Gating as a management strategy for controlling pedestrian flows

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1 Introduction

Multiple forecasts predict a strong increase in demand for public transport (PT) over the next couple of decades. This increase will put pressure on the pedestrian infrastructures associated with public transport: public transport vehicles and platforms, waiting areas, corridors or even the services available to customers (shops, ticket machines). The problems which can arise concern multiple actors. On one hand, users wish to move around freely and safely inside the infrastructure, implying low levels of congestion. On the other hand, the public transport operators try to maximize the number of passengers who use their services while minimizing the operational costs. Although these objectives seem antagonist to each other, there is one common aspect between them: avoiding poor user experience. In order to attract users to their system, PT operators must ensure that the level-of-service experienced by the passengers is acceptable. To achieve this, the operators must either limit the demand levels such that the infrastructure can support it, or increase the capacity of the infrastructure to cope with a larger demand.

This challenge of improving the efficiency of the infrastructure has been vastly studied in vehicular traffic over the past decades. Addressing this challenge gave birth to Dynamic Traffic Management Systems (DTMS) which aim at increasing the capacity of road networks by exploiting the fundamental relationships of traffic. For example, DYNASMART is an evaluation tool for advanced traffic management systems (ATMS), while DYNAMIT aims at providing prediction-based guidance for route choice. For an in-depth review, see Mahmassani (2001) and Ben-Akiva et al. (2003). Traffic management systems have various strategies available, some examples are ramp-metering, variable message signs, traffic signals or perimeter control. Unlike vehicular traffic, management strategies for pedestrian flows are still largely unexplored.

We propose a framework which is capable of evaluating and generating optimal management strategies for pedestrians. The objective is to design a flexible framework similarly to frameworks proposed for vehicular traffic, where the specificities of pedestrian traffic are taken into account. We develop, similarly to perimeter control, a gating strategy which can be used to control pedestrian flows. The calibration of this controller relies on two assumptions: 1) the existence of an aggregate fundamental diagram and 2) a linear relationship between the outflow from an area and the generalized flow within that area. Both of these assumptions have been verified based on empirical data collected in the train station of Lausanne (Switzerland), location chosen for the case study.

2 Methodology

The present section presents the main components of a framework aimed at evaluating and generating management strategies. A given management strategy can be split into various parts, for which we defined the following terminology. The first aspect concerns the action globally and is called the management/control *strategy*, while the second aspect refers to the actual operation of the given action and is called the management/control *policy*. The third is the measures used to apply the control policy and is called the management/control *devices*.

2.1 Simulation laboratory

The framework which is proposed for simulating and generating optimal control strategies is designed with real-time applications as the ultimate goal. This decision implies that the framework should be usable with either input from a real-life environment or a simulated environment. In vehicular traffic, such a simulation of real life is sometimes called a "plant" or a "simulation laboratory" (Ben-Akiva et al., 2003). We define three key components for such a framework: the pedestrian traffic, traffic controller and finally the control devices.

The traffic component concerns the interaction between the supply (walkable space) and the demand (pedestrian load). The pressure on the supply will influence the motion of pedestrians as they might decide to change route or perform a different set of activities due to congestion. The traffic controller must take decisions based on the state of the system. First the "state evaluation" which computes, based on the data transfered from the

"Pedestrian traffic" element, an estimation of the state of the system (for example density). Secondly, based on this state evaluation, the management policies are used to decide how to update the control devices by fixing the values of the control variables. Finally, the control devices apply the decisions taken by the controller. These three major components are organized in a cycle, as presented in Figure 1. The data passed to the traffic controller (simulated or measured) depends on the KPIs required to take the decisions. This can be pedestrian density, flow or travel time for example. The evaluation of the state of the system can be done based on any combination of the following: data from the current time, data from short term history or historical data. After the state of the system is estimated, the controller will compute, based on the control strategy which is used, the values of the various control variables. These values are then passed to the control devices, to be implemented by these devices.

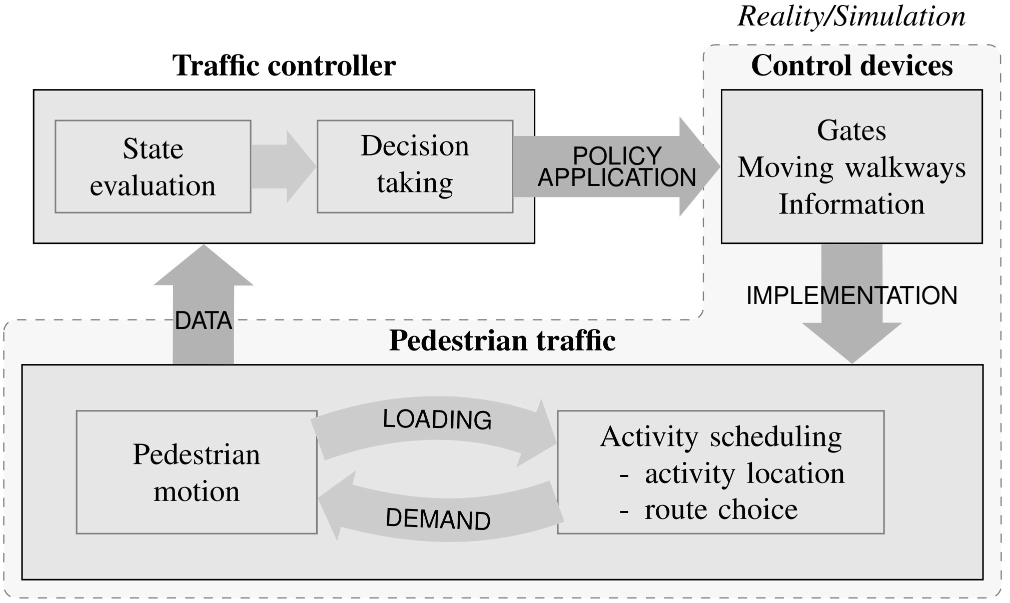


Figure 1: Interactions between the three main components in the framework. The dashed box surrounds the elements which can be either from "reality" or from a simulation.

2.2 Controller

The framework previously presented can be used with many different management strategies. To test the framework we use gates to control the flow of pedestrians entering a prespecified area, similarly to perimeter control for vehicular traffic (Keyvan-Ekbatani et al., 2012). The development of the proportional-integral (PI) controller relies on the following two assumptions: 1) the existence of an aggregate fundamental diagram and 2) a linear relationship between the outflow from an area and the generalized flow within that area. Thanks to the empirical data collected in Lausanne's main train station, both of these assumptions have been verified. The PI controller derived from the two assumptions stated previously and the conservation of pedestrian flow takes the following form:

$$q_{in}(k) = q_{in}(k-1) - K_P\left[\rho(k) - \rho(k-1)\right] + K_I\left[\hat{\rho} - \rho(k)\right] \tag{1}$$

where $q_{in}(k)$ is the inflow during time interval k, $\rho(k)$ the density measured in zone A, $\hat{\rho}$ the target density for zone A and K_P and K_I are the proportional and integral gains. Such "gains" represent the intensity with which the controller will react to the error between the measured and target densities. Both K_P and K_I must be estimated. This can be done either using the analytical expressions of these parameters, or a multivariate linear regression using least-squares on the empirical data. Figure 2 presents a simple case of gating where the flows entering the "junction" from two directions are controlled.

3 Preliminary results

The case study considered for testing the framework and the gating controller is the train station of Lausanne, Switzerland. This location was chosen as individual tracking data has been collected in 2013 during the morning peak hours (7h to 8h30). This data is used for the calibration of the parameters K_P and K_I from Eq. (1).

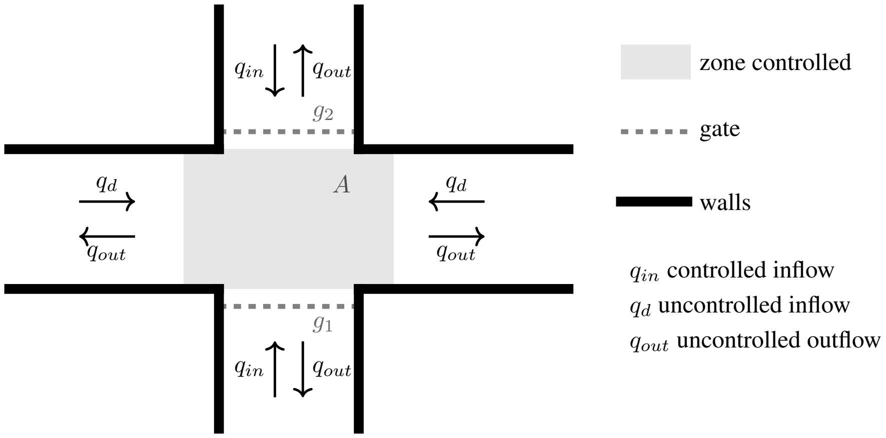
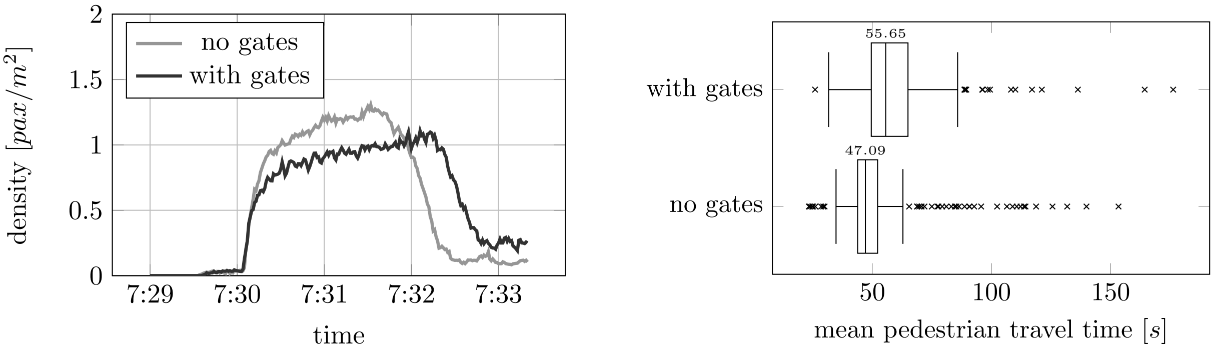


Figure 2: Schematic presentation of the gates controlling the inflow of pedestrians into a controlled zone denoted A. Each arrow represents a flow of pedestrians.



(a) Density levels

(b) Mean travel time per simulation

Figure 3: The objective of the controller to prevent the density from exceeding the threshold set at 1.0 pax/m^2 is met. Furthermore, the mean travel times of all pedestrians in the system is only increased by 18% (based on the median of mean travel times). The value above the box plots is the median of the mean travel times.

Two pedestrian underpasses connect the platforms to each other and the main hall in Lausanne's train station. Simulations have been performed on one of the two pedestrian underpasses where gates are installed at the bottom of the access ramps to one of the pairs of platforms (the setup is similar to Figure 2). The framework has been implemented using state of the practice models for the pedestrian motion and route choice. The social force model is used to model the motion of pedestrians (Helbing et al., 2005) and the route choice is modeled using the shortest path (Dijkstra, 1959). Although these models are relatively simple compared to more sophisticated approaches, the preliminary results are encouraging.

In order to evaluate the effectiveness of gating as a control strategy, two indicators are computed from the simulations. Firstly, the density inside the area under management is monitored throughout the simulation (which is also used by the PI controller). The second metric which is measured is the travel time of each pedestrian. We recall that the key objective of gating as a management strategy is to prevent the density from entering the flow-breakdown area. Therefore, in order to observe whether this objective is accomplished in a recurrent way, the mean density over multiple simulation runs is computed for two scenarios: one with gating and one without.

The scenario considered at this stage is the arrival of a train from which passengers alight. These individuals leave the platform and enter the pedestrian underpass and interact with other pedestrians already present. Figure 3 presents the results based on 100 simulation runs of the mean density inside the area under control (the junction at the bottom of the access ramp to the platform) alongside the mean travel time per simulation of all pedestrians in the system. The gating strategy effectively prevents the congestion from entering into the flow-breakdown stage, defined as a pedestrian density above 1.0 pax/m^2. Furthermore, the travel times of the pedestrians only increases by 8.5 seconds (18%). The extra travel time induced by congestion is limited.

4 Conclusion

We present a framework for controlling pedestrian flows using a dynamic traffic management system. This framework is made operational thanks to the usage of gating as a management strategy. The objective consisting of preventing high densities is reached while the travel times are not significantly impacted. Furthermore, the application of the framework shows that investigating dynamic traffic management systems for pedestrians is promising. Many different problems can be addressed with a well designed framework, such as analyzing pedestrian flows in shopping malls, the management of concert halls or conference centers or even evacuation scenarios.

In order to consolidate the preliminary results more advanced scenarios will be considered. The travel time of different groups of pedestrians will be analyzed for various scenarios and gating management policies. Alongside these simulations, more advanced models for pedestrian motion and route choice will be used.

Acknowledgments

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