Available online at www.sciencedirect.com
ScienceDirect
Simulation Modelling Practice and Theory 15 (2007) 935–969
SIMULATION MODELLING PRACTICE AND THEORY
www.elsevier.com/locate/simpat

A hybrid Petri nets-based simulation model for evaluating the design of railway transit stations

Fateh Kaakai [a,b,*], Said Hayat [b], Abdellah El Moudni [a]

[a] *Université de Technologie de Belfort-Montbéliard (UTBM), Laboratoire Systèmes et Transports (S.e.T), Site de Belfort, 90010 Belfort Cedex, France*

[b] *Institut National de Recherche sur les Transports et leur Sécurité (INRETS), 20, rue Elisée Reclus, BP: 317, F-59666 Villeneuve d'ASCQ Cedex, France*

Received 17 August 2006; received in revised form 24 April 2007; accepted 10 May 2007
Available online 26 May 2007

Abstract

Each year, according to European and American statistics, there are many serious injuries and even fatalities of travelers into railway transit stations. Furthermore, several studies have underlined that one of the major causes of these accidents is *the design of station facilities*. Consequently, it becomes more and more important for transit authorities to *evaluate* these facilities (platform, gates, stairs, escalators, etc.) under critical traffic conditions, such as rush hours or emergency situations. The purpose of this paper is to present a simulation model based on hybrid Petri nets able to help transit authorities to carry out performance evaluation procedures in order to prevent, to reduce and if possible to avoid these accidents which deteriorate the image of public transport in general and make it less attractive.

Keywords: Railway transit station; Modeling; Hybrid Petri nets; Formal analysis; Simulation; Performance evaluation; Design; Safety; Security

1. Introduction

Railway Transit Stations (RTSs) are stop points of a railway transportation line where a whole of facilities is available to allow the parking of public transports and the alighting and the boarding of passengers. This general definition includes subway stations, commuter stations, and (high speed) train stations. In the rest of the paper, expressions *railway transit station, transit station* or simply *station* will be equally used.

* Corresponding author. Address: Université de Technologie de Belfort-Montbéliard (UTBM), Laboratoire Systèmes et Transports (S.e.T), Site de Belfort, 90010 Belfort Cedex, France. Tel.: +33 3 84 58 33 51; fax: +33 3 84 58 33 42.
E-mail address: fateh.kaakai@utbm.fr (F. Kaakai).

1569-190X/$ - see front matter
doi:10.1016/j.simpat.2007.05.003

1.1. Motivation

The standard EN 13816 published in 2002 by the European Committee for Standardization [1] and the Transit Capacity and Quality of service Manual [2] are some of the works which deal with the *service quality in public transportation networks*. According to these, the maximal density of travelers into public transports or on waiting/queuing areas of station platforms must not be greater than 4 persons per m^2 for comfort and security purposes.

However, it can be observed that many RTSs, especially into busy multimodal hubs, do not respect this limit during rush hours. For instance, 670,000 travelers use everyday one of the biggest multimodal hubs of Paris called *Châtelet-Les-Halles* [3]. When the travelers' concentration becomes very high, the most fragile persons (children, old people, etc.) can be seriously affected by the movements of the crowd on the arrival of the public transport, resulting in *jostles, discomforts, falls, trampling*, etc. Indeed, several statistical analyses of accident data performed in Europe and United States of America such as [4–6] show that a lot of injuries[1] occur during the travelers' boarding and alighting and that these injuries are closely linked to the design of public transports and station platforms [7]. Moreover, transit platforms have critical passenger holding capacities, that if exceeded, could result in passengers being pushed onto tracks or roadways.[2]

On the other hand, some stations have been oversized compared to their real needs. In this case, travelers must cover longer distances resulting in discomfort (or hardness) for old people and an increase of the connection times. Moreover, a disproportionate space assignment in the downtown areas into which the main transit stations are generally established can raise strong problems for the future development of the transportation network.

To sum up, these observations clearly underline the real need to have at one's disposal an efficient tool for both *validating* design projects of new stations and *evaluating* the design of existing transit station facilities.

1.2. Relevant literature

Few papers in the literature deal with the performance evaluation of the design of RTSs. The main ones that are close to this issue can be classified into two main categories according to the nature of the suggested modeling approach: discrete or continuous.

Discrete simulation models such as [8,9] are suitable for describing RTSs during off-peak-periods when the number of travelers into the station is not high. For example, in [9] a model based on colored discrete timed Petri nets is suggested. In this paper, successive arrivals and departures of public transports are modeled using discrete transitions and all passengers having the same destination are represented by a single colored token. But when the number of travelers into the station becomes very high, during rush hours for instance, it is no longer possible to distinguish separate passengers or groups of passengers according to their destination. More precisely, the whole travelers are like a homogeneous set of travelers and their collective movements look like continuous flows. Is it therefore appropriate to represent a high number of travelers by a small number of tokens (in this model, there are as many tokens as destination choices)? And how is it possible to model continuous flows of travelers with only discrete places and transitions? Actually, these discrete models require a *fluidification* process [10,11] for being able to describe specific behaviors of the station when it operates under critical traffic conditions.

Continuous simulation models [12–15], often called microscopic simulation models, are generally based on pedestrian traffic flow theory. These continuous models are more elaborate than the discrete ones as they describe the pedestrian behavior at three levels: the strategic level (long term decisions), the tactical level (short term decisions) and the operational level (decisions for the immediate next moment). However, a continuous modeling approach is inadequate for modeling discrete events such as the public transport arrivals and departures at/from the station and the interaction between these discrete events and the continuous dynamics of

[1] For example, 2485 cases of injury in commuter railway stations were collected in USA from 1995 to 2000 ([6, p. 266]).

[2] For instance, each year in United Kingdom, 20–30 people die at stations (including suicide attempts). Into the first quarter of 2005, two passengers died in separate incidents when they fell from platforms and were struck by trains ([4, p. 7]).