Design assessment of Lisbon transfer stations using microscopic pedestrian simulation

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Abstract

This paper addresses predicting the impact of access gates on pedestrian flow operations in terms of levels-of-service, congestion levels, average walking times, delays incurred at the gates, etc. To tackle the problem at hand, pedestrian traffic operations for different station design alternatives are predicted using the microscopic pedestrian flow model NOMAD. This is done for reference situations (validation), as well as for the design alternatives. It turned out that model provided realistic results. Furthermore, the simple design guidelines used to set-up the design alternatives provided satisfactory levels-of-service to the transferring pedestrians, and the gates could be installed without compromising passenger safety. Nevertheless, the need to re-route, inefficient gate use and interactions between conflicting pedestrians flows caused small but significant delays to transferring pedestrians, that could not have been predicted without the use of an adequate micro simulation model.
Keywords: pedestrian flow, micro simulation models, infrastructure design.

1 Background

This paper concerns the assessment of a new gate system for 3 railway stations in Lisbon, Portugal, making it impossible for pedestrians not having a valid train ticket to access the train platforms. The three selected train stations are prototypical for other stations in the Lisbon area. The main purpose of the assessment study is then to answer the following questions:

1. How will the gate system effect the pedestrian flow operations?
2. What are the effects of different system layouts? Where should space be created for both the gates and the travellers using the gates?

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3. What is the difference between different gate systems?
4. What happens in an emergency situation (evacuation)?

To answer these questions, it was argued that a dynamic model was required, which is *microscopic* in terms of flow representation as well as in terms of the behavioral rules describing its dynamics. To ensure realistic predictions, the walker model must include the main characteristics of traffic flows, such as the correct behaviour in bottlenecks, dynamic lane formation, and self-organisation phenomena in crossing pedestrian flows [6], [8]; [1] describes the walker model featured in NOMAD, which is able to capture the aforementioned pedestrian flow properties. It was decided that a model was needed allowing pedestrians to choose their routes freely, rather than from a discrete set of routes. Since for modelling pedestrians familiar with the infrastructure, exploration-based approaches [7] may not be suitable, Hoogendoorn and Bovy [6] presented an approach to route choice under uncertainty in continuous time and space that does not require the prior specification of a discrete network, which is incorporated in the NOMAD model used in this research.

2 Overview of study methodology

The objective of this study is to predict the impacts of installing a new gate system in existing train stations in the Lisbon metropolitan area (Portugal), with the additional aim to establish a design methodology to correctly determine the type of gates needed, the required number of gates, and their locations, given certain design criteria.

2.1 Selection of railway stations

Three transfer stations were selected from the 69 train stations in the Lisbon area. The stations *Rossio* and *Cais do Sodré* were chosen due to the magnitude of the passenger flows, and their importance in connecting the suburban railway network with the Lisbon metro network. The station of *Carcavelos* was chosen for its topology prototypical for a number of Lisbon stations. Passenger volumes were determined on several key locations in the transfer stations for a number of days by manual counting.

2.1.1 Cais do Sodré

The *Cais do Sodré station* is divided in two areas (hall level and metro level); see Fig. 1. The major passenger flow arrives between 8:45 and 9:00. In this very busy period, 59% of the passengers are female (important for simulation purposes). Almost half of the group (47%) was between 17 and 30 years of age, and 61% was commuting. Of all passengers, 15% buys a ticket at the ticket office and 21% at the ticket machines. Besides by train travellers, the station hall is also used by travellers from/to the metro to/from other public transit services (bus, ferry). One of the major flows occurs at 8:47, when a train arrives from which an average of 700 passengers alight; 45% of this flow exits via the Station

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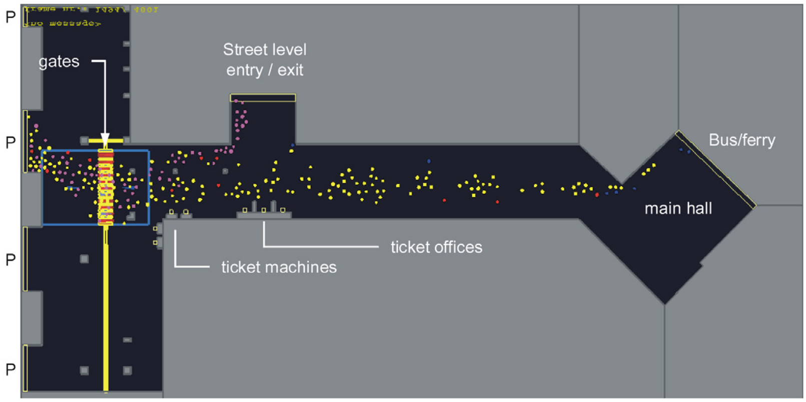
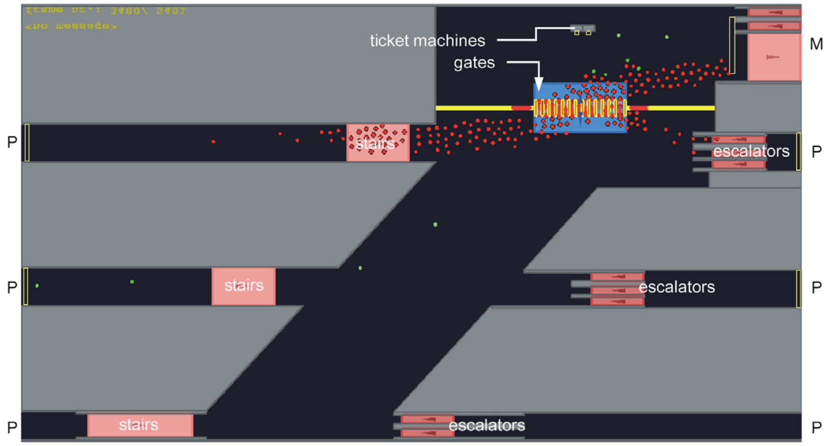
Hall and the remainder via the Metro hall. At 8:52 a train departs which ±120 passengers board; 42% access the platform via the station hall and the rest via the Metro.



a. Cais do Sodre hall level (current design + layout gate system to be installed); P: train platforms



b. Cais do Sodre, metro connection level (layout gate system to be installed); P: train platforms; M: metro.

Figure 1: Layout of the most important levels for the Cais do Sodré station for the current station layout (including the gates to be installed).

2.1.2 Rossio station

Of the *Rossio station*, two levels have been considered (see Fig. 2): the *Rossio station hall*, and the *connection hall* from the metro including the stairs and escalators upstairs to the platforms and a small part of the train platform. The busiest period is between 8:30 and 8:45 when 2750 passengers arrive at the station and 340 board the arriving trains. Approximately half of the alighting passengers use the metro, while the other half uses the hall to the exit to the street. Approximately 11% of the departing passengers buy a ticket at the ticket office; 26% buys a ticket at one of the ticket machines.

2.1.3 Carcavelos

The *Carcavelos* station consists of an underground station hall under the platforms, connected to the street level bus terminal via stairs and ramps (figure is not shown). This station's main use is the connection between the city and the Bus terminal. The busiest period occurs at the evening peak, between 18:30 and 18:45. From surveys, it was determined that 52% of the passengers are female; 48% is between 17 and 30 years of age, and 57% of the passengers are commuting. On average, 11% of the train passengers buy a ticket at the ticket office; 26% buys a ticket at either of the ticket machines.

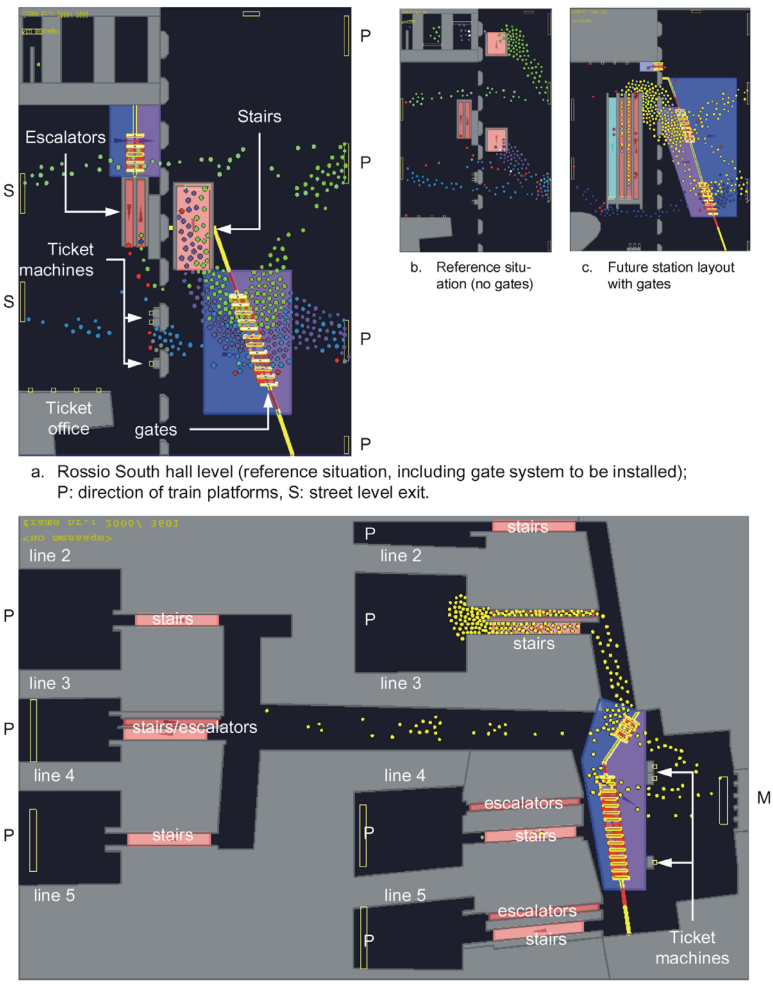


Figure 2: Overview of Rossio station layout: a) current with gates; b) current without gates; c) future with gates; d) metro connection level.

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2.2 Establishing design modifications considering access gates

The *number of gates* in a particular direction is determined by considering the average pedestrian demand in that direction during the busiest period of the day divided by the average capacity of a single gate (demand and supply variability is thus not considered in the design phase). Regarding the gate location, the designer also needed to incorporate for instance functionality requirements (i.e. passengers *not* using the trains are not hindered; the train platforms must be closed off), space requirements, etc., while ensuring that the gates should not result in major conflicting flows. It is important to notice that two gate systems have been considered: a *magnetic system* (25 Ped/min/gate) and a *contact-less system* (40 Ped/min/gate). Modified designs were established for the current situations, as well as for future station designs. In total, 5 reference situations and 9 design alternatives were established (see Tab. 1).

Table 1: Overview of considered simulation scenarios.

Scenario	Station	Ref	Evac	Layout	Gates (type & number) Type, To Train, From Train, Wheelchair			
					T	TT	FT	W
1	Cais do Sodre (hall)	X		Current				
2,3			x	Alt. 1	C	2	8	1
4				Future 1	C	2	8	1
5				Future 2	M	3	13	1
6	Cais do Sodre (metro)	x		Current				
7				Alt. 1	C	2	10	1
8	Rossio South hall	x		Current				
9				Alt. 1	C	2	12	1
10,11			x	Future 1	C	2	12	1
12	Rossio (metro)	x		Current				
13				Alt. 1	C	3	14	1
14	Carcavelos	x		Current				
15,16			x	Alt. 1	C	2	6	1
17,18			x	Alt. 2	C	2	6	1

2.3 Evaluation of the design alternatives and cross-comparison

The final step in the study is impact assessment of the gates on flow operations, level-of-service and safety by performing microscopic pedestrian simulation. This process is structured as a general model assessment study, and consists of the regular research steps described sequentially in the following sections. Using the predicted traffic operations we can then determine whether the followed design guidelines provide acceptable pedestrian traffic operations.

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3 Assessment objectives and performance indicators

The main *assessment objective* is to study the effects for a gate system design alternative (type and number of gates, gate locations, etc.) on:

1. Pedestrian flow operations, distinguishing *system level impacts* (congestion levels, flow operations) and *user level impacts* (level-of-service).
2. Safety in case of emergency situations (evacuation).

These general assessment objectives are to be quantified by considering the changes in the corresponding performance indicators (average densities, maximum densities, flows, levels-of-service, travel times).

4 Expected impacts of gate system

It is likely that the gates will form a new (active) bottleneck in the station, depending on changes in local supply and demand. Supply reflects the *effective capacity of the gates*, depending on both the capacity of a single gate, the number of gates, and their use. Note that also *secondary congestion effects* may result: queues at the gates may interfere with other flows, which are either directed towards another gate or not having to pass the gates at all. These effects can have a further negative effect on the effective capacity of the gates as well as worsen traffic conditions for passengers not having to use the gates at all (blocking back effects). Vice versa, flow operations may *improve* due to the separation of conflicting pedestrian streams. Another cause for increased travel times is the need to reroute (shortest routes through the facility will become somewhat longer). It is expected that the latter will only have a minor effect on the average travel times.

5 Pedestrian flow simulation and experimental design

Given the characteristics of the problem (see expected impacts), it was decided that a microscopic pedestrian simulation model is appropriate. In particular, the NOMAD model was chosen since it is a validated microscopic model that provides flexibility to include new infrastructure elements and sub models.

NOMAD distinguishes three levels of pedestrian behaviour

1. Activity scheduling, activity area choice and route choice level [3], [5];
2. En-route route choice (user-optimal gate choice)
3. Operational walking tasks [2]

The three levels are interrelated. For instance, the traffic operations determine the travel times and thus the activity scheduling and route choice. The route choice in turn determines at which gates pedestrians will arrive, etc. Note that the second level has been included in NOMAD to enable the modelling of the gates, and will be described in some detail in the ensuing. It is beyond the scope of this paper to describe levels 1 and 3.

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5.1 En-route route choice and choice behaviour in the gate areas

The en-route route choice modeling pertains to the pedestrian route choice near the gates, and has been included in the NOMAD model for the purpose of this study. It is hypothesized that the pedestrians at instant t choose the gate $i^*(t)$ that minimizes the *expected disutility* or cost $D_i(t)$

$$i^*(t) = \arg\min D_i(t) \tag{1}$$

This disutility $D_i(t)$ stems from the expected walking time $T_i(t)$ towards gate i and the expected waiting (queuing) time $W_i(t)$ at gate i before being served, i.e.

$$D_i(t) = aT_i(t) + bW_i(t) \tag{2}$$

where a, $b > 0$ are weights. The walking time $T_i(t)$ is determined by the walking distance to the gate and the free speed of the pedestrian (different for each pedestrian, depending on gender, trip purpose, age, etc.). The *expected waiting time* $W_i(t)$ is determined by the sum of the pedestrians heading towards the gate i and the pedestrians already waiting in the line at gate i, divided by the gate capacity. Only those pedestrians that are ahead are included in the prediction of the expected waiting time. The disutility is determined as soon as a pedestrian walks on the so-called *gate area* (special region near the gates). During the entire period at which the pedestrian is in this gate area, he or she will (re-) determine the expected utility based on the prevailing flow conditions. When conditions change during the period of walking to a gate, a pedestrian may change his or hers gate choice en-route. It is furthermore hypothesized that pedestrians form queues upstream of the gates, i.e. they walk towards a specific location at the tail of the prevailing queue of the chosen gate area. Having arrived at the head of the queue, the pedestrian incurs a certain service time and passes the gate.

5.2 Model input and output

The *input* to the NOMAD model consists of among other things:
1. Run-time parameters (e.g. length of simulation, time-step, graphical output).
2. Network topology (e.g. special infrastructure, emergency doors, gates).
3. Walking behavior parameters (e.g. age, gender, purpose of walking).
4. Activity scheduling and route choice parameters and OD demands;
5. Evacuation destinations and times.
6. Location of virtual detector loops.

For this study, the input data has been determined from the station plans (network topology), the new design plans drawn up by the architect (indicating the locations of the gates), the time table of the trains, and passenger counts to determine origin-destination flows.

The *output* of the simulation model NOMAD consists of:
1. Animations; snapshots of situation at predefined time instants.
2. Density and speed contour plots (mean and extreme values).
3. Output of the virtual detector loops.
4. Trajectories of each pedestrian and other pedestrian characteristics.

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5.3 Experimental design

The considered scenarios consist of five reference cases, alternative layouts, and four evacuation scenarios, yielding a total of 18 simulation scenarios (see Tab. 1). The reference simulations are used for both validation purposes (qualitative comparison of predictions with real-life observations) and for cross-comparison with the results of the gate system scenarios. Validation was achieved using the reference case simulations, which showed a close resemblance between the model and real-life operations.

Since NOMAD is a stochastic model, multiple simulation runs are required to derive statistically significant simulation results; 10 runs proved to be sufficient for the study purpose.

6 Assessment results

Let us now take a brief look at the traffic conditions predicted using NOMAD, and use these predictions to establish generic conclusions regarding the effect of the gates.

6.1 Cais do Sodré (scenarios 1-7)

In the reference situation (scenario 1), the *Cais do Sodré (hall)* simulations show no major problems occurring. The gate system (scenarios 2 and 3) does not give rise to big problems (see snapshot Fig. 1a). Although on average the travel times increase with approximately 4%, the travel speed increases with 3%. This implies that the additional travel time is mostly due to the need to detour. Moreover, it was observed that a better distribution of pedestrians over the walking area reduces the frequency of conflicts between pedestrians (so-called moderation effect). The magnitudes of the changes in experienced conditions depend on the considered OD relation. For instance, passengers coming from the street level entry / exit (Fig. 1a) walking to the upper train platform will experience a travel time increase of 22% and a *reduction* in their average walking speed of 13%. On the contrary, pedestrians walking through the station from the street level to the busses will on average experience a reduction in travel time of 5%, and an increase in the average speed of nearly 4%.

The *future design of the Cais do Sodré hall* (scenario 4) shows no active bottlenecks. Part of this is caused by the fact that a substantial pedestrian flow has been diverted (from the “old” hall corridor to the ferry corridor). Resulting in a reduction of 25% in the total travel demand. Although the situations are not completely comparable due to the large differences in layout, and the changed travel demand patterns, the average travel time increases with 14%, but the average travel speed increases with 5% (passengers on average need longer routes). Please note that the future Cais do Sodré hall situation was also equipped with low-capacity gates (scenario 5). Without going into detail, it appeared that the travel times were increased further, both because the gates were not used efficiently, and the need to divert from the optimal route. Furthermore, it turned

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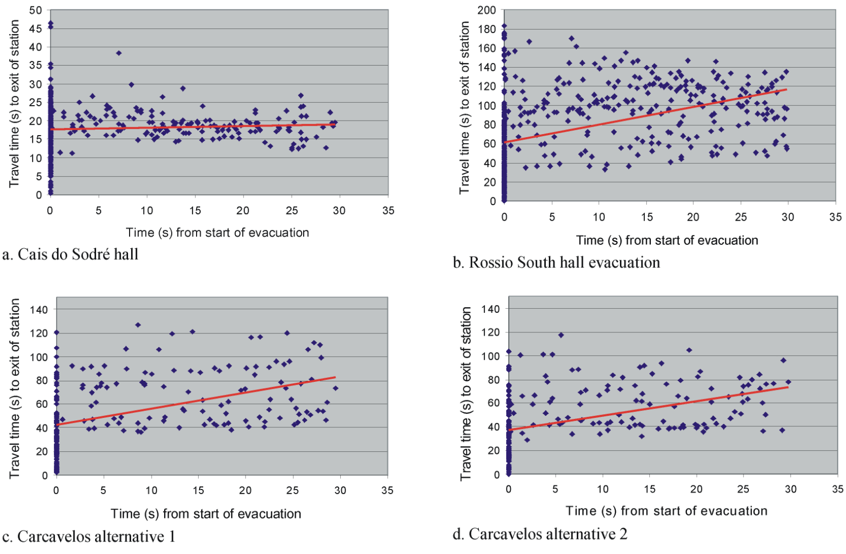
out that the number of low capacity gates needed in the other stations is too large given available space. Since all stations are to be equipped with the same system, the magnetic system was not considered further.

During *emergency conditions* (scenario 3), pedestrians have sufficient opportunity to get out of the station in time. Note that during emergency, the gates will open, as will special emergency doors. Considering the situation that an evacuation occurs when passengers are alighting from a busy train, it turned out that all passengers could exit the station within 45 seconds (Fig 3a, showing travel times from the start of the evacuation $t = 0$). Note the negligible increase in travel time as a function time, caused by moderate congestion occurring during evacuation. The model also predicts which of the emergency doors are used, and which are redundant based on their expected use.

The simulation of the *Cais do Sodre metro* connection level also shows no problems occurring (reference scenario 6 and gate system scenario 7, see snapshot Fig 1b). On the one hand, there is a minor increase in travel time due to the need to reroute and small waiting times and service times experienced at the gates. On the other hand, the separation of conflicting passenger flows causes a slight increase in the average walking speeds (approximately 5%).



a. Cais do Sodré hall
b. Rossio South hall evacuation
c. Carcavelos alternative 1
d. Carcavelos alternative 2

Figure 3: Evacuation times for different evacuation scenarios.

6.2 Rossio (scenarios 8-13)

In the reference situation (scenario 8, Fig. 2b), the predicted traffic operations in the *Rossio South Hall* are smooth during the entire simulation period. From the density plots (not shown), it is concluded that some negligible congestion occurs near the corners of the stairs. The simulation results show that the gates

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(scenario 9) will cause an average increase in travel time of 95%, which amounts of approximately 25 seconds (Fig. 2a). This increase is caused by the need to divert from the shortest route (average distance traveled increases with 71%; the average walking speed decreases with 11%). Given the small absolute travel time delays, we conclude that the gate system can be successfully implemented.

The future layout of the Rossio South hall (scenario 10) is substantially different from the current layout (Fig. 2c). Here, it turns out that the modified station design gives rise to substantial congestion levels and delays (i.e. not the gate system), due to the limited capacity of the new stairs / escalator. Also for the evacuation simulations (scenario 11), very significant congestion levels and delays are predicted. Fig. 3b shows that travel times can increase over 180 s, while the free travel time is less than 30 s. Furthermore, the densities become very high, meaning that the conditions become safety-critical. A special pressure indicator, reflecting the forces that act upon the pedestrians whilst evacuating, also shows this. From these results it was concluded that additional emergency exits need to be added.

The simulation for the *Rossio metro* reference situation (scenario 12) shows a significant build-up of congestion on the train platforms at the entries of the stairs and the escalators. This occurs for all platforms during the busiest 15-minute period during the peak. The gates at the Rossio metro station (scenario 13) do therefore not cause big additional problems, due to the moderating effect of the low capacity stairs and escalators (see Fig. 2d). The additional travel time (average increase of 12%) is completely accounted for by the need to take a small detour compared to the reference situation, yielding an increase of 11% in the average distance travelled. In all, the average walking speed decreases with only 1%. Let us also note that the simulations show that only a few gates are used by pedestrians leaving the station.

6.3 Carcavelos (scenarios 14-18)

In the current reference situation, the Carcavelos station (scenario 14) shows no flow problems (no regions of high density, high speeds, etc.). When trains arrive, the pedestrian flows smoothly exit the station at either the North or the South entrance. For alternative 1 (scenario 15), it is observed that no real problems occur. Hence, the proposed changes in the infrastructure as well as the installation of the gates yields only a small increase in the average travel times of 8%, again caused by the need to divert from the shortest route; average walking speed reduced by 2%. For design alternative 2 (scenario 16), pedestrian flows entering the station from the platforms on the left of the model are served by two gates only (per platform). This limited capacity gives rise to congestion, and an average increase in travel times of 14%, and a 5% decrease in average walking speeds. The delays are especially high for the passengers entering from the platforms on the left (increases upto 46%!). Hence, design 1 is preferred from the perspective of level-of-service provided to the traveller.

The Carcavelos evacuation scenarios (scenarios 16 and 18) showed a smooth evacuation where pedestrians can safely exit the facility. Note that during

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evacuation, the gates are not used anymore: according to the simulation model, all pedestrians use the high capacity emergency doors.

6.4 General conclusions regarding efficiency of gate use

The simulation results indicate that passengers incur an extra average delay of 10-20 seconds per passenger in the busiest quarter of the day as a result of gates installation. This delay is built up by:

1. Extra walking time as a result of longer walking distances.
2. Waiting times at gates.
3. Service times experienced at the gates.

As was suggested in the impact pre-assessment, the use of the gates determines to a large extent the offered level-of-service (i.e. capacity is not only determined by the number of gates, but also by their efficient use). Explanations for this are:

- Some gates are relatively far from the shortest walking path. According to observations, in many cases pedestrians accept extra waiting times instead of walking further to a free access.
- The so-called “blocking back effect”: in crowded situations with conflicting pedestrian flows not all the gates can be reached and used. In the considered station layouts, this is however uncommon. In some cases, separation of possibly conflicting flows may even improve traffic flow conditions.

The results presented here reflect the worst case based on the *busiest 15 minutes during the day*. In other periods, the passenger demands are known to be much lower, especially in case of the Rossio and Cais do Sodré stations. According to recent counts and resulting passenger demands, we conclude that:

- On Cais do Sodré and Rossio stations – by a much lower demand – the extra delays in all other periods will be much less than in the busiest 15 minutes (around 3-5 seconds).
- The passengers that experience a lower level-of-service due to installation of the gates will be around the 8-10% of all passengers per day.

Hence, although in most stations some congestion occurs, there is little need for extra gates, since these will most likely not be used during the other periods of the day (or even during the peak hour).

7 Conclusions and recommendations

This paper discussed a methodology and results of an ex-ante study into the effects of installing entry / exit gates in stations in the Lisbon metropolitan area using the microscopic simulation model NOMAD. Judging from comparing the model predictions with the observed pedestrian flow operations in the reference situations (validation), we can conclude that NOMAD is suitable to model pedestrian flows through transfer stations. Also the simulation of the access gates did not provide any problems.

Different design layouts were simulated. It was found that the simple rules used by the designers resulted in plans that offered an acceptable level-of-

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service. The emergency exits provide sufficient escaping opportunities. Regarding station layout design issues, the following recommendations can be made:

1. At stations with a *similar topology as the Carcavelos station*, it advised that:
   a. Enough space must be allowed between the gates and other infrastructure elements to avoid blocking back of queues.
   b. Gates (per direction) should be concentrated in blocks.
   c. Gates should be positioned as far away from platforms as possible, allowing a better distribution of alighting passengers.
2. At stations *with high passenger volumes*, it is recommended:
   a. To provide multiple exit choices to allow for distribution of the passengers. The comparisons between “current lay-out” and “future lay-out” in Cais do Sodré and Rossio revealed consistently better results for the solution with multiple exit opportunities.
   b. The positioning of gates close to staircases and narrow areas can cause severe blocking back problems.
3. Particularly for the Rossio station, the simulations performed with the future layout indicate potential problems associated to the concentration of exits. In this case, it was advised to reconsider this new layout by moving the stairs / escalators to the left, and let all escalators move into the outgoing direction. Finally in the current layout, another emergency door should be added.
4. At Cais do Sodré station, the gates will yield a moderation effect, i.e. they will cause a spatial redistribute of the high volume passengers flows through the station, thereby solving some of the current congestion problems.

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References

[1] Hoogendoorn, S.P. (2004). Pedestrian flow modeling by adaptive control. Transportation Research Board Annual meeting 2004 (pre-print CD-Rom).

[2] Hoogendoorn, S.P. and P.H.L. Bovy (2002). Normative Pedestrian Behaviour Theory and Modelling. *15th International Symposium on Transportation and Traffic Theory*, Adelaide, Australia 2002.

[3] Hoogendoorn, S.P. and P.H.L. Bovy. Pedestrian Route-Choice and Activity Scheduling Theory and Models. *Transportation Research B* (2003).

Computers in Railways IX, J. Allan, C. A. Brebbia, R. J. Hill, G. Sciutto & S. Sone (Editors)

[4] Hoogendoorn, S.P., and P.H.L. Bovy (2003). Simulation of Pedestrians flows by Optimal Control and Differential Games. *Optimal Control Applications and Methods* 24, 153-172.

[5] Hoogendoorn, S.P., P.H.L. Bovy (2003) *Pedestrian Travel Behavior Modeling*, paper presented at the 10th International Conference on Travel Behavior Research, Lucerne, August 2003.

[6] Hoogendoorn, S.P., W. Daamen (2004). Pedestrian Behavior at Bottlenecks. Accepted for publication in Transportation Science.

[7] Penn, A., and A. Turner (2001) Space Syntax Based Agent Simulation. In: *Proceedings of Pedestrian and Evacuation Dynamics 2001*. Schreckenberg, M., and S.D. Sharma (Eds.), 99-114.

[8] Weidmann, U. (1993) *Transporttechnik der Fussgaenger*. Eth, Schriftenreihe Ivt-Berichte 90, Zuerich (In German).

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