Deadlock Avoidance in Interorganizational Business Processes using a Possibilistic WorkFlow Net

Leiliane Pereira de Rezende and Stéphane Julia
Computing Faculty, Federal University of Uberlândia, UFU - Uberlândia,
2160, Av. João Naves de Ávila, 38400-902 Uberlândia, MG, Brazil

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Abstract: In this paper, an approach based on Siphon structures, possibilistic Petri nets and interorganizational WorkFlow nets is proposed to deal with deadlock situations in interorganizational business processes. A deadlock situation is characterized by an insufficiently marked Siphon. Possibilistic Petri nets with uncertainty on the marking and on the transition firing are used to ensure the existence of at least one transition firing sequence enabling the completion of the process without encountering the deadlock situation. Routing patterns and communication protocols that exist in business processes are modeled by interorganizational WorkFlow nets. Combining both formalisms, a kind of possibilistic WorkFlow net is obtained.

1 INTRODUCTION

An organization produces value for its customers by executing various business processes. 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). Due to complexity and variety of business processes, contemporary organizations use information technology to support activities which may include automate their processes.

A workflow process corresponds to the automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules (Members, 1994). A Workflow Management Systems (WFMS) is a system that completely defines, manages and executes workflow processes through the execution of software whose sequence of activities is driven by a computer representation of the workflow process logic (Members, 1994). They are a key technology for improving the effectiveness and efficiency of business processes within an organization (van der Aalst, 1998b).

Considering that modern organizations have to cope with complex administrative processes, WFMS have to deal with workflow processes shared among multiple organizations. These systems are critical to the functioning of many organizations. Most business information applications are large-scale software systems that provide essential support to companies in their business processes. 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). An 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 WFMS (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 proven, thus showing when business processes are following a rigid structure that does not allow deviations from the process description during real time execution. However, in (Fahland et al., 2011), a case study revealed that, on average, only 46% of 735 industrial business process models checked were in fact sound. In addition, as the synchronization of parallel processes can easily lead to a potential source

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of deadlock (van der Aalst, 2000), it can be difficult to establish the soundness correctness of complex interorganizational workflow processes. As a matter of fact, even proving the soundness correctness of local workflow processes is not a guarantee of the soundness correctness of the whole system (the interorganizational workflow model) as was shown in (van der Aalst, 1998b). Deadlock in this case comes generally from message ordering mismatches as shown in (Xiong et al., 2009).

There exist many research papers devoted to the deadlock problem. Over the last two decades, a great deal of research has been focused on solving deadlock problems in resource allocation systems such as computer communication systems (Tang et al., 2012), (Mohanty and Kumara, 2013), WorkFlow systems (Park and Reveliotis, 2001), (Kohler and Schaad, 2008), and flexible manufacturing systems (Gang and Ming, 2004), (Mohanty and Kumara, 2013), resulting in a wide variety of approaches. In addition, a variety of deadlock control policies based on Petri nets have been proposed for automated manufacturing system (Ezpeleta et al., 1995), (Huang et al., 2001), (Li and Zhou, 2004), (Uzam and Zhou, 2007), (Ahmad et al., 2011), (Chen and Li, 2011), (Chen et al., 2012), (Huang et al., 2012), (Li et al., 2012). From a technical perspective, most of the control policies resolving deadlocks are developed via state space analysis or structural analysis of Petri nets. Deadlock control policies based on structural analysis can avoid the state explosion problem successfully, but always forbid some legal states (Liu et al., 2013).

Considering that a deadlock situation within the Petri net theory (Murata, 1989) is characterized as a zero marking for some structural objects called Siphons (Boer and Murata, 1994), several algorithms to detect the Siphons and efficient methods for the synthesis of supervisors enforcing that the marking of the Siphons never become completely empty and ensuring the Petri nets are free from deadlock, have been proposed in (Barkaoui and Abdallah, 1995), (Chu and Xie, 1997), (Maruta et al., 1998), (Sadiq et al., 2000), (Iordache et al., 2002), (Awad and Puhlmann, 2008), (Silva et al., 2013). All these works are based on a kind of transformation of the process model and cannot be used at a monitoring level when a deadlock situation still exists in the control structure of the model.

In this paper, an approach based on Siphon structures, as well as possibilistic Petri nets and interorganizational WorkFlow nets is proposed to deal with deadlock situations in business processes. In particular, a kind of possibilistic WorkFlow net will be defined to treat in real time the deadlock situations that occur from message ordering mismatches 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 Siphon structure is defined. In section 5, the possibilistic 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 6 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). 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*.

Following, the formal definition of WorkFlow nets is presented.

Definition 1 (WF-net). *(Aalst and Hee, 2004) A Petri net* $PN = (P, T, F)$ *is a WorkFlow net if and only if:*

1. There is one source place $i \in P$ such that $\bullet i = \phi$;
2. There is one sink place $o \in P$ such that $o\bullet = \phi$;
3. Every node $x \in P \cup T$ is on a path from i to o.

A WorkFlow net has one input place (i) and one output place (o) because any case handled by the procedure represented by the WF-net is created when it enters the WFMS and is deleted once it is completely handled by the WFMS, i.e., the WF-net specifies the life-cycle of a case. The third requirement in Definition 1 has been added to avoid "dangling tasks and/or conditions", i.e., tasks and conditions which do not contribute to the processing of cases (Aalst and Hee, 2004).

Soundness is a correctness criterion defined for WF-nets and is related to its dynamics. A WF-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.

Following, the formal definition of Soundness property in WF-nets context is presented.

Definition 2 (Soundness)**.** *(Aalst and Hee, 2004) A procedure modeled by a WF-net $PN = (P,T,F)$ is Sound if and only if:*

1. For every state M reachable from state i, there exists a firing sequence leading from state M to state o. Formally:
$$\forall_M \left[(i \xrightarrow{*} M) \Rightarrow (M \xrightarrow{*} o) \right]$$
2. State o is the only state reachable from state i with at least one token in place o. Formally:
$$\forall_M \left[(i \xrightarrow{*} M \wedge M \geq o) \Rightarrow (M = o) \right]$$
3. There are no dead transitions in (PN, i). Formally:
$$\forall_{t \in T}\ \exists_{M,M'} \left[i \xrightarrow{*} M \xrightarrow{t} M' \right]$$

A method for the qualitative analysis of WF-nets (soundness verification) based on the proof trees of linear logic is presented in (Soares Passos and Julia, 2009) and another based on a reachability graph is presented in (van der Aalst et al., 2011).

The weak soundness property corresponds to the first requirement of the soundness property. Since the second requirement is implied by the first one, the only difference is the third requirement, i.e., for weak soundness property it is not required that there are no dead transitions, i.e. a WorkFlow net is weak sound if, and only if, for each token put in the place *Start* (i), one and only one token appears in the place *End* (o). This property states that starting from the initial state (just a token in place *Start*), it is always possible to reach the final state with one token in the place *End* (van der Aalst et al., 2011).

2.2 Interorganizational WorkFlow Net and Soundness

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

The local workflows interact at certain points according to a communication structure. There exists 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). Synchronous communication corresponds to the melting of some 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 3 formalizes the concept of an IOWF-net.

Definition 3 (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. $AC \subseteq P_{AC} \times \mathbb{P}(T^*) \times \mathbb{P}(T^*)$ corresponds to asynchronous communication relations[1].

Each asynchronous communication element corresponds to a place named 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

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

IOWF-net shown below. “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 exists 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”.

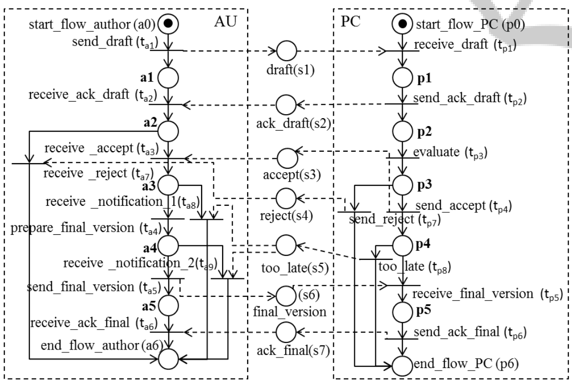


Figure 1: An interorganizational workflow.

Figure 1 shows the IOWF-net that models the process described above. This IOWF-net has two LWF-nets: *AU*, on the left, models the local workflow of the author and *PC*, on the right, models the workflow procedure followed by the program committee. Each of them has only one source and one sink place. In the LWF-net AU case, the source place is $start\_flow\_author$ and the sink place is end_flow_author. In the LWF-net PC, the source and sink place are $start\_flow\_PC$ and end_flow_PC, respectively. The places $draft$, ack_draft, $accept$, $reject$, too_late, $final\_version$ and ack_final are the communication places.

An IOWF-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 IOWF-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 interorganizational workflows is given below:

Definition 4 (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 IOWF-net shown in Figure 1 is locally sound but is not globally sound. One promptly notes that if the transition *too_late* of the LWF-net *PC* and the transition *send_final_version* of the LWF-net *AU* are fired, the messages *too_late* and *final_version* cross each other leading to a state of deadlock with a token in place $a5$ and the two messages are never received (a token in place *too_late* and a token in place *final_version*). Therefore, the IOWF-net does not satisfy the soundness property but satisfies the weak soundness property due to the fact that there exists at least one firing sequence, for example *send_draft*, *receive_draft*, *send_ack_draft*, *receive_ack_draft*, *evaluate*, *send_accept*, *receive_accept*, *prepare_final_version*, *send_final_version*, *receive_final_version*, *send_ack_final*, *receive_ack_final*, that reaches the final state.

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 they allow 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. $\Pi_o(p) = 1$ 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 there being the object o in place p. On the contrary, if $M(o,p) = 0$, there exists no possibility of there being o in p. A marking M of the net allows one to represent:

- *A Certain Marking*: each token is located in only one place (well-known state). Then $M(o,p) = 1$ and $\forall p_i \neq p, M(o,p_i) = 0$.
- *An Uncertain 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. 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 of a beginning of a firing and an immediate firing achievement. An uncertain firing (or 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 abduction in a knowledge base system.

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).

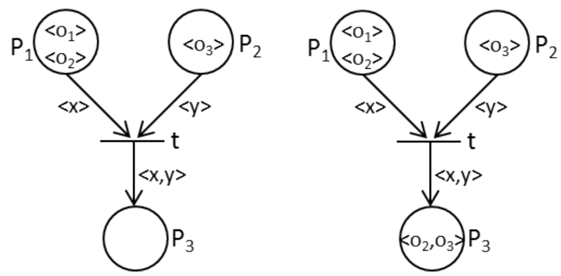
If $o_1,\ldots,o_n$ is a possible substitution for $x_1,\ldots,x_n$ for firing t, then several situations can be considered:

- t is not enabled by the marking but the associated interpretation is true; an inconsistent situation occurs and special treatment process of the net is activated;
- t is enabled by a certain marking and the interpretation is true; then a classical firing (with certainty) of an object Petri net occurs;
- t is enabled by a certain 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.

The pseudo-firing (or uncertain marking) is detailed through the example illustrated in Fig. 2. The place p_1 belongs to $Class_1$, p_2 to $Class_2$ and p_3 to the composite class $(Class_1, Class_2)$. The object instances of $Class_1$ have an attribute $date$. The interpretation, given by possibilistic distributions η_{xy} is:

$$\forall_y \begin{cases} uncertain & if(\tau < x.date) \wedge (signal(x)) \\ true & if(\tau \geq x.date) \wedge (signal(x)) \\ false & otherwise \end{cases}$$

where $signal(x)$ is $true$ when the associated sensor is active on a specific shop floor.



(a) (b)

Figure 2: Marking (a) Before firing; and (b) After pseudo-firing.

This function has the following semantics. Before the time *date*, the arrival of a message from the shop floor signaling that the object $< x >$ was involved in the event associated with the transition t, is *possible* but does not correspond to a normal behavior. Either the message is erroneous, or the representation of the shop floor state (the Petri net marking) is not consistent with the actual state. The imprecision concerning object $< x >$ will increase and the transition t associated with the corresponding event will be pseudo-fired.

On the other hand, receiving the message after a time *date* corresponds to normal behavior. So the firing of t should be a normal firing and the update of the shop floor state should be realized with certainty.

Let us consider the initial marking of Fig. 2(a); two substitution are possible for t: $S_1 =< o_1, o_3 >$ and $S_2 =< o_2, o_3 >$. Let us assume that $o_1.date = 20$ and $o_2.date = 40$.

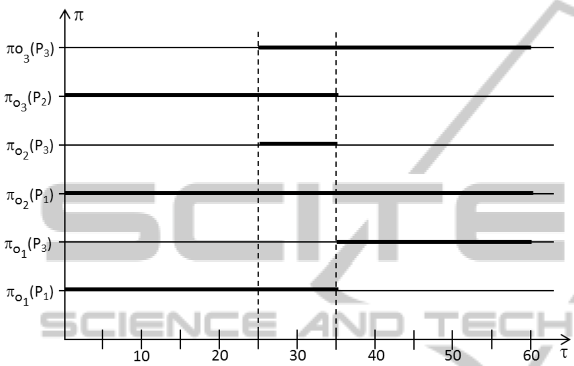


Figure 3: Possibility distribution of locations of o_1, o_2 and o_3.

At time $\tau_1 = 25$ let us suppose that $signal(o_2) = true$ and at time $\tau_2 = 35$, $signal(o_1) = true$. Fig. 3 depicts the possibility distributions of instances o_1, o_2 and o_3 as a function of time (the black lines represent a possibility equal to 1 and the bright lines a possibility equal to 0):

- at time $\tau = 10$, the firing of transition t is possible in the future for $y = o_3$ and for either $x = o_1$ or $x = o_2$ (transition is enabled and can be fired normally since $signal(o_i)$ is received);
- at time $\tau = 25$, $signal(o_2) = true$ is received but it does not correspond to a normal behavior ($o_2.date > 25$); $\eta_{o_2 o_3}(t) = uncertain$, and t is pseudo-fired with substitution S_2 (Fig. 2(b));
- after date $\tau > 25$ the marking is imprecise and cover two alternatives:
  - the event corresponding to the firing of t for tuple $< o_2, o_3 >$ has actually occurred; the information given by $signal(o_2)$ was right;
  - the event corresponding to the firing of t for tuple $< o_2, o_3 >$ has not actually occurred. This transition can still be fired, either by $< o_2, o_3 >$ or by $< o_1, o_3 >$;
- at time $\tau = 35$ the receipt of $signal(o_1) = true$ corresponds to a normal behavior ($o_1.date \leq 35$) and $\eta_{o_1 o_3}(t) = true$. As explained before, this case corresponds to the one in which the recovery algorithm is called. The application of the algorithm *cancels* the pseudo-firing of t for $< o_2, o_3 >$. As the marking is now precise and $\eta_{o_1 o_3}(t) = true$, transition t is fired (with certainty) with the tuple $< o_1, o_3 >$. It assume that $signal(o_2) = true$ was due to noise.

4 DEADLOCK SITUATIONS BASED ON EMPTY SIPHON

The presence of deadlock situations in Petri nets is due to the existence of particular structures called Siphons (Barkaoui and Abdallah, 1995). As special structures, Siphons are related to the liveness of a Petri net model and have been widely used in the characterization and prevention/avoidance of deadlock situations (Zhong and Li, 2011). The definition of a Siphon is the following:

Definition 5 (Siphon)**.** *Let P' be a non empty subset of P (set of places). P' is a Siphon iff $\bullet P' \subseteq P' \bullet$. The set of the input transitions of P' is included in the set of the output transitions of P'. Siphon P' is said to be minimal iff it contains no other Siphons as its proper subset.*

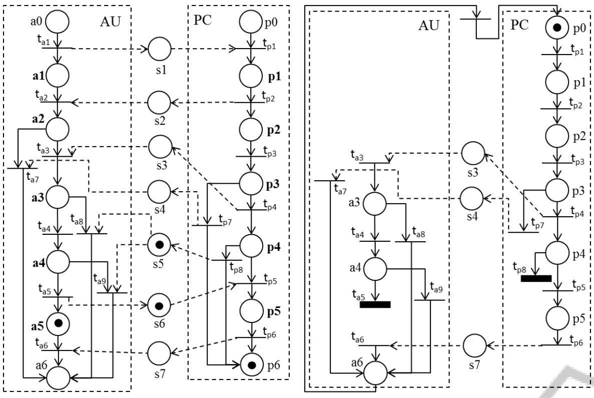
As there exists more output transitions than input transitions in the subnet, the subset of places P' can be emptied of its tokens, which leads to a deadlock situation (no transitions enabled in the Petri net). In order that a Siphon is not completely emptied of its token, it needs to contain at least a trap. The definition of a trap is the following:

Definition 6. *[Trap] Let P'' be a non empty subset of P(set of places). P'' is a trap iff $P'' \bullet \subseteq \bullet P''$. The set of the output transitions of P'' is included in the set of the input transitions of P''.*

The necessary and sufficient condition for the liveness in a marked Petri net is that every Siphon in a net must contain at least a marked trap (Hack, 1972). In addition, a necessary condition for the existence of a deadlock situation in a Petri net is for there to be at least an empty Siphon when considering the set of reachable markings (Iordache et al., 2002).

Several algorithms have been presented by different authors for the automatic detection of Siphon structures in Petri nets, such as the procedures based on Incidence Matrix (Murata, 1989), inequalities (Murata, 1989), linear algebra (Chu and Xie, 1997), logic equations (Karatkevich, 2007), and linear equations with slack variables (Ezpeleta et al., 1993).

An example of deadlock is presented in Figure 4(a). The corresponding siphon is repre-



(a) Deadlock situation (b) Empty Siphon

Figure 4.

sented in Figure 4(b). It is clear that if the firing sequence *send_draft* (t_{a1}), *receive_draft* (t_{p1}), *send_ack_draft* (t_{p2}), *receive_ack_draft* (t_{a2}), *evaluate* (t_{p3}), *send_accept* (t_{p4}), *receive_accept* (t_{a3}), *prepare_final_version* (t_{a4}), *send_final_version* (t_{a5}), *too_late* (t_{p8}) is fired, the Siphon in Figure 4(b) becomes empty through the firing of transitions t_{a5} and t_{p8} and a deadlock situation (Figure 4(a)) occurs for the marking *a5*, *too_late* (p_{s5}) and *final_version* (p_{s6}).

5 POSSIBILISTIC WORKFLOW NET

As pointed out in the introduction, the synchronization of parallel processes can easily lead to a potential source of deadlock. In addition, most of the deadlocks in a business process have structural causes that will not allow the process to reach its final state (Kohler and Schaad, 2008). Another important point to be considered, is the fact that if a deadlock situation exists in a workflow process, the only solution to avoid the deadlock situation if the model of the process cannot be explicitly modified will be to avoid the sequence of transition firing leading to the deadlock situation and to follow with another firing sequence allowing the final marking corresponding to the goal to be reached.

A model of the process that considers the existing Siphons of the global business model and based on the firing rules of a kind of possibilistic WorkFlow net will eventually allow one to deviate from firing sequences that empty Siphon. Such a model will then be able to deal with deadlock situations when the workflow model respects the weak soundness property.

This approach is divided into three consecutive phases. The first phase is a kind of static analysis phase and determines which transitions are responsible by emptying of the Siphon structures. In particular, it specifies the transitions that will have an uncertain interpretation. Such transitions will have to be pseudo-fired to explore in a kind of forward reasoning of their effect on the Siphon marking. In the second phase, the workflow process will be transformed into a possibilistic WorkFlow net and uncertain interpretations will be attached to the transitions encountered in the previous phase. Finally, in the third phase, the possibilistic WorkFlow net will be executed following the behavior of the possibilistic token player algorithm given in Figure 5. Such an inference mechanism will ensure that deadlock situations will be avoided during the execution of the process in the weak sound case, guaranteeing the existence of at least one firing sequence that will be able to reach the final marking of the process.

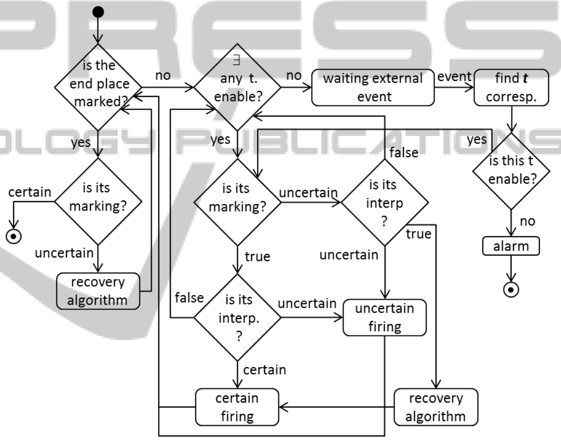


Figure 5: Possibilistic token player algorithm associated with autonomous local processes.

To illustrate the approach, the process that precedes the presentation of a paper at a conference, described in subsection 2.2 and represented in Figure 1, will be considered. This interorganizational WorkFlow net, as pointed out in the subsection 2.2, is not globally sound; soon it may be subject to some synchronization errors that can generate some structural deadlocks during its execution.

The first step to make the process free of deadlock during its execution is to determine the Siphon structures which can be emptied. As the focus of this paper is not to present a new algorithm for finding Siphon structures, the authors used the Petri net tool PIPE (Platform Independent Petri Net Editor) (Dingle et al., 2009). Through the use of the PIPE tool, 24 Siphon structures were found, from which 10 can be emptied (14 structures have trap and 10 do not). The Table 1 shows the 10 Siphon structures.

Not all the Siphons without traps will necessarily be emptied of theirs tokens. It will also depend

Table 1: Siphon structures referring to Figure 1.

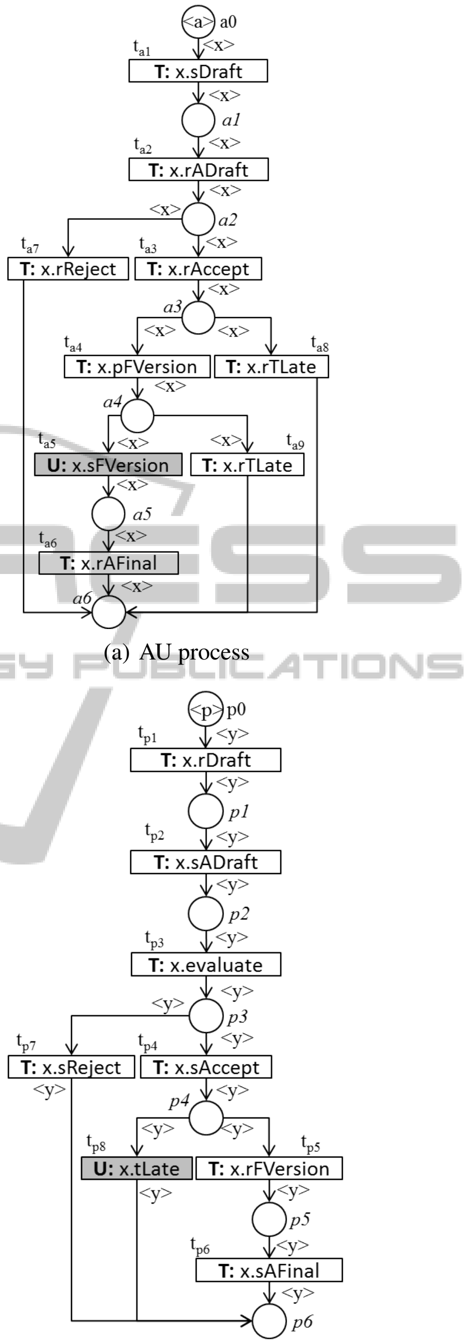
ID	Siphon
01	a3, a4, a6, s3, s4, s7, p0, p1, p2, p3, p4, p5
02	a2, a3, a4, a6, s2, s7, p0, p1, p2, p3, p4, p5
03	a0, a1, a2, a3, a4, a6, s7, p0, p1, p2, p3, p4, p5
04	a0, a1, a2, a3, a4, a6, s1, s7, p1, p2, p3, p4, p5
05	a0, a2, a3, a4, a6, s1, s2, s7, p1, p2, p3, p4, p5
06	a0, a3, a4, a6, s1, s3, s4, s7, p1, p2, p3, p4, p5
07	a2, a6, s2, s5, s7, p0, p1, p2, p3, p4, p5
08	a0, a1, a2, a6, s5, s7, p0, p1, p2, p3, p4, p5
09	a0, a1, a2, a6, s1, s5, s7, p1, p2, p3, p4, p5
10	a0, a2, a6, s1, s2, s5, s7, p1, p2, p3, p4, p5

on the global Petri net model behavior. By producing a reachable marking graph, it is possible to check that there exists only one deadlock state that occurs when the transitions *too_late* of the LWF-net *PC* and *send_final_version* of the LWF-net *AU* are fired in sequence. Considering this, the set of empty Siphons which lead to a deadlock situation in the Petri net model of Figure 1 will be composed of the Siphons 01, 02, 03, 04, 05 and 06.

Considering the set of empty Siphons defined above, the interpretation of the transitions will be classified as true or uncertain. As the transitions *send_final_version* and *too_late* are directly responsible for the emptying of the Siphon, they will have their interpretation classified as uncertain. The other transitions are not directly involved in the deadlock and will have their interpretation classified as true.

After defining the transitions that will be eventually pseudo-fired, in order to avoid a possible deadlock situation, the *PC* and *AU* processes can be transformed into possibilistic WorkFlow nets as illustrated in the Figures 6(a) and 6(b), respectively. From the point of view of a local process, the communication places of the interorganizacional WorkFlow net will be considered as simple external events associated with transitions. In particular, an interpretation will be attached with such transitions to indicate received messages. For example, the interpretation associated with the transition t_{p1} of the Figure 6(b) is true if a message is received from the model of Figure 1 through the communication place $draft$.

$< a >$ and $< p >$ are objects belonging to the class "Paper", as well as variables *x* and *y* and all the model's places. 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 conditions on the firing of transitions. An action corresponds to an application that involves the attributes of formal variables associated with incoming arcs, allowing for the modification of some specific attributes through the execution of some specific methods. In order to



(a) AU process

(b) PC process

Figure 6: *AU* and *PC* process using possibilistic WorkFlow net.

focus on the deadlock resolution problem, actions are not represented in this paper.

The conditions correspond to the following interpretations: the draft is ready to send to the *PC* ($sDraft$); the *PC* receives the draft ($rDraft$); the *PC* notifies the receipt of the draft to the author (*sADraft*); the *PC* acknowledges the receipt of the draft (*rADraft*); the evaluation was completed (*evaluate*); the *PC* decides to accept the paper (*sAccept*); the *PC* accepts the paper (*rAccept*); the *PC* decides to reject the paper (*sReject*); the *PC* rejects the paper (*rReject*); the author begins the preparation of the final version (*pFVersion*); the final version is ready to send to the *PC* (*sFVersion*); the *PC* receives the final version (*rFVersion*); the deadline for submission of the paper is reached (*tLate*); the paper is received after the deadline (*rTLate*); the *PC* notifies the receipt of the final version to the author (*sAFinal*) and the *PC* acknowledges the receipt of the final version (*rAFinal*).

Finally, in the third phase, the communicating processes *PC* and *AU* are executed considering the possibilistic token player algorithm given in Figure 5. For this, let us assume that the transitions t_{a1}, t_{a2}, t_{a3} and t_{a4} of the LWF-net *AU* and the transitions t_{p1}, t_{p2}, t_{p3} and t_{p4} of the LWF-net *PC* have already been fired(Figure 7(a) and 7(b)). If the transition t_{a5} of the LWF-net *AU* and the transition t_{p5} of the LWF-net *PC* are fired in sequence, the following scenario will occur:

- the transition t_{p5} of LWF-net *PC* is enabled by a certain marking and its interpretation is uncertain. Then, t_{p5} is pseudo-fired (Figure 7(c));
- the transition t_{a5} of LWF-net *AU* is enabled by a certain marking and its interpretation is uncertain. Then, t_{a5} is pseudo-fired (Figure 7(d));
- the end place ($p6$) of the LWF-net *PC* is marked by an uncertain marking. This means that through a pseudo firing sequence, the final marking of the process *PC* was reached without encountering a deadlock situation. Consequently, a recovery algorithm, presented in (Cardoso et al., 1989), is called to validate the sequence pseudo fired and to go back to a certain marking. In particular, this algorithm archives the pseudo-firing of the transition t_{p5} (Figure 7(e)) finalizing the execution of the process;
- the transition t_{a9} of the LWF-net *AU* is enabled by an uncertain marking and its interpretation is true. This means that through a pseudo firing sequence the process *AU* reached a transition that is not responsible for the emptying of the Siphon and, consequently, for the deadlock situation in the Petri net model of Figure 1. Consequently, the recovery algorithm, presented in (Cardoso et al., 1989), is called to go back to a certain marking. In particular, this algorithm cancels the pseudo-firing of the transition t_{a5} (Figure 7(f)) and fires with certainty the transition t_{a9} (Figure 7(g)).

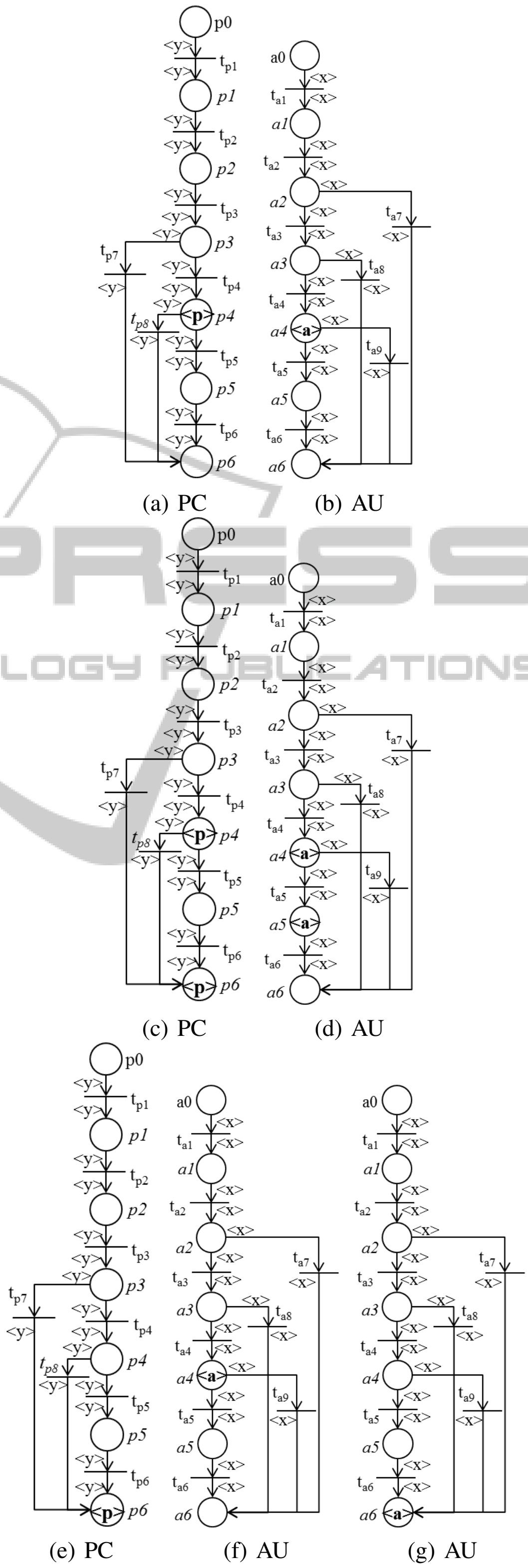


Figure 7: Simulation results of the scenario.

6 CONCLUSIONS

In this article, a possibilistic WorkFlow net model was presented with the purpose of dealing with deadlock situations in business processes not necessarily sound. Combining the routing structure of WorkFlow nets, communication mechanisms of interorganizational processes, uncertain reasoning of possibilistic Petri nets and theoretical results on siphon theory, the authors presented an approach that can deal with deadlock situations that can be reached during the real time execution of weak sound interorganizational workflow processes. Such an approach was applied to an example of a process that precedes the presentation of a paper at a conference.

The other works that deal with the problem of deadlock in interorganizational workflow processes alter the design of the non sound model during the analysis phase. Normally, the process's model is altered through the analysis of a reachable marking graph as in (van der Aalst, 1998b) or by adding a control place that forces the number of tokens in the Siphon to remain strictly positive as in (Silva et al., 2013). Comparing these works with the approach presented in this paper, the main advantage is that it ensures the existence of at least one transition firing sequence during the real time execution of weak sound interorganizational workflow processes, enabling the completion of the process without encountering a deadlock situation and without modifying the control structure of the model. In addition, the presented method works for the weak sound interorganizational workflow processes, given that most processes in practice do not satisfy the soundness property as was shown in (Fahland et al., 2011).

As a future work proposal, in order to validate experimentally such an approach, the model of the possibilistic WorkFlow net will have to be implemented on a Petri net software tool allowing for the programming of transition pseudo firing. It would seem that the CPN Tools software resources, permitting in particular the use of complex function calculus associated with the model's arcs, should be able to implement in a simple way some of the basic behaviors of a possibilistic token player. It will be interesting then to model and test a larger business process using the CPN Tools software through Monte Carlo simulation (Rubinstein and Kroese, 2008).

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