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Procedia Computer Science 109C (2017) 576–583

Procedia Computer Science

www.elsevier.com/locate/procedia

The 8th International Conference on Ambient Systems, Networks and Technologies (ANT 2017)

Modeling a bus network for passengers transportation management using colored Petri nets and (max, +) algebra

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Abstract

The purpose of this paper is to model and evaluate the performances of a bus network using Colored Petri Nets (CPN) and (max, +) Algebra. Our main contribution is to describe CPN with (max, +) equations in order to evaluate buses timetables and also boarding, disembarking and waiting times of passengers. Furthermore, the influence of buses limited capacity on passengers waiting times is studied. Simulation results will illustrate the applicability of the proposed methodology.

Keywords: Transport Network; Discrete Event Systems; Modeling; Performance evaluation; Colored Petri Nets; (Max, +) Algebra; Routing policy.

1. Introduction

The importance of public transport systems continues to grow. For that reason, public transport organizations and authorities, as well as public transport researchers, have implemented common management policies in order to propose improvements that can ensure the development of such networks and contribute to the efficiency of various services proposed to passengers.

Transportation networks can be seen as Discrete Event System (DES). The behavior of such systems is mainly characterized by parallelism, synchronization, concurrency and conflicts. In order to analyze and solve these complex phenomena, many techniques and methods have been developed. On one hand, thanks to the conceptual simplicity of the model and its intuitive graphical presentation, PN have been proven to be a powerful modeling formalism for various kinds of DES. On the other hand, (max, +) algebra is a powerful mathematical formalism that allows a linear analytic description and analysis of some DES like transportation networks. So, our study focuses on the development of (max, +) models capable of bringing solutions for performance evaluation of a transportation network.

To the best of our knowledge, we think that it is the first time where these tools are combined to model, analyze and evaluate the performance of a bus network. Our objective through this paper is to express CPN with (max, +) equations, in order to evaluate departure/arrival of buses from/to the various network stations and also boarding,

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10.1016/j.procs.2017.05.344

disembarking and waiting times of each passenger at every network station. Afterwards, the influence of the limited capacity of buses on passengers waiting time is studied.

This paper is organized as follows. Next section contains the related work. The considered public transport system is introduced in section 3. In Section 4, CPN model of the considered network is proposed. A mathematical modeling using (max, +) algebra is given in section 5. Performance evaluation and analysis are presented in section 6. The results of a case study is presented in section 7. Finally, in section 8, some conclusion remarks and indications of future work are reported.

2. Related work

Numerous studies discuss modeling and performance evaluation of transportation systems from different views. For instance,[5] presents a modular colored stochastic PN for modeling, analysis and real-time control of signalized intersections. Another method was proposed in[8] for modeling and analysis of air traffic control systems using hierarchical timed colored PN to facilitate the presentation of the aircraft behavior in terms of conditions and events. In the railway field,[4] has shown how to model railway traffic and dispatching actions like changing tracks and breaking or joining trains using the max-plus algebra. Furthermore,[2] used stochastic PN for modeling performances evaluation of self-service bicycles. This study focused on rebalancing the distribution of bicycles in various network stations in order to satisfy demands of users.

In a earlier research work on public trasportation systems (such as[7]) the present authors have proposed some models to evaluate the performances of a bus network in terms of passengers waiting times at connection stations. However, these early models did not consider some criteria like buses finite capacity, random passengers arrival, boarding and disembarking times of passengers and also their random destinations. All of these criteria are considered in the present study.

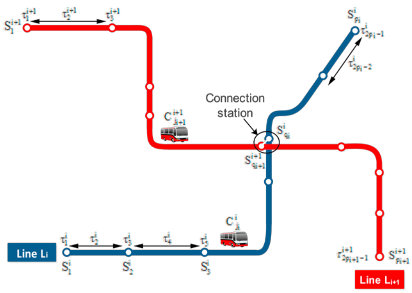

Fig. 1. The studied network

3. Studied Network

We consider a bus network assumed to be a generic structure for any bus transportation network. It is composed of two connected lines L_i and L_{i+1} with a single connection station (figure 1). Each line L_l ($l \in \{i, i+1\}$) is represented by p_l stops : departure and arrival terminus (S^l_1 and $S^l_{p_l}$), connection stop ($S^l_{q_l}$) and intermediate stops (S^l_2,..,$S^l_{q_l-1}$,$S^l_{q_l+1}$,..,$S^l_{p_l-1}$). Also, each line L_l is supposed to be served by a finite number n_l of buses. Every bus j_l ($1 \leq j_l \leq n_l$) is characterized by its limited capacity $C^l_{j_l}$ that refers to the maximum number of passengers to be transported at the same time. The arrival of passengers to their departure stops is given by stochastic events. For each line L_l, the following data are supposed to be known and fixed :

- The number n_l of buses circulating on the line L_l;
- The travel times $\tau^l_{2m_l}$ ($1 \leq m_l \leq p_l$) of buses between the station $S^l_{m_l}$ and $S^l_{m_l+1}$. For $m_l = p_l$, the travel time $\tau^l_{2p_l}$ refers to the return path of the buses from $S^l_{p_l}$ to S^l_1.
- The stop times $\tau^l_{2m_l-1}$ ($1 \leq m_l \leq p_l$) of each bus at station $S^l_{m_l}$.