Time and Business Process Management: Problems, Achievements, Challenges

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Abstract

Processes have been successfully introduced for modeling dynamic phenomena in many areas like business, production, health care, etc. Many of these applications require to adequately deal with temporal aspects. Process models need to express temporal durations, temporal constraints like allowed time between events, and deadlines. For checking the correctness of process definitions with temporal constraints, different notions and algorithms have been developed. Schedules for the execution of processes can be computed and proactive time management supports process managers to avoid time failures during the execution of a process. We present an overview of the problems and the requirements for treating time in business processes and the solutions achieved by applying results and techniques of research in temporal representation and reasoning. We reflect where expectations have not yet been met and sketch challenges in temporal representation and reasoning for addressing advanced requirements of the management of business processes.

2012 ACM Subject Classification Information systems → Process control systems; Applied computing → Business process management; Information systems → Temporal data

Keywords and phrases Business Process management, Temporal constraints, Scheduling, Process Evolution, Probabilistic Controllability

Digital Object Identifier 10.4230/LIPIcs.TIME.2020.3

Category Invited Talk

1 Introduction

Processes have been successfully introduced for modeling dynamic features in many areas like trade, production, health care, etc. in various forms like workflows [27], extended transactions [30], business processes [15], web-service orchestrations [12], distributed workflows [24], etc. In many of these application areas, temporal aspects are crucial for the correct and admissible execution of processes. This observation led to a substantial body of research to master the plenitude of temporal aspects of process engineering: expressing temporal aspects in process models, formulating different notions of correctness of process models with temporal constraints, checking the temporal correctness of process definitions, computing execution schedules for processes, recognizing and handling temporal exceptions, and supporting process controllers to adhere to temporal constraints at run-time with proactive time management (see [5, 20, 28] for overviews).

Managing business processes means to make decisions, and it is the duty of time management to support the different actors to make these decisions well informed. The primary actors within a BPMS (Business Process Management System) are process participants, process managers and process designer.

Support of process design achieved probably most attention. Process designers need formalisms to express temporal aspects of business processes. This includes representing temporal constraints such as deadlines, durations of activities, descriptive and prescriptive constraints. Descriptive constraints allow modeling temporal facts about the environment which is not controllable by the process manager, while prescriptive constraints denote goals, temporal properties which the process controller has to achieve. For an example, the constraint "money transfer lasts between 1 and 4 days" is a prescriptive constraint for banking processes, while it is a descriptive constraint for trading processes, giving the trading partners temporal restrictions but also temporal guarantees. Workflow time patterns [34] collected different patterns and notions for expressing various forms of temporal constraints. Process designers also need tools and techniques to check whether a process definition is feasible, in particular, whether it leads to a violation of temporal constraints.

Process participants need support for selecting items from work-lists. For this decision they need to know when each work item should be finished (internal deadline), and how important work items or process instances are. Information about the consequences of finishing work items late can lead to better decisions. Information about current and upcoming load can help to keep oversight and in particular to make decisions whether to accept additional obligations.

Process managers are responsible for the execution of business processes. They need support for decisions and policies scheduling and dispatching process instances and work-items to participants, Role resolution policies and capacity planning and management. A particular duty of process managers is to deal with exceptions including temporal exceptions and time - failures.

Many of these activities are already supported by current techniques of temporal representation and reasoning. The current state-of-the-art in support for temporal aspects of business process management is outlined in the next section. Then we will analyze some problems reducing broad acceptance of these technologies and sketch some areas where further research is needed.

2 State-of-the-Art

In the last two decades, a number of works on time management have appeared in the BPM community. These works mainly focus either on modeling aspects, or on reasoning aspects. However, despite the numerous efforts, no modeling or reasoning standards, or unified approaches, have been achieved yet.

Only in recent years a notable contribution has emerged under the modeling perspective, with the work on time patterns [34]. It systematically identifies and classifies a number of recurring temporal constraint patterns in BPM. This work has particularly high relevance, since it is based on the rigorous analysis of a vast number of real world processes, taken from different application domains (healthcare, administration, industry, finance). Time patterns are supported by a formal foundation. However, awareness from process designers and managers around time patterns for a uniform approach to time management is still missing.

Is there any promising formal framework, which may be adopted to both encode time patterns, and support temporal reasoning, thus highlighting the benefits of a standardized representation and fostering a uniform approach to process time management?

Various specializations of Temporal Constraint Networks (TCNs) are among the most refined formalisms available for modeling and solving temporal problems. A first formalization can be found in [13], where the Simple Temporal Network (STN) is introduced for modeling and solving the Simple Temporal Problem, i.e. verifying whether a given set of time-constrained time points admits an assignment of timestamps which fulfills all temporal constraints. To model uncertainties, the STN was extended into STN with Uncertainty (STNU) [35, 45], featuring contingent durations, and into Conditional STN (CSTN) [29, 43], including observed conditions. These networks were then combined into the CSTNU [29], which models unpredictability of both durations and conditions. Further extensions with increased expressiveness have been proposed in recent years, such as those which introduce decision time points to the CSTNU (CSTNUD) [46], or a degree of flexibility for reducing contingent durations to the STNU (STNPSU) [10, 33], or resources (CSTNUR) [11].

Contextually, the traditional notion of satisfiability of a set of temporal constraints is challenged by more advanced definitions of temporal correctness. Strong, weak, history-dependent, and dynamic controllability [9, 16, 44] are regarded as the most noteworthy such properties. They respond to the need to know whether correct schedules are possible, despite uncertainties. Techniques to verify such properties for TCNs have been proposed and improved over the years (e.g., [4]). Constraint propagation is among the most advanced and efficient of these techniques, with the added benefit that it makes implicit temporal knowledge explicit.

In the light of these advancements, in the last decade the BPM community started developing TCN-based approaches to represent the temporal aspect of processes, and to perform temporal reasoning on it, e.g. to verify temporal correctness [8, 17]. These approaches, however, were not met by widespread adoption yet.

3 Challenges

As outlined above, significant progress in research was made in the last two decades. Nevertheless, many of these techniques are not yet widespread in applications of BPM, and in some areas current approaches do not take into account recent developments in temporal representation and reasoning. For an example, predictive monitoring of processes [14], which among other issues tries to forecast whether a process will meet its deadline, is still based on satisfiability or consistency rather than on controllability ([3]). Most techniques for predictive monitoring rely nowadays on correlations derived by process mining [42] rather than on analytical temporal reasoning, using neural networks [41] rather than temporal constraint networks [32]. While it might be alright for highly repetitive processes, there is a considerable need for reasoning techniques for processes, with fewer instances, for frequently changing processes and for processes with a high number of variants, and for new processes. All these types of processes have in common that the relevant process logs are frequently too small for advanced process mining techniques.

Major roadblocks for the wider adoption of research results from temporal representation and reasoning seem to include the following:

- the inherent difficulty of some of the developed formalisms which are not popular with process designers
- popular constructs for the definition of processes (advanced control structures) are not supported, in particular loops, iterations, repetitions, and exception handling are not yet supported adequately
- focus on asymptotic complexity of algorithms rather than consideration of actual performance of algorithm for the typical size of real world application scenarios and without distinguishing between design time computations and the much higher performance and scalability requirements at run-time.
- connection of temporal aspects with other aspects of process execution, in particular capacity management, resource constraints, and cost.

Continuing, we will highlight a few of the areas, where considerable research needs are identified from the requirements of process management, which have the potential to further the adoption of temporal reasoning techniques.

3.1 Advanced Control Structures

BPMN, the Business Process Modeling Notation [36], for the better or the worse developed as the major notion for describing business processes in practice. Any technique for temporal representation and reasoning for business processes will have to support the control structures available in BPMN. This includes, in particular, loops and other repetitive structures. Unbounded loops ("while loops") currently are not really supported by temporal reasoning techniques. A process with a *while loop* is neither controllable nor dynamically controllable. We have to develop notions for the correctness of temporally constrained processes definitions which also include loops in an adequate way. Temporal control structures [37] and probabilistic controllability are candidate approaches.

BPMN features a plenitude of control structures and modelling notations. There are several research endeavours under way (e.g. [38]) to extend formalisms for temporal reasoning to include structures found in BPMN.

3.2 Temporal Data

Both data of type time (e.g. age) and addressing the need to know about the history of data (e.g. price of item when the order was sent, rather the actual process)

The data dimension is one of the major aspects of business processes requiring definitions of data flows and the relationships between data and decisions about the control flow, the production and usage of data as well as the formulation of execution constraints based on data [40] and data aspects in general are quite well developed. Comparatively little attention was paid to data of type time or timestamp, which can combine data constraints with temporal constraints and offer new possibilities for dealing with temporal aspects [25].

In addition, as processes are usually long-running, data might change over time, leading to the necessity of dealing with different versions of data, and managing these data in the sense of temporal data representations [7].

3.3 Conflicting Requirements

In practical applications designers and process managers face the problem of conflicting requirements or constraints. There is a need to support detecting, which constraints are (potentially) in conflict and to provide means to resolve conflicts, e.g., by assigning different priorities to constraints such as in [31], or by reasoning over the effects of constraint violations.

Not all requirements are created equal, in particular prescriptive requirements are frequently derived through negotiations, or are the result of designing service offerings for particular markets. Designers need tools and techniques to reason about which constraints are acceptable without losing controllability and for computing trade-offs between different constraints, such as in [26] for the design phase. Similar procedures are also needed for the run-time support for process managers to make decisions when reacting to exceptions and escalations.

3.4 Probabilistic Controllability

Currently, the most elaborated notion of correctness is the controllability, resp. dynamic controllability of process definitions [6]. These notions, however, have the disadvantage that they are binary properties, i.e. a process is either controllable or not. In addition, checking controllability relies only on the minimum and maximum duration of activities. We do not represent whether the maximum, resp. minimum duration is a rare exception.

In many practical applications, the strict notion of controllability is too strong, as frequently some risk is taken, when the process is started, that, e.g., it will violate temporal constraints. However, to rationally reflect on this risk, it is important to know how likely such a time failure is.

For many practical applications it is therefore desirable to extend this notion to capture more information. We envision to extend process model by including a distribution function for each (contingent) activity, representing the probability that an activity requires a certain amount of duration. And we extend the notion of controllability to express the probability that a temporal constraint is violated. Earlier approaches focused primarily on the risk of a deadline violation ([21, 22], but it is necessary to extend this to all temporal constraints.

A definition of (dynamic) probabilistic controllability should express whether there is a (dynamic) execution strategy which allows the execution of a process, such that the probability of violating any temporal constraint is below a given threshold.

Probabilistic controllability, by the way, is also a promising approach for overcoming the problem of (dynamic) controllability of processes with loops.

3.5 Process Evolution

Temporal representation of process definitions and their evolution creating temporal variants and versions are necessary. Process logs might be more difficult to treat with process mining procedures, if the underlying process definitions, or the process environment, or the context, resp. the environment of the process execution is changing [18]. Some of these problems have been recognized, e.g., in [1]. The adequate representation both of evolving processes models, the relationship between log entries and these temporal process models, as well as the time-related representation of process mining results, still need research.

Such representations are also needed for correct checking of the compliance of process instances to the evolving process models and constraints [28]. One of the difficulties is here that the evolution of processes frequently leads to a manifold of hybrid process instances which are partly conform to the old process definitions and partly accord to the new one. Temporal reasoning is also necessary to check the correctness of the evolution steps and the transformation regulations of process evolution steps [39]. Long running processes might even be affected by several succeeding schema evolutions. And it is important to recognize that processes are constantly in a need of adaptation, optimization, and further development [2], and therefore require adequate support of the continuous progress.

3.6 Temporal Aspects in Combination of Other Dimensions

Temporal aspects and temporal constraints can frequently not be considered in isolation, but they have to be treated in combination with other types of constraints. Recently, a combined representation and reasoning of temporal constraints with resource constraints was reported (e.g. [11]). With the consideration of resources, the consideration of their capacity is a next step. This also leads to the management of the capacity and the agenda of workflow participants, such as in [23].

Moreover, we have to see that mutual influences of durations and cost, which have to be considered together, lead to a notion of *affordable controllability*, meaning that there is an execution strategy within the budgetary limits avoiding any temporal constraint.

Another important dimension for planning process executions is the representation of risks that process activities cannot be executed as planned, or that assumptions about the environment do not hold [19] and the consequences of such risks for constraint satisfiability.

4 Conclusions

Representing temporal constraints and reasoning about the temporal properties of business processes, steering their execution and supporting their management, have come a long way since the first approaches to deal with temporal aspects of workflow system more than 2 decades ago. And the TIME community contributed many valuable results - mainly notions for the representation of temporal aspects, and formalisms and algorithms for temporal reasoning. Yet, still there are many requirements of Business Process Management which are not supported in a satisfactory way. It was the aim of this presentation to highlight some of the research needs and some ongoing research efforts, to address the challenges of a better support of temporal aspects in Business Process Management.

References

1 RP Jagadeesh Chandra Bose, Wil MP van der Aalst, Indrė Žliobaitė, and Mykola Pechenizkiy. Handling concept drift in process mining. In *International Conference on Advanced Information Systems Engineering*, pages 391–405. Springer, 2011.

2 Ruth Breu et al. Towards living inter-organizational processes. In *2013 IEEE 15th Conference on Business Informatics*, pages 363–366. IEEE, 2013.

3 Cristina Cabanillas, Claudio Di Ciccio, Jan Mendling, and Anne Baumgrass. Predictive task monitoring for business processes. In *International Conference on Business Process Management*, pages 424–432. Springer, 2014.

4 Massimo Cairo and Romeo Rizzi. Dynamic controllability of simple temporal networks with uncertainty: Simple rules and fast real-time execution. *Theor. Comput. Sci.*, 797:2–16, 2019. doi:10.1016/j.tcs.2018.11.005.

5 Saoussen Cheikhrouhou, Slim Kallel, Nawal Guermouche, and Mohamed Jmaiel. The temporal perspective in business process modeling: a survey and research challenges. *Service Oriented Computing and Applications*, 9(1):75–85, 2015.

6 Carlo Combi, Luke Hunsberger, and Roberto Posenato. An algorithm for checking the dynamic controllability of a conditional simple temporal network with uncertainty - revisited. In Joaquim Filipe and Ana Fred, editors, *Agents and Artificial Intelligence*, volume 449 of *Communications in Computer and Information Science*, pages 314–331. Springer Berlin Heidelberg, 2014.

7 Carlo Combi and Angelo Montanari. Data models with multiple temporal dimensions: Completing the picture. In *International Conference on Advanced Information Systems Engineering*, pages 187–202. Springer, 2001.

8 Carlo Combi and Roberto Posenato. Controllability in temporal conceptual workflow schemata. In *Business Process Management*, pages 64–79. Springer, 2009.

9 Carlo Combi and Roberto Posenato. Towards temporal controllabilities for workflow schemata. In *Temporal Representation and Reasoning (TIME), 2010 17th International Symposium on*, pages 129–136. IEEE, 2010.

10 Carlo Combi and Roberto Posenato. Extending conditional simple temporal networks with partially shrinkable uncertainty. In Natasha Alechina, Kjetil Nørvåg, and Wojciech Penczek, editors, *25th International Symposium on Temporal Representation and Reasoning, TIME*

2018, Warsaw, Poland, October 15-17, 2018, volume 120 of *LIPIcs*, pages 9:1–9:16. Schloss Dagstuhl - Leibniz-Zentrum für Informatik, 2018. doi:10.4230/LIPIcs.TIME.2018.9.

11 Carlo Combi, Roberto Posenato, Luca Viganò, and Matteo Zavatteri. Conditional simple temporal networks with uncertainty and resources. *Journal of Artificial Intelligence Research*, 64:931–985, 2019.

12 Florian Daniel and Barbara Pernici. Insights into web service orchestration and choreography. *International Journal of E-Business Research (IJEBR)*, 2(1):58–77, 2006.

13 Rina Dechter, Itay Meiri, and Judea Pearl. Temporal constraint networks. *Artificial intelligence*, 49(1-3):61–95, 1991.

14 Chiara Di Francescomarino, Chiara Ghidini, Fabrizio Maria Maggi, and Fredrik Milani. Predictive process monitoring methods: Which one suits me best? In *International Conference on Business Process Management*, pages 462–479. Springer, 2018.

15 Marlon Dumas, Marcello La Rosa, Jan Mendling, Hajo A Reijers, et al. *Fundamentals of business process management*, volume 1. Springer, 2013.

16 Johann Eder. Computing history-dependent schedules for processes with temporal constraints. In *International Conference on Future Data and Security Engineering*, pages 145–164. Springer, 2019.

17 Johann Eder, Marco Franceschetti, and Julius Köpke. Controllability of business processes with temporal variables. In *Proceedings of the 34th ACM/SIGAPP Symposium on Applied Computing*, pages 40–47. ACM, 2019.

18 Johann Eder and Christian Koncilia. Modelling changes in ontologies. In *OTM Confederated International Conferences" On the Move to Meaningful Internet Systems"*, pages 662–673. Springer, 2004.

19 Johann Eder and Walter Liebhart. Workflow transactions. In *Workflow handbook 1997*, pages 195–202. John Wiley & Sons, Inc., 1997.

20 Johann Eder, Euthimios Panagos, and Michael Rabinovich. Workflow time management revisited. In *Seminal Contributions to Information Systems Engineering*. Springer, 2013.

21 Johann Eder and Horst Pichler. Duration histograms for workflow systems. In *Engineering Information Systems in the Internet Context*, pages 239–253. Springer, 2002.

22 Johann Eder and Horst Pichler. Probabilistic calculation of execution intervals for workflows. In *12th International Symposium on Temporal Representation and Reasoning (TIME'05)*, pages 183–185. IEEE, 2005.

23 Johann Eder, Horst Pichler, Wolfgang Gruber, and Michael Ninaus. Personal schedules for workflow systems. In *International Conference on Business Process Management*, pages 216–231. Springer, 2003.

24 Sérgio Esteves and Luís Veiga. Waas: Workflow-as-a-service for the cloud with scheduling of continuous and data-intensive workflows. *The Computer Journal*, 59(3):371–383, 2016.

25 Marco Franceschetti and Johann Eder. Checking temporal service level agreements for web service compositions with temporal parameters. In *2019 IEEE International Conference on Web Services (ICWS)*, pages 443–445. IEEE, 2019.

26 Marco Franceschetti and Johann Eder. Negotiating temporal commitments in cross-organizational business processes. In *27th International Symposium on Temporal Representation and Reasoning (TIME 2020)*, 2020.

27 Diimitrios Georgakopoulos, Mark Hornick, and Amit Sheth. An overview of workflow management: From process modeling to workflow automation infrastructure. *Distributed and Parallel Databases*, 3(2):119–153, 1995.

28 Mustafa Hashmi, Guido Governatori, Ho-Pun Lam, and Moe Thandar Wynn. Are we done with business process compliance: state of the art and challenges ahead. *Knowl. Inf. Syst.*, 57(1):79–133, 2018. doi:10.1007/s10115-017-1142-1.

29 Luke Hunsberger, Roberto Posenato, and Carlo Combi. The dynamic controllability of conditional stns with uncertainty. *CoRR*, abs/1212.2005, 2012. arXiv:1212.2005.

30 Sushil Jajodia and Larry Kerschberg. *Advanced transaction models and architectures*. Springer Science & Business Media, 2012.

31 Akhil Kumar, Sharat R. Sabbella, and Russell R. Barton. Managing controlled violation of temporal process constraints. In Hamid Reza Motahari-Nezhad, Jan Recker, and Matthias Weidlich, editors, *Business Process Management - 13th International Conference, BPM 2015, Innsbruck, Austria, August 31 - September 3, 2015, Proceedings*, volume 9253 of *Lecture Notes in Computer Science*, pages 280–296. Springer, 2015. doi:10.1007/978-3-319-23063-4_20.

32 Andreas Lanz, Roberto Posenato, Carlo Combi, and Manfred Reichert. Controllability of time-aware processes at run time. In *On the Move to Meaningful Internet Systems: OTM 2013 Conferences*, pages 39–56. Springer, 2013.

33 Andreas Lanz, Roberto Posenato, Carlo Combi, and Manfred Reichert. Simple temporal networks with partially shrinkable uncertainty. In Stéphane Loiseau, Joaquim Filipe, Béatrice Duval, and H. Jaap van den Herik, editors, *ICAART 2015 - Proceedings of the International Conference on Agents and Artificial Intelligence, Volume 2, Lisbon, Portugal, 10-12 January, 2015*, pages 370–381. SciTePress, 2015.

34 Andreas Lanz, Manfred Reichert, and Barbara Weber. Process time patterns: A formal foundation. *Information Systems*, 57:38–68, 2016.

35 Paul H. Morris and Nicola Muscettola. Managing temporal uncertainty through waypoint controllability. In Thomas Dean, editor, *Proceedings of the Sixteenth International Joint Conference on Artificial Intelligence, IJCAI 99, Stockholm, Sweden, July 31 - August 6, 1999. 2 Volumes, 1450 pages*, pages 1253–1258. Morgan Kaufmann, 1999. URL: http://ijcai.org/Proceedings/99-2/Papers/083.pdf.

36 ObjectManagementGroup. Business Process Model and Notation (BPMN), Version 2.0. http://www.omg.org/spec/BPMN/2.0, 2011.

37 Horst Pichler, Johann Eder, and Margareta Ciglic. Modelling processes with time-dependent control structures. In *Int. Conference on Conceptual Modeling*, pages 50–58. Springer, 2017.

38 Roberto Posenato, Francesca Zerbato, and Carlo Combi. Managing decision tasks and events in time-aware business process models. In *International Conference on Business Process Management*, pages 102–118. Springer, 2018.

39 Stefanie Rinderle, Manfred Reichert, and Peter Dadam. Correctness criteria for dynamic changes in workflow systems—-a survey. *Data & Knowledge Engineering*, 50(1):9–34, 2004.

40 Nick Russell, Arthur HM Ter Hofstede, David Edmond, and Wil MP van der Aalst. Workflow data patterns: Identification, representation and tool support. In *International Conference on Conceptual Modeling*, pages 353–368. Springer, 2005.

41 Niek Tax, Ilya Verenich, Marcello La Rosa, and Marlon Dumas. Predictive business process monitoring with lstm neural networks. In *International Conference on Advanced Information Systems Engineering*, pages 477–492. Springer, 2017.

42 Irene Teinemaa, Marlon Dumas, Fabrizio Maria Maggi, and Chiara Di Francescomarino. Predictive business process monitoring with structured and unstructured data. In *International Conference on Business Process Management*, pages 401–417. Springer, 2016.

43 Ioannis Tsamardinos, Thierry Vidal, and Martha E. Pollack. CTP: A new constraint-based formalism for conditional, temporal planning. *Constraints An Int. J.*, 8(4):365–388, 2003. doi:10.1023/A:1025894003623.

44 Thierry Vidal. Handling contingency in temporal constraint networks: from consistency to controllabilities. *Journal of Experimental & Theoretical Artificial Intelligence*, 11(1):23–45, 1999.

45 Thierry Vidal and Hélène Fargier. Contingent durations in temporal csps: From consistency to controllabilities. In *4th International Workshop on Temporal Representation and Reasoning, TIME '97, Daytona Beach, Florida, USA, May 10-11, 1997*, pages 78–85. IEEE Computer Society, 1997. doi:10.1109/TIME.1997.600786.

46 Matteo Zavatteri and Luca Viganò. Conditional simple temporal networks with uncertainty and decisions. *Theoretical Computer Science*, 797:77–101, 2019.