

# Conformance Checking and Performance Improvement in Scheduled Processes: A Queueing-Network Perspective (Extended Abstract)

Arik Senderovich<sup>1</sup> Matthias Weidlich<sup>2</sup> Liron Yedidsion<sup>3</sup> Avigdor Gal<sup>4</sup>  
Avishai Mandelbaum<sup>5</sup> Sarah Kadish<sup>6</sup> Craig A. Bunnell<sup>7</sup>

**Abstract:** Conceptual models of service processes enable operational analysis and may be constructed automatically from event logs containing recorded traces of process execution. In this work, we target the analysis of resource-driven, scheduled processes based on event logs. 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 comparative analysis of queueing networks for both the schedule and the actual process execution. These results of this analysis are used to improve the operational performance of a process: we suggest adaptations of the scheduling policy of the service process to decrease the tardiness (non-punctuality) and lower the flow time. The work summarized in this extended abstract has been published in [Se16].

## 1 Operational Analysis of Scheduled Processes

Service systems play a fundamental role in domains such as transportation and the health sector. Services are provisioned by a *service process* [Du13, Da11], broadly defined by a set of activities that are executed by a service provider to serve particular clients. We focus on service processes that are *multi-stage* and *scheduled*. The former means that there is a series of interactions between a client and a service provider, or specific resources at a provider's end. Scheduled processes, in turn, are structured such that the arrival of clients as well as the basic activities of handling their requests are largely known in advance.

In this work, we target operational analysis of such multi-stage scheduled service processes. Specifically, we elaborate on methods to answer the following two 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?*

We address the above questions with a model-driven approach, exploiting a specific type of *queueing networks*. This choice is motivated by the need to capture the key actors of service

---

<sup>1</sup> Technion - Israel Institute of Technology, Haifa, Israel, sariks@tx.technion.ac.il

<sup>2</sup> Humboldt-Universität zu Berlin, Germany, matthias.weidlich@hu-berlin.de

<sup>3</sup> Technion - Israel Institute of Technology, Haifa, Israel, lirony@ie.technion.ac.il

<sup>4</sup> Technion - Israel Institute of Technology, Haifa, Israel, avigal@ie.technion.ac.il

<sup>5</sup> Technion - Israel Institute of Technology, Haifa, Israel, avim@ie.technion.ac.il

<sup>6</sup> Dana-Farber Cancer Institute, Boston, Massachusetts, United States, sarah\_kadish@dfci.harvard.edu

<sup>7</sup> Dana-Farber Cancer Institute, Boston, Massachusetts, United States, craig\_bunnell@dfci.harvard.edu

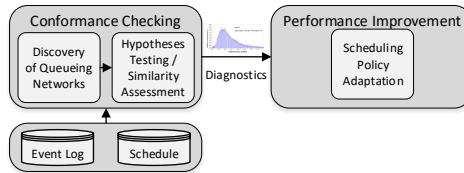


Figure 1: Overview of the approach to conformance checking and process improvement

processes (clients and providers), their interactions, and the dependencies of different stages of the service process, including parallel processing of activities [Bo06]. Against this background, we rely on *Fork/Join networks* [AG89], which serve as the foundation for analysis of parallel queueing systems [AMZ12].

## 2 Conformance Checking & Process Improvement

To address the question of conformance, we present a method that is grounded in queueing networks that are discovered for both the schedule and the actual process execution. We then apply statistical inference (hypotheses testing) and similarity assessment to validate the scheduling assumptions of the process. As outlined in Figure 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 answer the question of how 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. Our contributions can be summarized as follows:

*Conformance Checking:* Following the existing theory for validating (simulation-based) operational models against execution data [Sal1], we decompose the conformance checking problem along two dimensions, namely conceptual and operational. Conceptual conformance checks the assumptions and theories that underlie the schedule. To assess this type of conformance, we compare the schedule and the event log indirectly by means of Fork/Join networks that are discovered for both. These networks are compared through the lenses of their corresponding components: structure, routing, and server dynamics, which enables general insights beyond the level of instance-based conformance checking. Operational conformance checks the ‘predictive power’ of a schedule with respect to various performance measures (e.g., delay predictions). To this end, we measure deviations between the observed and the scheduled performance indicators.

*Process Improvement:* Conformance checking detects parts of the process that fail to conform (conceptually or operationally) to a given schedule. We handle lack of conformance by combining data-driven analysis via the Fork/Join model, and principles from scheduling research [Pi12]. Specifically, we target local improvement of service policy, whenever conformance is lacking. By default, scheduled processes often operate under the Earliest-Due Date first (EDD) service policy per node, thus ‘optimizing’ schedule-related performance measures (e.g., non-punctuality). Assuming that all cases are available at the beginning of the scheduling horizon, it is indeed optimal to use the EDD policy. However, when cases

arrive into the system at different times (according to schedule), we show that the EDD policy can be improved to achieve lower tardiness. Moreover, we show that without losing punctuality, our algorithms also improve other performance measures such as flow time.

### 3 Discussion

This work presents methods for conformance checking and performance improvement of scheduled multi-stage service processes, as they are observed in such domains as healthcare and transportation. We explore 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.<sup>9</sup> Our experiments demonstrate the usefulness of the validation method for detection of operational deviations and identification of root causes of deviations. As a second step, we evaluate the proposed process improvement technique by means of simulation and show that tardiness and flow time can be reduced by more than 20% using our scheduling policy.

**Acknowledgement.** We are grateful to the SEELab members, Dr. Valery Trofimov, Igor Gavako and especially Ella Nadjharov, for their help with the statistical analysis. We also thank Kristen Camuso, from Dana-Faber Cancer Institute for the insightful data discussions.

### References

- [AG89] Ammar, Mostafa H; Gershwin, Stanley B: Equivalence relations in queueing models of fork/join networks with blocking. *Performance Evaluation*, 10(3):233–245, 1989.
- [AMZ12] Atar, Rami; Mandelbaum, Avishai; Zviran, Asaf: Control of fork-join networks in heavy traffic. In: *Communication, Control, and Computing (Allerton)*, 2012 50th Annual Allerton Conference on. IEEE, pp. 823–830, 2012.
- [Bo06] Bolch, Gunter; Greiner, Stefan; de Meer, Hermann; Trivedi, Kishor S.: *Queueing Networks and Markov Chains - Modeling and Performance Evaluation with Computer Science Applications*; 2nd Edition. Wiley, 2006.
- [Da11] Daskin, Mark S: *Service Science*. Wiley.com, 2011.
- [Du13] Dumas, Marlon; Rosa, Marcello La; Mendling, Jan; Reijers, Hajo A.: *Fundamentals of Business Process Management*. Springer, 2013.
- [Pi12] Pinedo, Michael L: *Scheduling: theory, algorithms, and systems*. Springer Science & Business Media, 2012.
- [Sa11] Sargent, Robert G.: Verification and validation of simulation models. In (Jain, S.; Jr., Roy R. Creasey; Himmelspace, Jan; White, K. Preston; Fu, Michael C., eds): *Winter Simulation Conference*. WSC, pp. 183–198, 2011.
- [Se16] Senderovich, Arik; Weidlich, Matthias; Yedidsion, Liron; Gal, Avigdor; Mandelbaum, Avishai; Kadish, Sarah; Bunnell, Craig A.: Conformance checking and performance improvement in scheduled processes: A queueing-network perspective. *Information Systems*, 2016. DOI: <http://dx.doi.org/10.1016/j.is.2016.01.002>

---

<sup>9</sup> <http://www.dana-farber.org/>.