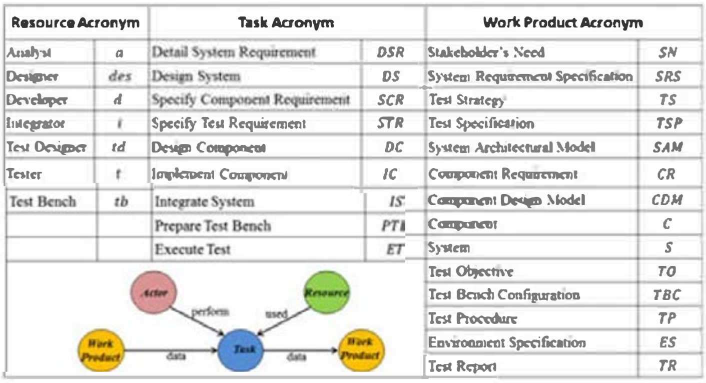
In the development environment, process information exists at two levels: model and instance levels. When a process is executed, its model is instantiated and a process instance representing the running process is obtained.

The model level relates to process information existing at build time and extracted from process models. For our example, model-level information is represented in Figure 1. The instance-level concerns process information existing at run-time. For example, the sub-process *Component Development* has three instances at run-time; each instance has two tasks: *Design Component* (*DC*) and *Implement Component*. Therefore, in the run-time environment, there are six task instances denoted as three DC_1, DC_2, DC_3 and three IC_1, IC_2, IC_3. The whole instance-level information of the process models of Figure 1 is represented in Figure 2.

If a PMS is used to manage and enact processes, the model-level information is stored in the process repository, and the instance-level information of running processes are stored in the execution log and the history log. When a change occurs, all this information are required in order to establish the dependencies among process instances to enable an in-depth impact analysis. We have two approaches to construct process dependencies:

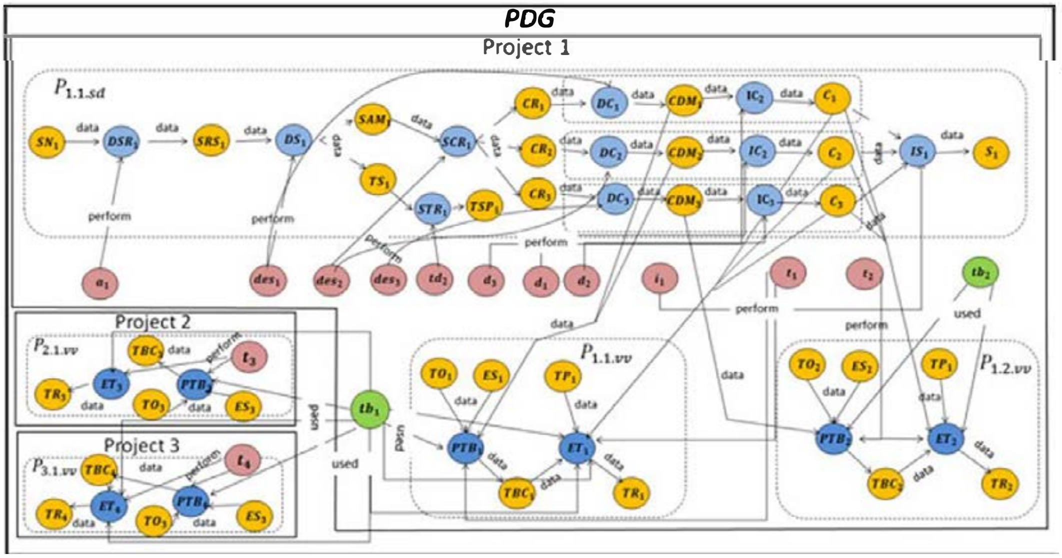
- *Querying the process logs at the time of change analysis to deduce the dependencies*: This approach requires extracting process information directly from different PMS's logs. It is advantageous in terms of data storage. However, making complex queries from the process repository and process logs is not easy because of the heterogeneity of the process data together with the process log's access characteristics within the context of activities that are long lived, open ended, and interactive [7].
- *Constructing a global dependency structure in parallel with the processes*' *execution to establish progressively the dependencies among process instances*: In some way, this approach duplicates the process information stored in the system. However, it can lead to an improvement in performance if an efficient support is chosen to represent and implement the global dependency structure.

After considering the trade-off between efficiency and storage, we choose the second approach and propose the usage of a graph structure called the *PDG* to represent the dependencies among process elements at run-time. PDG is continuously updated to reflect always current state of the system.



Resource Acronym		Task Acronym		Work Product Acronym	
Analyst	*a*	Detail System Requirement	*DSR*	Stakeholder's Need	*SN*
Designer	*des*	Design System	*DS*	System Requirement Specification	*SRS*
Developer	*d*	Specify Component Requirement	*SCR*	Test Strategy	*TS*
Integrator	*i*	Specify Test Requirement	*STR*	Test Specification	*TSP*
Test Designer	*td*	Design Component	*DC*	System Architectural Model	*SAM*
Tester	*t*	Implement Component	*IC*	Component Requirement	*CR*
Test Bench	*tb*	Integrate System	*IS*	Component Design Model	*CDM*
		Prepare Test Bench	*PTB*	Component	*C*
		Execute Test	*ET*	System	*S*
				Test Objective	*TO*
				Test Bench Configuration	*TBC*
				Test Procedure	*TP*
				Environment Specification	*ES*
				Test Report	*TR*

(a) Process elements acronyms



(b) Process information at instance-level of the scenario Δ

Figure 2. Process dependency graph representing the scenario *Δ*. (a) Process elements acronyms. (b) Process information at instance level of the scenario *Δ*.

3.2. Structure of process dependency graph

The PDG is defined as a directed graph composed of a set *N* of nodes and a set *E* of edges. Nodes and edges of a PDG are typed to describe different types of process elements (at instance level) and relations between them. We have four types of nodes and four types of edges, specified in the following definitions:

$$PDG = (N, E)$$
$$N = \{node_{task}\} \cup \{node_{workProduct}\} \cup \{node_{actor}\} \cup \{node_{resource}\}$$
$$E = \{edge_{data}\} \cup \{edge_{precede}\} \cup \{edge_{perform}\} \cup \{edge_{used}\}$$

3.2.1. Nodes of Process Dependency Graph. Each type of nodes has properties, which are defined as follows:

- $node_{task}$ represents an instance of a task.

$node_{task}$ = (*type*, *name*, *id*, *state*, *duration*, *parentProcessInstance*
type = (*singleInstance*, *multiInstance*)
state = (*created*, *inProgress*, *completed*, *aborted*)

In this paper, we handle human tasks and adopt the standard Web-Service Human Task (WS-HT) [8]. Furthermore, if a task can have multiple instances independent at run-time, its type is *multiInstance*.

- $node_{workProduct}$ represents a concrete work product (data) inside a process instance. The state of a work product is the same as the state of the task producing it.

$node_{workProduct}$ = (*type*, *name*, *id*, *state*)
type = (*singleWorkProduct*, *workProductSet*)
state = (*created*, *inProgress*, *completed*, *aborted*)

- $node_{actor}$ represents a real actor in the system. An actor may involve in several process instances. We assume that the state of an actor is managed by both the task management component and the resource management component integrated to the PMS.

$node_{actor}$ = (*role*, *id*, *state*)
state = (notAvailable, idle, active, waiting)

- $node_{resource}$ represents a resource that an actor uses to perform a task.

$node_{resource}$ = (*id*, *state*)
state = (*notAvailable*, *idle*,*active*, *waiting*)

3.2.2. Edges of Process Dependency Graph. Edges in PDG are used to represent different types of relationships among process elements. Properties and state of each type of edges are defined as follows:

- $edge_{perform}$ represents the association between an actor and the task that he performs. The state of the edge is the same as the state of the task that it points to. The reason to store this information twice is to facilitate the traversal that we will discuss later.

$edge_{perform}$ = (*id*, *process*, *Instance*, *StartTime*, *duration*)
state = (*inProgress*, *completed*, *waiting*)

- $edge_{data}$ represents the association between a work product (data) and a task using or producing it:

$edge_{data}$ = (*id*, *source*, *target*, *state*)
state = (*sent*, *notSent*)

- $edge_{precede}$ represents the association between two sequential tasks that share nothing between each other (i.e., no exchanged work products or shared resources).

$edge_{precede}$ = (*id*, *source*, *target*)

- $edge_{used}$: represents the association between a resource and an activity.

$edge_{used}$ = (*id*, *source*, *target*, *state*)

Figure 2 is provided to illustrate the PDG representing the system in the scenario *Δ* at run-time. To simplify the visualization of the PDG, process elements of only $project_1$ along with only affected elements in other projects are illustrated. In our scenario, shared elements among process instances are established by the work products *Component Design Model* CDM_1, CDM_2, CDM_3 and *Component* C_1, C_2, C_3. The shared element between projects is established by the resource *Test Bench tb*1.

4. CHANGE-AWARE PROCESS ENVIRONMENT

This section describes our solution to deal with poorly managed changes during process enactments. Although this work targets more specially on technical software and system engineering process, it can also be used by processes in other domains. Our aim is to consolidate two mechanisms of process management and change management to create a change-aware process environment as illustrated in Figure 3.

Our environment is composed of two main components: a PMS to execute and control processes and a *Change Management Component* to handle changes coming from running processes. In the next sections, we explain each component in details.

4.1. Process Management System

Process Management System (PMS) is a software that supports modeling, enactment, and monitoring of processes throughout their life cycles. In our proposal, PMS provides the basis to systematically control process actor's activities and to obtain a global view on the status of the organization development environment. The nucleus of a PMS is the *Process Engine* that is in charge of enacting processes. From process models stored in a *Process Model Repository*, the process engine creates new process instances and associates their tasks with corresponding resources taken from a *Resource Repository*. PMS includes a *Human Task Processor* that makes the process engine to interact with this component whenever a process instance reaches a human task. Resources of an organization can be human (process actors) or non-human (tools, platforms, etc.) and is supposed to be managed externally by a *Resource Management System*. The engine controls and keeps track of tasks execution. The information of running processes is stored in the *Execution Log*, and the historical information about process execution is stored in the *History Log* that later can be used to conduct process analysis. Our work aims at assisting process actors on managing run-time changes. To do so, the current *Human Task Processor* of the base PMS is enhanced to support new functionalities on change notifying and analyzing. Our extension is presented in Figure 3b as the *Change Management Component* that is described in the next section.

4.2. Change Management Component

The core of our proposal is the *Change Management Component* whose role is turning the process environment to a change-aware process environment. This component enables a coordination among main roles of the process environment known as process manager, process actors, and change manager in order to manage changes systematically inside the system. We remind that the change

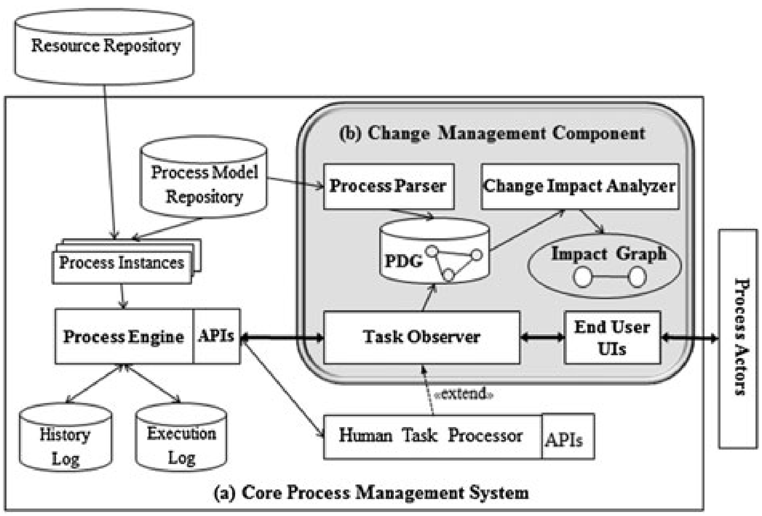


Figure 3. Change aware process environment.

management provided in this study was limited on informing an intentional change, estimating the impact of the requested change and notifying potential affected process actors. Applying and propagating changes is out of the scope of this paper. Figure 3b shows the main elements of our *Change Management Component* and are described as follows:

1. *Process Dependency Graph*: the *PDG* stored in a graph database is the main support for change impact analysis. It provides the global view of running processes and their dependencies. *PDG* is created and updated by the Process Parser and *Task Observer*; it is used by the *Change Impact Analyzer*.
2. *End User UIs*: A set of user interfaces to allow process actors (i.e., system and process actors) to interact with the core PMS to request their task list, claim and complete the tasks assigned to them. The novelty here is a new interface offering process actors the possibility to send a change request during their task execution. Thanks to this new functionality, process actors can integrate emergent changes, which are not described in their process model, into the process execution. Also, a new role *Change Manager* together with the interface are defined to centralize the change requests and show the result of potential change impacts.
3. *Process Parser*: This sub-component constructs the structure of a new process instance and adds this structure to the PDG. It will be invoked by *Task Observer* when a new process instance is created.
4. *Task Observer*: This sub-component is responsible for controlling process actors' tasks and keeping the PDG updated with the run-time events happening during task's life cycle. Besides the standard human task events defined by the WS-HT specification [8], we defined a new event *Change Request* and the corresponding handler to capture change requests sent asynchronously by process actors. When receiving a change request signal, *Task Observer* invokes the *Change Impact Analyzer*.
5. *Change Impact Analyzer*: When the *Change Manager* receives a change request, he can use this component for traversing the PDG and extracting the elements potentially affected by the change request. The result of the change impact analysis is an *Impact Graph* (*IG*) that gives some information to help the change manager on the change implementation decision and in informing the concerned elements in a timely manner.

In the next sections, we present the functionalities of the three sub-components *Process Parser*, *Task Observer*, and *Change Impact Analyzer*.

4.2.1. Process parser. This component is responsible for extracting from a process model the process information at schema level in order to construct the structure of the PDG.

Whenever a process engine creates a new process instance from a process model, the *Task Observer* invokes the parser to analyze the given process model and create a corresponding graph structure in PDG. For each activity in the process model, we extract its input output work products as well as identify the performing actors and resources needed for the task. Then the parser creates the corresponding PDG nodes representing these process elements and the PDG edges representing the relations between them. By default the parser handles an activity as a single-instance task. For multi-instances activities, their task instances will be created dynamically in PDG when the number of instances is known during the process execution. Afterwards, the PDG will be updated with run-time information by the *Task Observer* as the process execution progresses.

4.2.2. Task observer. The main role of *Task Observer* is keeping the PDG updated with the system state maintained by the process engine. Thus, it provides a sound basis for change impact analysis. To do so, *Task Observer* listens to run-time events happening in the system via the interaction with the process engine and process actors. Then it proposes the appropriate handlers for updating the PDG according to the occurring event.

We classify different events relating to any changes at run-time environment into three categories:

1. *Process Instance Event*: It concerns the events of creating or finishing (or aborting) a process instance. The event handler of this event type modifies the structure of the PDG: adding to the PDG the new nodes of the created process instance or deletes all nodes of finished process

instance inside the PDG. Constructing of the schema of a new process instance is realized by the *Process Parser* sub-component.

2. *Task Life cycle Event*: All events concerning the operations specified by WS-HT for human tasks [8] are regrouped in this category: claiming, releasing, completing, or aborting a task. The basic *Task Management Component* of the core PMS is responsible for these operations and, via different *event handlers* corresponding to a specific event, informs the process engine of the progression of the process instance execution. Using *Task Observer* as our own task service, we extended the basic *event handlers* for the above events to update correctly the PDG in each specific situation so that the PDG always represents the run-time state of the process instances.

    - When a process actor claims (or releases) a task, the states of the involved PDG nodes (i.e., claiming *actor node*, claimed *task node*) are updated and a PDG *perform edge* between these two nodes is created (or deleted). We supposed that PDG *actor nodes* are created from the list of process actors taken from the *Resource Repository*.
    - Basically, whenever a process actor completes or aborts a task, the state of the corresponding PDG *task node* and its related nodes (performing actor and produced work product) will be updated. If the subsequent task is *multi instance*, the update of the PDG becomes more complicated.
    There are many patterns describing situations where there are multiple threads of execution active in a process model. In this work, we focus on the pattern *Multiple Instances with a priori Run time Knowledge* [9] concerning the creation of multiple instances of a task within a process instance. The number of task instances depends on run-time factors, often the input data of the task. The task instances run concurrently and will be synchronized before triggering the subsequent task. Inspired from the pattern *To Multiple Instance Task Instance specific data passed by value* [9], we update the PDG based on the passing data elements from a single-instance task to a multi-instance task as shown in Figure 4.
    In this pattern, the output set *in wp* of the current task *t* is the input of a *multi instance* task *mt*. In such a case, when the current task *t* is completed, the cardinality *n* of its output set *in wp* determines the number of task instances of the subsequent task *mt*. For updating the PDG, the sub-graph from set *in wp* to *mt* will be duplicated *n* times. In each sub-graph the set work product node *in wp* is replaced with an item *in* wp_i in the set; the task node *mt* takes the run-time *id* of its task instance. If *mt* is a multi-instance sub-process, all nodes inside the sub-process will be duplicated. At the conclusion of *mt*, *n* instances mt_i will be connected to the merge task *m* in the PDG.Our example and discussion respectively presented in Figure 1 and Section 2.1 illustrate this special situation with the work product {*Component Requirements*}, which is the input of the multi-instance sub-process *Component Development Process*.

3. *Change Request Event*: This is a new event that we defined to allow process actors to send a change request at any moment when executing a task. Here we handle the run-time unofficial changes that cannot be previously foreseen and modeled in the process model. Changes can concern modifications on the process actor's work products, working time or resources required for his work. We defined a new *task handler* to allow the action *sending change request* from the process actors working environment. On the other side, the *Task Observer handler* is responsible

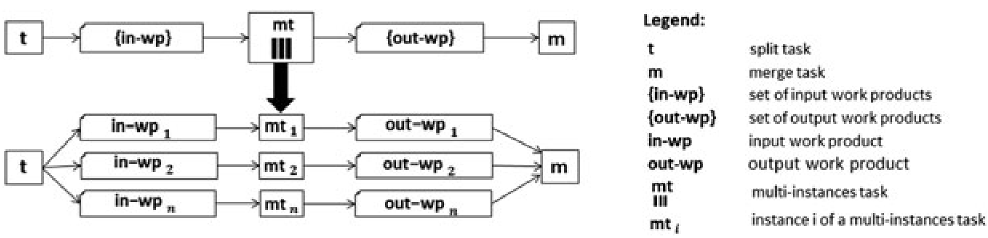


Figure 4. To multiple instance task instance specific data passed by value.

to catch the sent change request and then invoke the *Change Impact Analyzer* sub-component to extract from the PDG the elements potentially affected by the requested change.

4.2.3. Change impact analyzer. When the *Task Observer* receives the change request *CR*, it invokes the *Change Impact Analyzer* to analyze the impact of the change described in the *CR*.

In a change request *CR* (*changeInitiator*, *changedElement*, *changedType*):

- *changeInitiator* is the process actor who initiates the change.
- *changedElement* is the element that he wants to modify. The *changedElement* must be one of the elements related to the *changeInitiator*'s current task.
- *changeType* is the type of change that the *changeInitiator* wants to make. He can make *minor changes* for correcting small problems of a work product without causing reworking in other tasks. If he wants to evolve a work product whose changed content can result in reworking on other tasks, he has to make his change as *major changes*.

The *Change Impact Analyzer* carries out the impact analysis by traversing the PDG from the changed element thorough possible types of edges. The traversal can be conducted in backward or/and forward mode according to a specific type of change as presented in the Section 5. The result of the traversal is a digraph so-called *Impact Graph* (*IG*), which is an extraction of the global *PDG* but contains only the process elements impacted by the change. These elements are detected by the emerging dependencies among run-time process elements in the *PDG* based on shared data, resources or temporal sequences. The obtained *IG* is considered as the base to conduct impact analysis at different levels according to a specific need of change manager.

The impact can be direct if an element works with the changed element or indirect if an element works with an element impacted (directly or indirectly) by the change. Moreover, thanks to the *PDG* that keeps trace of all elements in the development, we can have a thorough analysis on different axes: by examining both nodes inside and outside of the *changeInitiator*'s process instances, we can identify the impacts on the elements in the scope of a project or in other projects; by examining all existing task nodes completed, current and future we can know which elements are really impacted or potentially impacted.

We can go further in such analysis by annotating the nodes of the *IG* with some interesting metrics such as resource costs or work product completion percentages. For instance, regarding any affected work product the percentage of its completion at the time of change can be estimated based on the duration of the task that produces it. This feature, which is dependent on a specific given domain for calculating the required metrics, is not presented in this paper but in our previous work [10].

We summarize the whole procedure of the *Change Aware Process Environment* in the Figure 5.

5. VALIDATION STUDY

This section presents the prototype CAPE developed to validate our proposal. First, we describe the implementation of CAPE. Second, we report the use of CAPE for a case study and the feedback of our industrial partners.

5.1. Prototype implementation

As described in Section 2, our key goal is to coordinate better process actors at the moment of change. To this aim, our prototype provides the functionalities that allows process actors to signal a change and inform concerned people. As presented in Section 4, we distinguish two types of changes: *minor changes* for correcting small problems of a work product without causing reworking and *major changes* for evolving a work product with possible reworking. CAPE can analyze the change impact of both.

This section presents our strategy to implement the two components of CAPE: PMS and *Change Management Component* that allow creating and updating the PDG as a basis of change analysis.

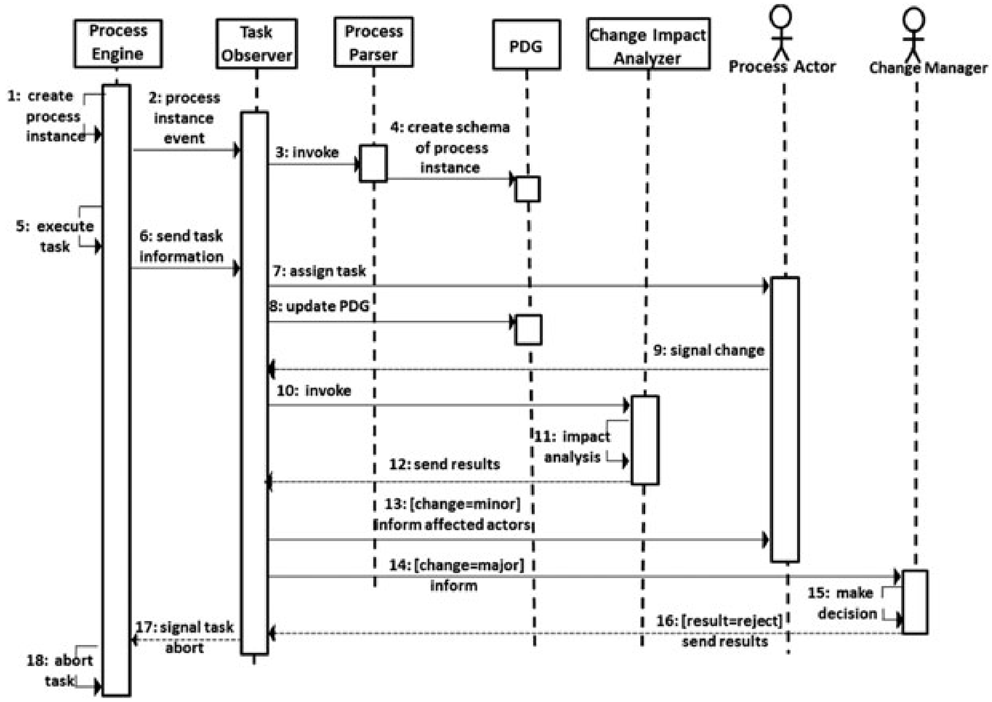


Figure 5. Procedure of change aware process environment.

- *Usage of jBPM as a basic PMS*: Our idea is to enrich an existing PMS with a change management mechanism and not develop a new PMS from scratch. First, we looked for PMSs supporting the *Software and Systems Process Engineering meta modeling language* (SPEM) [11]. However, to our knowledge, there are not mature and extensible process environment executing SPEM processes except some academic works as [12, 13] and the commercial tool IBM Rational Team Concert [14]. Thus, we turned to existing operational Business Process Management Systems that can be used to execute SPEM processes that are mapped to a executable business process language. Based on the features of existing BPMSs, we chose jBPM [15], a flexible, light-weight, fully open-source and extensible BPMS, for developing our PMS component. Like other BPMS, jBPM is composed of several components that each one resolves a particular function inside the BPMS architecture as shown in Figure 3a. jBPM proposed a basic *Human Task Processor*, a back-end task service that manages the life cycle of tasks realized by human users, based on the WS-HT standard specification [8]. To assist process actors on managing run-time changes, we used jBPM APIs (*WorkItemHandler* class) for re-implementing this task service as our *Change Management Component* that enhances the basic *Human Task Processor* with new functionalities on change notifying and analyzing. Thus, as part of the prototype, new user interfaces are developed to handle process actors' tasks in a task-list-oriented way.
- *Usage of Neo4j as a graph database to store PDG*: The PDG describing the running processes of an organization can be huge. Thus, in order to store and manipulate efficiently the PDG, we explored the use of NoSQL data management system, in particular on systems proposing native graph data management. A graph database is typically substantially faster for connected data sets and uses a schema-less, bottoms-up model that is ideal for capturing *ad hoc* and rapidly changing data [16]. To this aim, Neo4j [17], an object oriented and open-source graph database, has been chosen. Neo4j allows us to store and query the PDG in an efficient way thanks to its advantages on powerful traversal framework and the declarative graph query language Cypher. We used the Neo4j Core-Java-API to develop a Neo4j embedded application in our *Change Impact Analyzer*. Thus, we can benefit not only an object-oriented approach to manipulate the graph database, but also highly customizable high-speed traversal- and graph-algorithm implementations.

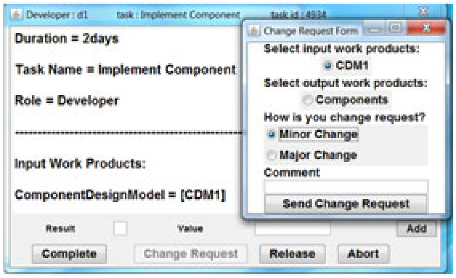


Figure 6. UI of developer d_1.

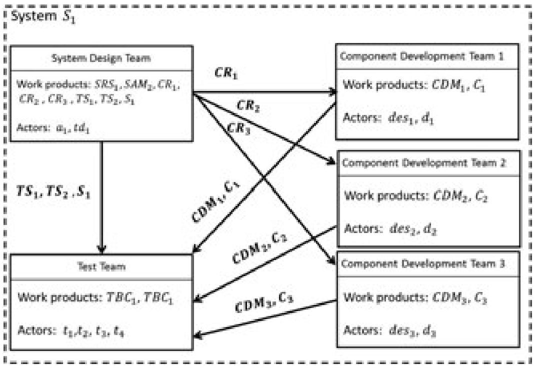


Figure 7. Simulation setup.

When facing a problem that necessitates a change, process actors evaluate the importance of the change and select the way to handle it with the help of CAPE. Figure 6 shows an example of the task user interface in CAPE for developer d_1 when he detects a minor problem on the work product CDM_1 and sends the change request. By choosing *minor change*, first CAPE helps the process actor to inform the change management component as well as the actors concerning to the changed work product, especially if it's responsible. Then he can continue performing his task after making the change. By choosing *major change*, first the process actor sends a change request to the change manager in order to analyze the change impact and make a decision. If the change is accepted, then the change manager informs affected actors and then the change initiator can carry out his task. If the change is refused, the process engine aborts the initiator's task.

5.2. Experiments

The experiment presented in this paper is a simplified version of a real case study conducted in the context of the project FUI[2] Agile tools for Conception and Validation of Systems (ACOVAS). We focus on the system integration phase where changes occur with high rates. To evaluate CAPE, we simulated the execution of the processes described in Figure 1 for three projects, using the same setup for $project_1$ as presented in Table I (cf. Section 2). Figure 7 gives the organizational model of $project_1$ and focuses on the elements concerned by change scenarios. In this project, the system is composed of three components C_1, C_2, $C3$ developed by three different teams. The system integration and the integration tests are carried out respectively by the system team and the test team. The development teams can be intern of a company or belong to different suppliers that can be geographically dispersed in different sites.

CAPE can handle change situations conform to two change patterns *correction* and *evolution* described as follows:

5.2.1. Correction pattern. As illustrated in Figure 8, this pattern concerns a situation when a process actor faces a *minor change* during his task tsk_2. To continue his task, he needs to change (correct) his

[2]FUI a French academic industry research program.

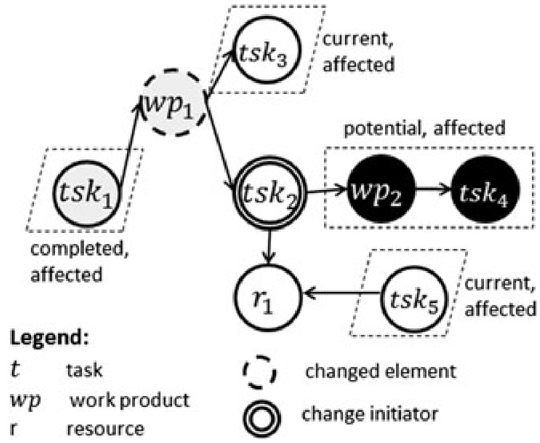


Figure 8. Correction pattern.

Table II. Correction scenario.

Pattern element	Process element	State	Responsible process actor
tsk_1	DC_1	Completed	des_2
tsk_2	PTB_1	Current	t_1
tsk_3	PTB_2	Current	t_2
tsk_4	ET_1	Potential	t_1
	ET_2		t_2
tsk_5	PTB_3	Current	t_3
	PTB_4		t_4
wp_1	CDM_2	Completed	des_2
wp_2	TP_1, TBC_1	Potential	t_1
	$TP_2,\ TBC_2$		t_2
r_1	tb_1	Current	t_1, t_3, t_4
	tb_2		t_2

input work product wp_1, which is produced by the completed task tsk_1. At the moment of change, task tsk_3 and tsk_5 are in parallel with tsk_2, and tsk_4 has not been started yet.

First, CAPE carries out a backward analysis to detect the completed elements concerned by the change that needs to be informed but does not need to rework on the changed element. Backward analysis is implemented by the traversing the PDG through the incoming data edge of changed element wp_1 that results in tsk_1. Second, CAPE runs a forward analysis to deduce the current or future elements that can be concerned by the change. Forward analysis is implemented by recursively traversing the PDG through all outgoing edges of changed element. According to the pattern, based on the shared work product wp_1, forward analysis gives us tsk_3 as an affected element and wp_2 and tsk_4 as potential affected elements. The correction on the wp_1 can add delay time on completing task tsk_2. Consequently, all the tasks need *ir* (i.e., tsk_5) will be impacted.

Table II shows one possible scenario based on the pattern in which the change happens in the $project_1$ when the tester t_1 faces a problem during his task *Prepare TestBench* to prepare the test bench tb_1. This problem requires a minor change on his input work product CDM_2 (previously produced by des_2 in the task *Design Model*). At the moment of change, another tester t_2 is using CDM_2 to prepare the test bench tb_2 for another test, and the testers t_3 and t_4 are waiting for the test bench tb_1 for their task respectively in $project_2$ and $project_3$. Figures 9 11 present the scenario simulated in CAPE. We can see that the impacted actors inside the $project_1$ (i.e., des_2 and t_2) as well as outside the $project_1$ (i.e., t_3 and t_4) are informed of the change.

5.2.2. Evolution pattern. The pattern in Figure 12 presents a situation when a *major change* (normally caused by the environment of the project) on the work product wp_1 (previously produced

Figure 9. UI of designer des_2.

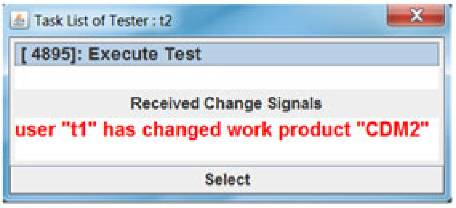


Figure 10. UI of tester t_2.

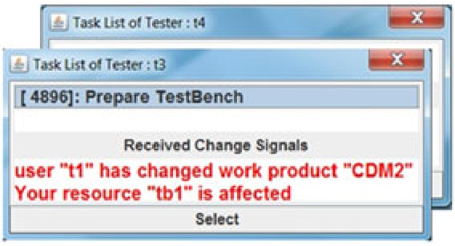


Figure 11. UI of tester t_3, t_4.

by tsk_1) is requested. The change necessitates creating a new task instance $tsk_1^{'}$ to modify wp_1. Such a change can impact the subsequent tasks of tsk_1, completed or current.

CAPE performs a forward analysis by traversing the PDG through outgoing data edges of changed element wp_1 to detect all the elements that are dependent on wp_1. As shown in the Figure 12, this analysis gives the list of impacted elements comprising the completed elements tsk_2 and wp_4 and the current task tsk_4. However, the rework on wp_1 does not have any impacts on elements tsk_2, wp_2, and $wp3$.

Normally, major changes require an in-depth analysis to better estimate the impact. Thus, it is important to identify the relevant and irrelevant elements to a change. This issue is especially demanding in the situation where the changed element is a *workProductSet* and it related to a multi-instance task whose number of instances is only known at run-time. Concretely, if the type of wp_1 is *workProductSet* and tsk_2 is a *multiInstance* task, the number of tsk_2's instances is determined by the number of wp_1's elements. When reworking wp_1, it may happen that only some of its elements are modified. In this case, it would be useful to identify which instances of tsk_2 will be affected by the changed elements in wp_1.

Table III shows one possible scenario of the pattern *Evolution* with emphasizing on the multi-instance elements. At the moment of change, all components C_1, C_2, and C_3 are implemented and integrator i_1 is performing the system integration (i.e., all precedent tasks of the task *Integrate System* are completed). The change happens when the des_2 needs to execute once again the task *Specify Component Requirements* to modify the work products *CR* (previously completed). *CR* is a *workProductSet* and is the input of the multi-instance task *DC*. In this scenario, we suppose that only the elements CR_1 and CR_2 of *CR* which are the input respectively of the instance DC_1 and DC_2 of the task *DC* are changed. Figure 13 show the impact analysis of this scenario that CAPE

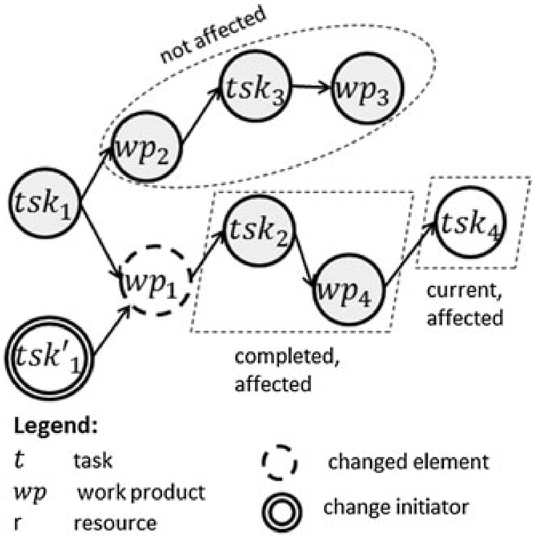


Figure 12. Evolution pattern.

Table III. Evolution scenario.

Pattern element	Process element	State	Responsible process actor
tsk_1	SRC_1	Completed	des_1
tsk'_1	SRC'_1	Current	des_2
tsk_2	DC_1	Completed	des_1
	IC_1		d_1
	DC_2		des_2
	IC_2		d_1
tsk_3	DC_3	Completed	des_3
tsk_4	IS_1	Current	i_1
	PTB_3		t_3
	PTB_4		t_4
wp_1	CR_1	Completed	des_1
	CR_2		des_2
wp_2	CR_3	Completed	des_3
wp_3	CDM_3, C_3	Completed	des_3
wp_4	CDM_1	Completed	des_1
	C_1		d_1
	CDM_2		des_2
	C_2		d_2

gives the change manager for this major change. The impacted actors are distinguished by the cause of impact, while des_1, des_2, d_1, d_2, t_1, t_2, and i_1 are affected by the change on their work products concerning the components C_1 and C_2, t_3 and t_4 in other projects are affected by sharing the test bench tb_1 with t_1. We can see that the actors des_3, d_3, and t_3 who work on the component C_3 are not affected.

5.3. Discussion

Our framework is based on the assumptions that a central graph database, a central resource repository, and an application server (e.g., jBOSS) are provided to support the change management in a distributed environment. However, because of the security policies of our industrial partners, currently, we could not deploy our prototype directly in their real development environment. So we conducted the validation with the participation of our partners on a simulated development environment on one

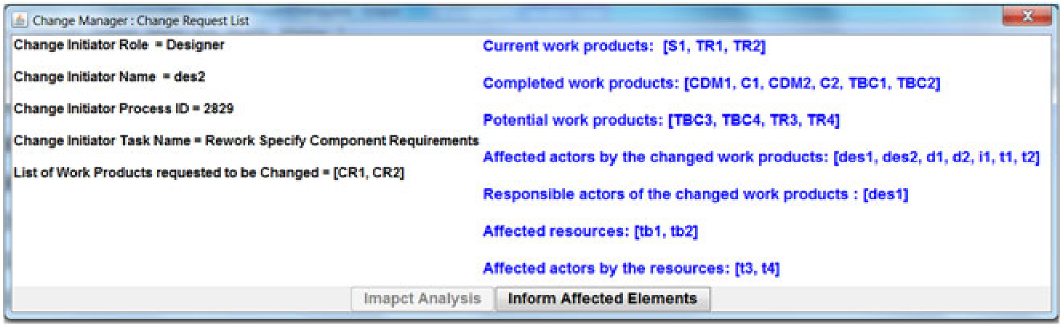


Figure 13. UI of change manager.

Table IV. Simulation results.

Impacts	Impacted Task	Scope	
		Intra project	Inter projects
Direct	Current	(A), (B), (C)	(C)
	Completed	(A), (C)	(C)
	Potential	(A), (C)	(C)
Indirect	Current	(C)	(C)
	Completed	(C)	(C)
	Potential	(C)	(C)

central machine. However, the simulation does not affect the feasibility of our proposal because the main work is done on the PDG.

We summarize in Table IV different types of impacts that should be analyzed when a change occurs. Then we point out which types of impacts that can be identified in three solutions: (A) without supporting tools (like actual solution of our partners in project ACOVAS), (B) with run-time information taken from a standard process environment (as jBPM), and (C) with information taken from our change-aware process environment CAPE.

The Table IV shows the advantages of CAPE compared with the solutions (A) and (B) in analyzing inter-projects change impacts as well as impacts on tasks at different states. CAPE has this capability thanks to the PDG, which provides a view of the whole system and also the history of system processes' execution. Another remark is that CAPE allows an immediate analysis and propagation of changes, whereas it takes more time in the solution (A) and (B). In (A), without supporting tools, changes propagation is done by human actors and often the change request has to be passed through many organizational levels so that its impact can be estimated. In (B), using only a standard process environment, impact analysis can be done by complex queries on various process logs, but lacking the information about the data and resources using by tasks, this analysis is rather limited.

The feedback of our partners on the preliminary results of CAPE is positive. They affirmed the needs of managing unofficial changes during the development process, especially for dealing with problems in the testing phase where time constrains are important, because physical and human resources are booked and allocated. Although additional works will be needed to develop a full solution that can be integrated to the real environment of our partners, they found that CAPE is helpful and motivated to continue working with us on the improvement of CAPE.

6. RELATED WORK

Change management can be tackled from different perspectives, such as process perspective, tool perspective, and product perspective [1, 3]. According to [3], tools and methods to support the change process can be divided into two groups: (1) those that help managing the workflow or documentation of the process and (2) those which support process actors in making decisions at a particular point in the engineering change process (e.g., the risk/impact analysis phase).

We use this structure to discuss some similar works on the tool perspective in Business Process, SSE communities.

Work flow/documentation support: Computer-based tools have been recognized as an essential to support engineering change [18]. In terms of academic works, Chen *et al*. [19] proposed a tool to support distributed engineering change management linking with concurrent engineering. Lee *et al*. [20] introduced a prototype for collaborative environment for engineering change management, which combines ontology-based representations of engineering cases, case-based reasoning for retrieval and a collaboration model. In the business process community, many of the existing works on change management focus on proposing mechanisms to enable process adaptation and changes propagation. Lanz *et al*. in [21] propose a tool to support process adaptation at run-time. Other researches [22, 23] have investigated solutions for process adaptation by allowing process actors to modify the process (e.g., add or delete a task). Reichert *et al*. in [24] conduct a good survey on the flexibility of workflow system in order to response better to changes. However, these studies apply the change without consideration of its impact and stay as prototypes, which are difficult to be validated for industries.

In the engineering domain, commercial tools such as IBM Rational Team Concert [14] and Siemens TeamCenter [25] provide the control for collaborative work. However, these tools in general are costly, very complex to use and to customize, thus few companies have adopted them in their environment. In the business process domain, many commercial tools have been developed, among them we cite the most interesting such as Bonita [26] and jBPM [15]. The positive point of these BPMSs is that they offer partial or full open-source API that enable extensions in staying with standardized and operational environments. Envisaging a validation of our prototype in software and system engineering, we need to keep this vision as standard and operational. That is why we developed our academic prototype based on jBPM.

Decision making support: A wide variety of techniques are used in the context of impact analysis and change propagation [18] in the engineering domain. There is currently no commercial package that helps predict the effect of a change; however, some work is being carried out in academic institutions [3]. Eckert *et al.* [1] based on a study conducted in Westland Helicopters, identified two types of changes: the emergent changes and the initiated changes. This particular study was based on the interviews conducted with the company's employees. They proved that by capturing the design knowledge and experience (e.g., source of change, interdependencies between parts and systems, etc.), in the form of experienced designers in the company, an automatic tool to identify the engineering change propagation can be developed. This work has further led to the development of a computer support tool by Jarrat *et al*. [27] to identify the risk of a change. They apply the *Change Prediction Method* to realize how changes spread through a product by using the *Design Structure Matrix* as the basis of the product model. The tool uses a simple model of risk, where the likelihood of a change propagating is derived from the past experience in terms of their occurrence and the impact such changes would have. This technique has been used in many other works [28, 29]. Grantham-Lough *et al*. [30] applied prediction methods for change propagation and risk estimations based on the functional decomposition of the product in early design stages. Their methods utilize history of design failures and assume that the behavior of past products is sufficiently similar to current or new products. As a result, tools show a diversity of approaches but based on prediction approaches and using past experiences. Their applicability reduces in the real-time change analysis when time plays a major role in informing the change affected partners.

Impact analysis of change is also an important topic in the research area of business process domain. In [5], a change propagation approach called *Refine Process Structure Tree* is proposed to deal with change in process choreographies. This approach addresses both phases of process change but only inside one process instance. The approval of a change is done by negotiations among change initiator and affected partners. By contrast, our approach derives the impact of change inside and among process instances and also provides useful metrics in order to facilitate the negotiation phase. Muler in [22] dealt with logical failures management in inter-workflow collaboration scenarios and extends the previous work [31] by adding temporal and qualitative implications of workflow adaptation. Temporal implications of an adaptation are determined by estimating the duration required to execute the dynamically adapted workflow and by comparing it with originally fixed time constraints. The metrics used in their approach are for deriving the essence of adaptation not for measuring the impact of the adaptation. Impact of change among process instances was not investigated as they considered only the impact of adaptation in one process instance.

7. CONCLUSIONS

To date, there is a gap between the process management and change management. No automation support for change management is one of the most popular causes of defects in multi-disciplinary engineering environments. Thus, as pointed out in [32], lack of integrated change management supports is one of the reasons of the limited acceptance of process environments in system and software industry. Combining the management of processes and changes to provide effective communication and synchronization through the system can decrease the cost of reworks [3].

Convinced by the aforementioned statement, we have developed a prototype of a *change aware process environment* that consolidates the process management and the change management into one development environment. In this environment, run-time changes which are not described in the process model can be integrated into process enactment. By providing process actors with the possibilities of notifying and analyzing changes, our environment allows them handle changes in a centralized and proactive way so that they can better anticipate and response to changes. Hence, we offer a process enactment more flexible but still controlled. A prototype, implemented in Java with the APIs of jBPM and Neo4j, is operational and is being validated with the case studies provided by our industry partners.

The key strength of this work is using run-time process information to establish hidden dependencies among processes, especially a process that supports multiple instances tasks and other processes in different projects. Those dependencies are invisible on the model level and only emerge at run-time via data exchanging or shared resources. By uncovering these dependencies, we could provide a more thorough and precise analysis on the impacts of changes. This advantage should be particularly helpful for System Engineering where the development involves often various teams in different domains and on extreme complex products. Thus, it is important to find out exactly the impacted elements among a huge set of process elements.

One weakness of this study was the limitation on the types of change request. We only dealt with the change concerning modification the content of a work product or the change on execution time or resource using time. Changes on process structure are not allowed at run-time. Another point that may limit the application of our approach is the strong assumption on the input process model. The current PMS requires a well-defined process model describing the activities of all process roles. This global model is needed for extracting the dependencies among process elements. However, in reality, it is hard to have such a process model.

To overcome the aforementioned deficiencies, we are working on a bottom-up approach for process modeling and enactment. The idea is letting each process actor describes his own work. Then, from separate process fragments, our PMS can construct progressively the PDG, use it to synchronize the activities of process actors, and also to construct the global process model.

ACKNOWLEDGEMENTS

Part of this research has been supported by the French research projects FUI ACOVAS and ANR InnoServ (Innovation de Services pour personnes fragiles). We are grateful to our industrial partners in ACOVAS project who have helped us on developing the case studies for our research and on validating our prototype.

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