Information Systems ■ (■■■■) ■■■–■■■

Contents lists available at ScienceDirect

Information Systems

journal homepage: www.elsevier.com/locate/infosys

Conformance checking and performance improvement in scheduled processes: A queueing-network perspective

Arik Senderovich [a,*], Matthias Weidlich [b,*], Liron Yedidsion [a], Avigdor Gal [a], Avishai Mandelbaum [a], Sarah Kadish [c], Craig A. Bunnell [c]

[a] Technion - Israel Institute of Technology, Haifa, Israel
[b] Humboldt-Universität zu Berlin, Berlin, Germany
[c] Dana-Farber Cancer Institute, Boston, MA, United States

ARTICLE INFO

Keywords:
Scheduled processes
Conformance checking
Process improvement
Queueing networks
Process mining
Scheduling
Statistical inference

ABSTRACT

Service processes, for example in transportation, telecommunications or the health sector, are the backbone of today's economies. Conceptual models of service processes enable operational analysis that supports, e.g., resource provisioning or delay prediction. In the presence of event logs containing recorded traces of process execution, such operational models can be mined automatically.

In this work, we target the analysis of resource-driven, scheduled processes based on event logs. We focus on processes for which there exists a pre-defined assignment of activity instances to resources that execute activities. Specifically, we approach the questions of conformance checking (*how to assess the conformance of the schedule and the actual process execution*) and performance improvement (*how to improve the operational process performance*). The first question is addressed based on a queueing network for both the schedule and the actual process execution. Based on these models, we detect operational deviations and then apply statistical inference and similarity measures to validate the scheduling assumptions, thereby identifying root-causes for these deviations. These results are the starting point for our technique to improve the operational performance. It suggests adaptations of the scheduling policy of the service process to decrease the tardiness (non-punctuality) and lower the flow time. We demonstrate the value of our approach based on a real-world dataset comprising clinical pathways of an outpatient clinic that have been recorded by a real-time location system (RTLS). Our results indicate that the presented technique enables localization of operational bottlenecks along with their root-causes, while our improvement technique yields a decrease in median tardiness and flow time by more than 20%.

1. Introduction

Service systems play a central role in today's economies, e.g., in transportation, finance, and the health sector. Service provisioning is often realized by a *service process* [1,2]. It can be broadly captured by a set of activities that are executed by a service provider and designated to both attain a set of organizational goals and add value to customers.

* Corresponding authors.
E-mail addresses: sariks@tx.technion.ac.il (A. Senderovich), matthias.weidlich@hu-berlin.de (M. Weidlich), lirony@ie.technion.ac.il (L. Yedidsion), avigal@ie.technion.ac.il (A. Gal), avim@ie.technion.ac.il (A. Mandelbaum), sarah_kadish@dfci.harvard.edu (S. Kadish), craig_bunnell@dfci.harvard.edu (C.A. Bunnell).

http://dx.doi.org/10.1016/j.is.2016.01.002
0306-4379/

Please cite this article as: A. Senderovich, et al., Conformance checking and performance improvement in scheduled processes: A queueing-network perspective, Information Systems (2016), http://dx.doi.org/10.1016/j.is.2016.01.002

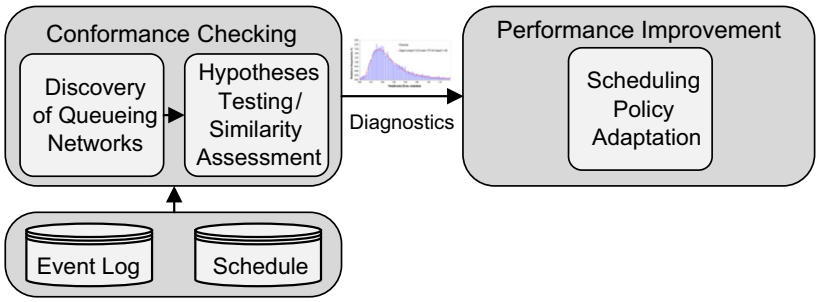

Fig. 1. An outline of our approach.

Independently of the domain, service processes can be classified by the amount of interactions between service providers and customers and the level of demand predictability and capacity flexibility. A service can be *multi-stage*, involving a series of interactions of a customer with a provider, or specific resources at a provider's end. Further, a process can be *scheduled*, meaning that the number of customers to arrive is known in advance, up to last moment cancelations and no-shows. Then, customers follow a schedule, which is a pre-defined series of activity instances, each having assigned a planned starting time for its execution, a duration, and the involved resource.

Multi-stage scheduled processes are encountered, for instance, in outpatient clinics, where various types of treatments are provided as a service to patients [3]. Here, a schedule determines when a patient undergoes a specific examination or treatment. Another example of multi-stage scheduled processes is public transportation, where schedules determine which vehicle serves a certain route at a specific time [4].

In this work, we focus on operational analysis for multi-stage scheduled service processes. Specifically, we aim at answering the following two key questions: *how to assess the conformance of a pre-defined schedule of a service process to its actual execution*? and *how to improve operational performance of the scheduled process*?

To address the first question, we present a method that is grounded in a queueing network for both the schedule and the actual process execution and applies statistical inference (hypotheses testing) and similarity assessment to validate the scheduling assumptions of the process. As outlined in Fig. 1, the conformance checking step yields diagnostics on operational deviations between the schedule and the execution of the process. The identified deviations then guide the efforts to improve the operational performance of a process. In particular, we target improvements in terms of decreased tardiness (lateness with respect to due dates) and lower flow time by adapting the scheduling policy.

We base our technique on a generalization of a specific type of *queueing networks*. This choice is motivated by the need to capture two aspects of service processes in particular. First, the key actors of service processes namely customers and service providers (or resources), and their complex interaction in terms of customer–resource matching policies (e.g. First-Come First-Served, Most-Idling Resource-First) [5] need to be specified. Second, a network model is required to define the dependencies of different stages of the service process, including parallel processing of activities [6]. Against this background, we rely on *Fork/Join networks* [7], which serve as the foundation for conformance checking and enable performance analysis of parallel queueing systems [8].

Our contributions can be summarized as follows:

(1) We present a method to assess the conformance of a schedule and the actual process execution based on queueing networks. By means of statistical inference and similarity assessment, we identify operational deviations along with their root-causes in terms of violated assumptions underlying the scheduling mechanism.
(2) We present a process improvement technique that relies on the identified root-causes to adapt the scheduling policy of the service process to decrease the tardiness and lower the flow time.

This paper is an extended and revised version of our earlier work that focused on conformance checking in scheduled processes [9]. In this work, we improve, extend and formalize the earlier proposed model validation technique. Furthermore, we complement the conformance checking approach with a process improvement technique.

We demonstrate the value of the proposed approach by a two-step evaluation. First, we apply the conformance checking techniques to RTLS-based data from a real-world use-case of a large outpatient oncology clinic namely the Dana-Farber Cancer Institute.[1] Our experiments demonstrate the usefulness of the extended validation method for detection of operational deviations and identifying root causes for them. As a second evaluation step, we present simulation-based experiments that evaluate the proposed process improvement technique and show that tardiness and flow time can be reduced by more than 20% using the adapted scheduling policy.

The remainder of the paper is structured as follows. The next section presents a detailed use-case of a process in an outpatient clinic to motivate our approach. The models for the service process data, specifically, the schedule and the event log, are presented in Section 3. Fork/Join networks

[1] http://www.dana-farber.org/.

Please cite this article as: A. Senderovich, et al., Conformance checking and performance improvement in scheduled processes: A queueing-network perspective, Information Systems (2016), http://dx.doi.org/10.1016/j.is.2016.01.002