On Enabling Time-Aware Consistency of Collaborative Cross-Organisational Business Processes

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Abstract. Collaborative Inter-Organisational Business Processes (IOBPs) are a major step in automating and supporting collaborations of organisations. In this context, collaborative IOBP are usually constrained by hard timing requirements. This paper proposes an approach for analyzing *temporal consistency* of collaborative IOBPs. The aim is to verify temporal consistency of IOBP and to provide the enactment service with largest intervals as starting time windows of the processes. The proposed approach enables organisations to detect, early on, temporal inconsistencies that may constitute obstacles towards their interaction. Indeed, it provides an enactment service, which provides each partner with information about temporal restrictions to respect by its own processes in accordance with the overall temporal constraints of all involved processes.

Keywords: Temporal Constraints, Collaborative Inter-organisational Business Process (IOBP), Temporal Consistency analysis.

1 Introduction

In today's organisations, business entities often operate across organisational boundaries giving rise to inter-organisational collaborations, which have received a great deal of attention during the last years. The reduction of commercial barriers helps organisations to create value by combining processes, increasing speed to market and reaching a bigger market share. On the basis of these expectations, we can find among others, the following factor: *to maximize the ability to offer competitive products or services within restrictive deadlines.*

In the context of such extended collaborations, collaborative inter-organisational business processes, or *IOBP* for short, are becoming one of the dominant elements in designing and implementing complex inter-organisational

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business applications. IOBP are typically subject to conflicting temporal constraints of the involved organisations. Hence, *temporal consistency* of business processes are one of the important and critical ingredients to consider.

Temporal consistency analysis of IOBP aims at verifying the capability of a set of processes to interact by exchanging messages in a successful way so that all the temporal constraints are respected. Among research works which have investigated the temporal consistency analysis problem, we mention the work detailed in [1,2] which deals with a collaboration constituted by only two processes. Moreover, theses works assume that all the processes must start at the same time. This is very restrictive and does not correspond to real life scenario applications where processes can belong to different organisations with different geographic and time zones.

In this paper we tackle the problem of analyzing the temporal consistency of IOBP. Our purpose is to provide an approach enabling organisations to detect, early on, temporal inconsistencies that may constitute obstacles towards their interaction. In case of temporal inconsistencies, our approach provides an enactment service, which allows to define automatically temporal constraints so that the formed collaborative IOBP will carry out successful timed collaborations.

This paper is organized as follows. A motivating example is introduced in Section 2. Section 3 presents a brief description of the timed model we consider and exhibits the proposed consistency analysis approach. A review of related literature is given in Section 4. Finally, Section 5 concludes.

2 Motivating Example

To illustrate the features of the proposed approach, we introduce a Web shopping scenario inspired by Amazon [3]. The booking process can be described as follows : When ordering books on-line, a collaboration between a customer, a seller company like Amazon and a shipper company like FedEx is established. Fig. 1 shows such a collaboration with the help of an excerpt of an IOBP involving the processes of different partners. The BPMN 2.0 standard, is used for the depiction of the IOBP. This latter represents a simple scenario in which the customer sends an order to the seller, makes payment and expects to receive the items from a shipper.

As shown in Fig. 1, different temporal constraints can be assigned to business processes. Theses constraints include duration of activities (e.g., the duration of the activity *Ship products* is 24 *hours*) and deadlines (e.g., $D_{Seller} = 35$ *hours* to denote that the execution of the *Seller* process takes no longer than 35 *hours*).

Additionally, dashed lines between activities depict message exchange. For instance, there is a message exchange between activities *Send order* of the *Customer* and *Receive order* of the *Seller*. In spite each business process is consistent against its temporal constraints, the IOBP does not intrinsically guarantee the satisfaction of the whole temporal constraints such as those related to deadlines. We see significant potential in proposing a consistency analysis approach. Indeed, it is clear that considering temporal constraints of the example while respecting process deadlines is a fastidious and error prone task.

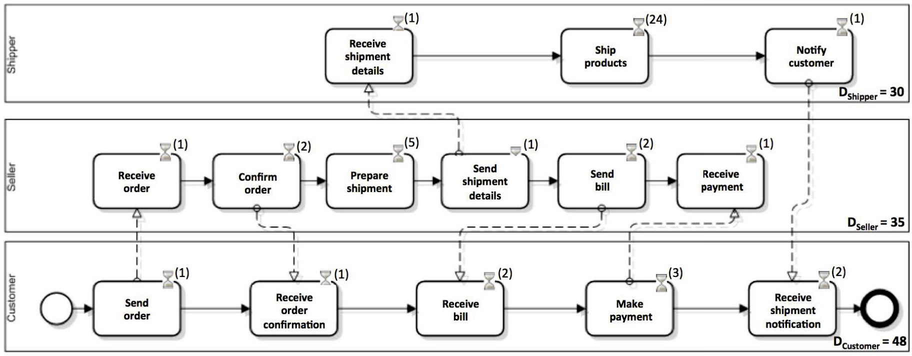

Fig. 1. Web shopping collaboration

3 Consistency Analysis of Inter-Organisational Business Processes

Given the problem description in terms of an IOBP; a set of communicating processes; enriched with a set of temporal constraints, the aim of the consistency analysis approach proposed in this paper is to verify temporal consistency of IOBP. We first describe the formalism of timed graphs, then we present the consistency checking steps that we propose.

3.1 Timed Business Process Modelling

As the basic modeling formalism we use *timed graphs* proposed in [1,2]. Fig. 2 shows the representation of a node with its duration, its earliest possible start and latest allowed end values.

Activity Name (Ai)	**Activity Duration (Ai.d)**
Earliest Possible Start (Ai.eps)	Latest Allowed End (Ai.lae)

Fig. 2. An activity node in the timed graph

In the sequel of the paper, we refer to activities of the motivating example with abbreviations using first letters' name of activities (eg. RSD to denote *Receive shipment details*). Fig. 3 exhibits the timed graphs of the processes of different partners involved in the motivating example, namely the *Shipper* (P_{Ship}), the *Seller* (P_{Sel}) and the *Customer* (P_{Cust}) processes. For more details about the calculation of the timed graph, we refer the reader to [1,2].

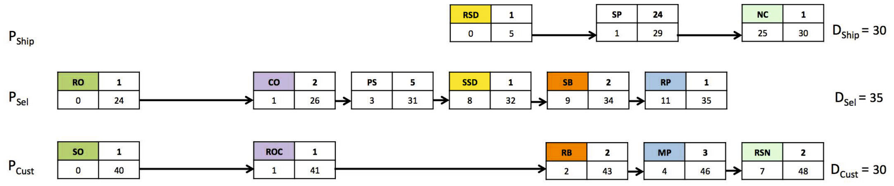

Fig. 3. Timed graphs of the *Shipper*, the *Seller* and the *Customer* processes

3.2 Consistency Checking Steps

The proposed approach consists in two steps.

-Analysing consistency of pairwise processes (Step 1) In order to check if **two processes** are temporally consistent, it must be checked if the execution intervals of both communicating activities overlap [2]. Hence, in order to check the temporal consistency of two communicating activities it must be checked if there is any temporal interval in which both activities can execute. In this context, we assume that the communication time is very small, thus, it is negligible.

$P_i \leftrightarrow P_j$[1] denotes that P_i and P_j are two processes exchanging at least one message, say between activities A_i and A_j. From the calcultaed timed graphs of both processes, we can deduce $A_i.[A_i.eps, A_i.lae]$ and $A_j.[A_j.eps, A_j.lae]$. In order to ensure that both P_i and P_j are consistent, we should ensure that the execution interval of all communicating activities, for instance A_i and A_j overlap [2].

Consider now clock C_i which is reset on the starting time of process P_i. Consequently, according to C_i, P_j should start executing on a time lag $x \in {P_j}_{/C_i}$. ${P_j}_{/C_i}$ denotes the interval delimiting the starting time of process P_j according to clock C_i while considering only direct communications between P_i and P_j. This time lag will shift the execution window of the communicating activity,A_j to be $A_j.[A_j.eps + x, A_j.lae + x]$. The condition of consistency is :

$$[A_j.eps + x, A_j.lae + x] \bigcap [A_i.eps, A_i.lae] \neq \emptyset \quad (1)$$

Let $x \in {P_j}_{/C_i}$ be the set of solutions satisfying the consistency condition (Eq.1).

$$ {P_j}_{/C_i} = \begin{cases} [min_{ji}, max_{ji}] = [A_i.eps - A_j.lae, A_i.lae - A_j.eps] \neq \emptyset & (2.a) \\ \emptyset & (2.b) \end{cases} $$

If there is an overlap of the execution interval of communicating activities, namely A_i and A_j, those activities are temporally consistent (Eq. 2.a). Otherwise, A_i and A_j are temporally inconsistent (Eq. 2.b). Namely, in order to decide if processes P_i and P_j are temporally consistent, all pairs of communicating activities, must be temporally consistent[2].

Conversely, if we consider C_j which is reset on the starting time of process P_j. We should find the following :

[1] Equivalent to $P_j \leftrightarrow P_i$ because $\leftrightarrow$ is commutative.

$$P_{i/C_j} = \begin{cases} [min_{ij}, max_{ij}] = [-max_{ji}, -min_{ji}] & \text{if } P_{j/C_i} \neq \emptyset \\ \emptyset & \text{otherwise.} \end{cases} \quad (3)$$

Starting from a set of processes, namely three processes P_i, P_j, and P_k. The output of *step 1* consists in bringing out the starting time bounds of each pairwise communicating timed processes. as follows :

$$\forall \{l, m\} \subset \{i, j, k\},\ P_{l/C_m} \text{ is computed.}$$

Step 1 is considered to be *completed successfully* iff $\forall \{l, m\} \subset \{i, j, k\}$, $P_{l/C_m} \neq \emptyset$ and *not completed successfully* otherwise.

As an example, let's consider the timed graphs of the shipper (P_{Ship}), the seller (P_{Sel}), and the customer (P_{Cust}) processes of the motivating example as depicted in Fig. 3. We are mainly interested in communicating activities, namely activities that are sender or receiver of the same message e.g. activities "Send order" (SO) of customer and "receive order" (RO) of seller (denoted ($SO \leftrightarrow RO$)) In the following, we apply Step 1 of the approach on pairwise communicating processes of the motivating example.

- $P_{Cust} \leftrightarrow P_{Sel}$:
  ($SO \leftrightarrow RO$) : $SO.[0 + x, 40 + x] \bigcap RO.[0, 24] \neq \emptyset$ then $x \in [-40, 24]$
  ($ROC \leftrightarrow CO$) : $ROC.[1 + x, 41 + x] \bigcap CO.[1, 26] \neq \emptyset$ then $x \in [-40, 25]$
  ($SB \leftrightarrow RB$) : $RB.[2 + x, 43 + x] \bigcap SB.[9, 34] \neq \emptyset$ then $x \in [-34, 32]$
  ($MP \leftrightarrow RP$): $MP.[4 + x, 46 + x] \bigcap RP.[11, 35] \neq \emptyset$ then $x \in [-35, 31]$
  Hence, $P_{Cust/C_{Sel}} = [-34, 24]$ (i.e. $[-40, 24] \bigcap [-40, 25] \bigcap [-34, 32] \bigcap [-35, 31]$)
- the same applies to $P_{Ship} \leftrightarrow P_{Sel} = [3, 32]$ and $P_{Ship} \leftrightarrow P_{Cust} = [-23, 23]$.

For example, the interval $P_{Cust/C_{Sel}} = [-34, 24]$ limits the starting time of the Customer process P_{Cust} to start not earlier than 34 hours before and no later than 24 hours after the starting time of the Seller process P_{Sel}. Assume then that the process P_{Sel} starts at time point 0 and P_{Cust} starts at time point -21 which means that this latter starts execution 21 hours before the process P_{Sel} starts. Since $-21 \in [-34, 24]$, the two processes suceed all their communication and hence they are consistent. Indeed, considering these latter starting times, we have $RO.[0, 24] \bigcap SO.[-21, 19] \neq \emptyset$, $CO.[1, 26] \bigcap ROC.[-20, 20] \neq \emptyset$, $SB.[9, 34] \bigcap RB.[-19, 13] \neq \emptyset$, and $RP.[11, 35] \bigcap MP.[-17, 25] \neq \emptyset$. Nevertheless, if the process P_{Cust} begins 26 hours after the starting time of process P_{Sel}, we obtain, $RO.[0, 24]$ and $SO.[26, 66]$. It is clear that $[0, 24] \bigcap [26, 66] = \emptyset$, and the two processes are not consistent since $26 \notin P_{Cust/C_{Sel}} = [-34, 24]$.
Step 1 is considered to be *completed successfully* since $\forall \{l, m\} \subset \{Ship, Sel, Cust\}$, $P_{l/C_m} \neq \emptyset$ (see Eq. 3).

Step 1 of our consistency approach considers only direct communication links between processes. For instance, given direct comminications between processes P_j and P_i one the one hand and between P_k and P_i on the other. *Step 1* computes the starting times of P_j (P_{j/C_i}) and P_k (resp. P_{k/C_i}) related to the starting time of P_i. In such a way, we have not yet considered the indirect communication between P_j and P_k; for the calculation of both P_{j/C_i} and P_{k/C_i}. Supposing at least one communication between processes P_j and P_k, additional calculations must be performed in order to adjust the intervals P_{j/C_i} and P_{k/C_i} accordingly; which will be the main focus of *Step 2*.

- Analyzing consistency of multiple processes (Step 2)

The aim of *Step 2* is to gather solutions for temporal inconsistencies while considering all involved processes in the IOBP (i.e. all communications between the processes). Indeed, it provides a set of constraints on the starting time of processes such that if each process satisfies the constraint, the whole collaboration is still possible to be successfully carried out. *Step 2* requires that *Step 1* be *completed successfully*.

In an inter-organisational business process, we can deduce implicit temporal relations beyond those resulting from direct communications between P_j and P_i. We argue that the communication between processes P_j and P_k, has an impact on both time intervals P_{j/C_i} and P_{k/C_i}.

In our approach, the transitivity behavior of the temporal relationships introduced by Allen in [4] helps to deduce a new interval P'_{j/C_i} from the two intervals P_{j/C_k} and P_{k/C_i} (the result of Step1). P'_{j/C_i} denotes the interval delimiting the starting time of process P_j related to the start of process P_i (related to clock C_i) while considering **indirect communication links** between processes P_i and P_j (precisely, the communication between P_j and P_k and between P_k and P_i). Given $P_{j/C_k} = [min_{jk}, max_{jk}]$ and $P_{k/C_i} = [min_{ki}, max_{ki}]$, P'_{j/C_i} is calculated as follows: $P'_{j/C_i} = [min_{jk} + min_{ki}, max_{jk} + max_{ki}]$.

As a result, we introduce P^{IOBP}_{j/C_i} to denote the resulting interval delimiting the starting time of process P_j regarding the starting time of process P_i while considering **both direct and indirect communication links** as follows :

$$P^{IOBP}_{j/C_i} = P_{j/C_i} \bigcap P'_{j\ /C_i} \quad (4)$$

Given processes P_i, P_j, and P_k on which we have already conducted *Step 1* of the approach. The output of *step 2* of our algorithm consists in bringing out the starting time bounds of each process P_l regarding another process P_m while considering all communication links between P_i, P_j, and P_k as follows :

$$\forall \{l, m\} \subset \{i, j, k\},\ P^{IOBP}_{l/C_m} \text{ is computed.}$$

Consider again the timed graphs of the shipper (P_{Ship}), the seller (P_{Sel}), and the customer (P_{Cust}) processes of the motivating example as depicted in Fig. 3. Provided also with the starting time intervals resulting from *Step 1* of our approach, namely, $P_{Ship/C_{Sel}} = [3, 32]$, $P_{Cust/C_{Sel}} = [-34, 24]$, and $P_{Ship/C_{Cust}} = [-23, 23]$. Let's conduct now *Step 2* of the approach.
$P^{IOBP}_{Ship\ /C_{Sel}} = P_{Ship/C_{Sel}} \bigcap P'_{Ship/C_{Sel}} = [3, 32] \bigcap [-57, 47] = [3, 32]$. ($P'_{Ship/C_{Sel}} = [-57, 47] = [-23-34, 23+24]$ deduced from $P_{Ship/C_{Cust}} = [-23, 23]$ and $P_{Cust/C_{Sel}} = [-34, 24]$). The same applies to $P^{IOBP}_{Cust\ /C_{Sel}} = [-20, 24]$.

Step 2 of the proposed approach has tightened the intervals $P_{Cust/C_{Sel}} = [-34, 24]$ to be $P^{IOBP}_{Cust\ /C_{Sel}} = [-20, 24]$ and has no impact on $P_{Ship/C_{Sel}}$ since $P^{IOBP}_{Ship\ /C_{Sel}} = [3, 32]$. The aim behind Step 2 is to omit some starting time points leading to consistent pairwise processes while considering only direct communication links between processes but fail to ensure consistent IOBP. Let's analyze the consistency of the IOBP after conducting Step 2 on the motivating example for the same starting time points presented above (suppose that P_{Sel} starts at time point 0 and P_{Cust} starts at time point -21). As argued in Step 1, P_{Sel} and P_{Cust} are consistent since all execution intervals of their communicating activities overlap. Neverthless, these starting times fail eventual communications between P_{Ship} and P_{Cust}. Given $P^{IOBP}_{Ship\ /C_{Sel}} = [3, 32]$, the execution time window of the activity *Notify Customer* (NC) balance between NC.[28, 33] (for the starting time 3) and NC.[57, 62] (for the starting time 32) and there is no eventual overlap with RSN.[-14, 27]. Hence, we can conclude that P_{Ship} and P_{Cust} are not consistent and the IOBP is not consistent anymore. If we consider now the intervals resulting from Step2, the proposed approach ensures that it exists starting time points leading to consistent inter-organisational business process. For instance, P_{Sel} starts at time point 0, P_{Ship} starts at time point 4, and P_{Cust} starts at time point -15. Indeed, all of execution intervals of all communicating activities of the IOBP overlap.

4 Related Work

The approach of Bettini et al. [5] provides temporal constraints reasoning and management tool offering the consistency checking of temporal requirements in workflows systems. Second, it monitors workflow activities and predicts their starting and ending time. Finally it provides the enactment service with useful temporal information for activity scheduling. Reluctantly, consistency algorithms have only been defined for activities of a single process and does not consider collaborative processes exchanging messages.

In [6,7,8,9,10], the authors use temporal properties in order to analyse the timed compatibility in Web service compositions. Several temporal conflicts are identified in asynchronous web service interactions. In this approach, the focus has been on the construction of a correct Web service composition using mediators. Nevertheless, the scope of this approach is limited to the verification of time constraints only caused by message interaction between services of the process.

In [11], Du et al. present a Petri net-based method to compose Web services by adding a mediation net to deal with message mismatches. Their approach implements both timed compatibility checking by generating modular timed state graphs. Compared to our work, they can only work at service level, and have limitation to cover the temporal dependencies of involved services in a business collaboration.

The approach proposed by Eder in [1,2] is closely related to ours since it uses the concept of timed graphs while analysing the consistency issue in inter-organisational collaborations. Nevertheless, this work is too restrictive since it assumes that both processes begin at the same time. Furthermore, only the case with two partners is considered.

5 Conclusion

In this paper, we proposed an approach aiming at discovering temporal inconsistencies that may constitute obstacles towards the interaction of business processes. Additionally, it gathers for solutions to resolve the temporal inconsistencies by providing each partner with temporal restrictions about the starting time of its processes in accordance with the overall temporal constraints of all involved processes. Consequently, as long as each process starts executing within the specified time period, the overall temporal constraints of the IOBP will be satisfied. Currently, we are working on a tool support for the proposed approach based on the Eclipse BPMN2 modeler.

References

1. Eder, J., Panagos, E., Rabinovich, M.I.: Time Constraints in Workflow Systems. In: Jarke, M., Oberweis, A. (eds.) CAiSE 1999. LNCS, vol. 1626, pp. 286–300. Springer, Heidelberg (1999)
2. Eder, J., Tahamtan, A.: Temporal Consistency of View Based Interorganizational Workflows. In: Kaschek, R., Kop, C., Steinberger, C., Fliedl, G. (eds.) Synchronization Techniques for Chaotic Commun. Syst. LNBIP, vol. 5, pp. 96–107. Springer, Heidelberg (2008)
3. van der Aalst, W.M.P., Weske, M.: The P2P Approach to Interorganizational Workflows. In: Dittrich, K.R., Geppert, A., Norrie, M. C. (eds.) CAiSE 2001. LNCS, vol. 2068, pp. 140–156. Springer, Heidelberg (2001)
4. Allen, J.F.: Maintaining knowledge about temporal intervals. Communications of the ACM 26(11), 832–843 (1983)
5. Bettini, C., Wang, X.S., Jajodia, S.: Temporal Reasoning in Workflow Systems. Distributed and Parallel Databases (2002)
6. Guermouche, N., Godart, C.: Timed Conversational Protocol Based Approach for Web Services Analysis. In: Maglio, P.P., Weske, M., Yang, J., Fantinato, M. (eds.) ICSOC 2010. LNCS, vol. 6470, pp. 603–611. Springer, Heidelberg (2010)
7. Guermouche, N., Godart, C.: Timed model checking based approach for web services analysis. In: ICWS. IEEE CS (2009)
8. Cheikhrouhou, S., Kallel, S., Guermouche, N., Jmaiel, M.: Enhancing Formal Specification and Verification of Temporal Constraints in Business Processes. In: Proceedings of the 11th IEEE International Conference on Services Computing (SCC). IEEE Computer Society (2014)
9. Kallel, S., Charfi, A., Dinkelaker, T., Mezini, M., Jmaiel, M.: Specifying and Monitoring Temporal Properties in Web Services Compositions. In: ECOWS. IEEE CS (2009)
10. Guidara, I., Guermouche, N., Chaari, T., Tazi, S., Jmaiel, M.: Pruning Based Service Selection Approach under Qos and Temporal Constraints. In: ICWS. IEEE CS (2014)
11. Du, Y., Tan, W., Zhou, M.: Timed compatibility analysis of web service composition: A modular approach based on petri nets. IEEE Transaction on Automation Science and Engineering (2014)