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Hanseler, Flurin; Hoogendoorn, Serge

Publication date
2018

Document Version
Final published version

Published in
hEART 2018: 7th Symposium of the European Association for Research in Transportation, 5-7 September, Athens, Greece

Citation (APA)
Hanseler, F., & Hoogendoorn, S. (2018). Optimal crowd management for congested metro stations. In *hEART 2018: 7th Symposium of the European Association for Research in Transportation, 5-7 September, Athens, Greece*

Important note
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Optimal crowd management for congested metro stations

F.S. Hänseler   S.P. Hoogendoorn

Delft University of Technology, The Netherlands.

In many urban transit systems, growing riderships are taking their toll on metro stations. Congestion increasingly impairs the comfort, capacity, and safety of their pedestrian facilities. Where an infrastructural enlargement is difficult, changes in their operation represent a primary alternative. Notable examples include gating [1], separation of counter-flow [2], or dynamic adaptation of escalator usage[1].

Such operational measures have large potential in terms of capacity and comfort improvement, but are currently not applied systematically. In fact, most operational measures are designed in a trial-and-error fashion, and often rely on pre-defined rules such as linear feedback laws [3]. In this contribution, instead, we develop a state-of-the-art macroscopic pedestrian model for metro stations, and use it to control infrastructure operations optimally.

The macroscopic station model extends a previously developed pedestrian flow model [4, 5] by accounting for typical pedestrian behavior in metro stations such as level changes, waiting, boarding and alighting. We capture pedestrian locomotion by facility-specific fundamental diagrams [6] that we combine with a potential field-based route choice model [7]. The choice of waiting positions on platforms is described by an empirically calibrated absorption model.

To quantify the performance of a metro station, we consider total travel utility. The utility of travelers is assumed to depend on their travel activity

[1] Examples from the engineering practice include the reversal of escalators at Amsterdam Zuid station during King's Day, or the dynamic adaptation of escalator speeds during the Oktoberfest in Munich.

and local crowding conditions. Empirical findings form the literature are used to describe the value-of-time of waiting, walking or level-changing pedestrians subject to prevailing density levels [8, 9].

We propose a simulation-based optimization framework, in which we control the operation of rail access facilities such that total travel disutility is minimized. We consider two management strategies [10, 11]: Dynamic reduction of passenger flows at check-in gates to reduce congestion (referred to as 'gating'), and gating in combination with dynamic escalator reversal. The optimization problem is formulated using a receding horizon approach, and solved by differential evolution [12]. This optimization method is useful in that it is global, applicable to non-linear mixed-integer problems, and in that it can be readily parallelized.

To assess and evaluate the proposed framework, we consider a case study of Amsterdam's Centraal metro station. Centraal station is a terminus station serving three metro lines on a single island platform[2] (Fig. 1). Originally designed as a civil shelter, it provides ample platform space that is accessible by three adjacent escalators and two lateral stairways. During peak periods, this access way is regularly congested, leading to travel time and comfort loss.

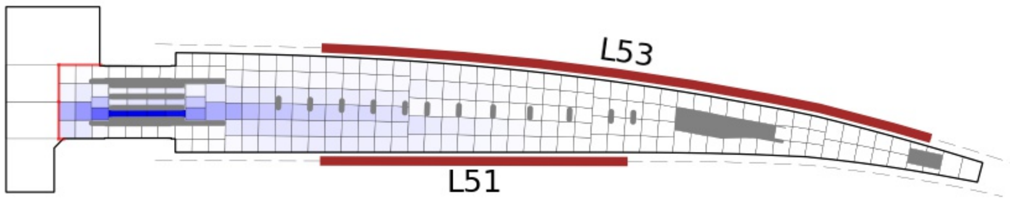

Figure 1: Snap shot of Centraal metro station at 08:16:45 on September 13, 2016, simulated with a macroscopic pedestrian flow model. Blue color represents pedestrian density (darker means higher density). Gray objects represent obstacles. The island platform is visible in the center-right; on the left the single access way is shown. Two metro trains (red) with line number 51 and 53 are idling.

For the evaluation of the case study, a rich data set is available. In collaboration with the municipality of Amsterdam and Amsterdam's metro operator, we have collected (i) minute-by-minute check-in/check-out counts at the access gate (thin red line on the left of Fig. 1), (ii) realized departure and arrival times, as well as (iii) destination split ratios required to associate

[2]We consider the station layout of September 2016, due to availability of suitable data.

outgoing travelers with individual metro lines. For validation, for a 30-day period in September 2016, Wi-Fi based density and walking time estimates are available.

At the time of writing, we have fully implemented the case study, and calibrated it using the aforementioned data. We have estimated the underlying route choice model and the alighting volumes of individual metro trains by minimizing the error in observed and simulated check-out counts.

Preliminary results show that gating leads to a measurable utility gain by reducing counter-flow and by preventing high densities in the narrow access way. Importantly, as the gating policy is dynamic, departing passengers are solely delayed in their access to the platform until the alighting flow has decayed, but typically do not miss their connection.

Currently, we are investigating the aforementioned operational measures in more detail, and plan to extend their evaluation to future scenarios. In particular, we are interested in their potential in case of demand increase as forecasted for the years 2020 (+14.2% compared to base case) and 2025 (+30.5%). Moreover, as a benchmark, we plan to examine a reactive, density-based PI-controller [1], where the control gains can be estimated using the aforementioned optimization framework.

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