ON THE ASSESSMENT OF THE ESCALATOR CAPACITY IN METRO STATIONS. BUCHAREST METRO CASE STUDY

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This paper presents some aspects related to the capacity assessment of design elements for metro stations, and focuses on the evaluation of escalator capacity, as long as it is considered both a restrictive element of total transfer capacity, and a qualitative element of the provided transport service. The paper takes into consideration a practical method for the estimation of the escalator capacity, which is mainly based on the user behaviour in occupancy of the escalator space. We use then this method to verify the provided capacity escalators in two main stations of the Bucharest metro and we reveal some needed actions in metro station design.

Keywords: public transportation; escalator in metro terminal; transfer capacity.

1. Introduction

The society of today is based upon large urban areas that have complexes transport networks, designed to serve the mobility needs of its citizens.

The moving belt systems, especially escalators and moving walkways became more than a simple component of the urban layout, and passengers expects that those systems would simplify the walking trips in indoor spaces and also in outdoor public spaces. We can mention the case of large cities that have such functional facilities in outdoor public spaces throughout the year (e.g. Genève, Barcelona, etc.)

In public transport stations, the moving belt systems are necessary design elements wherever elevation changes or there are longer distances, that must be travelled when carrying luggage. Also, these elements are important to keep a stable and high flow rate of passengers, even in congestion or high capacity conditions.

The most important advantages of the escalators, subject to this paper, are:
- The decrease of travel time in high-traffic facilities,
- The increase of travel distances that a pedestrian is willing to traverse by decreasing the physical effort of the pedestrian,

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- The improvement in the pedestrian flows characteristics for specific flows that passes through pedestrian areas with spatial constraints, thus providing the movement of a given number of passengers through an area with predefined dimensions (benefit that is highly important for multimodal transfer nodes).

The positioning of the escalators has various options depending on the design solution adopted for a specific station. The use of the escalators along with fixed stairs, also, leads to different layouts. The common-used layout in the existing metro station in Bucharest network consists in a pair of escalators that border a fixed stair.

The identification of an attractive and also functional layout is a difficult process to be realized in the design phase, because of the dependency of this layout to access variables and also to the positioning of various facilities in the station. The layout might become an element that decreases the quality of the provided transport service, if the travel through the pedestrian areas of the station is difficult or involves spending more time than expected. The use of escalators will lead to the increase of the comfort for the public transport users and to an easier travel through the public space [1], [2].

The design of public facilities, especially high-traffic public transport station is one of the most complex tasks. This gives one more reason for architects to ensure that they have considered the engineering results that describe in detail the dynamics of pedestrian circulation.

Although, the theoretical framework developed for the capacity estimation of escalators is based on the simulation of the movement of pedestrians, only certain components of pedestrian areas from a public transport station are subject to detailed analysis. The common practice for assessing escalators capacity is that of using design guidelines for a simple calculation of width of a passageway or the number of exits.

In the same way, regarding escalators, the typical method of capacity calculation consists in the use of manufacturer's guidelines, which provides information over standard loads or simple projected loading curves. This method has a number of flaws and imperfections because it does not consider the interaction between passengers using the escalators, or other factors that might influence the capacity of escalators [3].

The next section presents an overview of the main characteristics of the pedestrian flows that have an impact on the capacity of escalators. Then a method of capacity calculation is described. In the third section, based on the presented method, we evaluate the current capacity offered by the escalators from two high traffic metro stations, for which we consider the average daily loadings from a spring month (May, 2015). A discussion over the results is presented in the fourth

section, so that in the final section we can reveal some conclusions and recommendations.

2. Methodology

2.1. The behavioural description of pedestrian in public transport station

The escalators are design based on the needed area and the physical locomotion ability of the pedestrians [4]. The representation of an adult is realized based on the ellipse (Figure 1), taking into consideration not only the physical dimension of a person, but also considers factors as the space needed to feel comfortable, personal items, luggage and the space needed for the body in movement [5].
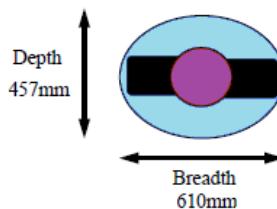

Fig.1. Human ellipse – area used in computation of the capacity of passenger facilities [4]

The walking trip of an individual is undertaken in a steady pace of 1.2 m/s [1], larger values are classified as running. The distance between each step is known as step length and in average has different values for males and females. This step length is around 0.79 m for males and 0.66 m for females [6].

Taking into consideration the aspects above, the escalators have steps with a sufficient run that allows the consecutive occupation of the escalators steps (a dimension of 0.4 m for a width of 0.3 m in average for a human foot). In terms of operating an escalator, it is important to understand the human ability to handle the interferences between stationary surfaces and moving surfaces, so the speeds of those installation is not higher than 1.22 m/s.

Also, because the movement on the escalator is allowed, another factor that must be considered is the walking speed for a person to climb/descend the stairs that normally is slower than the walking speed on plane surfaces. This speed is influenced directly by the specific preference of the user to walk or stand on the escalator. The studies showed that the walking speeds have a great variability, the average horizontal speed in climbing varies between 0.44 - 0.76 m/s, while in descend, the speed varies between 0.47 - 0.87 m/s [7].

The dynamics of movement of crowds involves 4 main factors: time, space, energy and information. Also, the standardized elements of the calculation described above offer information on the composition and decomposition of pedestrian flows over time [8]. The use of the occupied space allows the introduction of the level of service (LOS) concept, that was developed to assess the quality both of the infrastructure and the provided transport services [2], from A, for free circulation, to F, for complete breakdown in traffic flow.

2.2. Capacity assessment for different assumptions for the occupation of the escalator

In order to assess the capacity of escalator, it is necessary to consider the effect of the human ellipse over the travel using the escalator. Figure 2 shows pedestrian groups on the escalators, considering that the users are only standing. These grouping options are possible only if the escalators provide sufficient width.
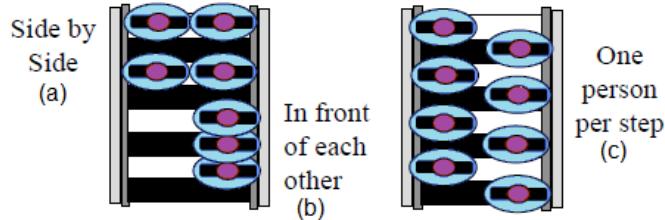

Fig. 2. The representation of some assumptions for the occupation of escalator: a) – side by side with one unoccupied step between individuals; b) – in front of each other with no free step between them; c) – one person per step, alternatively, on each side [9]

In common situations, it is observed that on an escalator passengers are often avoiding the direct contact. Thus, a successive occupation of the escalators like in the Figure 2, case b, is rarely encountered and mostly when people know each other, or in the case of high-volume flows when the installation is used at capacity.

The assessment of the capacity of an escalator must consider the speed of the escalator, the location of the escalator in relation to the pedestrian flow and also in relation to the access gates, but also, it must consider variables like the percentage of persons walking/standing on the escalators, vertical rise, the distance of escalator from platform etc.

The studies showed that there is a relation between the speed of the escalator and its capacity. So, the evaluation of capacity can be realized by using a number of regression equations, like the ones described by Mayo [10]. In his work, he describes a multiple regression equations, which includes as regression

factors, the speed of escalator – denoted by v (m/min), the vertical rise – h (m) and the traffic flow – q (pedestrians/h). Mayo defines the maximum capacity by:

$$C_M = 0.4050 \cdot v - 0.00051 \cdot v^2 - 0.2667 \cdot h + 0.0112 \cdot q + 0.00069 \cdot h \cdot v - 1.2 \, (\text{pass/h}) \quad (1)$$

and the mean capacity by:

$$C_m = 0.4733 \cdot v - 0.00055 \cdot v^2 - 0.081 \cdot h + 0.016 \cdot q + 0.0029 \cdot h \cdot v - 68.3 \, (\text{pass/h}) \quad (2)$$

Fruin [11] describes in detail the dynamics of crowd movements, underlying the following relevant aspects regardless the geographical location of the studied stations:

- The existence of the "empty step" phenomenon justifies the fact that usually the capacity of an escalator is smaller than the theoretical capacity. Even in high traffic situation, there are empty steps on escalators. This phenomenon is explained by two aspects, first is the inability of the user to board the unit quickly enough (hesitancy on boarding) and second is the personal desire for personal space (the reasoning comes from the comfort desire – the achievement of personal space).

- The observations regarding the user's behaviour in case of standing on escalators can be extended to the walking on stairs scenario. In this case, the passengers choose to keep two vacant steps between themselves. As a consequence, the traffic volume as a variable in the capacity equation can be considered the same, because leaving the two steps between themselves; users can walk with higher speeds easily.

As a conclusion, it can be stated that stairs and escalators have different patterns in terms of use then the passageways and corridors.

3. Evaluation of capacity of escalators in metro station. The case of Bucharest metro

3.1. Passengers flow statistics

In order to undertake an analysis for this design element of transport station, we used traffic data from the existing metro network of Bucharest. The metro transport network in Bucharest consists in 51 stations from which only 41 have escalators. In total, in the 41 stations, there are 138 escalators, placed especially in the access areas before the entrance gates and a smaller number are used to connect the platform and the station hall [12].

Among the stations that have escalators are also the most loaded stations in the network, along with the ones that make the connection between the urban

public transport and the regional transport. Also, the escalators are a common design element for the newly operated stations and more, they are used in the design phase for all new stations. Over the time, it was proved that escalators are vertical transport systems with a highly important role in the increase of attractiveness of a transportation system for all users' categories. So, this paper emphasizes the role of these moving systems in the current network, by showing its potential especially regarding the transfer capacity.

Based on records of Bucharest metro operator METROREX in working days (May, 2015), we computed the average daily passenger traffic in each metro station (boarding/alighting passengers/day). The passenger traffic statistics were also used to calculate the transfer flow between lines in the station used for transfer, as shown in Table 1. Almost 71% of the total metro transfer flow occurs inside two main stations, namely Piata Victoriei and Piata Unirii; this is the reason why we selected these two stations for checking the capacity of transferring escalators, with described method.

Table 1

The daily and hourly average passenger transfer flow in Bucharest metro stations

Metro station	Daily transfer flow (Passengers/day)	Hourly transfer flow (Passengers/h)
Eroilor	13830	3788
Izvor	232	21
Timpuri Noi	340	42
Republica	1260	333
Piata Unirii	75316	21402
Dristor	11090	2884
Basarab	18164	4870
Gara de Nord	7539	2431
Piata Victoriei	58344	17641
Nicolae Grigorescu	4749	992
Total	190864	54404

3.2. Transfer capacity provided by the escalators in Bucharest metro stations

The theoretical capacity of an escalator, in the case of each step is occupied by 2 passengers and the speed of the escalator is 39 m/min is 195 pass/min. This capacity is rarely achieved, because of passengers' behaviour on using the escalators.

For *the first assumption*, of using of escalators on standing side, the capacity of half the escalator is calculated taking into consideration the speed of the escalator and the percentage of steps used by passengers. The capacity of half the escalator is calculated taking into consideration the speed of the escalator and the percentage of steps used by passengers. In this case, the capacity is:

$$C_s = T_s \cdot p_s \text{ (pass/min)} \tag{3}$$

where T_s is   the number of steps per minute, computed as v/A ratio, with v the speed of escalator and A the depth of an escalator step;

p_s -   the proportion of step surface used whilst standing.

The known data are v = 39 m/min and A = 0.4 m. The assumed occupancy behaviour is for congestion conditions, meaning one passenger standing on each step (according to Figure 2, case c), and hence p_s = 0.5. Thus, the capacity of the standing side is C_s = 49 pass/min.

For *the second assumption*, of using of escalators on walking side, a walking passenger needs usually to have two clear steps between themselves and the person in front; this behaviour does not affect the escalator capacity, due to the user's speed added to escalator's speed, compensating somehow the loss in capacity [8]. Thus, capacity is computed as:

$$C_m = T_m \cdot p_m \text{ (pass/min)} \tag{4}$$

where T_m is   the number of steps per minute, computed as (v+u)/A, with u the speed of passenger walking up the escalator;

p_m -   the proportion of step surface used whilst walking.

In this calculation we assume that on average passengers keep 2 steps empty between them, so p_m = 0.33, and their speed while walking up the escalator is u = 34 m/min. Therefore, the capacity of the walking side results C_m= 60 pass/min.

Consequently the total capacity of an escalator used for standing and walking equally, in the case of Bucharest metro station is around 100 pass/min.

Our first observation is that the speed of the escalators in the transport system in Bucharest is placed under the values used in other European metro networks with 11%. Thus a lower capacity results [7].

Currently, the most used stations in the metro network are Piata Unirii, a transfer station with 3 lines merging and Piata Victoriei with 2 metro lines merging (see the metro network scheme in [12]). In the below transfer schemes we use the following notation: E for escalator; S – stair; C – corridor; P – platform; the accesses are denoted by letters A, B, C, D and the branches are

numbered from 1 to 10; e.g. E-A2 represents the escalator to access A2; C-P1 represents the corridor to platform 1.

3.3. *Check of capacity for the existing escalators in Piata Unirii station*

The representation of passenger routes in the Piata Unirii station is shown in Figure 3. The transfer area consists in the corridor C-P1, which ends with 3 escalators and the fixed stair, S-P2, having a level difference of 5.5 m (marked with red in Figure 3). Two escalators work from Piaţa Unirii 2 (PU2) to Piaţa Unirii 1 (PU1) and one escalator from Piaţa Unirii 1 (PU1) to Piaţa Unirii 2 (PU2).
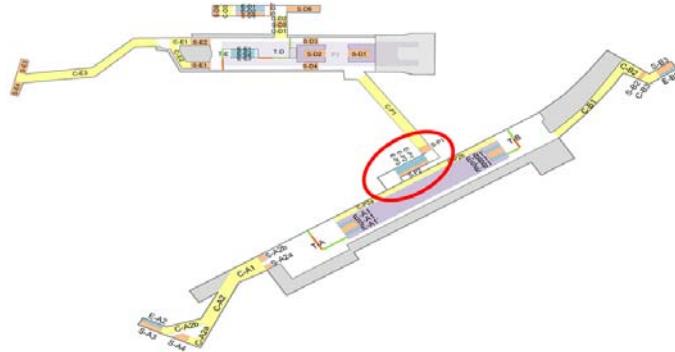
Fig. 3. Transfer between Piata Unirii 1 to Piata Unirii 2

The hourly transfer capacities provided by escalators in the assumption of using the escalators for walking and standing are 12000 passengers/h for the direction PU2 - PU1 and 6000 passengers/h for PU1 - PU2. For the fixed stair the capacity is calculated in normal operation condition (1 m width provides 28 pass/min) and it results 3360 pass/h. Total transfer capacity for fixed stair and the escalators is 21360 pass/h.

Based on the transfer flow matrices for Piata Unirii station presented in Table 2, we observed that using these assumptions for peak hour, the transfer is provided by a service operated near to the maximum capacity, meaning at LOS D. From the recorded data, the main conclusion is that the escalators are adapted for the evening peak, providing the service at 91% of the total transfer in both directions, in optimum condition, meaning a satisfying level of comfort for users, or a LOS D.

On contrary, for morning peak in PU1 - PU2 path, the provided capacity is less than necessary capacity. The estimated transfer trips are about 14100 pass/h, and they can be transferred in 1.17 h, using the escalators in the current operational features. In this circumstance, the users are forced to use the escalator

in congestion conditions (2 persons on each step, as in Figure 2, case a), meaning a capacity of 195 pass/min.

The peak hour passenger transfer flow matrices for Piata Unirii station

Morning peak			Evening peak		
Passengers/h	PU1	PU2	Passengers/h	PU1	PU2
PU1	-	14101	PU1	-	6852
PU2	7301	-	PU2	12927	-

For the opposite direction PU2 - PU1, the escalators provide sufficient transfer capacity (over the necessary with an estimated 40%). In this case, with escalators used at the theoretical capacity, the transfer capacities in the morning peak are 11700 pass/h for direction PU1 - PU2, 12000 pass/h for direction PU2-PU1 and 3360 pass/h for stairs.

Therefore, the transfer in morning peak, for PU1 - PU2, is realized in congested conditions, with the escalators operating at their maximal functional parameters, and additionally, the stairs fully used only for this direction, meaning at LOS E and sometimes even LOS F. However, in case of the future demand increasing, the technical improvements for the transfer escalators need to be considered.

3.4. Check of capacity for the existing escalators in Piata Victoriei station

Regarding the transfers in Piata Victoriei (Figure 4), between Pia a Victoriei 1 (PV1) and Piata Victoriei 2 (PV2), the shortest path route consists in using also the escalators. For each transfer path, two escalators can be used; the vertical level difference is 5.7m. The routes have a second alternative with longer travel time involving stairs.
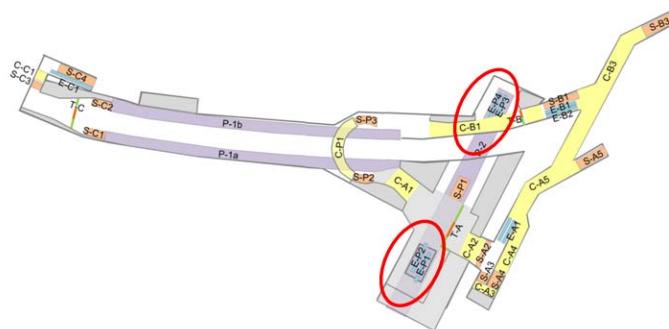

Fig. 4. Transfer between Piata Victoriei 1 to PiataVictoriei 2

The hourly capacities provided for transfer using the escalators in the assumption of using the escalators for walking and standing are 12000 pass/h for direction PV2 – PV1, 12000 pass/h for PV1 – PV2 and 7380 pass/h for stairs. Total transfer capacity is 24000 pass/h.

Based on the transfer flow matrices (Table 3), the total hourly transfer flow is around 18000 pass/h in the morning peak time and around 16000 pass/h in the evening peak.

Table 3

The peak hour passenger transfer flow matrices for Piata Victoriei station

Morning peak			Evening peak		
Passengers/h	PV 1	PV2	Passengers/h	PV 1	PV2
PV1	-	5406	PV1	-	10768
PV2	12235	-	PV2	4731	-

Globally, the transfer capacity provided on the transfer routes is sufficient, but we observed that the transfer flow is not balanced on the directions in the same way as capacity. In the morning peak, the major transfer flow is directed from PV2 to PV1, platform P-1b, with a measure of 9788 pass/h. The transfer routes are the following: *(1)* P-2 – E-P2 – C-P1 – P1b; *(2)* P-2 – E-P4 – C-B1 – P1b and *(3)* P-2 – S-P1 – C-P1 – P1b. The first two routes are situated at the ends and start from the platform with escalators, while the last is a central route, with no escalator on its path.

From authors' own records, it is found that the load of platform P2 is 70% on the area between S-P1 and the E-P3/4, while the rest of the platform is occupied at 30% from the total capacity. In this respect, on the part of the platform with higher loading, the transfer flow to P-1b is 6118 pass/h, so the escalator E-P4 cannot serve the entire transfer flow in the current assumption, but only in the case of using the escalators at their theoretical capacity. The 6118 passengers/h estimated to transfer in the morning peak using the escalator can leave the platform in 1.02h, leading to a congested situation on platform P-2 with the clearly expressed necessity of using the stairs.

Therefore, the morning peak traffic and the transfer between PV2-PV1, for platform 1b are described in Table 4. We observed that the escalator E-P4 is operated in the morning peak in congested condition with the occupancy of each step in a compact way, so the human ellipses overlap, leading to an increase in the discomfort of the transfer users.

Because of its specific configuration of the platforms, in terms of flows there are significant differences along with different non uniform loadings of the platforms. Also, due to the unbalanced values of the morning and evening peak transfer flow, a dynamic approach in terms of operation of the escalators might lead to an increase in the comfort of the passengers.

Table 4

Comparison between the recorded morning peak passenger traffic volume and the provided capacity

Transfer PV2 - PV1	Platform PV 2	Escalator P2	Stair P1	Escalator P4
Morning peak traffic volume (pass/h)	12235	3671	2447	6118
Transfer capacity (pass/h)	24870	6000	3690	6000

4. Conclusion

In the Bucharest metro stations, the escalators were considered as optional design elements, justified only by the need to make the stations accessible to mobility impaired passengers. Therefore, the speed of the escalators are low in comparison to operation speed of escalators from other European metro networks (15% slower), and consequently the capacity is around 100 pass/min. Their use for evacuation purposes is restricted, and the station design focuses especially on the dimensioning fix stairs.

The analysis of the pedestrian behavioural in public transport station demonstrates that the present method used to calculate the escalator capacity is inappropriate. We described an assessment method of the escalator capacity for different scheme of passenger behaviour. The method was applied to investigate the provided capacity of escalator in two main metro stations from Bucharest, in morning and evening peak hours. The results indicate levels of service for passenger transfer from D - corresponding to circulation for most pedestrians, with significant difficulty, to F - corresponding to widespread breakdown in traffic flow and many stoppages. Consequently, measures are necessary to increase the passenger transfer capacity and the presented method represents a useful tool for decision makers in assessment of different proposed measures.

A conventional but expensive solution could be using new escalator gears, which allow higher speed of the escalators. In this case, further models of simulation of passenger transfer are necessary to estimate the escalator capacity, because higher speed of the escalators could lead to inability of users to board the unit quickly enough. Also further study on passenger safety issues in boarding and alighting phases is necessary.

A less expensive solution could be the adaptive operation of escalators, in order to release the platforms in less time than currently in the peak hours, offering also high levels of comfort and safety.

Generally, for any measure proposed to increase passenger transfer capacity, supplementary analysis of user flow and passenger behaviour is necessary. Therefore we emphasize:

- The need of keeping statistic data on traffic flow, especially for the transfer station, for a rigorous determination of the characteristics of use of

escalators and transfer spaces and consequently for the adjustment of the operation of escalators to the demand.

- The need of a detailed study on the specificity of behavioural models for Bucharest metro users of the station spaces around the escalators. The behaviour of users in the approach of the escalators has a great impact on how people use the steps of the escalators.

It is also, necessary to continue the research to evaluate the real capacity of escalators not only in relation to the behaviour of the users, but also in relation to the frequency of the metro service provided and the level of traffic in discomfort/risk conditions.

Acknowledgement

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