Conflicts Analysis for Inter-Enterprise Business Process Model

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ABSTRACT

Abstract: Business process (BP) management systems facilitate the understanding and execution of business processes, which tend to change frequently due to both internal and external change in an enterprise. Therefore, the needs for analysis methods to verify the correctness of business process model is becoming more prominent. One key element of such business process is its control flow. We show how a flow specification may contain certain structural conflicts that could compromise its correct execution. In general, identification of such conflicts is a computationally complex problem and requires development of effective algorithms specific for target system language. We present a verification approach and algorithm that employs condition reachable matrix to identify structural conflicts in inter-enterprise business process models. The main contribution of the paper is a new technology for identifying structural conflicts and satisfying well-defined correctness criteria in inter-enterprise business process models.

Keywords: Business Process Modeling, Conflicts Detection, Conflicts Analysis, Conditional Reachable Matrix, Business Process Analysis

1. INTRODUCTION

In this information age, e-Business is key to business survival. As reported by AMR Research Inc., e-Business drastically increases the need to effectively manage complex, cross-enterprise business processes. e-Business Process Management (eBPM) requires a combination of process modeling and analysis, application execution, workflow management, application integration, and process intelligence. Consequently, Business processes related to inter-enterprise exchange are becoming increasingly important. A flow specification may contain certain structural conflicts that could compromise its correct execution. The research presented in this paper focuses on inter-enterprise BP verification in a computational effective way.

Lots of work existed in BP modeling and verification domain. A verification method used in APM [1] is adapted the algorithms coming from Yang's in PPP [2]. The method is to construct a complete state transition diagram to simulate all possible execution paths of the process and check whether they are consistent. This, however, would face the combinatorial explosion problem leading to poor performance. In [3] some verification problems are covered and the complexity of selected correctness problems are identified, but no concrete verification procedures are available. In [4] and [5] verification procedures based on Petri net are proposed. The technology presented in [5] is developed for checking the consistency of transactional workflows including temporal constraints. However, the technology is restricted to acyclic workflows and only gives the necessary conditions. In [6] a reduction technology is proposed, which defines a soundness criterion, and the class of workflow processes considered is in essence acyclic free-choice Petri nets.

This paper differs from the above approaches by focusing on inter-enterprise BP. A few papers explicitly focus on the problem of verifying the correctness of interorganizational workflows [7, 8]. In [7] the interaction between domains is specified in terms of message sequence charts and the actual overall workflow is checked with respect to these message sequence charts. A similar, but more formal and complete approach is presented by Kindler, Martens, and Reisig in [8]. The authors give local criteria, using the concept of scenarios (similar to runs or basic message sequence charts), to ensure the absence of certain anomalies on the global level.

Rest of the paper is organized as follows. In section 2, we define and explain a generic business process modeling language to build process models. In section 3, we analyze the structural conflicts of inter-enterprise BP model and give a correctness criterion. On the basis of structural conflicts analysis, a verification approach that employs condition reachable matrix is presented in section 4. Section 5 concludes the paper.

2. INTER-ENTERPRISE BUSINESS PROCESS MODELING

Fig.1 shows our modeling objects which includes: nodes, connectors and flows.

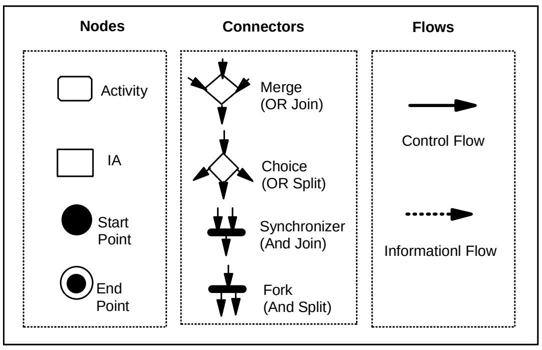

Fig.1 Inter-Enterprise BP modeling objects

There are mainly four types of nodes: ***Activity*** is a work to be done to achieve certain objectives. ***IA*** (Information Artifact) corresponds to the exchange of message between multiple BPs. The model should have one ***Start Point*** and at least one ***End Point***.

There are four types of BP logical connectors: **Choice (OR-Split)**, **Merge (OR-Join)**, **Fork (AND-Split)** and **Synchronizer (AND-Join)**. A*nd-split* is used to represent concurrent paths within a BP. A*nd-join* is applied to synchronize such concurrent paths. *Or-split* is used to model mutually exclusive alternative. *Or-join* is applied to join mutually exclusive alternative paths into one path.

There are two types of flows: ***control flow*** and ***information flow***. *Control flow* links two nodes in the intra-enterprise BP model. *Information flow* links two IAs or IA-with-activity to represent information sending/receiving action.

3. STRUCTURAL CONFLICT DEFINITION IN INTER-ENTERPRISE BP

Some BP modeling assumptions are given firstly in this section. Following the general structure validity definition, the concrete structural conflict definitions in both intra and inter BPs are given separately, as the foundation for the new conflicts detection approach introduced in section 4.

Assumption
A process model based on above modeling objects constructs a Directed Acyclic Graph (DAG), which conforms to the following assumption:

1. It doesn't have any loops which are edges from a vertex to itself;
2. It doesn't have any multiple edges between pairs of nodes;
3. It doesn't have any iteration structure;

Terms and Definitions
Before identifying structural conflicts and presenting the correctness criteria for inter-enterprise BP model, some definitions need to be introduced firstly. (See Definition 1-4)

Definition 1: ***An instance subgraph*** represents a subset of business process model that may be executed for a particular instance of a business process.

An instance subgraph can be generated by visiting its nodes on the semantic basis of underlying modeling structures. The or-split, which is exclusive and complete, is the only structure in a business process model that introduces more than one possible instance subgraphs. At runtime, the BP model selects one of the alternative execution paths for a given instance of the business process by activating one of the outgoing flows originating from the or-split condition object.

Figure 2 shows a business process graph and its two instance subgraphs.

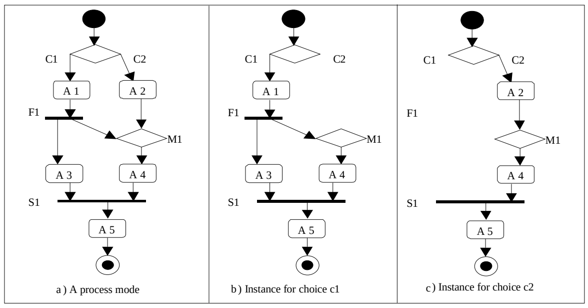

Fig.2 Example intra-BP Model with flow deadlock structural conflicts

Definition 2: ***Choice Path*****:** A choice path of node *n* is a sequence of choice branch *<c1,c2...ck>* from start point to node *n*.
Choice path is a useful definition that represents a node in some instance subgraph of the BP model. A node may have several different choice paths. *ChoiceSignpost* is a choice set which represents the entire choice path by set. If two nodes in intra-enterprise BP model have the same choice path, then the two nodes are always in the same instance subgraph. Activities A1 and A3 serve as a good example in Figure 2.

Definition 3 :***An intra-enterprise BP model (Intra-BPM) is a tuple:***
Intra-BPM=(*N*, *F*)**, where:**
– *N* is a finite set of nodes (without IA).
– $F \subseteq (N \times N)$ is a finite set of control flows representing directed edges between two nodes.

Definition 4 :***An inter-enterprise BP model (Inter-BPM) is a tuple:***
Inter-BPM=(*N1,F1,N2,F2,M,T*)**, where:**
– *N1* is a finite set of partner1's nodes (without IA).
– $F1 \subseteq (N1 \times N1)$ is a finite set of partner1's control flows.
– *N2* is a finite set of partner2's nodes (without IA).
– $F2 \subseteq (N2 \times N2)$ is a finite set of partner2's control flows.
– *M* is a finite set of IA pairs.
– *T* is a finite set of information flows representing directed edges between two nodes.

A formal notation of BP model used in the conflicts detection is given as follows.
For each flow $f \in F$:
– *start*[*f*] = *n* represents start node *n* of *f.*
– *end*[*f*] = *n* represents end node *n* of *f.*
For each node and connector $n \in N$:
– *type*[*n*]∈ {*Start Point, End Point, Merge, Synchronizer, Fork, Choice, Activity*} represents type of *n.*
– *dout*[*n*] : number of outgoing flows from *n*.
– *din*[*n*] : number of incoming flows to *n*.
– *Choicesignpost*[*n*,*i*] where $n \in N$ *and* $1 \leqslant i \leqslant$ *din*[n] ,represents choice set of node n entry *i* from start point to node *n*. If the node has only one entry(for example :activity), parameter *i* can be omitted.
For each IA pair $m \in M$ has only one sender and one receiver:

– *Receiver*[*m*]= *n*={ *m* : *m* ∈*M* , *n: n* ∈*N1*∪*N2*, *type*(*n*)={activity} and ∃*t* ∈*T*,where *start*[*t*]=*m* and *end*[*t*] = *n* }, *n* is the receiver activity of the IA pair *m*.

– *Sender*[*m*]= *n*={ *m* : *m* ∈*M* , *n: n*∈ *N1*∪*N2*, *type*(*n*)={activity} and ∃*t* ∈*T*, where *start*[*t*] = *n* and *end*[*t*] = *m* }, *n* is the sender activity of the IA pair *m*.

Inter-Enterprise BP Structure Conflict Definition

Definition 5: A business process model is said to be structural correct if and only if it is:

1. Syntactical correct: Each object satisfies object types and the number of incoming and outgoing flows connected to it.

2. Reachability and termination error free: Each node is reachable from the Start Point and the End Point can be reached from this node.

Before the verification for BP structural conflicts, basic syntax checking is performed to ensure that the model conforms to the modeling language syntax and that all necessary assumptions of its components have been defined. It is important to point out that structural conflicts are not the only types of errors possible in business process models. However, they do represent the primary source of errors in flow specifications and can be identified independently. Inter-enterprise BP structural conflicts are separated into two categories: intra-BP and inter-BP conflicts. Intra-BP model correct criterion guarantees proper termination of the model for all instance subgraph. Inter-BP model correct criterion guarantees proper interaction of multiple partners for all instance subgraph.

Definition 6 :*Correct intra-enterprise BP model:* For any instance subgraph, the procedure will terminate eventually at end point.

The or-join and and-join are the only two structure in a business process model that may cause the improper flow termination till end point. With this understanding, two structural conflicts in intra-enterprise BP model are identified: flow deadlock and lack of exclusion.

Flow deadlock - Joining exclusive choice with a synchronizer results into a flow deadlock conflict.

A flow deadlock at a synchronizer structure blocks the continuation of a business process path since one or more the incoming transitions of the synchronizer are not triggered. Figure 2 shows an instance subgraph with flow deadlock structural conflict. In figure 2 c), the process instance will have a deadlock at synchronizer S1 if it selects choice C2. Accordingly, this instance would not terminate properly as A5 can not be executed.

Lack of exclusion - Joining two or more concurrent paths with a merge structure introduce lack of exclusion conflict.

A lack of exclusion at a merge structure causes unintentional multiple activation of nodes that follow the merge structure. Figure 3 shows an instance subgraph with the lack of exclusion structural conflict. In figure 3 c), the process instance will have a lack of exclusion if it selects choice C2, since two parallel activities A3 and A4 will multiply activate the nodes that follow the merger node M1, then the instance would not terminate properly.

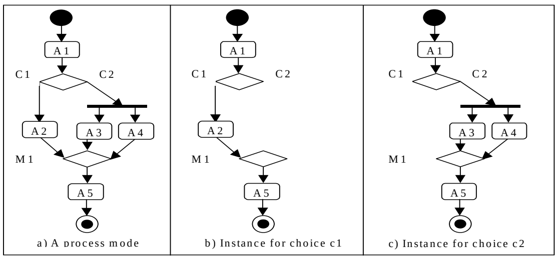

Fig.3 Example intra-BP Model with exclusive join structural conflicts

It can be identified that, the correctness criteria for intra-enterprise BP model is that the model is free of flow deadlock and lack of exclusion structural conflicts. A BP model is free of flow deadlock structural conflicts if it does not generate an instance subgraph that contains only a proper subset of the incoming nodes of an and-join node, i.e. for any synchronizer in the model, the *ChoiceSignposts* of the all synchronizer entry are equal. A BP model is free of lack of exclusion structural conflicts if it does not generate an instance subgraph that contains more than one incoming nodes of an or-join node. i.e. for any merge in the model, the any two *ChoiceSignposts* of the all merge entry have no intersection.

Definition 7 :*well mapping inter-enterprise BP model:* for any instance subgraph in inter-enterprise BP model, all IA in it are well mapping**.**

Usually, an inter-BP model has no dangling IA, which represents there is no sender or receiver for the IA, but it can not ensure that the inter-BP model is well mapping. For example, a pair IA links two activities. If the two activities' *ChoiceSignposts* (choice path) are not equal, then it means there some two instance subgraphs that the activities existed are not matched. So well mapping inter-enterprise BP model not only has no dangling IA, but also each pair of instance subgraph has no dangling IA. An inter-BP model is not well mapping just because the activities connected with IA pair have different choice path (*ChoiceSignpost*). A corresponding structural conflict in inter-BP model is identified as follows:

Different choice path structural conflicts - Two activities connected with IA pair have different *ChoiceSignpost.* A Different choice path structural conflict results into some instance subgraph has dangling IA.

Figure 4 shows an inter-BP model with different choice path structural conflict. Partner A selects choice C1 during the runtime, then partner A can only produce IA11 and IA22 is dangling.

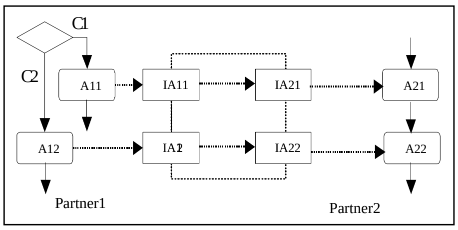

Fig.4 Example inter-BP Model with choice mapping structural conflicts

Definition 8 :*well ordered inter-enterprise BP model:* In a well mapping inter-enterprise BP model, the partial order of IA pairs enable both side procedure terminate eventually at end point for any instance.

At runtime, the BP model of each partner executes a sequence of defined activities depending on the path chosen. Some activities may produce or consume IA. If an activity needs consuming IA, the activity can be executed only when the IA is available. Otherwise the activity would never be activated. Corresponding structural conflicts are identified as follows.

IA deadlock - Inconsistent sequence of IA production/consumption results into an IA deadlock. An IA deadlock between partners blocks the continuation of a business process path of both side since two activities need IA and the IA is not available.

Figure 5 shows an inter-BP model with IA deadlock structural conflict. At runtime, activity A11 in partner A need to consume IA11 and then activate A12 to produce IA12. However, activity A21 in partner B need to consume IA21 and then trigger A22 to send IA22. So the inter-BP model would deadlock.

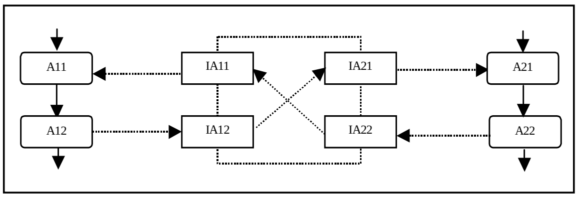

Fig. 5 Example inter-BP Model with IA deadlock structural conflicts

Lack of synchronization - Inconsequent sequence of IA production/consumption introduce a lack of synchronization. Strictly speaking, lack of synchronization will not result into deadlock of the inter-BP model, but it is not economical in the real life. Figure 6 shows an inter-BP model with two kinds of lack of synchronization structural conflict.

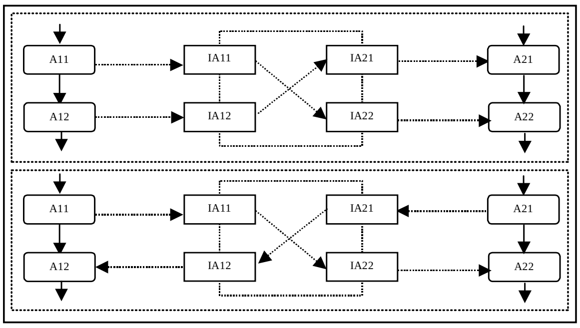

Fig. 6 Example inter-BP Model with Lack of synchronization structural conflicts

Given the basic correctness definition above, the complete correctness criterion for inter-BP model are introduced in Definition 9.

Definition 9 :*A correct inter-enterprise BP model satisfies the following requirements:*

(1) Each intra-enterprise BP model is correct;
(2) Inter-enterprise BP model is well mapping;
(3) Inter-enterprise BP model is well ordered;

The common point in both cases of conflicts detection is to examine all possible instance subgraphs of a BP model. The or-split is the only structure in a business process model that introduces more than one possible instance subgraphs. The number of possible instance subgraphs could grow exponentially as the number of or-split and or-join structure increases in a BP specification. Therefore, a brute force method to generate all possible instance subgraphs of a BP model to ensure correctness is not computationally effective.

4. CONFLICTS DETECTION ALGORITHM

In this section, both effective intra/inter BP conflicts detection algorithms are introduced, given the innovative definition of condition reachable matrix as basis.

Condition Adjacency Matrix

Suppose that $G=(N,F)$ is an intra-BP model where $|N|=n$. For simple, here we suppose $type[n]$={activity}. The condition adjacency matrix $A(G)$, with respect to the nodes, is the $n\times n$ matrix with I as its $(i,j)th$ entry when node ni and nj are directly adjacent, and Φ as its (i,j)th entry when they are not adjacent, and choice set, for example $\{C1\}$, as its (i,j)th entry when they are adjacent by choice $C1$.

Condition Reachable Matrix

According to condition adjacency matrix of an intra-BP model, node condition reachability can be calculated. The condition reachable matrix represents the mutually reachable properties of any two nodes in the model. Its generation procedure is described as follows.

Procedure: Condition reachable matrix generation

(A(G): n×n condition matrix)
M:= A(G);
For i:=1 to n
Begin
  for j:=1 to n
  Begin
    If M[j,i]≠ Φthen
      For k:=1 to n
        Begin
          A[j,k]:=A[j,k]∪ A[i,k]∩[Mj,i]}
        End
  End
End

Conflicts Detection Algorithm

The intra-BP conflicts detection procedure is described as follows.

Procedure: *Intra-BP model structural conflicts detection*

For any node n, n ∈N
If type(n)={synchronizer} and Choicesignpost[n,1]= Choicesignpost[n,2]= ......= Choicesignpost[n,k] (k is the number of entry of node n) Then
  The BP model contains no flow deadlock conflicts
Else
  Report node n with flow deadlock

If type(n)={merge} and Choicesignpost[n,i]$\cap$ Choicesignpost[n,j]$\neq \Phi$, i$\neq$j (i and j are the any two entry of node n) Then
Report node n with exclusive join conflicts

Inter-BP conflicts detection procedure is described as follows.

Procedure: *Inter-BP model structural conflicts detection*
For any IA pair m, m $\in$M
If Choicesignpost[Receiver(m)]$\neq$Choicesignpost[Sender(m)] Then
Report nodes Receiver(m) and Sender(m) with choice mapping structural conflicts
For any two IA pair mi and mj, mi$\in$M,mj $\in$M
Switch
Case 1 (Receiver(mi)$\in$N1 and Receiver(mj)$\in$N1) or (Receiver(mi)$\in$N2 and Receiver (mj)$\in$N2)
If (Receiver(mi)$\rightarrow$Receiver(mj) and Sender(mj)$\rightarrow$Sender(mi)) or Receiver(mj)$\rightarrow$Receiver(mi) and Sender(mi)$\rightarrow$Sender(mj)) Then
Report the four activities that link IA pair mi and mj contains lack of synchronization conflicts
Case 2 (Receiver(mi)$\in$N1 and Receiver(mj)$\in$N2) or (Receiver(mi)$\in$N2 and Receiver(mj)$\in$N1)
If Receiver(mi)$\rightarrow$Sender(mj) and Receiver(mj)$\rightarrow$sender(mi)) Then
Report the four activities that link IA pair mi and mj contains IA deadlock conflicts
If Sender(mi)$\rightarrow$Receiver(mj) and Sender(mj)$\rightarrow$Receiver(mi)) Then
Report the four activities that link IA pair mi and mj contains lack of synchronization conflicts
Here$\rightarrow$ is a reachable symbol. For example, for node n1 and n2, n1 $\rightarrow$n2 represents n2 is reachable from n1.

5. CASE STUDY

An inter-enterprise BP model is shown in Figure 7.

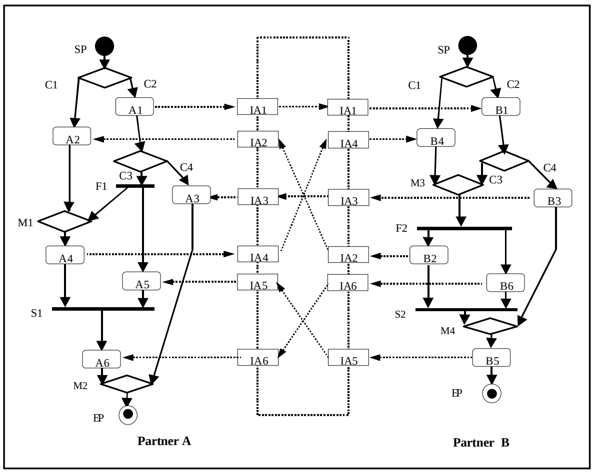

Fig. 7 An inter-enterprise business process model

Corresponding condition adjacency/reachable matrices can be seen in Table 1~4.

Table. 1 Condition adjacency matrix of partner A

	SP	A1	A2	A3	A4	A5	A6
SP	Φ	C2	C1	Φ	Φ	Φ	Φ
A1	Φ	Φ	Φ	C4	C3	C3	Φ
A2	Φ	Φ	Φ	Φ	I	Φ	Φ
A3	Φ	Φ	Φ	Φ	Φ	Φ	Φ
A4	Φ	Φ	Φ	Φ	Φ	Φ	I
A5	Φ	Φ	Φ	Φ	Φ	Φ	I
A6	Φ	Φ	Φ	Φ	Φ	Φ	Φ

Table. 2 Condition reachable matrix of partner A

	SP	A1	A2	A3	A4	A5	A6
SP	Φ	C2	C1	C2 $\cap$C4	C1$\cup$(C2$\cap$C3)	C2$\cap$C3	C1$\cup$(C2$\cap$C3)
A1	Φ	Φ	Φ	C4	C3	C3	C3
A2	Φ	Φ	Φ	Φ	I	Φ	I
A3	Φ	Φ	Φ	Φ	Φ	Φ	Φ
A4	Φ	Φ	Φ	Φ	Φ	Φ	I
A5	Φ	Φ	Φ	Φ	Φ	Φ	I
A6	Φ	Φ	Φ	Φ	Φ	Φ	Φ

Table. 3 Condition reachable matrix of partner B

	SP	B1	B2	B3	B4	B5	B6
SP	Φ	C2	C1$\cup$(C2$\cap$C3)	C2 $\cap$C4	C1	I	C1$\cup$(C2$\cap$C3)
B1	Φ	Φ	C3	C4	Φ	I	C3
B2	Φ	Φ	Φ	Φ	Φ	I	Φ
B3	Φ	Φ	Φ	Φ	Φ	I	Φ
B4	Φ	Φ	I	Φ	Φ	I	I
B5	Φ	Φ	Φ	Φ	Φ	Φ	Φ
B6	Φ	Φ	Φ	Φ	Φ	I	Φ

Let's use the synchronizer S1 in partner A side, and Merge M4 in partner B side to illustrate the conflicts detection procedure introduced in the paper.

ChoiceSignpost[S1,1]=*ChoiceSignpost*[A4]=C1$\cup$(C2$\cap$C3),
ChoiceSignpost[S1,2]=*ChoiceSignpost*[A5]=C2$\cap$ C3,
As *ChoiceSignpost*[S1,1]$\neq$*ChoiceSignpost*[S1,2], there is a flow deadlock reported at S1.

Similarly,
ChoiceSignpost[M4,1]=C1$\cup$(C2$\cap$C3),
ChoiceSignpost[M4,2]=C2 $\cap$C4,
ChoiceSignpost[M4,1]$\cap$*ChoiceSignpost*[M4,2]=(C2$\cap$C4)$\cap$ [C1$\cup$(C2$\cap$C3)]=(C2$\cap$C4)$\cap$(C1$\cap$C3)=Φ
Hence, M4 is free of lack of exclusion structural conflict.

Different choice path structural conflict of the given inter BP model can be analyzed through comparing the partners' condition reachable matrices, as shown in Table 4.

Table. 4 Different choice path structural conflicts analysis

	SP	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**
SP	Φ	C2	C1	$C2 \cap C4$	$C1 \cup (C2 \cap C3)$	$C2 \cap C3$	$C1 \cup (C2 \cap C3)$
	SP	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**
SP	Φ	C2	$C1 \cup (C2 \cap C3)$	$C2 \cap C4$	C1	I	$C1 \cup (C2 \cap C3)$
Conflict	No	No	Yes	No	Yes	Yes	No

Let us analyze IA deadlock in this case. For two pairs of IA: m2=IA2 and m4=IA4, the activity of Receiver[m2] is A2, which belongs to partner A, and the activity of Receiver[m4] is B4, which belongs to partner B. From the condition reachable matrix of the two partners(as shown in table 2 and table 3.), we can find:A2→A4 and B4→B2. At runtime, activity A2 in partner A need to consume IA2 and then activate A4 to produce IA4. However, activity B4 in partner B need to consume IA4 and then trigger B2 to send IA2. So the inter-BP model would deadlock at activities: A2 and B4. Similarly, we can find all the IA deadlock in the inter-BP model.

6. CONCLUSIONS

In this paper we report our approach of using condition reachable matrix technology for detecting structural conflicts in inter-enterprise business process models. A graphic process model representation is provided as basis for our verification approach and corresponding algorithms. Correctness criteria of inter-enterprise BP model and major several types of structural conflicts are identified. An effective algorithm based on condition reachable matrix is then illustrated for both intra and inter-BP structure conflict verification.

The approach is intuitive and natural. Structural conflicts can be identified easily and accurately with the generating of condition reachable matrix. Whereas, as different parties may have different vocabulary/symbol to represent the same condition branch expressions, the algorithm we reported in this paper still need to rely on user participation to avoid reporting ontology misunderstanding as conflicts.

Although the approach presented in this paper deals with business process model that can be represented by a directed acyclic graph (DAG), our further study finds the method can be applied to BP model with cycles and iteration structure.

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