
# The impact on pedestrian walking times of counterflow

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## Abstract

Exploiting the full potential of pedestrian infrastructures is becoming vital in many environments which cannot be easily expanded to cope with the increasing demand. This is particularly true of train stations in many dense cities since space is limited. One solution to improve the level-of-service experienced by pedestrians is to regulate and control their movements with a dynamic traffic management system. In order to develop and test pedestrian specific control strategies a simulation laboratory is implemented. This numerical environment allows the validation of two control strategies dedicated to pedestrian dynamics: gating and flow separators.
The effectiveness of these strategies has been investigated firstly by using a proof-of-concept setup to explore the sensitivity to some parameters, and secondly by simulating a subpart of the train station in Lausanne (Switzerland). Both strategies achieve their respective goals by preventing excessive congestion and decreasing the pedestrian's walking times.

## Keywords

Pedestrian simulation, traffic control, dynamic traffic management

# 1 Introduction

Just as road traffic, pedestrian traffic suffers from congestion which can induce extra travel time, cost and hazardous situations. Preventing such congestion should be a concern of the operator of any pedestrian infrastructure. This is true for conference centers, transportation hubs such as train stations and airports or even shopping malls for example. Although these infrastructure have different goals, the people using them have the same desire: being able to move without being hindered by other pedestrians. To achieve this, operators can rely either on static design measures during the construction phase of an infrastructure, or on dynamic devices to regulate the movement of pedestrians. The latter involves a more general framework, common in road traffic: dynamic traffic management systems (DTMS).

Multiple frameworks have been proposed in the literature for classical road DTMS. Some example are DYNAMIT (Ben-Akiva *et al.,* 1998), DYNASMART (Mahmassani, 2001) and METANET (Messmer and Papageorgiou, 1990). This list is far from exhaustive, for a further overview see Ben-Akiva *et al.* (2003a) where the authors present in detail the major challenges associated with DTMS frameworks for road traffic. Simulation has become a major tool as analytical models rely on questionable assumptions. Furthermore, they propose a simulation laboratory which can be used to evaluate the effectiveness of control measures by separating the traffic model from the management center. This emphasizes the two major components of any DTMS: a traffic model (dynamic traffic assignment) and a control center.

Only recently has traffic mangement for pedestrian been investigated. Naturally, the same two fundamental components are required.

On one hand the modelling of pedestrian motion has been an active area of research over the last couple of decades (Kouskoulis and Antoniou, 2017, Duives *et al.,* 2013). But on the other hand, few dynamic control strategies have been proposed for pedestrian traffic. We therefore discuss some specificities of DTMS for pedestrians. Although the high-level concepts are similar, in practice many constraints are different when focusing on pedestrian dynamics. Given the lack of control strategies which focus on daily operations and are solely dedicated to pedestrian traffic, two dedicated control strategies are investigated. The first can regulate pedestrian movements thanks to devices similar to gates. The second improves the pedestrian's movements by preventing counter-flow by separating the flows. These strategies are integrated into a pedestrian DTMS such that their impact can be measured in a simulation laboratory (or plant). To evaluate the effectiveness of these strategies, firstly a a proof-of-concept scenario is considered, and secondly an analysis is performed on a subpart of the train station in Lausanne (Switzerland).

To reach this objective, the article is structured as follows. After this introduction and literature review, the second section presents some of the specificities of a dynamic traffic management system for pedestrians. The third section presents in detail the two control strategies which we designed to improve the pedestrian dynamics. Finally, before the conclusion, case studies present the impact of the control strategies in two different environments. Firstly a proof-of concept setup where the advantages and sensitivity to compliance are explored. Secondly, a real-life scenario is used to investigate a more complex infrastructure.

# 2 Literature

Pedestrian simulation models, which are required by a DTMS, are widespread in the literature. Three major paradigms exist (microscopic, mesoscopic and macroscopic) and within each one many different sub categories can be found. For an in-depth review of these motion models, see Duives *et al.* (2013). The operational questions are not sufficient for modelling pedestrian flows. Tactical models, also know as route-choice, are required. Similarly to the motion models, there are many different flavours. Stubenschrott *et al.* (2014) and Guo and Huang (2011) present two major directions, namely graph-based and potential based tactical models. These elements compose together a dynamic traffic assignment model (DTA), see Mahmassani (2001) for more details. Nevertheless, to build a DTMS framework the second component is missing: pedestrian control strategies (Dubroca-Voisin *et al.,* 2019).
When considering road traffic many different possibilities exist. Ramp metering (Papageorgiou *et al.,* 1991), signalized intersections, variable message signs (Ben-Akiva *et al.,* 2003b), perimeter control (Ramezani *et al.,* 2015) are only a small subset of the alternatives. Some of these ideas have been transposed to pedestrian traffic.
Recently, a framework for controlling LOS in a pedestrian infrastructure has been presented in Zhang *et al.* (2016). The walkable space is represented in a bi-level way: a graph combined with cells. The same target density is enforced on each link by controlling the pedestrian's walking speed. This approach is difficult to apply in transportation hubs as the demand presents very high spatial and temporal fluctuations, making uniform density or speed not desirable. Similarly to the previous study, a macroscopic pedestrian movement model was used to assess and design the strategy for controlling the opening and closing times of access gates to metro stations (Bauer *et al.,* 2007). The scenarios were based on special events where the demand significantly exceeds the daily operation's demand. Nevertheless, although the authors use most of the components required in the design of a framework for the generation of management strategies, no complete framework is proposed, indeed, each component is used independently.
For daily operations, Jiang *et al.* (2018) propose a coordinated control scheme across multiple metro (light rail) stations. The author's goal is to ensure that all passengers can get on their desired service. This objective is achieved by regulating the inflow into the stations by using a

buffer zone just outside the station. Reinforcement learning is used given the large scale network and the computational cost induced by such network.

Most the attention has been guided towards reactive and offline strategies. The optimal configuration of traffic lights for signalized crosswalks has been studied for example Zhang *et al.* (2017). The authors propose a MILP to optimize the configuration of the green, orange and red phases to minimize the pedestrians delay while satisfying vehicular traffic constraints.

The effectiveness of some crowd management actions was observed in a real-life situation in (Campanella *et al.,* 2015), where a Brazilian metro stop offered very poor LOS and possibly dangerous situations during the new-year celebrations. Some management strategies had been planned and used to prevent critical situations while some reactive actions were also used. Qualitative observations where done and compared to operations from the previous years. The authors emphasize the need for an integrative framework including pedestrian simulations for evaluating various crowd management strategies.

One area which has been more thoroughly investigated is controlling pedestrian dynamics in emergency situations. The goal is to measure and minimize the time required for all pedestrians to leave an infrastructure. The difference with daily operations lies in the pedestrian behaviour and the final objective. For example, the optimal placement of exits and furniture inside rooms is analysed in Hassan *et al.* (2014) using a cellular automata model (Blue and Adler, 2001) and simulated annealing for the optimization. Similarly, flow is regulated in order to maximize discharge in a corridor during an evacuation in Shende *et al.* (2011).

# 3 Pedestrian dynamic traffic management

The specificities of pedestrian traffic require adaptations to road DTMS and a complete overhaul of the control and management strategies. These changes are discussed in the following sections. But first, we define a terminology regarding the control strategies to clarify the discussion. The difference between control and management is made with respect to compliance. Control strategies impose some actions, while management strategies allow the individuals to decide whether to follow or not the guidance. Strategies can be reactive if they take decisions based on measurements or anticipative (or proactive) if they rely on an estimation of the future state of the system. Finally different subparts of a "control strategy" need to be defined. The control *devices* are the physical objects used to apply the decisions taken by the control *policy* which takes the state of the system as input and returns the updated state of the devices.

## 3.1 DTMS for pedestrians

All dynamic traffic management systems rely on the traffic dynamics. The latter can be either real-world scenarios when the DTMS is applied in real situations, or a simulation when the objective is to explore the possible control strategies. Naturally, a DTMS focused on pedestrian traffic follows the same general rules. At this stage, we focus on the second setup: using a simulation framework for testing and designing management strategies.

**Pedestrian motion** Naturally, the models used for simulating pedestrian motion are different than those used by road modellers. Nevertheless, a similar categorization can be made based on the level of detail of the agents which are modelled. Indeed, pedestrian traffic can be modeled using many different motion models. These can be macroscopic, mesoscopic or microscopic (Duives *et al.,* 2013). Each category of model addresses the trade-off between computational time and the level of detail in different ways. The macroscopic models are generally fast to compute, but pedestrian specific information is not readily available. Microscopic models provide highly detailed information about the individual agents but can be very expensive to compute. And finally, mesoscopic model lie in-between: they provide some information regarding groups of individuals without the excessive computational time.
The choice of models depends on the scenario under investigation. If the scenario involves a compact infrastructure and the control strategies require disaggregate information, then a microscopic simulator would be better. On the other hand, very large scale infrastructures with strategies impacting pedestrian at an aggregate level require faster motion models as the computational cost is larger. Nevertheless, no explicit rule can be defined. This decision relies strongly on the context. Motion models as described previously are not sufficient for pedestrians to navigate around infrastructures. A route choice model is required to address the tactical decisions. There are multiple paradigms for modeling route choice. Graph-based Stubenschrott *et al.* (2014) and potential-based Guo *et al.* (2013) are two common approaches which can take into account congestion.
Although the road and pedestrian traffic modelling approaches show similarities, there are some major differences. The first is compliance. Unlike vehicles, pedestrian do not have a set of strict rules to follow. Albeit some social rules do exist, but are still flexible and very much sensitive to interpretation. Secondly, pedestrian flow is multi-directional, with very fast changes in speed and direction.

**Traffic controller** The traffic controller can be considered as the "brain" of the system. The state of the system is monitored through various KPIs which can take into account different

aspects of the pedestrian dynamics. Not only can the traffic controller use measurements from the system (density, flow, speed, etc) but predictions can also be incorporated to include information about the future (model predictive control). Data which comes from measurement devices is denoted as $\tilde{\cdot}$ and data coming from predictions is denoted $\cdot^{+}$ in Figure 1.
The controller can also include an optimization component which searches for the best set of parameters for a given future time interval based on some prediction. Given the stochastic and complexity of the simulation, a simulation-based optimization scheme as presented in Figure 2 can be used.

**Control devices** The most significant difference between a DTMS for pedestrians and one for road traffic resides in the possible control strategies. Unlike vehicles, pedestrians (generally) are not constrained by lanes nor regulations. This means pedestrians have many more degrees of freedom. Therefore to control the pedestrian's movements, either completely new elements must be introduced (like gates, traffic lights, lanes) or strategies must "softly" influence the pedestrians. Some examples of soft strategies could attract the pedestrians to less crowded areas by using "points of interest" or more directly by providing information. The major drawback and challenge regarding "soft" strategies is the pedestrian compliance. Some individuals will choose to follow the guidelines, while others won't.

**Interactions** The interactions between these three elements take place through the control policy and control devices, as presented in Figure 1. The state of the traffic is evaluated by the controller, which then passes this information onto the control policy. Next, the control policy computes the desired state of the devices which finally implement the control strategy.

## 4 Control strategies

Two control strategies are presented in this section. The first aims at preventing excessive congestion while the second splits the pedestrians based on their walking direction to prevent counterflow.

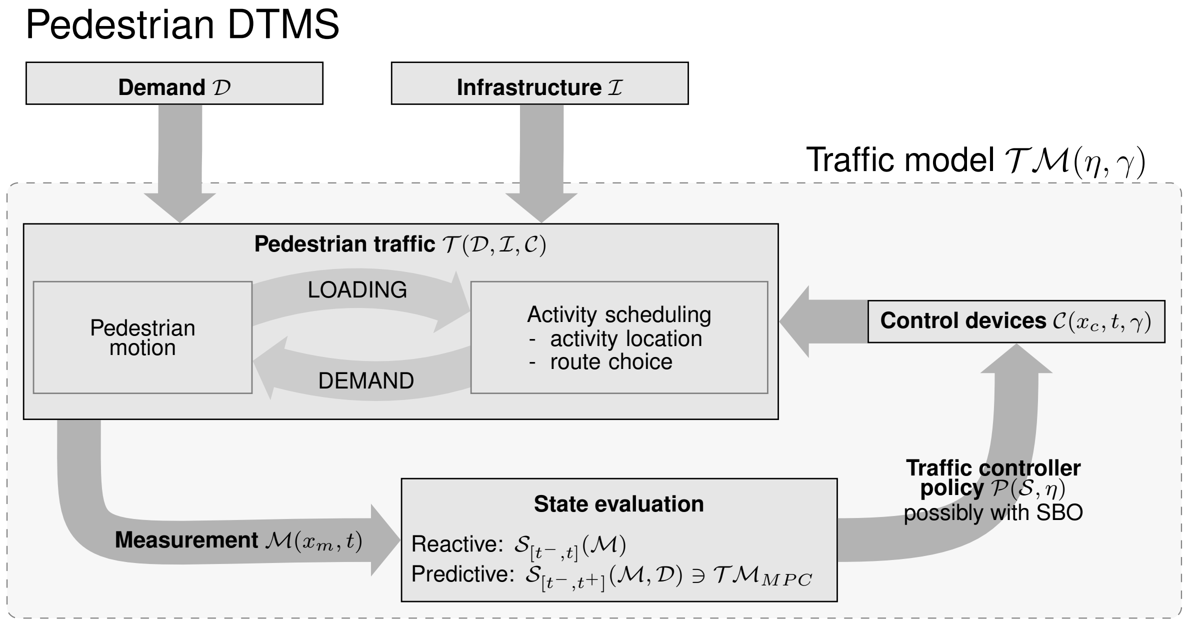



Figure 1: DTMS for pedestrian traffic. The pedestrian demand and infrastructure can be seen as inputs to a DTMS. The dynamic equilibrium exists between the pedestrian motion and route choice as they will impact each other. The traffic controller's goal is to reach some pre-specified target in order to improve some indicators.

## 4.1 Gating

In a similar way to ramp metering and signalized intersections , the movement of pedestrians can be controlled near intersections. As there are many different sub-routes inside intersections, high congestion will prevent pedestrians from following there ideal path. Therefore, we propose a gating scheme which can control the flow of pedestrians in real-time. This requires the following elements to be defined: an indicator to evaluate the current state and a control law linking this indicator to the controlled flow.

**Indicator definition** One of the challenges with developing an accurate indicator for pedestrians resides in the very high temporal and spatial variability. Another challenge lies in the dependency on pre-defined zones. For example, when computing the average pedestrian density inside an area, the limits of the area can strongly impact the computed density. To circumvent these problems, we are using Voronoi tessallations to compute individual pedestrian densities. This way, a pedestrian specific density value is obtained at a given time. The Voronoi density of pedestrian $p$ at time $t$ is denoted by $\rho_p(t)$.

As we have detailed information regarding the current level-of-service each pedestrian is ex-

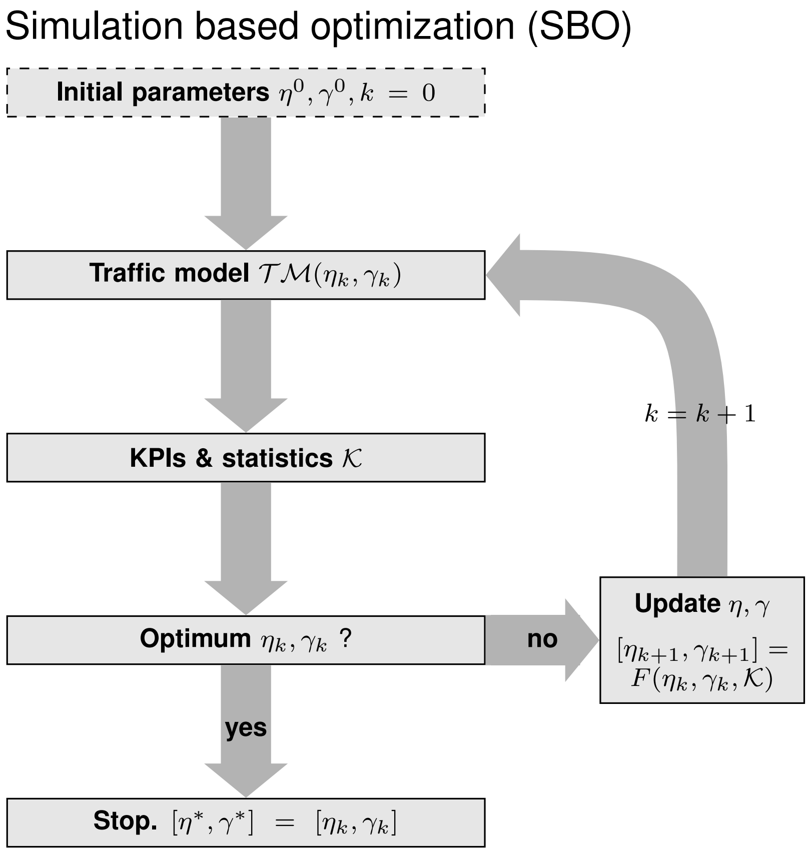



Figure 2: Simulation based optimization framework for finding the optimal parameters with respect to some specified KPI. This can be used either to do offline optimization of the control parameters or real-time optimization in a rolling horizon approach.

periencing, we can define an indicator which takes into account the high spatial variability. As pedestrians who experience low density can still move freely, we focus on those with high associated densities. Firstly, we define the difference between "low density" and "high density". This is done by setting a threshold $\bar{\rho}$, below which pedestrians can move freely and above which pedestrians are in a congested state. Thanks to this threshold, we can define the indicator $\kappa$:

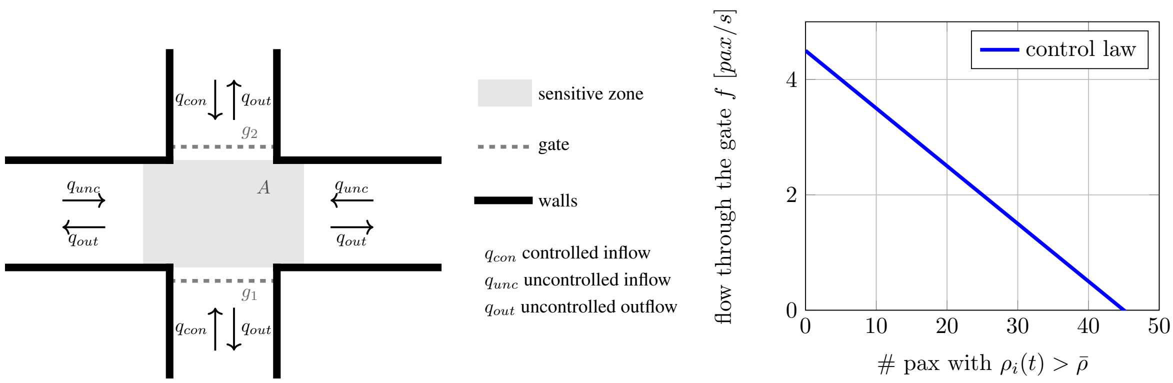
$$\kappa(t) = \sum_{p \in \mathcal{P}} [\rho_p(t) > \bar{\rho}] \tag{1}$$

where $\kappa(t)$ can be read as “the number of people at time $t$ who’s density exceeds the threshold $\bar{\rho}$ ” and $\mathcal{P}$ is the set of pedestrians close to the intersection.

**Control law** The total pedestrian flow into the intersection must be regulated based on this measured indicator $\kappa$. This control law can take many different forms, hence we assume a linear law as this simplifies the calibration process thanks to the fewer number of parameters which must be estimated. The proposed law therefore takes the following form:

$$f(\kappa) = a \cdot \kappa(t) + b \quad (2)$$

where the two parameters $a$ and $b$ must be estimated. This is done thanks to the analysis of simulated and empirical tracking data. The parameter $b$ is fixed such that the allowed flow when $\kappa = 0$ is equal to the maximum capacity of the corridor where the gate is installed. The interpretation of the second parameter is more involved.
We exploit the pedestrian-specific densities to decide at which congestion level the gates let no pedestrian through. This way, we fix an upper bound on the number of pedestrians who are allowed to suffer from excessive density. The event when one pedestrian suffers from density above the density threshold $\bar{\rho}$ is not a significant problem, but if this takes place often and many pedestrians experience high densities then the situation is problematic. Therefore the gates stop allowing pedestrians into the critical area when too many pedestrian experience a poor level-of-service.




(a) Schematic setup. (b) Control law.

Figure 3: Gates are used to control the inflow into the corridor intersection. The flow is function of the density inside the intersection.

## 4.2 Flow separators

As experienced by many individuals and shown in studies Burstedde *et al.* (2001), counter flow in pedestrian traffic is responsible for a significant increase in travel time. This happens as people have to "slalom" between the people coming in the opposite direction. In order to prevent this, we propose a control strategy for preventing counter flow in corridors: flow separators. Counter flow can be prevented by splitting the corridors dynamically based on the pedestrian flows coming in each direction. Figure 4 presents a schematic setup where a flow separator is installed in a corridor.

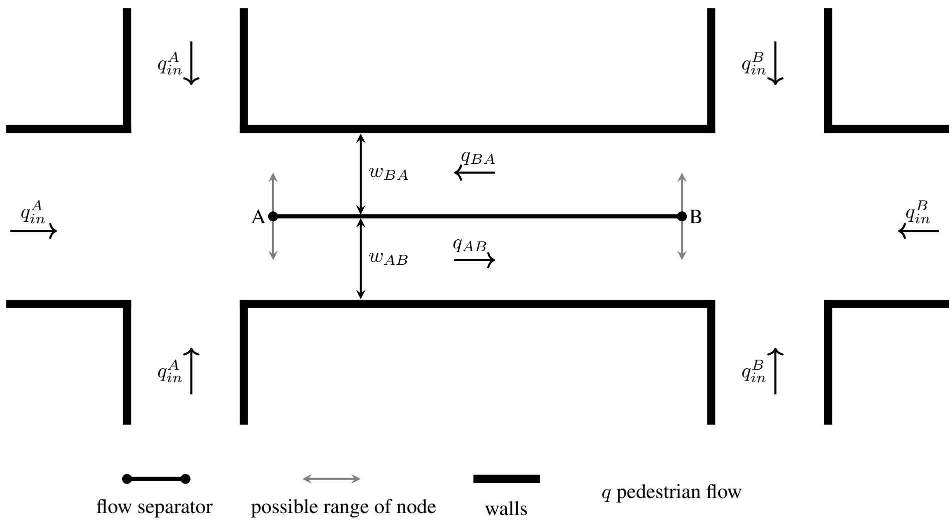



Figure 4: The width dedicated to each direction is adjusted based on the flows entering the corridor.

Unlike the gating strategy, there is no feedback loop for the dynamic separators as the pedestrian flows are measured upstream from the devices. This situation could occur when an important queue forms in front of the separator, inducing spillback. Nevertheless, we assume that this situation does not occur. Therefore, the width available for the pedestrians moving from $A$ to $B$ is function of the flows going from $A$ to $B$ and the flows going from $B$ to $A$. These flows can either be measured (past or present) or predicted (future):

$$w_{AB} = f(\tilde{q}_{AB}, q^{+}_{AB}, \tilde{q}_{BA}, q^{+}_{BA}), \tag{3}$$

where $w_{AB}$ is the width dedicated to pedestrians walking from $A$ to $B$, $\tilde{q}_{AB}$ is the measured flow from $A$ to $B$, $q^{+}_{AB}$ is the predicted flow from $A$ to $B$.
Making the strategy operational requires specifying the function $f$. Not only can the measured and predicted flows be combined in various ways, but the functional form can also change. In general, increasing the complexity of the functional form increases calibration complexity. Therefore to keep the calibration to a strict minimum, we propose a function which relies only the measured flows at the current time:

$$w_{AB}(t) = f(q_{AB}(t), q_{BA}(t)), \text{ with} \tag{4}$$

$$f(q_{AB}(t), q_{BA}(t)) = w \cdot \frac{q_{AB}}{q_{BA} + q_{BA}} \tag{5}$$

where $w$ is the total corridor width. This way, the width dedicated to each direction is proportional to the flows. In order to prevent the width dedicated to a specific direction become too small for pedestrians to move freely, there are lower and upper bounds on the widths. These bounds, denominated $w_{AB}^{min}$ and $w_{AB}^{max}$ correspond to the minimum width required by an individual to walk comfortably along a corridor (Weidmann, 1993). The full specification of the width, at time $t$, dedicated to pedestrian walking from $A$ to $B$ is therefore:

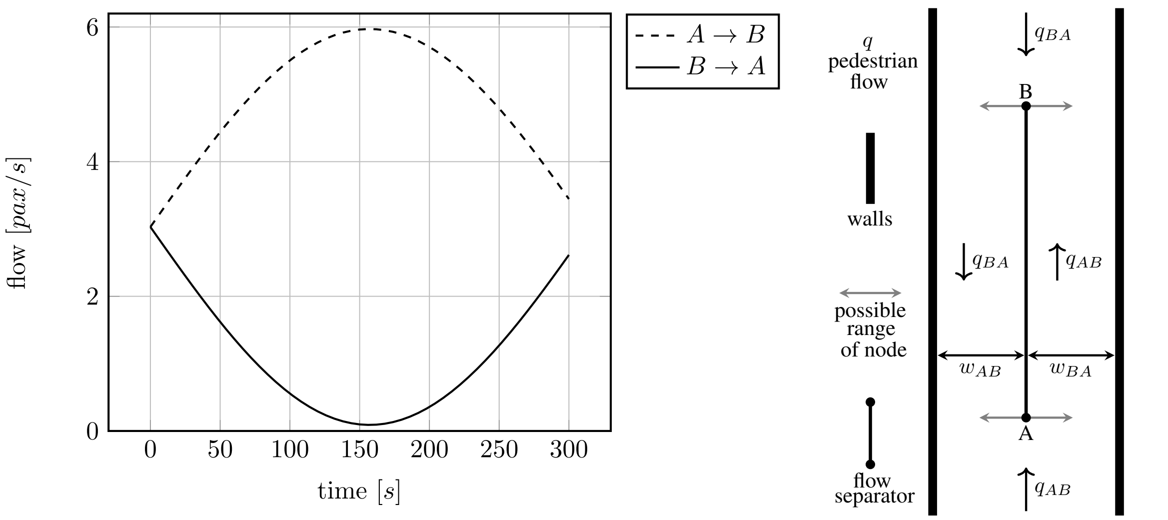
$$w_{AB}(t) = \begin{cases} w_{AB}^{min}, & \text{if } w \cdot \dfrac{q_{AB}}{q_{AB} + q_{BA}} \leq w_{AB}^{min} \\ w_{AB}^{max}, & \text{if } w \cdot \dfrac{q_{AB}}{q_{AB} + q_{BA}} \geq w_{AB}^{max} \\ w \cdot \dfrac{q_{AB}}{q_{AB} + q_{BA}}, & \text{otherwise} \end{cases} \tag{6}$$

# 5 Case study

The results for the flow separators are presented here. Two scenarios are considered, first a proof-of-concept setup and then a real-life case based on the station in Lausanne.

## 5.1 Flow separators

The control strategy presented in the previous section has been implemented in a pedestrian simulator. This simulator uses the pedestrian motion model from NOMAD (Campanella, 2016). First, the impact of the dynamic flow separator is compared to the "no strategy" situation and a static version of the flow separators. The static version is a fixed separator in the middle of the corridor. Secondly, the effectiveness of this control strategy is shown for different demand levels. Finally, a sensitivity analysis to the compliance (i.e. following the rules) is accomplished. The demand pattern shown in Figure 5(a) is used to evaluate the effectiveness of the dynamic flow separators. The demand various following two sine functions with a shift in the period. We chose such a pattern as this is a rough approximation of the flows which can occur inside a train station when trains alight their passengers. This demand pattern is used in all numerical experiments, except in some cases the amplitude is changed.
As the simulation is a stochastic process, multiple runs of the same setup must be performed to evaluate the stability of the process. From each of these simulations, one indicator is computed (either the median or the variance of the travel times), then we consider the mean of this indicator across simulations. Therefore we have either the mean of medians, or the mean of variances to consider.




(a) Demand pattern.

(b) Corridor infrastructure.

Figure 5: Proof-of-concept infrastructure and demand pattern used for the simulations.

### Influence of dynamic flow separators

The flow separators are tested on the short section of corridor presented in Figure 5(b). The objective is to decrease the travel time and also the variation in travel time of the pedestrians. The improvement is significant when comparing the "no separator" scenario to the "with separator" scenarios (Figure 6). The number of simulations to perform has been determined by using Figure 7, where the mean square error (MSE) is computed using bootstrapping. This technique is used since no analytical solution exists for estimating the MSE of the medians. The number of simulations required to guarantee an acceptable MSE is fixed at 60. The MSE is already acceptable for our purpose and it decreases slowly after this point. For all subsequent simulations, we target 60 replications.

Naturally, flow separators will not be efficient for all scenarios and demand patterns. In order to explore the flow domains where the flow separators are efficient, the same demand pattern is used but the amplitude is changed. The results from this sensitivity analysis to demand are presented in Figure 8. For very low demand levels, the flow separators induce a small increase in travel time since the pedestrian must add a small walking distance to cross the corridor to the same side. This excess is quickly compensated as from a demand of 1.0 passengers per second the flow separators are beneficial when considering the medians of travel times (Figure 8(a)). If we consider only the medians, then dynamic flow separators have little benefit on the travel times compared to the static flow separators. Nevertheless, when considering the travel time variance per simulation, the dynamic flow separators are beneficial for the pedestrians. At

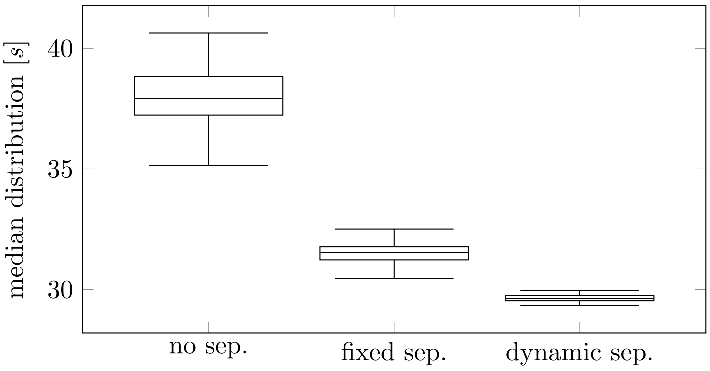



Figure 6: The pedestrian flow separators are very efficient for reducing the travel times. 100 simulations were performed, and for each simulation the median travel time is computed. The boxplots of the medians per scenario show that the travel time and variance in travel time are significantly reduced.

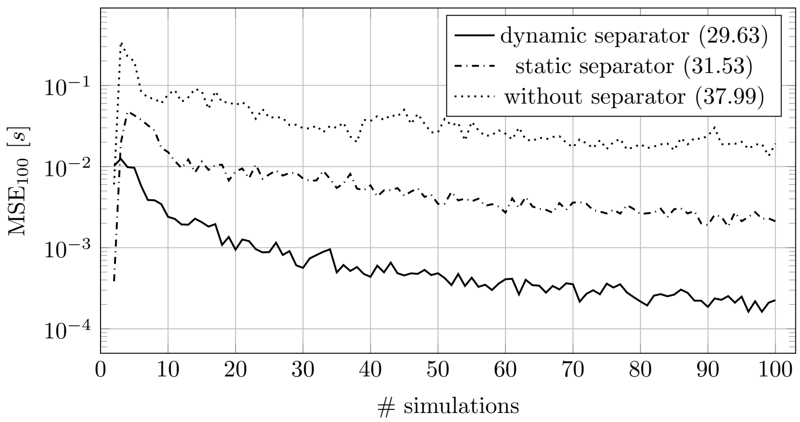
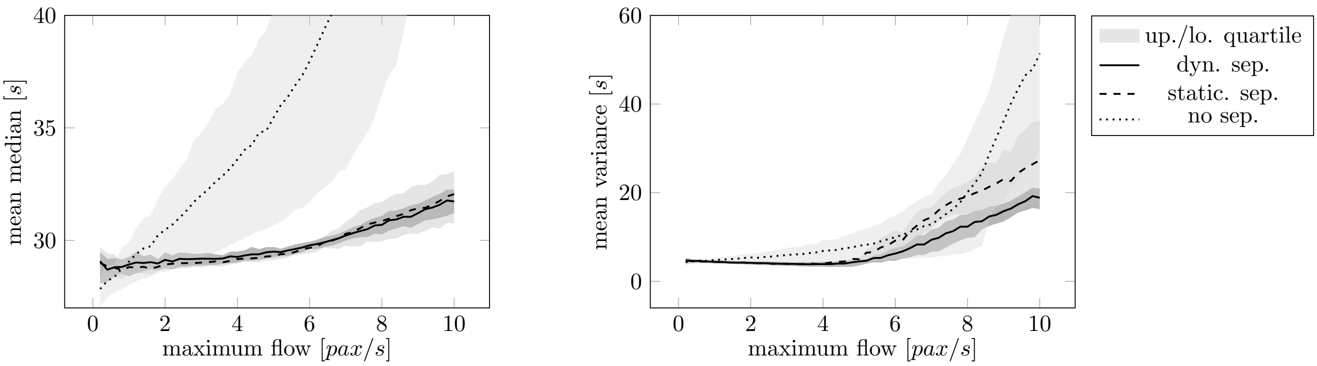



Figure 7: The mean square error computed using bootstrapping for the three scenarios. The usage of flow separators means the required number of simulations to reach a given error is significantly lower.

high demand levels, the variance is significantly lower when dynamic flow separators are used instead of static ones (Figure 8(b)).




(a) Mean of median travel times.

(b) Mean of travel time variance.

Figure 8: Travel time median and variance analysis for the different scenarios considered. The bands indicate the upper and lower quartiles of the distributions.

### Sensitivity to compliance

As pedestrians are generally not restricted in their movements, nothing enforces the pedestrians to follow the rules. Therefore, the impact of compliance to the rules is explored in this section. The objective is to explore the cost induced by a small percentage (5% or 10%) of the pedestrians taking the sub-corridor dedicated to the opposite walking direction.
Figure 9 presents the travel time variance for full compliance, 5% and 10% of un-compliant pedestrians. Figure 10 shows the median travel time per direction for the three compliance scenarios. When considering Figure 9, it is clear that the case with 100% compliance shows the lowest variance in travel, which is expected. As already seen from Figure 8(b), the dynamic flow separators present clear advantage as they keep the variance lower compared to a static separation of flows. This behaviour is also true for cases where a small percentage of pedestrians do not follow the rules. The dynamic flow separator keeps the travel time variance significantly lower than the static case, this is indicated by the gray lines being above the corresponding black lines from Figure 9.

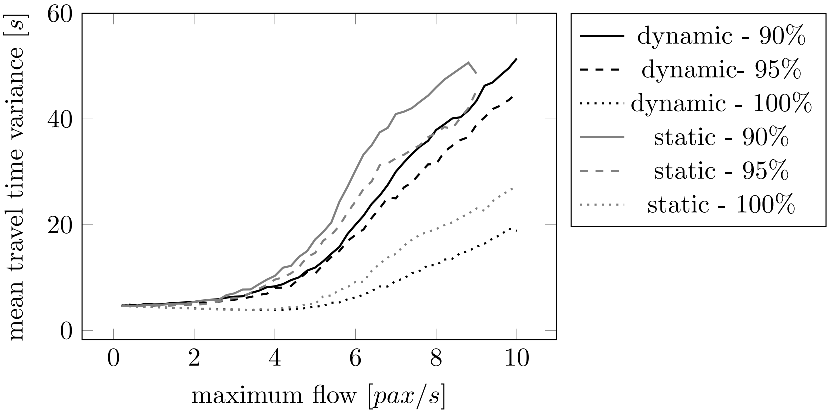
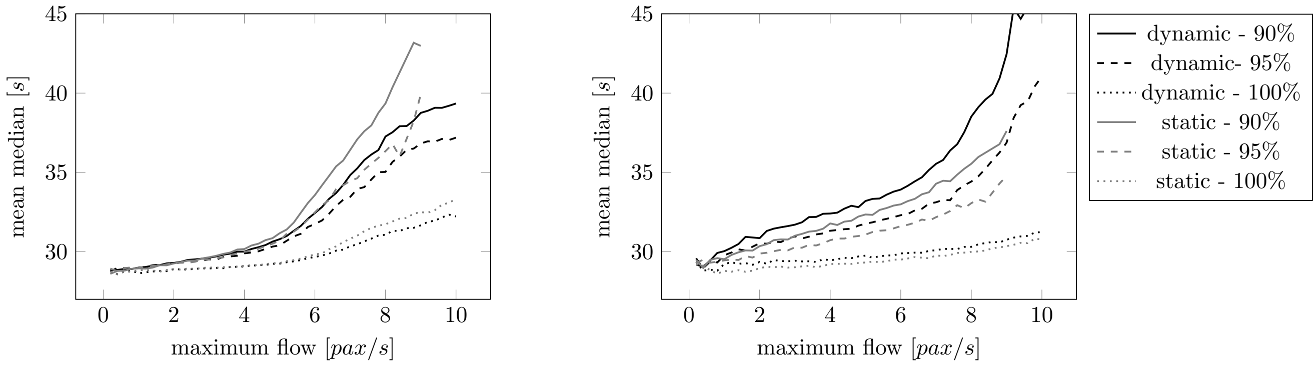



Figure 9: Comparison of the travel time variance between the static flow separators and the dynamic ones for different compliance levels. The dynamic flow separators effectively reduce the variance in travel time for higher demand levels.

By analyzing the travel time medians per direction, we can see two opposite situations. The pedestrian flow going from *A* to *B* is the dominant flow, while the opposite flow from *B* to *A* is the dominated one (i.e. a small group of people moving against a larger group). First of all, the general behaviour of the dynamic flow separator is to give more space to the larger flow. This means that the dominant flow will generally benefit from this strategy, while the dominated flow will see it's reserved space decrease. Hence it is generally penalized by this approach. The impact on the travel times will therefore reflect this idea, as seen in Figure 10. When comparing the dynamic to the static flow separator for the dominant flow (Figure 10(a)), the dynamic flow separator is beneficial for this group. On the other hand, for the dominated flow (Figure 10(b)) the opposite is true: the dynamic version increases the travel times of the pedestrians. This happens because this group has less space to move around in, hence creating higher congestion.




(a) Pedestrians moving from $A \rightarrow B$. (b) Pedestrians moving from $B \rightarrow A$.

Figure 10: Travel time comparison for the opposing directions with different compliance levels. The dynamic flow separators are useful for reducing the impact of the uncompliant pedestrians.

## 5.2 Train station corridor

After exploring the impact the separation of pedestrian flows has on a single straight corridor. The impact on a more complex and realistic infrastructure is analysed. Individual tracking data has been collected for ten days in 2013 for both pedestrian underpasses (PIs) of the main station in Lausanne, Switzerland. This data is firstly used to validate the pedestrian simulator which is chosen, but more importantly as demand scenarios for testing the effectiveness of pedestrian flow separators. The general idea is the same, prevent head-on collisions between pedestrians by dedicating parts of the corridor to each flow direction. This is done by installing three independent flow separators in the corridor, as seen in Figure 11. The demand pattern which is taken from the empirical data is presented in Figure 12. Since only ten days of data are available, using these days as separate replications isn't possible for statistical reasons therefore we considered these ten days as independent scenarios. For each of these ten scenarios, a given number of simulation replications where performed to build the distribution of the KPIs. In this case, we kept travel time but also investigated mean walking speed.

Since the travel time of all pedestrian are not significantly impacted, we categorized the walking times into groups based on the trip characteristics. Two criteria are used: trip length and number of times pedestrians must cross the "junctions" (or equivalently the number of left turns they

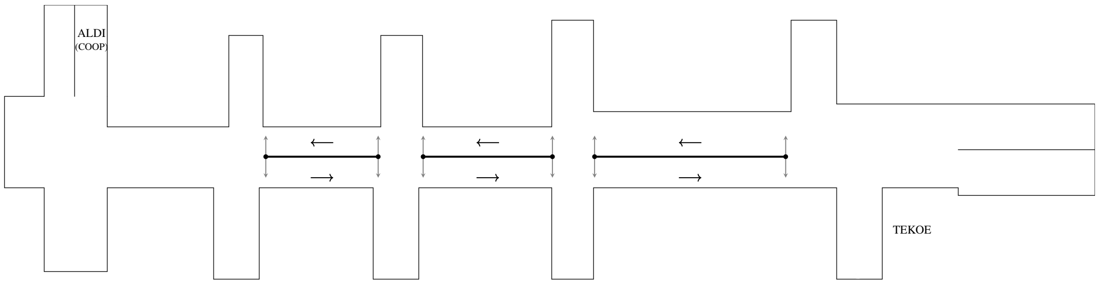



Figure 11: Western pedestrian underpass from the station in Lausanne, Switzerland. Three flow separators are installed in the central part of the corridor.

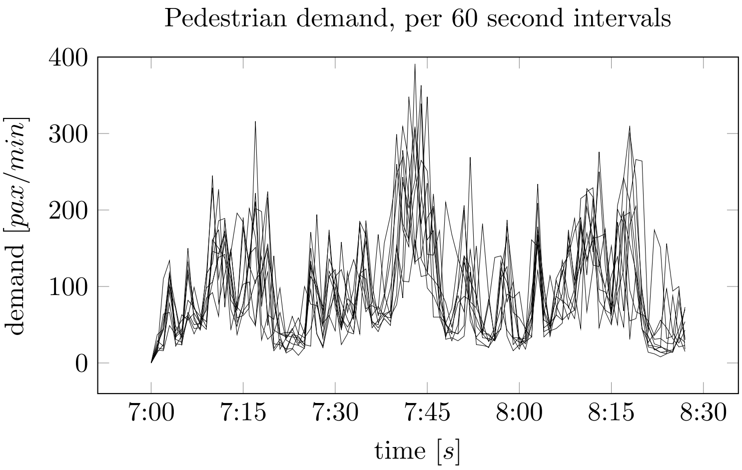
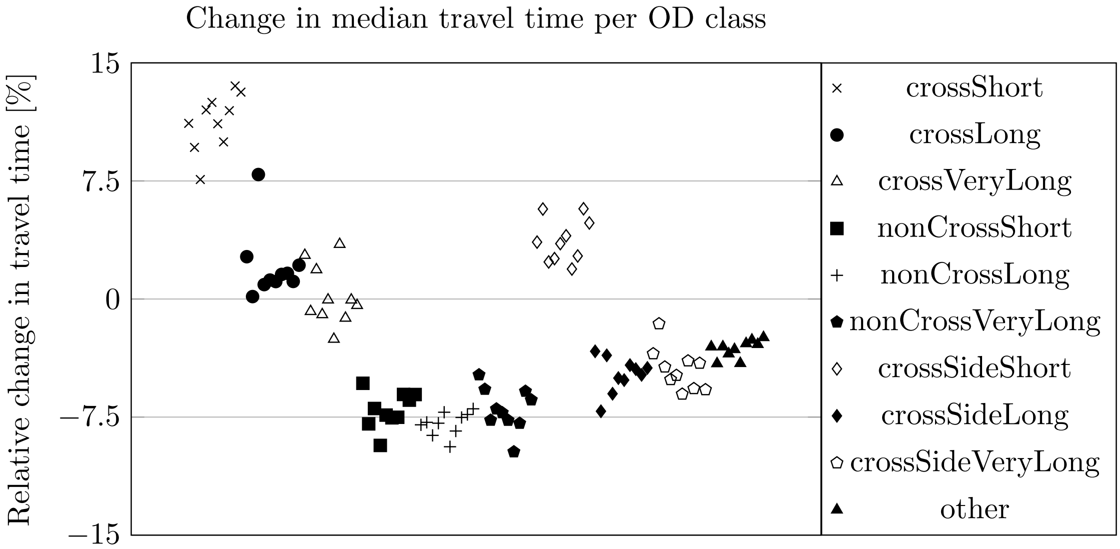



Figure 12: Aggregate empirical demand pattern used as input in the simulations for evaluating the flow separators. Each curve represents one day (ten days in total). The influence of the cyclic timetable is visible at 7h15, 7h45 and 8h15 since a peak in demand appears at those time.

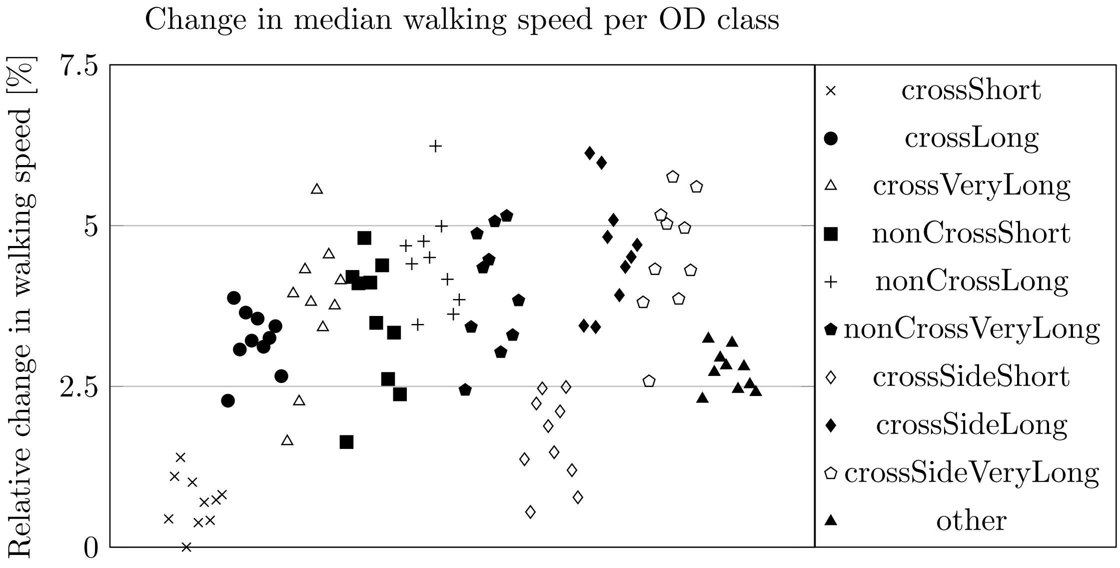
must do). This leads to nine groups in total since there are three different trips lengths and three different groups of "left-turns": zero left turns, one left turn and two left turns. The comparison of the median of median travel time and average walking speed for each group are presented in Figure 13. In these figures, each point indicates 50 replications of one scenario (based on the empirical data).

The impact of the flows separators depends on the group under examination. If pedestrians did not require to make any left turns (i.e. cross the junction areas), their travel time decreases regardless of the length of their trip. This sub-population benefits from this control strategy. The group of pedestrians doing on left turn are positively influenced if they are doing a "long" trip. The short trips where the pedestrian change side of the corridor (one left turn) suffer from an increases travel time. Finally, trips involving two left turns are at best not affected by the flow separators. This is the case since the walking time gained by the separated flow is compensated by the time needed to cross twice the junctions.

At this stage it might be tempting to say that this is caused simply by the extra walking distance induced by the usage of flow separators. By considering the change in average walking time (Figure 13(b)), it is clear that all groups of pedestrians benefit from the flow separators as their walking speeds increase. This happens since the flow separators effectively prevent the weaving effects and head-on collisions between pedestrians. Some groups do indeed walk a longer distance, but their travel time is not impacted since the can walk it faster.




(a) Travel time change per OD class when flow separators are installed in the main corridor. The travel times decreases for class which don't involve crossing the corridor in any way. For longer trips, the travel time decreases even if pedestrians must cross the corridor.




(b) Mean speed evolution after flow separator are used. The mean speed per OD class increases for all classes except two: pedestrians who cross the corridor with short trips.

Figure 13: Impact of the flow separators on the travel time and average walking speed of the pedestrians using the western underpass.

# 6 Conclusion

After discussing some of the specificities of pedestrian traffic compared to road traffic, we successfully managed to improve the walking time of pedestrians in two different infrastructures. The proof-of-concept setup emphasized the significant gain which can be made by separating the flows by direction. Furthermore, the impact of a small percentage of the pedestrian which do not comply to the rules has also been considered. The numerical simulation of western underpass in the station of Lausanne using flow separators have also been investigated. Pedestrians can move around more freely thanks to this control strategy, although the trips for some classes are longer. Future work will explore in more detail the sensitivity to compliance for the flow separators and also analyze the possible improvements that gating can bring to a real life situation. Secondly, the optimization of the control parameters will be explored using a simulation-based optimization framework like simulated annealing.

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