Computer modeling analysis of METRO ticket gates impact to evacuation procedures

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Abstract: Subway rail system is considered the best choice for big cities to solve surface transportation problems in terms of congestion, efficiency, and speed. The increasing use of these facilities by more and more passengers has made vital the need to ensure high safety standards. The effective structure of the evacuation plan in an emergency event is essential. A critical factor for a successful evacuation is the proper functioning of the egress paths that must be clear of any obstacles.
To ensure the passengers' proof-of-fare (POF) public transport organizations have installed ticket validation machines proportionally in the facilities. In Athens METRO system, ticket gates providing automatic fare collection have replaced these ticket validation machines. Both POF systems may be considered as egress path obstructions that need to be taken into account in the initial evacuation plan design, since these POF installations provide different available width on the evacuation paths.
The paper investigates the impact of prior ticket validator and modern automatic fare collector machines on evacuation procedures in Athens METRO stations. The impact evaluation is based on three factors: i) total evacuation time, ii) time spent in queues (overcrowding effect) and iii) egress path flow rate, evacuation obstruction, human behavior.

1. Introduction
In Athens, one of the most populous capitals of Europe, there is a mass transit system to serve the needs of residents and visitors consisting of road network (e.g. buses), airports and rail network (METRO). The increasing use of public transport means creates the need to use strict safety standards in order to avoid undesirable consequences in case of an emergency. In METRO stations, this need is imperative due to their specific characteristics that differentiate them from the surface transit network in the following parameters:
• absence of natural lighting for the majority of cases
• requirement for continuous artificial ventilation
• limited orientation awareness of its users
• evacuation routes and smoke paths are, sometimes, overlapping each other
• exit route paths are always ascending and thus causing fatigue to evacuees
Therefore, METRO stations require special attention in the development of an emergency evacuation plan as well as on the design of egress routes.
To ensure the passengers' proof-of-fare (POF), the Athens Public Transport Organization has established the "smart" electronic ticket. The implementation of the "smart" electronic ticket, allows calculating the number of total passes (including the free and reduced-fare) through the boarding card that contains a memory chip. In this way, the ticket evasion phenomenon can be effectively dealt with.
Moreover, accurate and reliable data can be gathered concerning the passengers’ traffic in the station as well as the money income helping the Organization to plan new services and improve existing ones. To use the new smartcards in the Metro and the suburban railway system, electronic fare gates have been installed for entering as well as exiting the stations. As a result, the commuter flow changed, affecting also the way of the evacuation process taking place with the new validation machines compared with the old ones.

The critical difference between the old and the existing validation machines is the space they occupy in the station. The old machines were like vertical rectangular boxes at a small height next to each other with a gap between them (Figure 1). The passengers had to validate their ticket on the machine and pass by the side area. In the existing machine system, the ticket is validated at the automatic fare gates that have been placed where the old validation machines were located. Approaching the electronic ticket or card at the machine, the system determines if the validation has been done successfully and the gate opens automatically (Figure 2). In case of emergency, the gates (glass doors) are designed to open automatically, so that passengers can evacuate the area immediately without having to validate the ticket during station evacuation.

Figure 1. Ticket validation machines (previous installation)

Figure 2. Automatic fare gates (existing installation)

The difference in the installation affects the flow rate of the area since the effective width for people to pass through changes. To be more specific, the flow rate of a door or a corridor depends on the effective width according to \( F_c = F_s \times W_e \) (where \( F_c \) is the calculated flow rate, the \( F_s \) is the specific flow and \( W_e \) is the effective width of the passage) and the people density as presented in Figure 3 [1]. Both installation function as obstacles in the exit route and previous studies have proved that although fire codes require emergency exits to be clear of obstacles, there is a large uncertainty regarding the situations on which positive effect of obstacle could be observed [2] [3] [4]. In addition, above a critical people density, a
crowd moves as a fluid instead of a sum of individuals. At densities of about 7 pers/m² the crowd becomes almost a fluid mass. Shock waves pass through crowds and cause people to move long distances against their will, and some may not really hit the ground [5]. Meaning that the fluid mechanic equations may be used to predict the crowd movement in high density conditions such as METRO station evacuation.

Figure 3. Specific flow with regard to the people density

The designed metro station safety plan is based on previous validation machines and since the new automatic fare gates occupy more space on egress route, a new evacuation study should be applied. Therefore, the purpose of this paper is an attempt to record the changes in the evacuation procedure in a METRO station by the use of the new automatic fare gates (AFG) compared to the old ticket validation machines (TVM) and investigate the evacuation effectiveness of the new installation. The impact on evacuation procedure is based on three factors: i) total evacuation time, ii) time spent in queues (overcrowding effect) and iii) egress path flow rate.

2. METRO Station Analysis

The following studied METRO station is located in Athens, the capital of Greece, and has started to operate in 2007. This station was not considered to be one of the crowded traffic stations and was constructed mainly with the prospect of a future upgrade of the surrounding area. It consists of two side platforms and 3 levels: 1) platform at height of +0 m, 2) concourse level at height of +10 m and 3) the surface of the station at +25 m height. The length of each platform is 110 m and there are four escalators of 1.1 m width and two stairs of 2 m width each that lead from concourse level to the platform level. The validation machines are located in concourse level in which the access from the surface is via two escalators of 1.1 m width each and one stair of 3.2 m each. A simplified plan of the station is presented in Figure 4.
During its first operation, TVMs were installed as shown in Figure 5. There were 6 machines of 0.11 m width and 0.2 m length each located in the north area of the concourse level (Figure 5) with a passage width of 0.8 m to 1.7 m for passengers’ movement (Figure 6).

In the past 3 years this installation has been replaced by automatic fare gates (AFG) that were placed in the same area (Figure 7). The new installation consists of five machines (3 default and 2 large) with a width of 0.3 m (default machine) or 0.5 m (large machine) and a length of 1.5 m each. The large machines are used for better service of disabled people. The intermediate width between AFG machines for passengers’ movement is shown in Figure 8.
The total free width for passenger to pass from the TVM is 8.3 m while in AFG is 3.85 m. Therefore, the following evacuation analysis will reveal the possible impact on evacuation procedure.

3. Evacuation Simulations – Results

Computer evacuation modeling has become the more appropriate method to simulate the evacuation in any type of building. In comparison to hand calculations in which passengers’ movement is controlled solely by the capacity of the egress elements as described in hydraulic flow and therefore speed changes according to the egress element and remains constant. In real evacuation conditions, passengers optimize their egress time according to their preference and unique personal criteria and this is something that can be modelled, to a certain degree, by the algorithms used in software models. The simulations took place in Pathfinder agent model software. Pathfinder is an agent-based egress and human movement simulator which uses a space triangulation in order to calculate occupants decision in evacuation progress by avoiding contact with obstacles and other occupants as well [6] [7]. The following assumption have been made in order to complete the simulations:

- Number of passengers: Since the traffic data of the station was not available and the worst case scenario demands two trains with 6 cars each are arrived in the station simultaneously, the assumption of the total number of passengers is 1000 that are distributed as 200 in north platform, 320 in south platform, 120 in north train and 360 in south train (Figure 9).

- Occupants speed: The occupants’ speed is a crucial parameter for the evacuation time and proposed by several researchers with regard to age, occupancy type, smoke presence, physical condition and more [8] [1]. In this study a constant value of 1.19 m/s was adopted and the speed is affected by the interaction of station geometry and other occupants’ movement.
3.1. TVM Installation

In the case where ticket validation machines are installed, passengers evacuate the platform in 125 sec and the station total evacuation time is 355 sec. The passengers’ density is increased in places where the width of the exit route decreases as shown in figure 10. More specifically, the overcrowding effect, which is observed with dark red color (density is 3 occs/m²) appears in front of train cars doors, at the beginning of the fixed stairs and escalators from the platform level to the concourse level, at the TVM area and finally on the stairs that lead to final exit.

Queues of passengers are formed at the points of a high density of people. At these points the speed ranges from 0 m/s to 0.2 m/s. By calculating the duration of dark red color appearance (overcrowding effect), the total queuing time in each area is determined. Table 1 (with location reference on Figure 11) shows the queuing time in specific areas resulting in the “bottleneck” of the evacuation procedure at the final escalators and fixed stairs that lead to the surface.

Regarding the flow rate at the TVM passages, as presented in Table 2 the passage no. 1 (Figure 6) provides the highest average flow of 1.92 pers/sec while the total average flow of the whole installation is 6.13 pers/sec.
Figure 11. Fixed stairs and escalators location

Table 1. Passengers queuing time in specific areas for TVM installation

| Queuing location                  | Passengers queuing time (sec) |
|----------------------------------|-------------------------------|
| Escalator P05                    | 30                            |
| Escalator P06                    | 18                            |
| Fixed Stairs P03                 | 36                            |
| Escalator P07                    | 53                            |
| Escalator P08                    | 0                             |
| Fixed Stairs P04                 | 15                            |
| Escalator P04                    | 74                            |
| Escalator P03                    | 40                            |
| Fixed Stairs P02                 | 68                            |
| Escalator P02                    | 109                           |
| Escalator P01                    | 104                           |
| Fixed Stairs P01                 | 85                            |
| Ticket Validation Machines Area (TVM) | 136                         |
| Escalator C01                    | 160                           |
| Escalator C02                    | 149                           |
| Fixed Stairs C01                 | 153                           |

Table 2. Flow rates at TVM passages

| Passage   | Distance (m) | First in (s) | Last out (s) | Total use (pers) | Flow Avg (pers/sec) |
|-----------|--------------|--------------|--------------|------------------|---------------------|
| Passage 1 | 1,7          | 35,7         | 218,9        | 351              | 1,92                |
| Passage 2 | 1,3          | 52,3         | 217,7        | 171              | 1,03                |
| Passage 3 | 0,8          | 48,6         | 214,9        | 78               | 0,47                |
| Passage 4 | 0,8          | 43,1         | 206,8        | 97               | 0,59                |
| Passage 5 | 0,8          | 48,3         | 202,9        | 62               | 0,40                |
3.2. **AFG Installation**

In the case where automatic fare gates are installed, passengers evacuate the platform in 125 sec and the station total evacuation time is 386 sec. The passengers’ density is increased in places where the width of the exit route decreases as shown in Figure 12. The overcrowding effect, which is observed with dark red color (density is 3 occs/m²) appears in front of train cars doors, at the beginning of the fixed stairs and escalators from the platform level to the concourse level, and at the AFG area. It is important to mention that high density and overcrowding effect is not observed in the stairs (fixed and escalators) that lead to the surface.

![Figure 12. Maximum passengers’ density in the station during evacuation in AFG installation](image)

Similarly to TVM installation, queues of passengers are formed where the density of people is highest and at these points the speed ranges from 0 m/s to 0.2 m/s. By calculating the duration of dark red color appearance (overcrowding effect), the total queuing time in each area is determined. Table 3 (with location reference on Figure 11) presents the queuing time in a specific area resulting that the “bottleneck” of the evacuation procedure is located at the AFG area.

Regarding the flow rate at the AFG passages, as presented in Table 4 the passage no. 2 (Figure 8) provides the highest average flow of 1.4 pers/sec while the total average flow of the whole installation is 3.82 pers/sec.

**Table 3. Passengers queuing time in specific areas for AFG installation**

| Queuing location | Passengers queuing time (sec) |
|------------------|-----------------------------|
| Escalator P05    | 9                           |
| Escalator P06    | 0                           |
| Fixed Stairs P03 | 19                          |
| Escalator P07    | 0                           |
| Escalator P08    | 0                           |
| Fixed Stairs P04 | 43                          |
| Escalator P04    | 73                          |
| Escalator P03    | 45                          |
| Fixed Stairs P02 | 63                          |
| Escalator P02    | 94                          |
Table 4. Flow rates at AFG passages

| Passage | Distance (m) | First in (s) | First out (s) | Total use (pers) | Flow Avg (pers/sec) |
|---------|--------------|--------------|---------------|------------------|---------------------|
| Passage 1 | 0,75 | 37,2 | 310,3 | 237 | 0,87 |
| Passage 2 | 1,2 | 43,9 | 309,9 | 373 | 1,40 |
| Passage 3 | 1,1 | 46,5 | 307,7 | 234 | 0,90 |
| Passage 4 | 0,8 | 58,9 | 300,1 | 156 | 0,65 |

By adopting the “Jam time” parameter that describes the total duration of a passenger, in which his speed remains less than 0.25 m/s (~25% of its maximum speed) meaning waiting in queues (overcrowding effect), the following Figure 13 is created. This figure shows that in the case of TVM installation the 35% of the population subject to less than 10 sec jam effect, while in the AFG the 20% of population subject to less than 10 sec jam effect. In addition, in the TVM case only 9% of people subject to more than 60 sec jam time, unlike AGF that 43% of people subject to more than 60 sec.

Figure 13. Passengers’ jam time distribution

4. Conclusions
The platform evacuation time is the same for both installations (less than 4 minutes) since there is no intervention on platform access to the concourse level. The station evacuation in the case of AFG installation lasts 30 sec more, compared to the case of TVM installation, which leads to 10% more time to evacuate. This is due to the limitation of the existing space for the flow of passengers in the AFG machines installation making this area the "Bottleneck" in the evacuation procedure. The total queuing
time in the AFG area is almost 4 minutes and the jam time effect is greater than TVM installation. Given that in areas with high densities, people may become anxious, suffer from panic attacks or other psychological effects, long overcrowding effect in such places should be avoided. Since the density of passengers in the ticket validation area is high in both scenarios and the flow rate is depending linearly on effective width, it would be expected that since the ratio of TVM total width to AGF total width is 2.16, the total average flow rate ratio would change accordingly. However, the flow rate ratio between TVM and AFG is 1.6 meaning that people behave rather rationally than like fluids in order to evacuate an area.

It should be noted that despite the fact of evacuation time increment by using the new automatic fare gates in METRO stations, this innovation provides data that will be used to achieve a more controlled and effective evacuation. More specifically, by using the electronic ticket the total number of passengers that enter and exit the station can be counted in real-time making possible to determine the passenger flow in the station as well as to simulate more precise evacuation scenarios.

This paper is a first approach on how evacuation procedure could be affected by the installation of the new machines in existing METRO stations and more data need to be collected in order to come up with more accurate results.

Acknowledgments

The authors would like to extend a special note of appreciation to Thunderhead Engineering group, for providing academic license to use and work on Pathfinder platform as well as for the excellent and direct cooperation of its members.

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