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ORIGINAL RESEARCH PAPER

The temporal perspective in business process modeling: a survey and research challenges

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Abstract One key perspective when dealing with business process management is time. All business experts agree upon the fact that time is a key resource for processes within organisations. Indeed, time managing is an effective cost reduction strategy and thus ensures profit maximization for organisations. As a result, business managers, researchers, and academicians in management are striving to have full-support of temporal aspects in current business process management suites. Consequently, modeling and managing temporal requirements in the business process field is becoming a topic of intensive research. This paper presents a survey of the existing approaches to specifying and verifying the temporal perspective in business processes. Furthermore, this paper provides a critical and comparative analysis of the studied approaches and stands out major challenges to be addressed to substantially enhance the time management in the business process management field.

Keywords Temporal constraints and dependencies · Business process modeling (BPM) · Workflow · Web service composition · Inter-organizational business process (IOBP)

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1 Introduction

Business is migrating from business-to-consumer (B2C) applications to business-to-business (B2B) ones in order to deal with the ever increasing economic pressure and to enhance the overall competitiveness. When addressing the issue of B2B, one organisation may collaborate with many others with complementary skills to form an inter-organizational business process (IOBP). For instance, the emergence of the IOBP field gave already a major contribution to the aeronautic sector, in which more than 50 % of the supply chain is sub-contracted. Furthermore, the aeronautic sector's strategy is migrating from one-tier sub-contractor to an important number of sub-contractors with a distributed control over the different sub-contracting processes (eg. A given organisation, say A, subcontracts its subprocesses to other organisations, say B1 and B2. Similarly, B1 and B2 rely on other subcontractors such as C1, C2, and C3 to achieve their processes).

In this context, the temporal perspective is crucial since temporal constraints must be respected. All business experts agree upon the fact that time is a key resource for processes within organisations. Satisfying time constraints such as time deadlines is vital for the processes of the aviation industry, since the violation of such constraints may lead to critical situations and could even threaten the aviation safety. Nevertheless, such systems are lacking in an effective management of temporal constraints. A temporal constraint is a condition for controlling the system behavior over time. It specifies restrictions that occur across time [9,26]. Temporal constraints play a crucial role in the business process development and management. Consider the following example of temporal constraints:

An Aircraft Manufacturer, say organisation A of the aforementioned example, could cancel a submitted order to one of its contractors, say organisation B1. Nevertheless, once the organisation B1 has triggered a subcontracting activity to organisation C1, the order cannot be cancelled anymore. Additionally, order modification is only allowed maximum 15 days after the order was received in maximum. Moreover, the Aircraft Manufacturer can not receive orders from 1st to the 8th of the month due to the availability of some resources. The activity Deliver goods of the Aircraft Manufacturer process have to start no later than 20th of the month once the process starts.

Different specification methods and verification techniques and tools have been developed to deal with such setting [5,22,27,40]. Nevertheless, the temporal resource management in business processes, especially in huge and collaborative processes as used in the aviation industry, is still a challenging research task. Several research questions still require answers:

How to explicitly model the different temporalities of the processes specifications to avoid their violation? How to verify temporal satisfiability of processes specifications? How to communicate temporal constraints between different partners of IOBPs for effective negotiations? How to efficiently stand out the elected partner in a collaboration (i.e. the best provider according to temporal constraints)? How to safely advertise the temporal data while preserving the partner privacy? How to correlate temporal constraints with other constraints such as data, and resource constraints?

This paper surveys the current state of the art in specifying and verifying the temporal perspective in business processes. But the main focus of this paper is the specification step. Few research attempts however have been made to carry the same overview of this research field (see, for instance [15,38]). Nevertheless, these overviews are not as focused as the one presented here since they do not elect time as a first time citizen in the business process modeling (BPM) phase. The work presented in [15] discusses the urgent need for service composition and surveys the different existing composition strategies and points out essential research challenges. The survey paper proposed in [38] gives a very general overview of the current state of the art of formal verification of real-time systems. For that issue, different specification languages and verification frameworks have been compared.While the existing survey papers give a general study of business processes, the overview made in our paper focuses on time-related specification and verification techniques currently used in the business process modeling area.

This paper is structured as follows. Section 2 gives an overview on the existing temporal constraints specification and verification methods in the business process field. Section 3 presents a rich evaluation and discussion. Section 4 highlights the emerging research challenges to address in the field of time management in business processes. Finally, Sect. 5 concludes.

2 Overview on the existing temporal constraints specification methods

As a first step of this work, we give a classification of the existing temporal constraints models. Mainly, the studied approaches are collected from three research areas: workflows, Web service composition, and inter-organizational domain. These research areas can be generalized and seen from a business process field perspective.

2.1 Temporal constraints in the workflow research field

The major contribution of Time-BPMN [20], is the extension of business process modeling notation (BPMN) [36] with a large set of required temporalities. This extension deals with additional temporal constraints and dependencies between business process activities. This work presents a classification of flexible and inflexible temporal constraints (eg. As Soon as Possible and As Late as Possible) and temporal dependencies (eg. Start-to-Finish and Start-to-Start). This extension does not permit to model temporal constraints relating to the duration of the business process activities (eg. A given activity lasts x time units and x may be limited by a certain interval). Time-BPMN [20] is limited to the specification phase since no verification mechanism of temporal constraints conflicts is provided.

The work presented in [40] proposes a formal specification of BPMN [36] with timed automata. First, the authors extend BPMN to handle temporal constraints (i.e., the minimum and maximum execution time of a task), resource constraints, and concurrency constraints (i.e., the number of instances executable in parallel). Second, they provide an automatic mapping of the extended BPMN onto timed automata. Computation tree logic (CTL) formulas are used to specify the different properties to be verified by the UPPAAL model checker. This approach aims at verifying some features, such as deadlocks and bottlenecks. The scope of this paper is limited to a small subset of BPMN elements. Additionally, this BPMN extension permits to specify temporal constraints related to only one activity within the business process model and does not consider timed properties related to a set of activities, such as inter-activities temporal constraints.

Huai et al. [24] present a method for verifying BPMN [36] models based on time Petri nets. The proposed method supports the analysis of model structure (dead task, deadlock and infinite loops) and tests the time conflicts of the model. First, the authors translate the BPMN model to time Petri nets. Second, they construct the reachability graph of the

Petri nets in order to verify the model structure. Furthermore, they exhibit the time choreography verification algorithm to verify time conflicts. The proposed algorithm proceeds by the accumulation of clock constraints of terminated activities and assigns them to the corresponding activated activities within the tested path. This work presents the advantage that clock constraints are propagated to tasks and message flows, which makes explicit the implicit timed conflicts due to service interaction. In addition, time choreography verification algorithm supports the case where the business process activities are not connected in sequence order. In this proposal, the authors intend to formally specify the temporally-constrained model with time Petri nets without adding any temporal information to the BPMN model itself. The first limitation is related to the lack of temporal dependencies between multiple activities of the business process, which makes the proposed time choreography verification algorithm very limited. In addition, this work stresses the need to differentiate between the model structure analysis and the time conflict analysis.

The major contributions of the approach cited in [14] is that it can dynamically check the temporal violations of multiple concurrent workflow processes with resource constraints. First, the authors construct the sprouting graph models of the time workflow nets (TWF-nets) [29] for multiple workflow processes. Second, they update the sprouting graph at different checking points and check the temporal constraints. Finally, and most importantly, the violation paths and solutions (by modifying the duration of some activities) are given. Moreover, they use the UPPAAL model checker to verify the correctness of their approach. This work verifies only temporal constraints of this form: an activity a_j should end its execution no later than x time units after the activity a_i starts. If there is a conflict among temporal constraints, this paper does not offer any solution. The complexity of the construction of the sprouting graph becomes high when the number of resource constraints increases. This is identified as the major weakness of this approach.

In [31,32], Lu et al. model flexible business processes in which part of process modeling decisions are entrusted to domain experts who make execution decisions at runtime. For example, in a flexible selling process, sales representative can decide to execute only one or more activities to fulfil the request processing goals. Additionally, there exist many possible combinations of selected activities. The adaptation of a process instance is governed by selection constraints (i.e. to select what tasks to perform) as well as scheduling constraints (i.e. how these selected tasks are executed, e.g., order of execution, in sequence or parallel). In [31], the authors present how to specify the selection constraints. The quality of the constraint specification is checked through the formal machinery of selection constraint network. For this purpose, the Ad-Hoc Sub-Process of the BPMN notation is used to model the dynamic parts of the workflow. In addition, the scheduling constraints are the focus of the work detailed in [32]. In this latter, scheduling constraints between tasks of the business process are modeled with Business Process Constraint Network (BPCN). This paper seeks to explore the consistency of BPCN by providing a Path-Consistency Algorithm.

In the same context, the DECLARE approach [37] also aims at supporting instance-level process adaptation by defining a set of workflow constraints to regulate flexible changes. The authors of the DECLARE tool introduce a constraint-based process modeling language *ConDec* which is based on Linear Temporal Logic (LTL) formula. This language uses an open set of constraint templates to define relations between the business process activities. The use of LTL formula limits the scope of the modeled temporal dependencies of activities. Indeed, LTL formula can not express fixed durations separating two given activities. Furthermore, the approach lacks for mechanisms to verify possible conflicting combination of constraints.

In [35], the authors try to graphically and formally model the absolute and relative deadline constraints. Relative deadline constraints refer to the fact that a task a_j should start no later than x time after task a_i finishes. Furthermore, the above mentioned work detailed a dynamic verification mechanism of the specified absolute and relative deadline constraints. To cope with that issue, a set of control points are selected from the execution phase for the verification of each temporal constraint. The time perspective modelisation detailed in this work is very limited since the modeled constraints are separated from the workflow model. Furthermore, we should point out that this approach models atomic constraint whilst multiple constraints could coexist together. Consequently, the approach can not verify multiple constraints nor time conflicts occurring between these constraints.

The particularity of the approach of Bettini et al. [5] is that it merges several research directions on temporal workflow models and on temporal constraint networks. Regarding the model of temporal constraints, Temporal Constraint with Granularity (TCG) graph is used. In this latter, every task of a workflow is represented by two nodes, corresponding to the start and the end times of the considered task. Furthermore, the edges are labeled with an interval representing the allowed time distances between the connected nodes. Additionally, this paper provides temporal constraints reasoning and management tool offering the following services: first, it checks the consistency of complex temporal requirements. 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. A schedule is said to be free when it is possible to statically fix the start times of all tasks of the workflow without constraining their durations.

Time modeling and management in the clinical workflow domain has been widely investigated by Combi et al. [10–12]. In [10], the authors propose a general conceptual workflow model considering both activities and their temporal properties. Among the proposed temporal constructs, we can notice: the duration (the activity duration) and delays (the edge duration), the relative constraints, the absolute constraints, and the periodic constraints. Based on these constructs, the authors developed a tool named Temporal Workflow Analyzer (TWA) to support workflow modeling at workflow design time.

2.2 Temporal constraints in web service composition research field

Previously, we have presented existing time specification approaches in the field of workflows. This section covers the basics of temporal constraints specification and verification approaches in the web service composition research field.

The authors in [27] address the problem of qualitative and quantitative analysis of timing aspects of Web service compositions. To capture the timing aspects of BPEL4WS processes, the Web Service Timed State Transition Systems (WSTTS) formalism is introduced in [28]. For the verification, they use the NuSMV model checker. The authors verify the composition against a large set of temporal properties such as deadlock and the termination of the procedure within a given delay. Furthermore, the approach aims at calculating the maximal and minimal duration time of the process. This work has the advantage not only to check whether a certain time-related requirement is satisfied, but also to compute extreme time bounds that satisfy such requirement. Nevertheless, considering only timing aspects of BPEL4WS processes limits the mentioned approach to the service oriented research field. Verifying the timing requirements on the model (exp. BPMN) results in a generalized approach applicable to a service oriented implementation as well as to other possible implementations.

The approach proposed in [25] covers the specification of temporal constraints for the web service domain using a new proposed language, XTUS-Automata. In the specification phase, this work presents temporal specification patterns (i.e. patterns for duration properties, pattern for temporal properties over cardinalities, and pattern for absolute time properties). This work combines timed automata (TA) and extended time unit system (XTUS) to allow specifying temporal properties involving relative time as well as absolute time. Furthermore, this work conducts a formal verification of deadlock using the model checker UPPAAL. Finally, it presents an aspect-based monitoring mechanism, in which formally specified temporal constraints are translated automatically to modular aspect code in the aspect-oriented workflow language AO4BPEL. It is worth noting that this paper offers interesting specification patterns by which we can cover a large set of real world workflow temporal constraints. For instance, the proposed patterns enable the designer to use time variables, obtained from the parameters of the exchanged messages, in the specified temporal constraints. Nevertheless, this work is unable to verify the existence of temporal constraint conflicts.

In [22], the author uses temporal properties in order to analyze the compatibility in Web service composition. A formal model abstracting messages, data, data constraints as well as temporal constraints, based on timed automata is proposed. Based on the defined model, the UPPAAL model checker was used to detect some structural problems due to temporal conflicts. So far in this approach, the focus has been the construction of a correct web service composition. For this end, a mediator is generated, whenever it is possible, to overcome the web service collaboration incompatibility issues. The clock ordering process is used to verify deadlock freeness due to time constraints conflicts. Nevertheless, the scope of this paper is limited to the verification of time constraints only caused by message interaction between services of the process.

In [23], the authors propose a framework to check temporal requirements on choreographies. This is achieved by the verification of the composed annotated BPEL processes. This work enables efficiently to specify time constraints such as estimated execution time of activities and temporal delay between two activities or messages. Furthermore complex temporal requirements could be expressed. For instance, the absence pattern with delay (exp. A given activity a_j can not occur between a duration of time after the occurrence of an activity a_i) and the response pattern with delay (exp. Every occurrence of an event e1 must be preceded by an occurrence of an event e2 within a time interval). The timed business processes are automatically translated into the formal modeling language, Fiacre [3]. An automatic mapping tool from BPEL timed processes into Fiacre specification is provided for that aim. The TIme petri Net Analyzer (TINA) [4] model checker tool is used for complex real-time requirements automatic checking. This work has the advantage of supporting synchronous as well as asynchronous services. This work has attempted to provide a modeling environment inspired from BPMN to visually specify the temporal requirements. Nevertheless, in this work, the authors does not consider the type of properties.

Benatallah et al. have widely invested in checking compatibility and replaceability analysis in timed protocols of web services [1,2]. The approach detailed in [1] models business protocols as deterministic finite state machines. The scope of this work is limited to synchronous services and temporal requirements can only be associated to messages inside the same service.

Many research has been conducted on QoS-aware service composition. Service composition (or Web service composition) is the task of combining services together to create a more complex, value-added composite service. QoS is a broad concept that encompasses a set of non functional properties, such as response time, throughput, and availability. Many algorithms have been proposed to solve the service composition problem by trying to achieve the optimal solution that satisfies QoS requirements while satisfying the functional goal. Approaches like [13,42] focus particularly on time-related QoS attributes. Indeed, Xu et al. [42] proposed an algorithm that can efficiently build service compositions with minimal response time and maximal throughput. The particularity of the approach detailed in [42] is that, it permits to handle a large-scale service composition in a very short time. We must not lose sight of research approaches which focus on the time-based scheduling problem such as [39]. This latter elaborates allocation and scheduling of shared service resources (i.e. service resources are allocated to multiple requirements with the specified quantities and scheduling).

2.3 Temporal constraints in the inter-organizational research field

This subsection is dedicated to explaining research attempts to specify and verify temporal constraints in IOBPs, crossing the organizational boundaries.

Eder et al. [17] focuses on checking temporal consistency in interorganizational workflows. In this context each organization contributes to the interorganizational workflow through its process view. Process views are a prevalent modeling approach for interorganizational workflows. They include a subset of the activities of the organizational private workflow needed for collaboration. Indeed, it allows to organisations to well interact with others while preserving their organizational privacy. The proposed approach checks if the interorganizational workflow is temporally consistent by checking if its participating views are temporally consistent. The authors assume that two views are temporally consistent if the execution intervals of both corresponding activities overlap. Corresponding activities are activities that communicate together (i.e. activities that are sender or receiver of the same message). To check the temporal consistency of two corresponding activities, it must be checked if it exists any temporal interval in which both activities can be executed. For that, the authors use the concept of temporal plans and use timed activity graphs as the basic modeling language. Once the duration of each activity of the workflow is fixed, the different earliest possible start values and the latest allowed end values are calculated. For their classification, the authors differentiate between the best and the worst cases. It is clear that assuming that the different activities of the workflow have a deterministic duration is quite restrictive. Additionally, this approach enables to specify only deadline constraint temporal dependencies between activities of the process. By checking only the corresponding activities of the different views, the authors implicitly suppose that the temporal constraints are synchronized based on message synchronization which is not always true because the views may not start executing at the same time and thus it is insufficient to compare only the intervals of the corresponding activities. In addition, the authors do not mention any other issue for full consistency like messaging conformance, data flow conformance or structural conformance.

Time conformance has been studied by Eder and Tahamtan in [16]. It consists in checking whether a timed orchestration satisfies a timed choreography by generating temporal execution plans. The temporal plans calculation comes from the operations research field and represents valid execution intervals of the activities of both orchestrations and choreographies. The algorithm calculating the timed graphs and checking temporal conformance is detailed in [16]. For each iteration, the algorithm proceeds by calculating the temporal graph whilst allows for checking if the conformance condition is met. The conformance condition verifies that for each activity the sum of its earliest possible start and its duration must be less or equal to its latest allowed end for both best and worst cases. The durations of activities are presented by deterministic values which limits the scope of this work. The authors do not consider temporal constraints crossing the boundary of an activity or event-related temporal constraints.

In the context of Inter-Organizational Workflows, [34] proposes the CoopFlow approach. It deals with the deadline constraints conformance verification without exposing the private processes of the involved partners. The authors demonstrate how missing deadlines while delivering the required services may cause a global failure execution, even if the business behavior complementarity of the involved services is ensured. Based on the CoopFlow approach and using Time Petri nets theory, the authors propose a method for modeling and advertising temporal requirements for cooperative activities on the abstracted version of business processes by using observers. In fact, they prove that a deadline local verification process executed by a partner can lead to a deadline conformance in the resulting interconnected workflow. However, several limitations need to be considered.

1. In this paper, no method is proposed for the deadline local verification process. i.e., the authors always suppose that the temporal workflow of the second partner has not violated any time constraint of the abstracted temporal workflow of the first one but they do not provide any means to ensure this verification.
2. This work is restricted to acyclic Petri nets (without loops or cycles).

3. Deadline constraints are added only between cooperative activities (which are visible by the cooperation candidates) but not between two private activities or between one private and one cooperative activity.
4. This work allows modeling and advertising only one deadline constraint per workflow. Therefore, the deadline constraint is limited to measuring the allowed time distance between two activities a_i and a_j.

The authors in [33] discuss the application of Inter-Organizational Workflows (IOW) for automating processes in the collaborative context. A case study of emergency healthcare is presented in order to show the feasibility of the proposed temporal extension of the CoopFlow approach detailed in [34]. This paper presents a proof of concept for automating the temporal conformance process in CoopFlow. The authors noticed the use of TIme petri Net Analyzer (TINA) [4] and Little Parametric Tool (LPT) tools [21] for verification purposes. Nevertheless, no more details concerning the verification are provided. Throughout this paper, the authors focused on mentioning negotiation aspects of temporal constraints in the presented case study but no negotiation strategy is detailed.

The approach proposed in [19] considers the modeling and the verification of process constraints related to quality management using process patterns. (ex. Every execution of an activity a_i must be preceded or followed (resp directly preceded or directly followed) by an execution of an activity a_j.) The authors have already provided in [18] a process pattern definition language; i.e., the Process Pattern Specification Language (PPSL); to visually model the corresponding constraints. Furthermore, a translation of the PPSL models into temporal logic is ensured. In parallel, the labeled transition system (LTS) is generated from the business process model. Finally, the temporal logic formulas are checked against the LTS representation by the NuSMV model checker. An Eclipse plugin is offered as a tool support for the specification and the verification of these quality constraints.

3 Evaluation and discussion

Throughout this survey paper, we provide a representative overview of the major efforts of time management in the business process field. The evaluation results are presented respectively in Tables 1, 2, and 3. Space limitations prevent presenting all the approaches discussed above, so we have omitted some of them being only focusing on a very limited scope of time management. Table 1 presents an attempt to compare existing research approaches with regard to the supported temporal constraints. Indeed, we identified three major categories of temporal constraints:

1. *Intra-activity temporal constraints:* Temporal constraints (TC) associated to activities within business process models such as : activity duration, start/end activity (temporal constraints associated to start and end events of activities) and cardinality temporal constraints.
2. *Inter-activity and Inter-Event temporal constraints:* Temporal constraints crossing the boundary of an activity or an event. We can mention, for instance, the *Temporal Dependency* (a temporal relationship between two activities is in which one activity depends on the start or finish of another activity in order to begin or to end), the *Absence Constraint*, and the *Business process deadline*.
3. *Inter-Processes temporal constraints or Collaborative temporal constraints:* Temporal constraints crossing the boundary of one process. For example, the *Deadline of message exchange*, the *Exchanged Temporal data* (i.e. these temporal data are exchanged between processes involved in a collaboration), and the *TC correlated with resource constraints*.

Table 2 highlights the different characteristics of each approach according to the following criteria:

1. *How temporal requirements are modeled within the approach?* Eg. the standard BPMN, the TWF-nets, etc.
2. *What properties against which the business process is verified?* Eg. the structural properties (i.e. the analysis of dead tasks, bottlenecks, deadlocks and loops), the time conflicts of the model, the user-defined temporal constraints (exp. the deadline constraints and the absence constraint), etc.
3. *How this verification is proceeded?* Eg. model checker tools, algorithms, etc.

Table 3 summarizes the relative advantages and disadvantages of each discussed approach.

Based on the above observations, we identified that most of the already studied constraints include the temporal perspective. The temporal constraints are usually correlated with other constraints such as data [22] and resource constraints [14,40]. Notably, in the constraint-based process models, we can find scheduling constraints associated with selection constraints [31,32]. Consequently, there have been several attempts to model the different constraints in the business process diagram itself using the defacto industrial standard for business process modeling, BPMN [20,23]. The use of a graph-based modeling approach of business processes as BPMN, is a competitive advantage. Indeed, the visual appeal of the graph-based modeling approaches makes them useful for all kinds of workflow designers [30] (i.e. No technical background is required). Similarly, other research efforts [14,22,24,25,33,34] opted for formal specification languages with modeling capabilities such as Petri nets and

Table 1 A comparative table of the supported temporal constraints (TC) in the existing business process models

Approaches [Ref.]	Intra-activity TC			Inter-activity and inter-event TC			Inter-processes TC or collaborative TC		
	Duration of activities	Start/end activity TC	TC over cardinality	Temporal dependency	The absence constraint	Business process deadline	Deadline of message exchange	Exchanged temporal data	TC correlated with resource constraints
Gagné et al. [20]		√		√					
Watahiki et al. [40]	√								
Huai et al. [24]	√						√		
Du et al. [14]	√								√
Kazhamiakin et al. [27]	√			√		√	√		
Kallel et al. [25]			√	√			√	√	
Guermouche [22]				√		√			
Eder et al. [16,17]	√	√				√			
Makni et al. [33,34]	√			√		√			
Guermouche et al. [23]	√			√	√		√		
Bettini et al. [5]	√			√					
Combi et al. [10–12]	√	√		√					
Wong et al. [41]	√								

Table 2 Evaluation—how existing research approaches model and verify the temporal constraints (TC)

Approaches [Ref.]	How TC are modeled?	What properties are verified?	How this verification is proceeded?
Gagné et al. [20]	BPMN		
Watahiki et al. [40]	BPMN + Timed Automata	Bottlenecks + deadlocks	UPPAAL model checker
Huai et al. [24]	Time Petri nets	Dead task + deadlock + infinite loops	The reachability graph of the Petri nets
		The time conflicts of the model	The time choreography verification algorithm
Du et al. [14]	Time workflow nets (TWF-net)	Duration between two activities less than s time units	Algorithms + UPPAAL model checker
Kazhamiakin et al. [27]	Web Service Timed State Transition Systems (WSTTS)	Deadlock + maximal and minimal duration of the process	Model checker NuSMV
Kallel et al. [25]	XTUS-Automata	Deadlock	UPPAAL model checker
Guermouche [22]	Timed Automata	Compatibility analysis of the web service choreography	Algorithms
		Deadlock	UPPAAL model checker
Eder et al. [16,17]	Timed activity graphs + time conformance	Temporal consistency + time conformance	Algorithms
Makni et al. [33,34]	Time Petri nets	Time conformance	TINA model checker and LPT
Guermouche et al. [23]	A modeling environment inspired from BPMN + the Fiacre specification	The absence constraint with delay	TINA model checker
		The response constraint with delay	
Bettini et al. [5]	Temporal constraint with granularity (TCG) graph	The consistency	Algorithms
Combi et al. [10–12]	A proposed conceptual workflow model	Temporal consistency	Algorithms
Wong et al. [41]	Communicating sequential processes (CSP)	Time compatibility	FDR model checker

Timed Automata. Whereas, other approaches like [41] opted for CSP as a process algebra language, which lacks for graphical support. The approach followed by Pesic et al. [37] is somewhat different from the others since it models the constraints apart from the business process model (eg. by LTL formulas). The approach cited in [31], for instance focuses

Table 3 Advantages and disadvantages of the existing research approaches

	Advantages	Disadvantages
Gagné et al. [20]	Rich specification of TC in BPMN	No formal specification is proposed
		No verification mechanism is provided
Watahiki et al. [40]	Extension of BPMN to handle TC	Only a small set of TC is supported
	Automatic mapping to a formal language is proposed	No solutions for detected temporal violations
	Verification mechanism is provided	The verification is limited to the structural properties of the process
Huai et al. [24]	Distinction between the model structure analysis and the time conflict analysis	Only a small set of TC are supported
		The scope of the time choreography verification algorithm is limited
Du et al. [14]	Support of shared resource constraints	The complexity of the algorithm becomes high when the number of resource constraints increases
	Violation paths and solutions are given	
Kazhamiakin et al. [27]	Rich verification approach	Limited application domain of the proposed approach
Kallel et al. [25]	New formal language is proposed	Unable to detect the temporal constraint conflicts
	Set of specification patterns are offered	
	Support of relative and absolute time specification	
Guermouche [22]	Solutions for temporal violations are proposed	Limited to the verification of time constraints caused by message exchange
Eder et al. [16,17]	Distinction between best and worst execution cases	Only a small set of TC is supported
Makni et al. [33,34]	Both modeling and advertising of TC for cooperative activities are supported	Many suppositions are not proved
Guermouche et al. [23]	Rich specification of TC inspired from BPMN	No consideration for the type of properties
Bettini et al. [5]	Monitoring of TC in workflow activities	Only a small set of TC is supported
	The starting and ending time of activities are predicted	
	Support of activity scheduling	
Combi et al. [10–12]	Support of relative and absolute time specification	No solutions for detected temporal violations
Wong et al. [41]	Mapping of BPMN onto a formal language is proposed	Only a small set of TC is supported

on constraint-based modeling approaches and it is interested in selection and scheduling constraints.

When considering the business process model itself, there are works that consider different constraints for one business process. Others take into account the cooperation between more than one business process both in the web service composition field and in the IOBP field. When addressing the issue of IOBP, it is inevitable to reason about the migration of the different constraints between the private and the public workflows. There are several ideas for further research especially in the IOBP field. We can, first focus on elaborating a generic modeling approach which supports different constraint modeling such as temporal constraints and other associated constraints, namely, resource and data constraints. When dealing with temporal constraints, we remarked the lack of absolute time constraints in the majority of the works. In addition to that, just one work has modeled time points obtained from the execution phase [25]. Some works have used constraints indicators like optional and mandatory but none of them has tried to prioritize constraints. Adding priorities especially to optional constraints can assist the designer in choosing the best business process (i.e. which violates optional constraints with lower priority) especially when different BP models are possible. Constraint prioritizing is more and more interesting when coping with constraints from different nature (temporal constraints, resource constraints, and data constraints) knowing that these constraints are implicitly interrelated. We propose to deal with sequence, choice and concurrency structures and thus adopting best and worst cases of execution.

We now turn our attention to the temporal requirements verification problem. Temporal verification mechanisms are of paramount importance since they enable to detect, early on, possible temporal conflicts and to react to them effectively.

In this context, although many efforts confound the time conflict verification of the model (i.e. the violation of some temporal requirements) with the structure verification (i.e. the analysis of dead tasks, bottlenecks, deadlocks and loops) [25,40], there are some works which have tried to differentiate the two verification processes [14,22,24]. To cope with the time conflict verification, there are some works which have neglected the intra-activity temporal requirements (eg. the duration of the modeled activities) [22]. On the other hand, there are some approaches which have neglected the inter-activity temporal dependencies [24,40]. Besides, the approach detailed in [14] has tried to include the two different temporal requirements. Additionally, there are some efforts concentrating on verifying other issues such as time conformance [16,34] and the absence constraint [23].

Once the verification process is conducted and a possible violation is detected, only few approaches [14,22] tried to detect erroneous paths and to propose solutions. So far, the approach detailed in [14] have presented a dynamic checking approach of temporal constraints for concurrent processes sharing resources. Indeed, they provide solutions to modify the duration of some activities to address the detected violations. Additionally, the author in [22] has considered the use of mediators when dealing with the compatibility analysis of the web service choreography. The idea of mediators proposed in [22] sounds very promising since it has succeeded in resolving a large set of temporal violations.

Typically, researchers in the field of time management in the business process field are invited to widen the set of possible solutions to temporal constraints violations. From the research directions that have to be considered, we can notice the modification of the allocation policy of the shared resources and the change of the overall business process structure arriving at the substitution of some activities.

Finally, we can proceed by monitoring or enforcing the different constraints in the execution phase. Another line of research is to study constraint-based business process models which offer design decisions at the execution time and enable different process variants.

4 Research challenges

Business managers, researchers, and academicians in management are striving to have full-support of temporal aspects in current business process management suites [6]. Obviously, modeling and managing temporal requirements has long been a topic of intensive researches. Hence, with the help of the critical and comprehensive analysis presented within this survey paper, we pointed out that this emerging research field still face a multitude of challenges. The succeeding listing illustrates the major challenges to be addressed to substantially enhance the time management in the business process management field:

– Proposing a business process model supporting the different temporal requirements beyond those illustrated in this paper [8]: to enable the specification of temporal constraints related to one activity as well to Ad-Hoc sub processes and concurrent business processes sharing resources and exchanging messages. It would be interesting to address the different deadline constraints, the constraints related to the start and end events of the business process activities, temporal constraints over cardinality, temporal points from the execution phase, etc.
– Improving the existing process view generation methods in order to define the mapping of a large set of temporal requirements from private to public process models [7].
– Defining a mapping mechanism from the business process model to a suitable formal language for future verification purposes. And if necessary, proposing a new formal language to well support the specification of all the temporal requirements.
– Investigating efficient verification approaches to diagnose potential temporal violations of the process model early enough. In this context, it is beneficial to verify the business process against several issues such as structural properties (i.e. the analysis of dead tasks, bottlenecks, deadlocks and loops), time conflicts of the model, user-defined temporal constraints (exp. the deadline constraints and the absence constraint) and time conformance of the IOBP (similarly the compatibility analysis in the web service field).
– Defining violation identification mechanisms and proposing relevant primitives, such as process adaptation, to resolve violations.
– When considering multiple temporal constraints, the designer may be eligible for multiple process diagrams. Choosing the suitable process model may not be so easy especially when there is no process model satisfying all the set of constraints at the same time. We admit that adding priorities to temporal constraints of the model might have merit. Indeed, higher priority may be assigned to urgent temporal constraints as in the aeronautic domain, the healthcare treatment domain, etc. Lower priority may be assigned to some temporal constraints of the model (e.g., temporal constraints which ultimate goal is no more than accelerating the process deadline as in some production or maintenance processes). Constraints prioritization allows the designer to identify the best process diagram for each case, provides earlier feedback and enables thus to foresee how each impacts process execution. In other words, it may be able to help the designer manage its processes more cost-effectively since he will be able to suggest changes at the modeling step early on before reaching the execution step.
– Following the temporal verification process, error detection presents a step toward achieving a conflict-free process model, especially for processes, which fail to meet their timing requirements. It would be interesting to also support error correction [14,22] , following the

error detection (i.e. the detection of the erroneous path or portion of the process model). As eventual error correction, we can notice the modification of the duration of some activities, the adaptation of the starting time of the process, releasing some non urgent temporal constraints (i.e., with lower priority), the use of mediators, the modification of the allocation policy of the shared resources and the change of the overall business process structure arriving at the substitution of some activities.

5 Conclusion

In this paper, we presented a survey on business processes specification and verification while considering the temporal perspective. To do so, we have analyzed and compared existing approaches for modeling and verifying time-related properties on business processes. Mainly, the studied approaches are collected from three research areas: workflows, Web service composition, and inter-organizational domain. We noticed that these research areas can be generalized and seen from a business process field perspective. Based on this study, we first gave a classification of the existing temporal properties models. Moreover, we have conducted analysis and evaluation and pointed out the challenges which sets foundations for full temporal support in business process modeling area. We are convinced that defining solutions to the defined challenges will significantly improve the IOBP temporal support, helps to achieve process automatisation and thus helps organisations to get advantage over competitors and to maximize its revenue.

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