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Abstract

Efficient alternatives to private transport are becoming truly necessary at a time when road traffic congestion increases and vehicle emissions are a constant problem.

Public transport is, therefore, an essential part of the sustainable development of cities: network’s organization is a major factor, as long as it allows efficient and comfortable transfers in interchanges, providing to passengers a sense of continuity on their trips. However, these network nodes are often associated with high pedestrian flows with constraints on pedestrian movement, which discourages their use.

The analysis methods for the performance of public transport interchanges are usually based on aggregate values, which may result in highly optimistic results. However, since the development of microsimulation tools allows different ways of measuring these infrastructures’ performance, it becomes necessary to establish appropriate guidelines, similar to those already in place for conventional analysis.

With this in mind, and based on different studies regarding the use of microsimulation, a set of “best practices” were compiled, and a complete methodology suggested, so that it can be applied to both existing interchanges and to the planning of future ones. One major change (compared with conventional methods) involves considering 30-second periods in the performance analysis, instead of considering the average value of the simulated period.

In order to apply this methodology, a microsimulation model of the Colégio Militar/Luz subway station (in Lisbon) was developed, after which a diagnosis of the current situation was done and different alternative scenarios tested, to both take advantage and demonstrate the potential of these tools.

1. Introduction

Currently, public transport interchanges are crucial points of the transport system, since they allow passengers to transfer between different lines or transport modes. However, the walking distances that are created add some undesired uncertainty and inconvenience to their trips (Ceder et al., 2013; de Abreu e Silva and Bazrafshan, 2013; Guo and Wilson, 2011; Hadas and Ranjikar, 2012; Kalakou and Moura, 2014; McCord et al., 2006; Nesheli and Ceder, 2014).

Simultaneously, microsimulation tools have been evolving in the past years, and it is possible to simulate the individual behavior of each pedestrian and the interaction between them, as well as a reliable representation of the surrounding environment (Fernandes et al., 2013).

Yet, since the interchange analysis didn’t follow, to date, any set of “guidelines” or “best practices” (Galiza et al., 2009), this work’s objective was to define a methodology that compiles the different items to collect and analyze, so that it can be applied to other public transport interchanges. At the same time, a major improvement to current practices was considering periods of 30 seconds in the performance analysis of the different areas.

This paper starts with a summarization of the main research developments on the pedestrian circulation on
interchanges, as well as the main characteristics of the microsimulation tools, particularly the chosen one for this work, the PTV Vissim (Chapter 2). On Chapter 3, the proposed methodology is described, and Chapter 4 presents the analysis of the case study, which is based on the subway station of Colégio Militar/Luz, in Lisbon. Finally, on Chapter 5 the main conclusions and suggestions are summarized.

2. Literature review

2.1. Pedestrian circulation on interchanges

Most of the pedestrian transfers on a public transport journey require a walking distance which adds an additional uncertainty to the overall time, making the quality of the connection between the two modes a main aspect on the public transport passengers’ satisfaction. For the same reason, passengers usually prefer direct journeys, to avoid that uncertainty (Ceder et al., 2013; Guo and Wilson, 2011; Hadas and Ranjitkar, 2012; McCord et al., 2006).

Therefore, the interchange is a place that allows the passengers to transfer between modes and aggregates and redistributes the pedestrian flows in order to improve the operational efficiency of the transport system (Domingues, 2011; IMTT, 2011; Shah et al., 2013; Sun et al., 2010; Terzis, 1998; Yang et al., 2010; Zhang et al., 2009).

There are several critical points on an interchange, and Transport for London (2009) identifies three main zones: movement spaces, opportunity spaces and decision spaces. One of those decision spaces are the ticket barriers, which create an “intermediate step” on passengers’ trip and increase their journey time. Ticket barriers represent one of the most critical points of public transport interchanges, not only for the presence of crowds but also because for its complexity (Davidich et al., 2013).

One way of predicting the capacity of an interchange is using the “fundamental diagram”, which correlates the three main characteristics of the pedestrian movements: flow, density and speed (Daamen et al., 2005; Davidich and Köster, 2012).

Indeed, the pedestrian speed is of vital importance and it depends on several aspects, both individual characteristics (age, sex, culture, body size, health conditions, luggage, group size, trip motive, etc.) or from the environment (temperature, location, type of floor, presence of obstacles or bidirectional flows and pedestrian density, for instance) (Chattaraj et al., 2009; Cheng et al., 2014; Fruin, 1987; Galiza and Ferreira, 2013; Galiza et al., 2009; Hoogendoorn and Daamen, 2005; Johansson et al., 2008; Kholoshevnikov et al., 2008; Koh and Zhou, 2011; Lam et al., 2003; Löchner, 2010; Miguel, 2013; Qu et al., 2014; Rotton et al., 1990; Shah et al., 2015, 2013; Willis et al., 2004; Yuen et al., 2013).

According to Libano Monteiro (1994), each stream of pedestrians should be planned to avoid crossing with other streams. However, since it is not always possible, pedestrians usually organize themselves “efficiently”, through the spontaneous formation of unidirectional “stripes” (Helbing et al., 2005; Johansson et al., 2008; Moussaïd et al., 2011; Singh et al., 2009). Alternatively, several types of physical obstacles could be used as dividers, like plants, barriers, columns or furniture (Helbing et al., 2005; Seriani and Fernández, 2015).

2.2. Pedestrian circulation models

Explanatory models of human behavior during circulation improved significantly during the second half of the twentieth century. There are two main types of models: the macroscopic models, that focus on the analysis of the observable dimensions (like density and flow), and the microscopic ones, focused on modeling the individual behavior of each pedestrian (Brščić et al., 2014; Zanlungo et al., 2011).

On the side of microscopic models, Helbing and Molnár (1995) were responsible for the “social force model”. Despite its relative simplicity, this model reproduces quite accurately the dynamics of pedestrians (Johansson et al., 2008) and corrected several weaknesses of other models (Helbing and Molnár, 1998). According to the “social force model”, the pedestrian desired speed is similar to a “social force”, which represents the effect of the surrounding environment (other pedestrians or obstacles) on the pedestrian behavior and will cause the motivation to act (Figure 1).

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2.3. Quality assessment and performance analysis of interchanges

The assessment of the quality of interchanges has been studied in the past twenty years, not only by several academic researchers but also by the European Commission, funding several research projects like PIRATE (Promoting Interchange Rationale, Accessibility and Transfer Efficiency), GUIDE (Group for Urban Interchanges Development and Evaluation) or MIMIC (Mobility, InterModality and InterChanges).

Regarding a quantitative performance analysis, the “level of service” is still the most used indicator (Galiza et al., 2009). Fruin (1987) was responsible for the used reference values for sidewalks, corridors, stairways and waiting areas, that depend on pedestrian space, density, flow per unit width and average speed (TRB, 2003).

According to De Gersigny et al. (2010), the level of service should be at least “C” at corridors and waiting areas, while it should reach “D” at stairways.

2.4. Pedestrian microsimulation

Pedestrian microsimulation has become a very powerful tool in the past few years, although it requires higher computational resources (Kretz et al., 2011). Its success is due to the ability to simulate the behavior of each individual agent of the system, thus the simulation is influenced by the interaction of all the agents and results in a more accurate and realistic representation (Bandini et al., 2014; Fernandes et al., 2013; Helbing et al., 2005).

There are several software products that allow pedestrian microsimulation, but Vissim stands out from the others, as it was the first professional tool to enable the simulation of pedestrians and vehicles simultaneously, as well as the interactions between them (Bönisch and Kretz, 2009; Cortés et al., 2010). Since 2008, Vissim (through its ‘Viswalk’ module) uses the “social force model” from Helbing e Molnár (1995), which allows the definition of different types of pedestrian and their own characteristics (speed, body size, etc.) but requires high amounts of data, time and highly accurate calibration and validation (Fellendorf and Vortisch, 2010; Fernandes et al., 2013; Galiza and Ferreira, 2013; Galiza et al., 2009; PTV, 2013).

3. A performance analysis methodology using microsimulation

Even though different performance analysis of interchanges have been conducted for decades using the work of Fruin (1987), there is still a lack of guidelines regarding the use of microsimulation for this purpose (Galiza et al., 2009).

Therefore, a methodology that could be replicated in different transport interchanges where comparable results were needed was established. For that, the recommendations of many researchers of the subject were followed, but there were also consideration for the specifics of the Portuguese reality and the available data.

Galiza et al. (2009) suggest four key steps on these types of analysis (Figure 2): first, the correct definition of the scope of the work; secondly, the collection of all the required data for the correct characterization of the “base scenario”; as a third step, modeling that “base scenario”; and, finally, studying the desired changes in infrastructure, demand or supply.

When choosing the scope of the work and its main objectives, the necessary inputs for the correct characterization and modeling of the problem should be defined, as well as the methodology and the type of output needed (Galiza et al., 2009).

It may be necessary to consider an extensive collection of data in order to “feed” the microsimulation model. For instance, to use the correct demand of the infrastructure, the actual ticketing systems (which allow access to the information in real time), video surveillance cameras and passenger counts are some of the possibilities.

To measure the pedestrian walking speed, the tracking technique (Zacharias, 1993) can be used. However, other elements like the number of passengers in each ticket booth (and comparing it to the total number of passengers), the time spent to pass the ticket barrier, number of people waiting in the line to buy a ticket, the number of passengers with bags or children and the group composition are also useful to build the microsimulation model (Fernández et al., 2010).

The modeling of the public transport supply is also essential to ensure that the correct flows are modeled, considering the real patterns of arrivals and departures.

It is important to remember that any kind of data collection must consider “typical days”, which means that days with severe seasonal effects, special events or incidents should be discarded (Fruin, 1987).

It is also necessary to ensure that the calibration of the microsimulation model is extremely accurate so that it can be used to obtain reliable estimates (Galiza et al., 2009).
The validation should ensure a good match between the model and the modeled system (Teknomo et al., 2006). To evaluate the similarity between the modeled flows and the real flows, Galiza et al. (2009) recommend a difference no higher than 5% regarding the sum of all flows of the modeled interchange. The authors also recommend the use of the GEH indicator, considering that at least 85% of the values should be less than 5 and there is no GEH higher than 10 (DMRB, 1991). According to the rules of the Federal Highway Administration for road microsimulation models (FHWA, 2004), GEH should also be lower than 4 for the sum of all flows.

To validate the model, other aspects can be used: time between two points in the interchange, percentage of pedestrians in each ticket barrier, number of passengers in queue, for instance.

Modeling an interchange with microsimulation tools allows for a closer view of the pedestrians’ movement and the perception of the constraints that really affect them. Additionally, it is possible to obtain from the model the pedestrian density (in pedestrians/m²), and, consequently, the level of service. However, the usual analysis often focus on the hourly average level of service, which will lead to more favorable results and eliminates many of the advantages of using a microsimulation model.

For that reason, it is suggested that the assessment should be based on two different criteria:
- Hourly average level of service;
- Number of 30-second periods during which the level of service is worse than the acceptable minimum.

The second point is based on the one used to calculate the design hourly volume (DHV) of a designed road. The volume used is not the “busiest” hour, but the 30th most loaded of the year (the volume that is exceeded 29 times during the year). Above this value, the volume of traffic rises exponentially (the slope of the curve changes noticeably), so the DHV represents a kind of compromise between economic and operational aspects (AASHTO, 2001; CCDR-N, 2008).

Depending on the place on the station and on the station itself, the number of periods for which it is “affordable” to have worse levels of service should be different. For instance, within the zone of the ticket barriers, when the level of service is worse than “C” during more than 30 seconds, it is likely to exist an inefficient situation.

An alternative way of assessing the efficiency of the interchange should be the measurement of the delay experienced by the passengers, based on the measurement of the unconstrained travel time and the real travel time inside the interchange; this should be a more useful comparison between alternative scenarios.

Finally, alternatives to the “base scenario” should be tested further, particularly when its performance is not good. However, even with a satisfactory result, the response of the infrastructure to demand growths should be assessed.

The alternative scenarios can also be related to changes on the supply side or changes in the infrastructure, like a change in the location or the number of ticket barriers, kiosks or shops, vending machines or customer service centers. There also might be the opportunity to test physical obstacles to guide passenger flows more efficiently (Nai et al., 2012) or the creation of escalators or moving walkways.

4. Case study analysis: the Colégio Militar interchange

To apply the suggested methodology and test different solutions, the interchange of Colégio Militar, in Lisbon, was chosen as case study.

This is an intermodal interchange where the blue line of Metropolitano de Lisboa (the local subway system) connects to Santa Apolónia rail station and Amadora Este (outside Lisbon), as seen on Figure 3, and it has also several urban and suburban bus operators services (Carris, Rodoviária de Lisboa and Lisboa Transportes).

![Figure 3 – The location of Colégio Militar interchange. Source: Metropolitano de Lisboa](image-url)
evening). The three bus operators have a total number of 21 lines at this station.

It has nine access points, four of them from the bus station and one with internal connection to Colombo shopping center. On the inside, the station has a central lobby that allows the access to the boarding platforms through 22 ticket barriers (Figure 4): the “base schema” consists in 8 barriers dedicated to incoming passengers and 14 dedicated to exiting passengers (which include the two “special” barriers, dedicated to passengers with reduced mobility or with large volumes, which are automatically reversible).

Figure 4 – Ticket barriers in Colégio Militar/Luz subway station.

4.1. Data collection

To help modeling the infrastructure, the subway company (Metropolitano de Lisboa) provided the detailed blueprints of the station. Additionally, a few other dimensions that were not available were collected that were not available yet (e.g., stairs’ steps and ticket barriers dimensions). Additionally, different elements that could become obstacles – like ticket booths, shops, kiosks, vending machines and hawkers – were identified.

The ticketing data of a normal week of 2014 was also requested to the Metropolitan Transport Authority of Lisbon (AMTL, Autoridade Metropolitana de Transportes de Lisboa). In other words, it corresponds to a week of ticket validations on the subway station of Colégio Militar/Luz, as well as on the other stations of the subway network and on the buses that pass by the station.

In order to represent the passengers’ movement inside the station and attend to the demand oscillations inside the rush hour, the peak hours were refined to 15-minutes periods, which allows to more clearly identify the busiest periods. Thus, according to the ticketing data, the morning peak hour takes place between 8:30 a.m. and 9:30 a.m., while the afternoon peak hours occurs between 6:00 p.m. and 7:00 p.m. (considering both incoming and exiting passengers).

Some additional corrections were made to the ticketing volumes, namely an increase of 1.2% on the demand between 2014 and 2015 and an additional volume of 8.1% due to the estimated fraud (both values taken from Metropolitano de Lisboa official documents) (ML, 2015). Some assumptions have also been made, namely a maximum transfer time (time interval between ticket validations) of 60 minutes and some compatibility regarding a group of tickets that were not included in the data received.

The total number of passengers considering their previous or following journey leg is shown on Table 1.

Table 1 – Estimated demand at the station on morning and afternoon peak hours.

<table>
<thead>
<tr>
<th>Movement</th>
<th>8:30 – 9:30 a.m.</th>
<th>6:00 – 7:00 p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>➡️</td>
<td>288</td>
<td>180</td>
</tr>
<tr>
<td>➡️</td>
<td>16</td>
<td>25</td>
</tr>
<tr>
<td>➡️</td>
<td>23</td>
<td>75</td>
</tr>
<tr>
<td>➡️</td>
<td>572</td>
<td>1,480</td>
</tr>
<tr>
<td>➡️</td>
<td>169</td>
<td>329</td>
</tr>
<tr>
<td>➡️</td>
<td>25</td>
<td>107</td>
</tr>
<tr>
<td>➡️</td>
<td>45</td>
<td>150</td>
</tr>
<tr>
<td>➡️</td>
<td>960</td>
<td>1,338</td>
</tr>
<tr>
<td>Source: Autoridade Metropolitana de Transportes de Lisboa</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The passengers’ transfers were distributed through the entries and exits nearest to the bus stops. However, in addition to the ticketing data received, a plan of data collection in the station was necessary, since most of the passengers did not have a previous or subsequent leg in their trips. The data collection was carried out in May 2015 and included:

a) Passenger counts on the “decision points” (junctions) of the station;

b) Pedestrian speeds measurement;

c) Pedestrian passing times through the ticket barriers;

4) Pedestrian waiting times at the ticket booths and ATM.

The sampling counts were carried out for 10 to 20 minutes at each point during the two peak hours, and proved the strong relationship of the station with the Colombo shopping center, both in the morning peak hour and the afternoon peak hour. The calculated distributions were later applied to the volumes for which the entry or exit was unknown.

The walking speed was measured from 96 passengers in free flow, using the tracking technique in a straight path (with about 32 meters long), recording the sex and apparent age of the observed passenger. The result of this measurement revealed an average speed of 1.38 m/s (Figure 5), not much far from Fruin (1987), Willis et al. (2004) or Costa (2010) observations. The time spent to cross the ticket barriers was measured for 224 passengers, which resulted in an average time 8% lower...
on exit movements comparing to entry movements (Figure 6).

Additionally, the time spent on the ticket booths and ATM machines and the number of passengers in the ticket booth line were also measured, as well as all the “intermediate movements” inside the station (e.g., going to the coffee or to the ticket booth) and the dwell time of the trains.

![Average walking speed](image)

**Figure 5** – Measured walking speed of the passengers.

![Average time spent to cross the ticket barriers](image)

**Figure 6** – Measured time spent to cross the ticket barriers.

### 4.2. “Base scenario” model

The “base scenario” model consists of 134 areas (corridors or waiting areas), 208 obstacles (walls, columns or barriers, as seen on Figure 7) and 21 stairways (between the lobby and the platform, and between the station and the surface). The modeling of the station was limited to the entrance/exit of the subway station, but it included all the “intermediate movements” of the passengers in an attempt to ensure the highest possible realism.

Based on the ticketing data, the flows for each movement in the 15-minutes periods of the peak hours were modeled, while the subway services were created with the frequency of arrivals described by Metropolitano de Lisboa (with a random variation to ensure the existence of subways arriving to the station in both directions). The measured walking speeds were introduced in the software for the circulation in corridors, while for the stairs the values obtained by Kretz et al. (2008) were used.

Regarding some specific aspects of modeling, the flows at the station were represented in two different ways: the distributions obtained from the data collection and the ticketing data were introduced as “pedestrian static routes”, while the choice of the ticket barrier to enter/exit the station was modeled as “pedestrian partial routes”, letting the model decide which was the path (or barrier) with lower delay in each moment. In each barrier it was included also the time spent by the passengers to cross it.

For the calibration and validation tasks, several values for the main parameters of the “social force model” were tested, and the final solution consists on smaller values of ReactToN, $A_{social}$, $B_{social}$, $A_{social,iso}$ and $B_{social,iso}$ (Table 2), the ones that directly influence the distance between pedestrians, which seemed to be high with the original parameters. All the modeled routes have their “dynamic potential” activated, with the default Vissim parameters. Additionally, the time step of the model was switched to 0.2 s.

To validate the model, four key indicators have been chosen:

- Passengers flows in each entrance and exit of the station;
- Walking speed in the measured section;
- Passenger “share” in each group of ticket barriers;
- Visual comparison between the observed situation and the microsimulation model (namely the reproduction of some pedestrian behaviors).

Since the model requires a warm up period (during which the station is not yet with the real flows), the analysis period was chosen to be the intermediate 30-minute period of the simulation hour (between the seconds 900 and 2,700 of the simulation).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau$</td>
<td>0.4 s</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.176</td>
</tr>
<tr>
<td>ReactToN</td>
<td>5 pedestrians</td>
</tr>
<tr>
<td>$A_{social}$</td>
<td>0.2 m/s²</td>
</tr>
<tr>
<td>$B_{social}$</td>
<td>2.0 m</td>
</tr>
<tr>
<td>$A_{social,iso}$</td>
<td>2.0 m/s²</td>
</tr>
<tr>
<td>$B_{social,iso}$</td>
<td>0.1 m</td>
</tr>
<tr>
<td>VD</td>
<td>3 s</td>
</tr>
</tbody>
</table>

The comparison between the pedestrian flows modeled and the real ones revealed a GEH lower than 5 in all the paths, as well as a GEH lower than 4 in the total volume. With regard to the walking speed, the individual values get from each pedestrian showed that approximately 98% of the pedestrians in the morning peak hour and 89% in the afternoon peak hour revealed a walking speed 5% smaller than the “desired speed”.

Passengers’ “choices” in the ticket barriers zones were also compared with the ticketing data, with good results for several groups of barriers in the morning peak hour. In the afternoon peak hour, where the “dynamic potential” is more “requested”, passengers do greater detours, due to a more congested situation.
Finally, some visual comparisons were also taken out, for both modeled periods. Some of the intended behaviors were, in fact, observed in the model, including the queue formation around the ticket barriers and the number of passengers in ticket booths.

For the performance analysis, the level of service was calculated for a set of areas (circulation areas or waiting areas), presented in Figure 8. The circulation areas never reach a level of service lower than "C" in any moment of the two peak periods, even though there are some congested moments due to the "platooned" exit of the passengers; the only occurrence of a level of service "C" is during the afternoon peak hour, and only in the corridors that lead to the Colombo shopping center.

In the waiting areas, and during the morning peak hour, only one point reaches an average level of service of "D", even if during some moments the level of service reaches the levels "E" or "F". In the afternoon peak hour, several waiting areas near the ticket barriers present an average level of service of "D", which reveals a higher probability of longer queues.

The model data was grouped in periods of 30 consecutive seconds and ordered by the growth of pedestrian density from one period to the other (60 periods of 30 seconds). According to Figure 9, after the 55th most loaded period the growth of densities is exponentially higher; for this reason, it was set as limit the existence of more than 5 periods of (at least) 30 seconds in the analyzed 30 minutes in which the level of service was "D" or worst.

With this criteria, and within the afternoon peak hour, the existence of at least 5 periods of 30 seconds with level of service of "D" or worse were identified, located in the entry ticket barriers nearer to the Colombo shopping center. In the exit direction, there were also several barriers that presented a level of service lower than "C". In the morning peak hour, the clearance time is always smaller and no serious problems were found.

Figure 7 – Ticket barriers in the microsimulation model.

Figure 8 – Circulation areas and waiting areas analyzed in the "base scenario".
4.3. **Scenario analysis**

Since this is an interchange with more than 25 years, the ability to change the infrastructure is very small. For that reason, 4 alternative scenarios regarding other type of changes were chosen, based on the “base scenario”:

- Scenarios A1/A2: changes in the layout of the ticket barriers zones;
- Scenario B: creation of new kiosks in the corridors;
- Scenario C: creation of routing systems that ensure unidirectional flows.

Additionally, it was also tested an increase in the demand in the “base scenario” and in the other four alternative scenarios.

**4.3.1. Changes in the layout of the ticket barriers zones**

The areas close to the ticket barriers are where more congested periods occur. For that reason, alternative solutions should be studied, in order to improve the overall performance of the station.

A feasible solution could be to simply increase the number of barriers; however, as it currently happens, the number would be highly oversized for the off-peak periods. For that reason, different solutions with lowers levels of investment were decided to be tested first.

In a first scenario (scenario A1), a solution was tested where only the direction of the ticket barriers was changed – all the barriers from the same group should be only entry or exit barriers. In a second scenario, the ticketing system was changed to an “open system”, which means that the ticket barriers could be totally removed, with the passenger registration done with video surveillance and frequent inspection operations or with new upcoming technologies (scenario A2).

**Scenario A1 – Changes in the direction of the ticket barriers**

This solution demands, in some cases, greater routes to some passengers but largely eliminates some of the major constraints caused by the bidirectional flows in the ticket barriers areas.

The analysis carried out for both peak periods showed that the average level of service was never worse than “B”, although some levels of service of “D”/“E”/“F” were registered during some moments. The average delay time per passenger on their exit from the station decreases about 10% in the morning peak hour and 14% in the afternoon peak hour with this new solution.

**Scenario A2 – Elimination of the ticket barriers (“open ticketing system”)**

Although is not common to have “open systems” in heavy transport modes (like subway or rail), the existing technologies nowadays make this possible even for large passenger volumes.

So, in the tested scenario, it was decided to maintain the existing delimitation of the central lobby (where the information about the subway service is placed), removing just the ticket barriers. However, in an “open system”, the elements that exist in the central lobby (ticket booths or information about the service) could be rearranged.

The results corroborate the advantages of this type of system: the average delay time of the passengers is reduced by more than 40% in both peak periods.

**4.3.2. Creation of new kiosks in the corridors**

Given the inexistence of major problems in the corridors of the station, there is the possibility of creating new kiosks in order to generate additional revenues to the infrastructure manager (in this case, Metropolitano de Lisboa).

Therefore, scenario B consists of the placement of two kiosks of different sizes in two different corridors where the level of service is less favorable in the “base scenario” (corridors near the Colombo shopping center).

Both in the morning peak hour and in the afternoon peak hour, only slight impacts were seen in these areas. In no case the minimum level of service is worse than “C”, so the placement of this new commercial equipment would be possible. It should be noted, however, that the possible reductions of space due to the queues in these places were not considered.
4.3.3. Creation of routing systems that ensure unidirectional flows

Although the corridors did not present greater constraints in any of the peak periods of the “base scenario”, the unidirectional volumes encourage the use of physical elements to separate the different flows: in the morning peak hour, some corridors present a distribution of 83%/17%, while in the afternoon peak hour the distribution is 56%/44% (but the flow is three times higher).

So, in scenario C, the impact of physical separators that force the passengers to follow on a one-way corridor (Figure 10) was evaluated. The comparison between the average delay times of the passengers revealed that no substantial gains were obtained from the placement of those elements (mostly due to the additional detours that some passengers have to realize).

4.3.4. Demand increase

As a complement to the previous scenarios, the impact of an increase in the demand was also studied, since it is most likely to happen in the next years: the blue line is set to be expanded in 2020, and this station will work as a bifurcation, so its importance is going to increase. On the other hand, two new office towers above the Colombo shopping center are planned for construction, which should also increase the demand of this station.

Therefore, the “base scenario” and the four alternative scenarios were tested to an overall increase of 20% in the demand of the afternoon peak hour (since it is clearly the most congested one) and the results are summarized below:

- In the “base scenario”, several areas present an average level of service of “E”, and this indicator reaches “D”, “E” or “F” in almost 50% of the 30-second periods;
- In scenario A1, some areas present a higher number of levels of service of “D” comparing to the current demand, and within longer periods;
- In scenario A2, the station “responds” well to the demand increase, with only slight increases on the average delay of each passenger;
- In scenario B, the levels of service remain almost unchanged, proving that the new commercial kiosks could be put even with higher demands;
- Finally, in scenario C, the average delay increases 12% when compared to the current demand and the new physical elements remain unjustified.

5. Conclusions

The analyses carried out for the Colégio Militar/Luz subway station allow for a quick perception of the potential of microsimulation tools applied to the performance analysis of public transport interchanges.

The different analyses showed the existence of moments where the level of service gets worse than “C”; however, in average terms it would not be possible to detect those moments or to figure out their extension. For that reason, the consideration of the 30-second periods as suggested in the methodology allows a better knowledge of the real performance of an analyzed infrastructure.

The tested changes in the different scenarios provide significant reductions in the average delay times of the passengers and an improvement on their satisfaction regarding the walking conditions through the station. The tested demand increase also proves that, even if the present situation is not perfect, it could get worse if no intervention is done in this interchange.

The observed constraints are similar to many others that occur in other subway stations in Lisbon and in the rest of the world. Therefore, the suggested methodology aims to become a contribution to the discussion on the use of microsimulation models on interchanges analysis and the benefits of these models.

However, deeper research should be done in order to develop a more consistent and systematic approach regarding to the consideration of the 30-second periods in the performance analysis of the level of service. The criteria used in this case was obtained for the current demand and the specific number of arrivals observed in Colégio Militar/Luz, so it is important to build a richer database in order to apply this methodology to other interchanges.

Also, it is worth keeping in mind that Lam and Cheung (2000) recommend caution in the application of international
examples, since different interventions or reference values should be adjusted to each reality, which means that results can't be directly transferred. For instance, the analyzed case study does not seem to recommend the use of routing systems to ensure unidirectional flows (maybe due to its demand volumes); however, this technique is applied all over the world and recognized as a contributor to performance improvements (Helbing et al., 2005; Seriani and Fernández, 2015).

There are some limitations that these tools will not be able to avoid (the erratic behavior of tourists or unfamiliar passengers, for instance), but those particular cases generally represent a very small number of situations and they are not evaluated with current methodologies. The phenomena of walking in groups is also one type of behavior that is not considered in current microsimulation tools, but may be represented in upcoming tools, increasing the quality of this kind of analysis.

Finally, a full cooperation between operators and transport authorities is essential to an effective improvement of the interchanges performance.

References


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