Possibilistic Interorganizational Workflow Net for the Recovery Problem Concerning Communication Failures

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Abstract: In this paper, an approach based on interorganizational WorkFlow nets and on possibilistic Petri nets is proposed to deal with communication failures in business processes. Routing patterns and communication protocols existing in business processes are modeled by interorganizational WorkFlow nets. Possibilistic Petri nets with uncertainty on the marking and on the transition firing are considered to express in a more realistic way the uncertainty attached to communication failures. Combining both formalisms, a kind of possibilistic interorganizational WorkFlow net is obtained. An example of communication failure at a process monitoring level that precedes the presentation of a paper at a conference is presented.

1 INTRODUCTION

Workflow Management Systems are a key technology for improving the effectiveness and efficiency of business processes within an organization (van der Aalst, 1998b). Business processes represent the sequences of activities that have to be executed within an organization to treat specific cases and to reach well defined goals (Aalst and Hee, 2004). Over the last few years, Business Process Management has become important in order to raise service quality and a company's performance (Hofstede et al., 2010).

An organization produces value for its customers by executing various business processes. Due to complexity and variety of business processes, contemporary organizations use information technology to support activities and possibly also automate their processes. Business Process Management systems are software systems used for automation of business processes (Pesic, 2008).

In addition, as modern organizations have to cope with complex administrative processes, Workflow Management Systems have to deal with workflow processes shared among multiple organizations. Each business partner has to define private workflow processes that are connected to other workflow processes belonging to the other partners of the same organization (Silva et al., 2013). The interorganizational workflow model corresponds then to a finite set of WorkFlow nets loosely coupled through asynchronous communication mechanisms (van der Aalst, 1998b).

Many papers have already considered Petri net theory as an efficient tool for the modeling and analysis of Workflow Management Systems (van der Aalst, 1998a; Aalst and Hee, 2004; Soares Passos and Julia, 2009). The WorkFlow nets, acyclic Petri net models used to represent business processes, are defined in (Aalst and Hee, 2004).

Soundness property is an important criterion which needs to be satisfied when treating workflow processes. In fact, good properties of well-defined formal models such as WorkFlow nets can easily be proved when business processes are following a rigid structure that does not allow deviations from the process description during real time execution.

However, recently, it was shown that business processes do not easily map to a rigid modeling structure. The business processes are implemented such that they "fit the system", which can cause various problems (Pesic, 2008). First, due to a mismatch between the preferred way of working and the system's way of working, companies may be forced to "run" inappropriate business processes. Second, two parallel realities may be created: the actual work is done "outside the system" in one way , and later registered in the system in another way (Pesic, 2008).

Attempts to consider a certain level of flexibility

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in process definition have already been proposed by several authors.

In (Mohammed et al., 2007), a deviation-tolerant approach in process execution is presented. In this approach, two process models coexist during the monitoring of the process. The first one corresponds to the expected behavior and the second is dynamically built, based on the visible actions of human actors. The two models of the process are permanently compared and analyzed in order to detect deviations. Once a deviation is detected, a deviation tolerance model attached to the preset process is used to decide whether to accept or to reject the deviation. The problem in dealing with two models is that the monitoring activity can easily be overloaded implying a decrease in the system's performance.

In (Pesic et al., 2010), Aalst et al. created a declarative workflow management system that uses constraint workflow models to achieve an optimal balance between flexibility and support. The basic idea is that anything is allowed and possible unless explicitly forbidden. To implement this idea the authors used a Linear Temporal Logic (LTL) and the ConDec language. A limitation of this approach is the state explosion that occurs when an automation process is generated from the constraints for analysis.

Some authors, such as (van der Aalst et al., 2006; Rozinat and van der Aalst, 2008; Munoz-Gama, 2010; van der Aalst et al., 2012), evaluated the conformance between the process model and the execution log of the process. For this, they developed metrics for measuring the relationship between predefined process models and actual results presented in the form of event logs. The problem with this approach is that the verification is carried out after the process execution.

A very promising alternative for dealing with flexibility in business processes seems to be those approaches based on uncertain knowledge as that presented in (Cmpan and Oquendo, 2000). The model of the process is then given through fuzzy sets and possibilistic distributions that permit a natural representation of uncertain and imprecise information. This alternative has already been shown in the flexible manufacturing systems (Valette et al., 1982; Murata et al., 1999; Asato et al., 2012).

One of the first studies which combines fuzzy and possibilistic representation of information with the precise structure of a Petri net when considering discrete event systems is the one described in (Cardoso, 1999) and (Cardoso et al., 1999). The main feature of possibilistic/fuzzy Petri nets is to allow one to reason about the aspects of uncertainty and change in dynamic discrete event systems.

In (de Rezende et al., 2012) an approach based on WorkFlow nets and on possibilistic Petri nets is proposed to deal with non-conformance in Business Processes. Its limitation is that it uses only a single processes. In this paper, an approach based on interorganizational WorkFlow nets and possibilistic Petri nets is proposed to deal with communication failures in business processes. In particular, a kind of possibilistic interorganizational WorkFlow net will be defined to treat the communication failures that occur between the local WorkFlow nets.

The remainder of this paper is as follow: in section 2, the definition of interorganizational WorkFlow nets and soundness correctness criterion are provided. In section 3, an overview of possibilistic Petri nets is given. In section 4, the possibilistic interorganizational WorkFlow net is presented and an example based on a process that precedes the presentation of a paper at a conference illustrates the approach. Finally, section 5 concludes this work with a short summary, an assessment based on the approach presented and an outlook on future work proposals.

2 INTERORGANIZATIONAL WORKFLOW NET

Before introducing the interorganizational WorkFlow nets (IOWF-net) and the soundness property for these nets, it is necessary to introduce the WorkFlow nets (WF-nets) and soundness in the single organizational context.

2.1 WorkFlow Net and Soundness

A Petri net that models a workflow process is called a WorkFlow net (Aalst and Hee, 2004; van der Aalst, 1998a). A WorkFlow net satisfies the following properties (van der Aalst, 1998a):

- It has only one source place, named *Start* and only one sink place, named *End*. These are special places such that the place *Start* has only outgoing arcs and the place *End* has only incoming arcs.
- A token in *Start* represents a case that needs to be handled and a token in *End* represents a case that has been handled.
- Every task t (transition) and condition p (place) should be on a path from place *Start* to place *End*.

Soundness is a correctness criterion defined for WorkFlow nets and is related to its dynamics. A WorkFlow net is sound if, and only if, the following three requirements are satisfied (Aalst and Hee, 2004):

- For each token put in the place *Start*, one and only one token appears in the place *End*.
- When the token appears in the place *End*, all the other places are empty for this case.
- For each transition (task), it is possible to move from the initial state to a state in which that transition is enabled, i.e. there are no dead transitions.

2.2 Interorganizational WorkFlow Net and Soundness

An interorganizational WorkFlow net (IOWF-net) is essentially a set of loosely coupled workflow processes modeled by a Petri net. Typically, there are n business partners which are involved in one "global" workflow process (Aalst, 1999). Each of the partners has its own "local" workflow process, that is private, and where a full control exists over it.

The local workflows interact at certain points, according to a communication structure. There are two types of communication: asynchronous communication (corresponding to the exchange of messages between workflows) and synchronous communication (which forces the local workflows to execute specific tasks at the same time) (Prisecaru and Jucan, 2008). Synchronous communication corresponds to the melting of a number of transitions (Aalst, 1999).

In this paper, the synchronous case is not considered, since we consider that each organization controls its own process. Only asynchronous communication protocols will be considered. Definition 1 formalizes the concept of an IOWF-net.

Definition 1. ***(IOWF-net)*** *(van der Aalst, 1998b) An interorganizational WorkFlow net(IOWF-net) is a tuple* $IOWF = (PN_1, PN_2, ..., PN_n, P_{AC}, AC)$*, where:*

1. $n \in \mathbb{N}$ is the number of local WorkFlow nets (LWF-nets);
2. For each $k \in \{1, ..., n\} : PN_k$ is a WF-net with source place i_k and sink place o_k;
3. For all $k, l \in \{1, ..., n\} : if\, k \neq l$, then $(P_k \cup T_k) \cap (P_l \cup T_l) = \emptyset$;
4. $T^* = \bigcup_{k\in\{1,...,n\}} T_k$, $P^* = \bigcup_{k\in\{1,...,n\}} P_k$, $F^* = \bigcup_{k\in\{1,...,n\}} F_k$ (relations between the elements of the LWF-nets);
5. P_{AC} is the set of asynchronous communication elements (communication places);
6. $AC \subseteq P_{AC} \times \mathbb{P}(T^*) \times \mathbb{P}(T^*)$ is the asynchronous communication relation[1].

Each asynchronous communication element corresponds to a place name in P_{AC}. The relation AC specifies a set of input transitions and a set of output transitions for each asynchronous communication element.

The workflow which precedes the presentation of a paper at a conference, presented in (van der Aalst, 1998b), will be used to understand the definition of IOWF-net showed above. "This workflow can be considered to be an interorganizational workflow with two loosely coupled workflow processes: (1) the process of an author preparing, submitting and revising a paper, and (2) the process of evaluating and monitoring submissions by the program committee. In this case, there are two 'organizations' involved in the interorganizational workflow: the author (AU) and the program committee (PC). The author sends a draft version of the paper to the program committee. The program committee acknowledges the receipt and evaluates the submission. The paper is accepted or rejected by the program committee. In both cases the author is notified. If the paper is rejected, the workflow terminates, otherwise the author can start preparing the final version. After completing the final version, a copy is sent to the program committee and the program committee acknowledges the receipt of the final version. If the final version is not received by the program committee before a specific due date, the author is notified that the paper is too late. A paper which is too late will not be published in the proceedings".

Figure 1 shows the IOWF-net that models the process described above. This IOWF-net has two LWF-nets: AU and PC. The LWF-nets AU, on the left, models the local workflow of the author. The one on the right, the LWF-nets PC, models the workflow procedure followed by the program committee.

An IOWN-net which is composed of a number of sound local workflows may be subject to synchronization errors. In addition, it is also possible to have an interorganizational workflow which is globally sound but not locally sound (van der Aalst, 1998b). To define a notion of soundness suitable for IOWNF-nets, Aalst in (van der Aalst, 1998b) defined the *unfolding* of an IOWF-net into a WF-net.

In the *unfolded* net, i.e. the U(IOWF-net), all the local WF-nets are connected to each other by a start transition t_i and a termination transition t_o. Moreover, a global source place i and a global sink place o have been added in order to respect the basic structure of a simple WF-net. Asynchronous communication elements are mapped into ordinary places(P_{AC}). The result of the unfolding is a new WF-net.

The soundness property definition for interorgani-

[1] $\mathbb{P}(T^*)$ is the set of all non-empty subsets of T^*

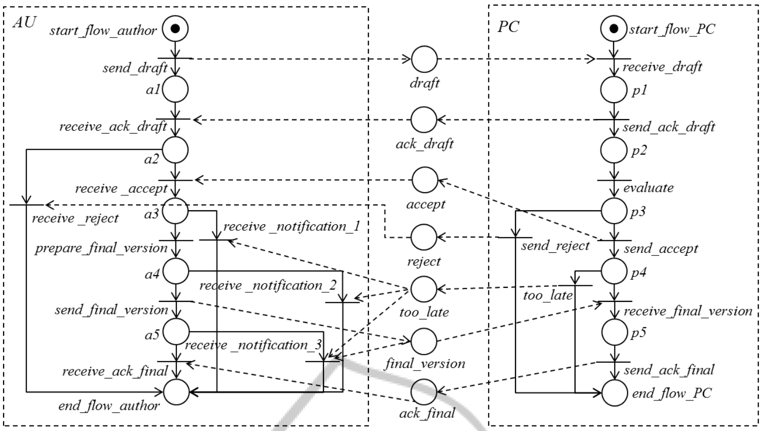


Figure 1: An interorganizational workflow.

zational workflows is given below:

Definition 2. ***Soundness*** *An interorganizational WorkFlow net (IOWF-net) is sound iff it is locally sound and globally sound. IOWF-net is locally sound iff each of its local WorkFlow nets PN_k is sound. IOWF-net is globally sound iff U(IOWF-net) is sound.*

The interorganizational workflow net shown in Figure 1 is locally and globally sound. Then, the U(IOWF-net) satisfy the soundness property.

3 POSSIBILISTIC PETRI NET

Possibilistic Petri nets are derived from Object Petri nets (Sibertin-Blanc, 2001). In particular, in the approach presented in (Cardoso, 1999), a possibilistic Petri net is a model where a marked place corresponds to a possible partial state, a transition to a possible state change, and a firing sequence to a possible behavior. The main advantage in working with possibilistic Petri nets is that it allows for the updating of a system state at a supervisory level with ill-known information without necessarily reaching inconsistent states.

A possibilistic Petri net model associates a possibility distribution $\Pi_o(p)$ to the location of an object o, p being a place of the net, thus allowing a possibilistic distribution to the model:

- *A Precise Marking*: each token is located in only one place (well-known state).
- *An Imprecise Marking*: each token location has a possibility distribution over a set of places. It cannot be asserted that a token is in a given place, but only that it is in a place among a given set of places.

$\Pi_o(p) = 1$ represents the fact that p is a possible location of o, and $\Pi_o(p) = 0$ expresses the certainty that o is not present in place p. Formally, a marking in a possibilistic Petri net is then a mapping:

$$M : O \times P \longrightarrow \{0,1\}$$

where O is a set of objects and P a set of places. If $M(o,p) = 1$, there exists a possibility of having the object o in place p. On the contrary, if $M(o,p) = 0$, there exists no possibility of having o in p. A marking M of the net allows one to represent:

- *A Precise Marking*: $M(o,p) = 1$ and $\forall p_i \neq p, M(o,p_i) = 0$.
- *An Imprecise Marking*: for example, if there exists a possibility at a certain time to have the same object o in two different places, p_1 and p_2, then $M(o,p_1) = M(o,p_2) = 1$.

A possibilistic marking will correspond in practice to knowledge concerning a situation at a given time.

In a possibilistic Petri net, the firing (certain or uncertain) of a transition t is decomposed into two steps:

- *Beginning of a Firing*: objects are put into output places of t but are not removed from its input places.
- *End of a Firing*: that can be a firing cancellation (tokens are removed from the output places of t) or a firing achievement (tokens are removed from the input places of t).

A certain firing consists the beginning of a firing and an immediate firing achievement. A pseudo-firing that will increase the uncertainty of the marking can be considered only as the beginning of a firing (there is no information to confirm whether the normal event associated with the transition has actually occurred or not). To a certain extent, pseudo-firing is a way of realizing forward deduction.

The interpretation of a possibilistic Petri net is defined by attaching to each transition an authorization function $\eta_{x_1,\ldots,x_n}$ defined as follows:

$$\eta_{x_1,\ldots,x_n} : T \longrightarrow \{False, Uncertain, True\}$$

where $x_1,\ldots,x_n$ are the variables associated with the incoming arcs of transition t (when considering the underlying Object Petri net).

If $o_1,\ldots,o_n$ is a possible substitution to $x_1,\ldots,x_n$ for firing t, then several situations can be considered:

- t is not enabled by the marking but the associated interpretation is true; an inconsistent situation occurs and a special treatment of the net is activated;
- t is enabled by a precise marking and the interpretation is true; then a classical firing (with certainty) of an object Petri net occurs;
- t is enabled by a precise marking and the interpretation is uncertain; then the transition is pseudo-fired and the imprecision is increased;
- t is enabled by an uncertain marking; if the interpretation is uncertain, t is pseudo-fired;
- t is enabled by an uncertain marking and the interpretation is true: a recovery algorithm, presented in (Cardoso et al., 1989), is called and a new computation of the possibility distribution of the objects involved in the uncertain marking is realized in order to go back to a certain marking.

Concepts about possibilistic Petri nets will be illustrated through a practical example in the next section.

4 POSSIBILISTIC INTERORGANIZATIONAL WORKFLOW NET

The transitions in a classic Petri net represents the execution of activities and a process state change. In particular, each event occurring during the execution of the process will be associated with a transition as a boolean variable. Such a variable will be essentially seen as an external value corresponding to a message received from an activity (or received from another process or sent to an activity). Possibly, internal values depending on certain token attributes will enable some transitions too.

As pointed out in the introduction, the difficulty to model business processes completely, considering the set of all existing alternatives, is almost impossible due to its complexity. From this, some inconsistencies can occur between the model of the process and the real process execution. A classical inconsistency in the interorganizational case will be a communication failure (a lost message or a delayed message that did not appear at the right moment).

As each local process of an interorganizational WorkFlow net is modeled by a Petri net, it can be directly executed using a specialized inference mechanism called "*token player* algorithm" that allows for a simplified monitoring of the represented process model. A classical token player algorithm, as the one defined in (Cardoso and Valette, 1997), is only based on normal expected events. If an unexpected event occurs, the process stop or needs to be repaired manually.

A model of the process based on the routing structure of WorkFlow nets, on the communications between the local workflow processes of an interorganizational WorkFlow net and on uncertain marking and firing of a possibilistic Petri net will then produce a kind of possibilistic interorganizational WorkFlow net that will be able to deal with certain deviations, such as failure communication, unexpected, delayed or lost events, in business process monitoring.

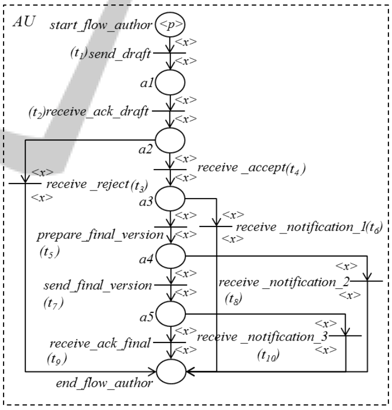


Figure 2: *AU* process using possibilistic WorkFlow net.

The process that precedes the presentation of a paper at a conference, described in Subsection 2.2 and represented in Figure 1, will be used to illustrate the approach. In this paper, only the *AU* process will be transformed into a possibilistic WorkFlow net as illustrated in Figure 2 and the communication places are considered as external events associated with the transitions of the local WorkFlow net.

$< p >$ is an object belonging to the class "Paper", x is a variable of the same class "Paper" and all places of the model belong to the class "Paper" too. Each transition has an interpretation and an action attached to it defined by the designer. The interpretation is used to manage the occurrence of each event in the system by imposing restrictions on the firing of transitions. The action is an application that involves the attributes or methods of formal variables associated with incoming arcs allowing for the modification of some specific attributes. Some actions can be executed only after the certain firing of the transition and others, with a modifier attached to it, for any type of firing

Considering the *AU* process, represented by the Figure 2, the expected behavior, after the author sends a draft version of the paper to the program committee, is to receive two messages sent by the program committee, one referring to the notification of receipt of the draft and another concerning the acceptance or rejection of the paper.

A deviation of the expected behavior can easily occur if, for example, the program committee does not notify the receipt of the draft or delay the sending of the notification of the acceptance or rejection of the paper. Logically, the author should continue preparing the article even without knowing if it was accepted or rejected (firing of transition t_3 or t_4).

Knowing that the object instances of class "Paper" have the attribute *date*, responsible for defining the time limit needed to wait for normal event occurrence time, the interpretations of transitions t_2, t_3, t_4, t_5 and t_6 are given by the following distributions:

$$\eta_x(t_2) = \begin{cases} true & if(ack\_draft) \\ uncertain & if(\tau \geq x.date) \wedge (\neg ack\_draft) \\ false & otherwise \end{cases}$$

$$\eta_x(t_3) = \begin{cases} true & if(reject) \\ uncertain & if(\tau \geq x.date) \wedge (\neg reject) \\ false & otherwise \end{cases}$$

$$\eta_x(t_4) = \begin{cases} true & if(accept) \\ uncertain & if(\tau \geq x.date) \wedge (\neg accept) \\ false & otherwise \end{cases}$$

$$\eta_x(t_5) = \begin{cases} true & if(accept) \wedge (\neg too\_late) \\ uncertain & if\ \neg\ (accept\ \vee\ too\_late) \\ false & otherwise \end{cases}$$

$$\eta_x(t_6) = \begin{cases} true & if(too\_late) \\ false & otherwise \end{cases}$$

where τ is the current time, ack_draft is true when the program committee acknowledges the receipt of the draft, $reject$ is true when the paper is rejected by the program committee, *accept* is true when the program committee accept the paper and too_late is true when the paper is received after the deadline.

The normal expected behavior of the *AU* process, after sending the draft to the program committee, corresponds to the recognition (ack_draft) of the receipt of the draft and after the acceptance ($accept$) or rejection ($reject$) of the paper before a specific due date indicated by the attribute *date* associated to the object $< p >$. If the expected messages are received in time indicated by the attribute *date* associated to the corresponding object, all the transition firing will be certain and all the markings will be precise.

An abnormal behavior will happen if the current time reaches the value of the attribute date of the object $< p >$ and no message has been received from the program committee for the corresponding event. In this case some pseudo-firing will have to occur and the imprecision about some objects will increase.

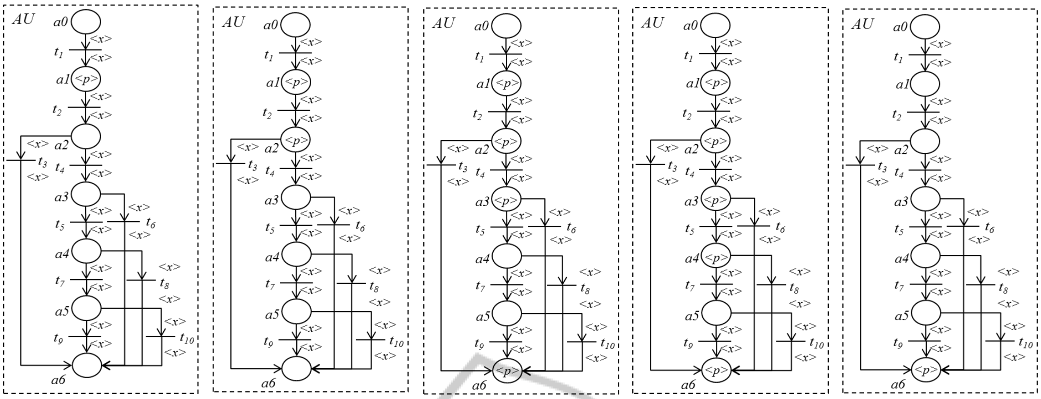
Let's assume the transition t_1 is fired at date $\tau = 10$ (Figure 3(a)) and that the actions associated to transitions t_1, t_2, t_4 and t_5 responsible for updating the waiting time limit for the event's occurrence are the following:

$$\begin{gathered} Action(t_1) : x.date = \tau + 5 \\ Action(t_2) : x.date = \tau + 45 \\ Action(t_4) : x.date = \tau + 5 \\ Action(t_5) : x.date = \tau + 45 \end{gathered}$$

if $ack\_draft = false$ and $reject = false$ all the time and $accept = true$ at $\tau = 80$, the following scenario will occur:

- at current time $\tau = 15$, the transition t_2 is enabled by a certain marking and its interpretation is uncertain ($\eta_{<p>}(t_2) = uncertain$). Then, t_2 is pseudo-fired executing the action associated to it ($Action(t_2) : x.date = \tau + 45 = 60$) (Figure 3(b));
- at current time $\tau = 60$, the transitions t_3 and t_4 are enabled by an uncertain making and the interpretation attached to them is uncertain ($\eta_{<p>}(t_3) = uncertain$, $\eta_{<p>}(t_4) = uncertain$). Then, t_3 and t_4 are pseudo-fired executing just the action associated to transition t_4 ($Action(t_4) : x.date = \tau + 5 = 65$) (Figure 3(c));
- at current time $\tau = 65$, the transition t_5 is enabled by an uncertain marking and its interpretation is uncertain ($\eta_{<p>}(t_5) = uncertain$). Then, t_5 is pseudo-fired executing the action associated to it ($Action(t_5) : x.date = \tau + 45 = 110$)(Figure 3(d));
- at current time $\tau = 80$, the transition t_4 is enabled by an uncertain marking and its interpretations becomes true ($\eta_{<p>}(t_4) = true$). This situation occurs because the notification of the receipt of the draft by the program committee never arrives and the paper was accepted but with a delay in the response on the part of *PC* process. Consequently a recovery algorithm, presented in (Cardoso et al., 1989), is called to go back to the certain marking of Figure 3(e), archiving the pseudo-fired transition t_4 and canceling the pseudo-firing of transitions t_3 and t_5.

This scenario in a classical WorkFlow net would lead to an inconsistency due to the interpretation associated to transition t_4 becoming true without the pres-



(a) $\tau = 10$ (b) $\tau = 15$ (c) $\tau = 60$ (d) $\tau = 65$ (e) $\tau = 80$

Figure 3: Simulation results of the scenario.

ence of a token in a_2 to enable the transition t_4 as illustrated in the Figure 4 in highlight. In practice, a human actor would easily deal with such a delay but a classical WorkFlow net would reach a global inconsistency.

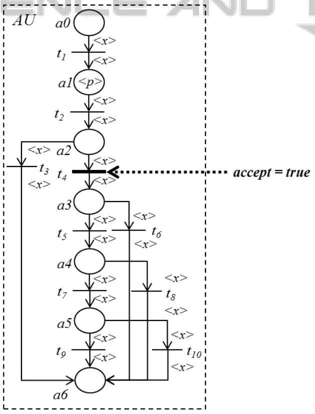


Figure 4: An possible inconsistency in a classical WorkFlow net.

To take into account the kind of incident with an ordinary Petri net based on the classical token player defined in (Cardoso and Valette, 1997), several new transitions should be created to consider all possible abnormal scenarios. As a consequence, the corresponding graph would rapidly become completely unreadable and complex.

Each workflow process of the interorganizational process structure will follow the behavior of the possibilistic token player algorithm given in figure 5. In particular, such an inference mechanism will ensure that small deviations within the interorganizational structure will not necessarily lead to inconsistencies.

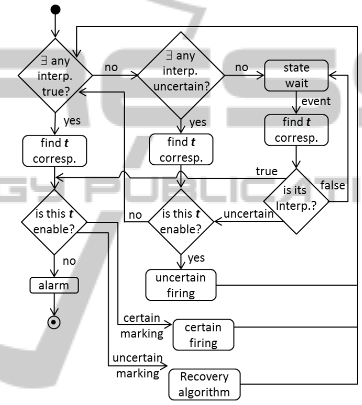


Figure 5: Possibilistic token player algorithm associated to autonomous local processes.

5 CONCLUSIONS

In this article, a possibilistic interorganizational WorkFlow net model was presented with the purpose of dealing with communication failures in business processes. Combining the routing structure of a WorkFlow net, the communication mechanisms between the local workflow processes and the uncertain reasoning of possibilistic Petri nets, it was possible to deal with some communication failures that can happen during the execution of an interorganizational workflow process. Such an approach was applied to a process that precedes the presentation of a paper at a conference.

The occurrence of lost, delayed, spurious events are handled by pseudo-fired until the moment a correct event occurs to return to a certain marking. Comparing the behavior of this approach with other works dealing with the problem of deviations, its main advantage is that the deviations are discovered and recovered at the moment of execution (at the execution time) and several possibilities of the execution are created through the uncertain reasoning. In addition, the fact that a formal process model which allows one to prove some of the good properties, like the soundness property for example, was combined with a possibilistic approach which is very well adapted to the concept of flexibility and robustness in processes. However, the approach does not permit models with loops and pseudo-firings in transitions that have already been pseudo-fired.

As a future work proposal, it will be interesting to present a communication failures recovery approach in a interorganizational workflow process not necessarily sound, knowing that in practice, the inherent flexibility of legacy systems does not always allow for the production of a process model that respects the soundness property.

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