A System Dynamics approach to public transportation strikes and travelers' behavior in the city of Rome

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Abstract

Public transit strikes are disrupting normal passenger behavior and force a change in travel patterns. Despite their significance, their study in the literature is limited. The purpose of the present paper is to investigate what are the effects of public transit strikes on passengers' behavior in an urban environment. The model was developed in the context of the ATTACS project and is a "spin off" the main research objective of the project. The city of Rome, Italy was used as reference case. Different scenarios of public transit strikes were simulated. The results showed an – expected- increase in the demand for private transportation. However, the traffic does not increase much for the city center because it is already high enough in the reference case. The effects of the strike seem more visible in the peripheral zones of the city, both in the behavior of all modes of transportation and in terms of economic activity.

Keywords: System Dynamics, public transportation, passenger behavior

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1. Introduction

Public transport strikes disrupt the normal travel behavior of passengers and increase the disturbance of the transportation network (Zhu & Levinson, 2012). They tip the balance between recurrent and unpredictable delays, thus forcing passengers to make increased use of their private vehicles (Rietveld, Bruinsma, & Van Vuuren, 2001).

The impact on the reliability of public transportation can change the passengers' behavior towards its use (van Exel & Rietveld, 2001). The subsequent change in transportation patterns hinders the ability of decision-makers to evaluate the needs and lacks of public transportation (Wei & Chen, 2012), which in turn increases the questions whether public transportation can cope with the increased demand that is (and expected to be) observed in the context of urban mobility (Amekudzi, Thomas-Mobley, & Ross, 2007); (Beirão & Cabral, 2007); (Farahani, Miandoabchi, Szeto, & Rashidi, 2013).

The purpose of this paper is to investigate how public transit strikes affect travelers' behavior and what is the impact on the public transportation system itself.

The model (and the present paper) came of the ATTACS (*__A__ssessing the economic impacts of __T__errorist __T__hreats or __A__ttacks following the __C__lose down of public transportation __S__ystems*) project, whose purpose is to investigate the economic consequences in an urban environment, when its transportation network is hit by an act of terrorism. The ATTACS project was co-funded by the European Union and more specifically by the Prevention of Fight against Crime Programme (European Commission-Directorate-General Home Affairs)[5].

The structure of the model and the conceptual similarity between a disruption by an act of terror and a disruption by a strike, offered the opportunity to test the effects of a public transport strike for the city of Rome.

The next sections of the paper include: A review on the literature about public transit strikes on section 2. Section 3 describes the model, while results are presented in section 4. Finally, conclusions and a discussion on the implications of the results are presented in section 5.

2. Public transit strikes in the literature

Strikes occur more frequently in the sector of public transportation than any other. The reasons can be attributed to a higher level of unionization and the ongoing regulatory reform that occurs in many European countries (van Exel & Rietveld, 2001). Especially for the city of Rome, Italy, the number of strikes that occurred in 2015 exceed the number of 1000 (Radio Vaticana, 2015). The high number is a result of the co-existence of several unions within the transportation sector (such as separate unions for the drivers of the public buses and for those that work in trams).

The results from these strikes in Rome do not differ substantially from similar occurring in various cities. A higher level of congestion and lower speeds for private cars are observed throughout all the studied strikes (Lo & Hall, 2006); (van Exel & Rietveld, 2001) (van Exel & Rietveld, 2009). However, passenger behavior seems more sensitive to the length of the strikes, especially when it constrained by factors such as car ownership and residence.

Blumstein and Miller (1983) argued that car ownership is a key factor when determining the alternative mode during a strike. Furthermore, increase in total traffic due to public transit strikes, could be explained

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[5] More information on the project can be found on the website: http://www.attacs.eu

by “dropped-off” trips and increased vehicle occupancy. Moreover, a public transit strike results in a change in the travel patterns. For example, it has been reported that a public transit strike increases the demand for taxi services (Anderson, 2013).

However, the transportation literature is extremely limited on the subject, despite its significance (van Exel & Rietveld, 2001); (Zhu & Levinson, 2012). Even more so in the field of System Dynamics, despite its use for many aspects of transportation such as:

- General urban transportation (Evilyn & Soehodho, 1999); (Koltchanov, Karsky, & Casanova, 2002); (Raux, 2003); (Jifeng, Huapu, & Hu, 2008)
- Transportation management (Mayo, Callaghan, & Dalton, 2001); (Bivona & Montemaggiore, 2010)
- Traffic congestions (Mehmood, Saccomanno, & Hellinga, 2003); (Gonzalez & Winch, 2006); (Armah, Yawson, & Pappoe, 2010)
- Disruptions in the transportation system (Armenia, Tsaples, & Carlini, 2015); (Armenia S. , et al., 2015)

Nonetheless, to our knowledge, no study has dealt with the effects of a public transit strike on the transportation system itself and the behavior of the passengers.

3. Model structure

The main structure of the ATTACS model concerns an urban transportation system. The model simulates the operation of the system with a time horizon of one working day. Moreover, to account for the topological characteristics of the network, the model is divided in zones of the urban environment and accounts not only for the connection of the different transportation modes within a zone, but also among the different zones. The Figure below illustrates a schematic, top-down conceptualization of the transportation network.

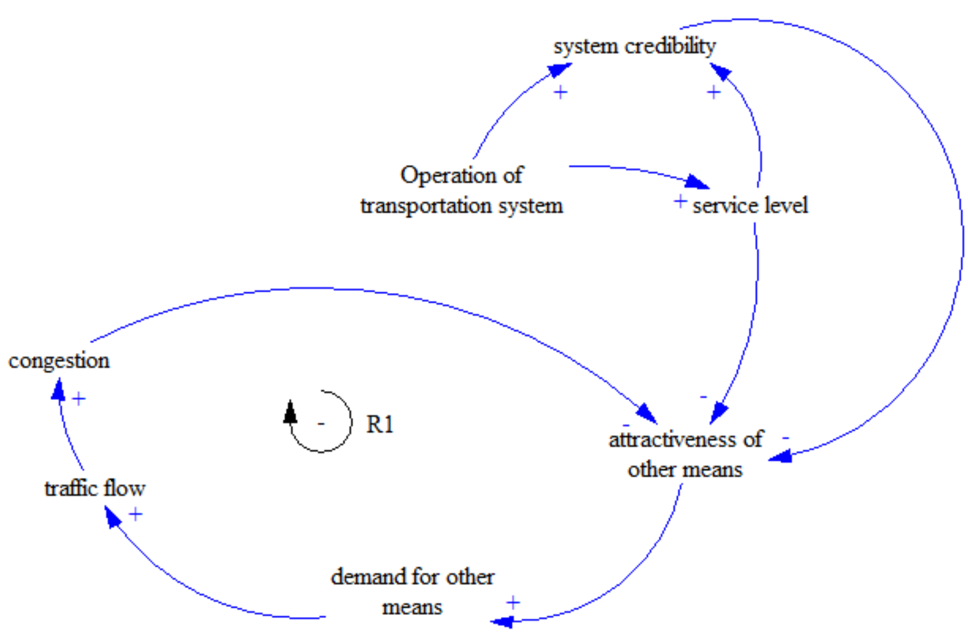

Figure 1 Causal Loop Diagram of the transportation network

In the core of every transportation mode lies its service level. It is influenced by the operation of the specific mode and by its credibility. The service level and the credibility of a particular transportation mode will determine how attractive it is and thus, how attractive are the alternative means of transportation. Increased attractiveness for other means of transportation means increased flows (whether of passengers or vehicles) for those modes, thus a negative loop is formed, which drives the system to an equilibrium.

As it was mentioned earlier, the simulated urban environment is divided into zones. Each zone has its own attributes, population and modes of transportation. For the ATTACS project, the city of Rome, Italy was chosen as a basis for input values and reference behavior, due to the availability of data and experts who consulted on the project. The city of Rome is divided in 15 zones, corresponding to the administrative division of the city.

The subway network contains stations, trains and the routes they follow. If a zone has metro stations within its limits, passengers can enter the stations and wait at the platforms. The waiting time depends on how often a train arrives at the specific station. Once a train is in the station, the number of passengers that can board is determined by the maximum capacity of the particular train. The excess passengers can either wait for the next train to arrive or they leave the subway network and search for alternative modes of transportation.

Once on the train, the passengers follow its (pre-determined) route. An Origin-Destination matrix determines where the passengers will step off along that route. Once out of the train, the passengers either leave the stations (and are added in the zone population) or they change platforms with the purpose of changing lines.

A similar structure was developed for the movement of the trains. They can enter stations only if there is an empty place for them and they wait at the platform for the passengers to board and un-board. Once they are ready to leave, they continue to their predetermined routes. The following figure demonstrates a high-level depiction of the metro structure.

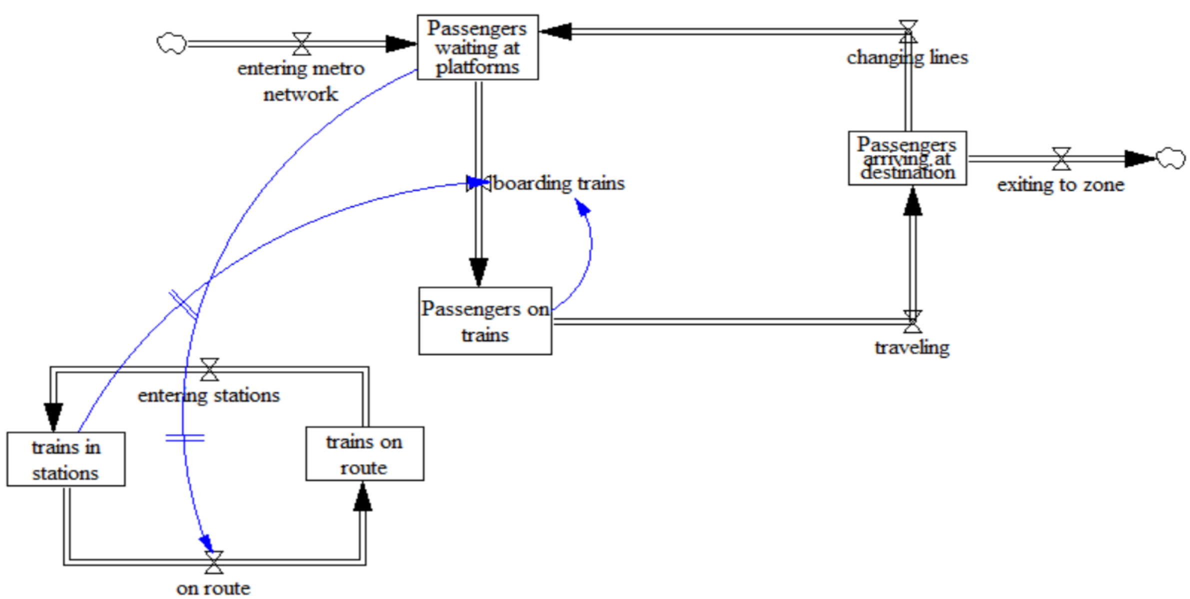

Figure 2 High-level depiction of the subway structure of the ATTACS model

The rest of the public transportation is denoted in the ATTACS model as Other Means of Transportation (OMT for the remainder of the paper) and it means buses, trams etc.. The conceptualization of the OMT structure is similar to that of the subway. When passengers choose OMT as their preferred mode, they wait for the public vehicles to arrive, board and follow their routes. The Origin-Destination matrix determines where along that route they will step off.

The private transportation's main elements are cars. In each zone, at the beginning of the simulation time, there is a specific number of cars, parked in the available spots of the zone. During the simulation, cars – when used- move continuously either within the zone or to another based on the Origin-Destination matrix. Travelers that use cars either look for a parking place (they can park only if there are empty spots) when in the destination zone or move towards the limits of the zone in order to go to another.

The continuous movement of the cars is determined by the topological characteristics of the zone. These are major roads, minor roads (with their respective capacities), parking spots and focal points. Focal points can be thought of as those parts of the road arteries that connect different zones. Thus, when cars travel through a zone to another, they are allocated in the respective focal points and can only enter the destination zone if its capacity can absorb them. A key performance indicator was constructed to measure the traffic flow for each zone; it is calculated by dividing the number of cars within a zone to the maximum capacity of that zone. The traffic KPI determines the velocity of the cars and hence, the time to travel from one zone to another. The Figure below demonstrates the structures of OMT and private transportation.

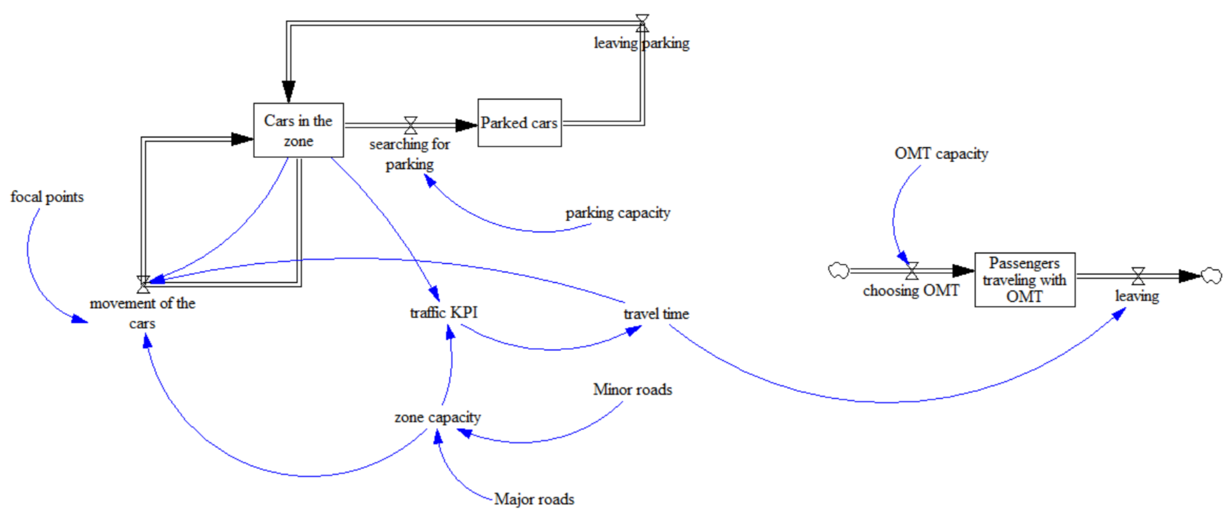

Figure 3 High-level depiction of the OMT and private transportation of the ATTACS model

The basic element that drives the behavior of every mode of transportation is the population of the zone. Each zone starts with a fixed population, a percentage of which travels for business and a percentage for leisure. The graphical function that determines those percentages changes throughout the simulation time; people who travel for business seek transportation earlier in the morning, reach a peak around noon and again in the afternoon when it is assumed that they return from their work. People who travel for leisure seek transportation later in the day and reach their peak after noon and again later in the evening.

Their choice of transportation mode depends on a number of factors, both quantitative and qualitative. These factors range from the accessibility to a particular mode to the comfort it provides to its users. All these factors are combined to form the attractiveness of each particular mode. It should be mentioned that those factors change throughout the simulation time, thus the attractiveness of every mode changes dynamically. For example, when the attractiveness of private transportation increases, people are using it more and more driving its attractiveness down and increasing the attractiveness of the metro and OMT. Consequently, more and more passengers are using public transportation forcing its attractiveness to decline, turning people once again to private transportation.

Moreover, an important aspect of the ATTACS model is the credibility of each transportation mode, which is one of the factors that determines the choice of passengers. In the context of the ATTCS project, credibility is denoted as fear of using a specific mode. The project's main purpose is to investigate the effects of a terrorist attack, thus it was deemed important to include it in the model. Nonetheless, a public transit strike is a disruptive event and credibility (after calibration) can be considered as an alternative (and inverse) measure of fear. No matter the name, the variable is determined by the coverage of the media; the larger the extent of the strike the larger the media coverage, thus the credibility of the specific mode decreases, driving people to use one of the remaining alternatives.

The Figure below depicts the entire model in a conceptual, aggregate manner.

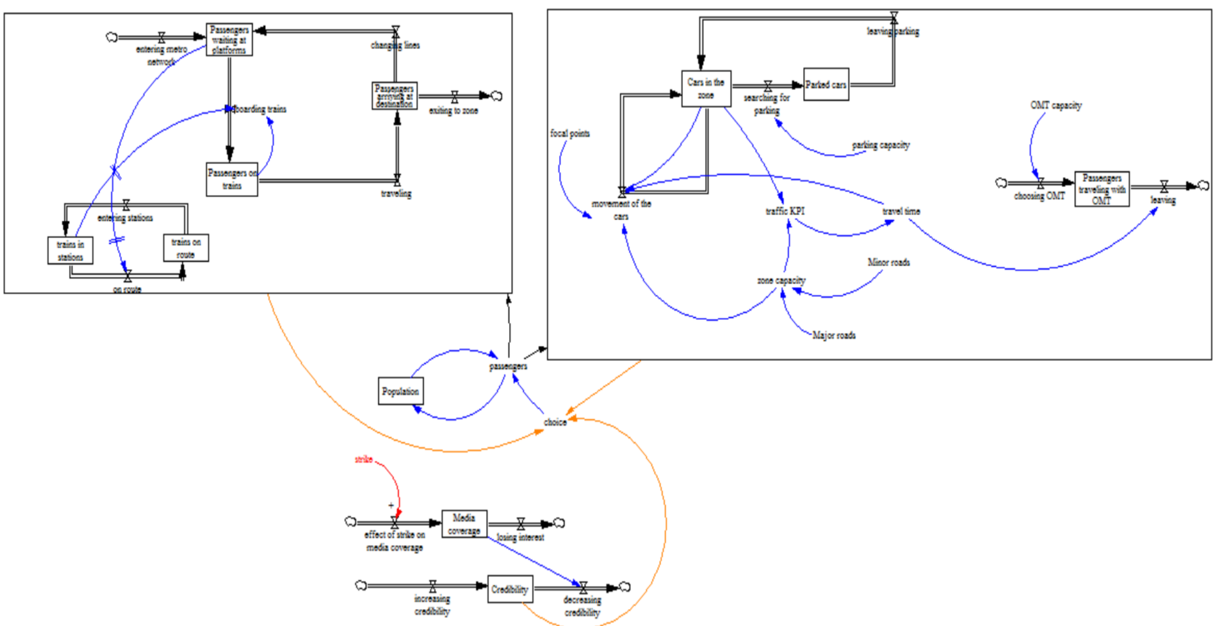

Figure 4 An aggregate depiction of the ATTACS model

Finally, to provide another indication of the effects of an urban transit strike in the entire urban environment, a small structure that accounts for the entertainment industry was created. The industry includes cafes, restaurants and bars. People spend a certain amount at specific points in the day and the money are accumulated into a stock. The scheme does not depict reality, but serves as another indicator of the direction of the change that a strike could cause in an urban environment.

The conceptualization of the ATTACS model was facilitated and validated in a series of workshops, held in the city of Rome, with experts from various fields. For more details on the experts, please check: http://www.attacs.eu/expert-users.html

4. Results

As it was mentioned, the reference case for the model[6] was simulated with the city of Rome in mind. Furthermore, results were validated with the help of experts from ATAC S.r.l., Rome's main mobility operator. For the purpose of this paper, five different scenarios were developed and simulated:

- Reference case: in which the results of the model are presented without the effects of any kind of critical event
- Scenario 1:A strike on the entire railway sector for the entire simulation time
- Scenario 2: A strike on the entire railway sector for the entire simulation time, but without prior notification to the passengers
- Scenario 3: A strike on the entire railway sector from the beginning of the simulation time until the first peak of the day (11.00am)
- Scenario 4: A strike on the entire railway sector from the beginning of the simulation time until 14.00pm

For reasons of economy and clarity, the results of only two zones will be presented: zone 1 (city center) and zone 6. The choice of the particular zones facilitates the demonstration of the effects on two completely different zones. On the one hand, there is the city center with the dense transportation network, its attractiveness to local population and tourists alike and the constant traffic. On the other hand, there is zone 6, which has no metro stations and is considered more "quiet" than zone 1.

4.1 Reference case

Zone 1

For zone 1, the demand for public and private transportation is depicted in the Figure below.

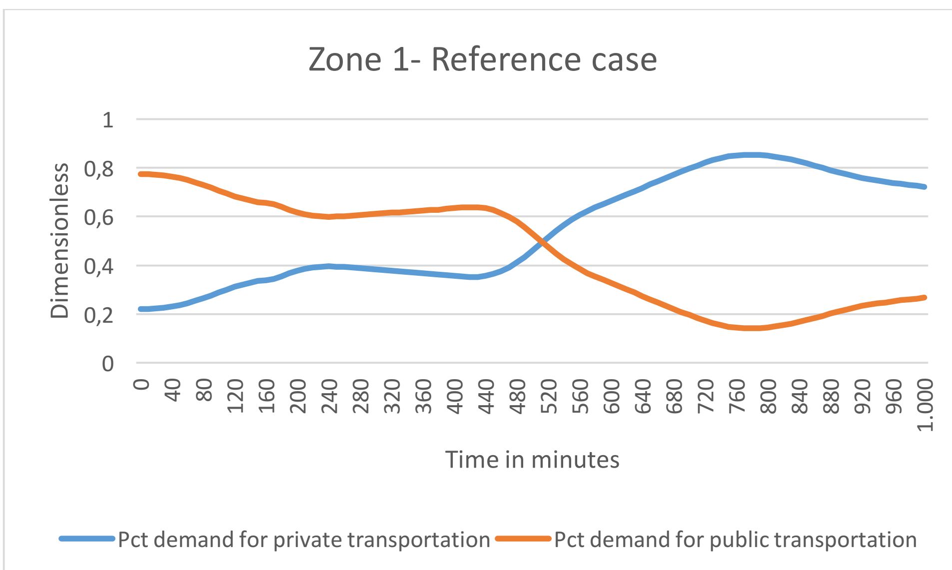

Figure 5 Pct of demand for public and private transportation for reference case

At the beginning of the simulation time, public transportation seems more attractive to passengers. As more and more are traveling with public means, its attractiveness decreases and passengers prefer private

[6] The model was developed on Powersim

transportation. After 14.30 pm (520 min from the beginning of the simulation time), private transportation is more attractive until the end of the simulation.

As a result, the traffic KPI in zone 1 remains high for almost the entire simulation time. The high level of the KPI can be attributed to the limited number of roads in the zone (there are many roads closed due to the existence of historic monuments) and the large number of people that visit (or travel through) zone 1 daily.

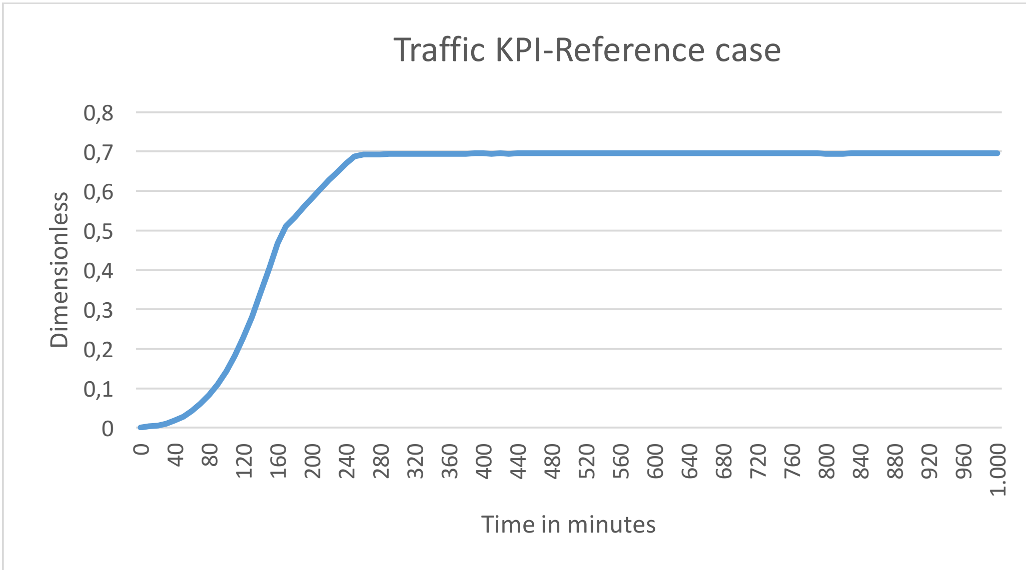

Figure 6 Traffic KPI for zone for the reference case

The large number of people in the zone results in a high level of revenues for the entertainment industry for the zone (Figure 7).

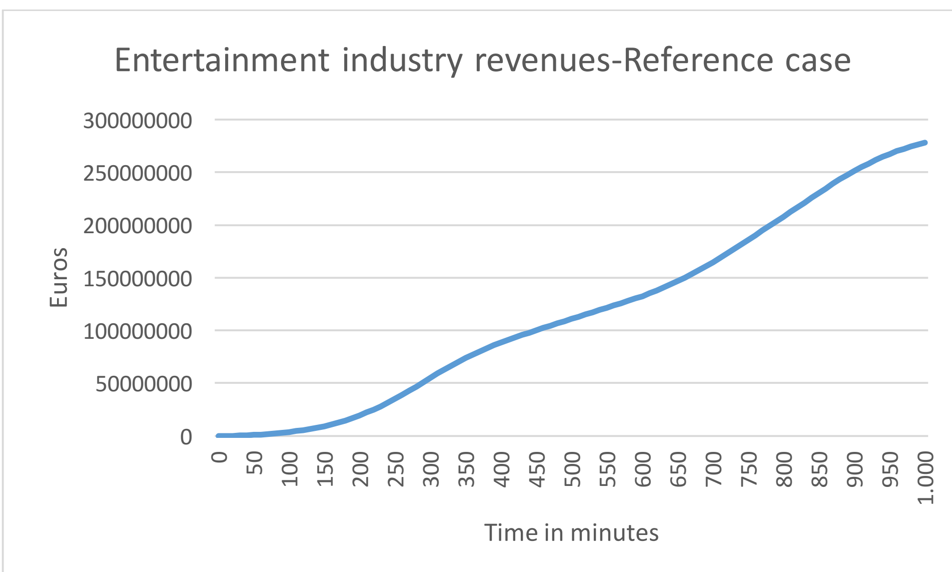

Figure 7 Revenues for the entertainment industry of zone 1- Reference case

Zone 6

On the other hand, for zone 6 the lack of a metro network results in a decreased demand for public transportation from the beginning of the simulation, with an increasing demand for private transportation. The Figure below depicts the demand for public and private transportation for zone 6.

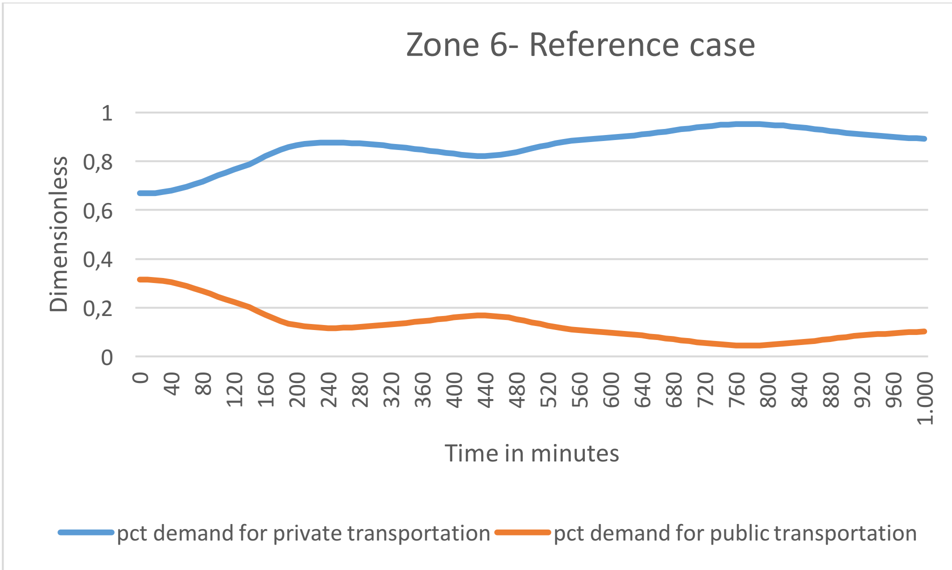

Figure 8 Pct demand for public and private transportation for zone 6- Reference case

However, the large area of the zone (in km^2) in addition to its less attractive nature results in a relatively low traffic KPI, which reaches its peak during the morning hours that people travel for work (Figure 9).

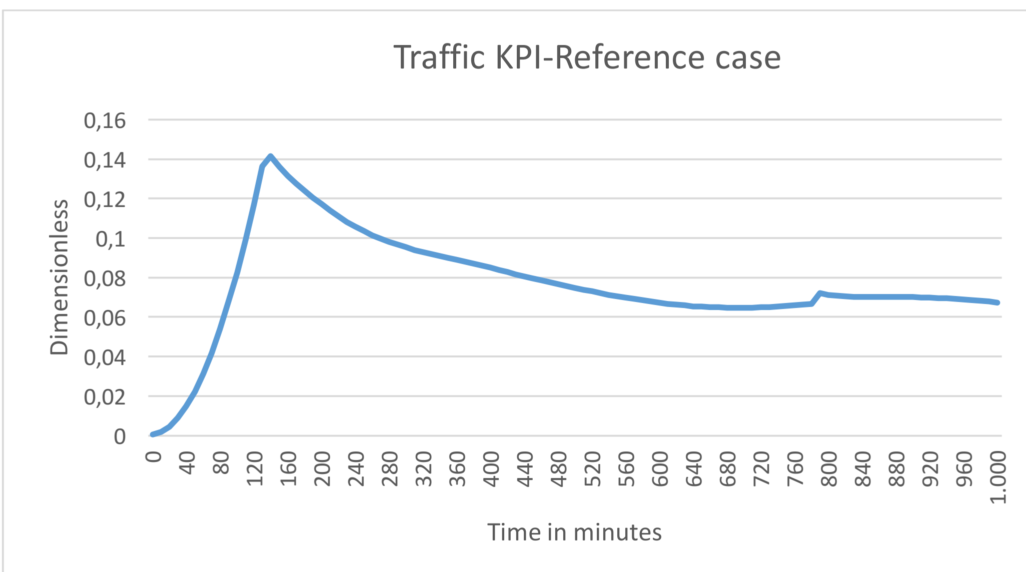

Figure 9 Traffic KPI for zone 6- Reference case

Similarly, the revenues for the entertainment industry are lower, compared to those of zone 1. This is not surprising and once again can be attributed to the less "attractive" nature of the zone.

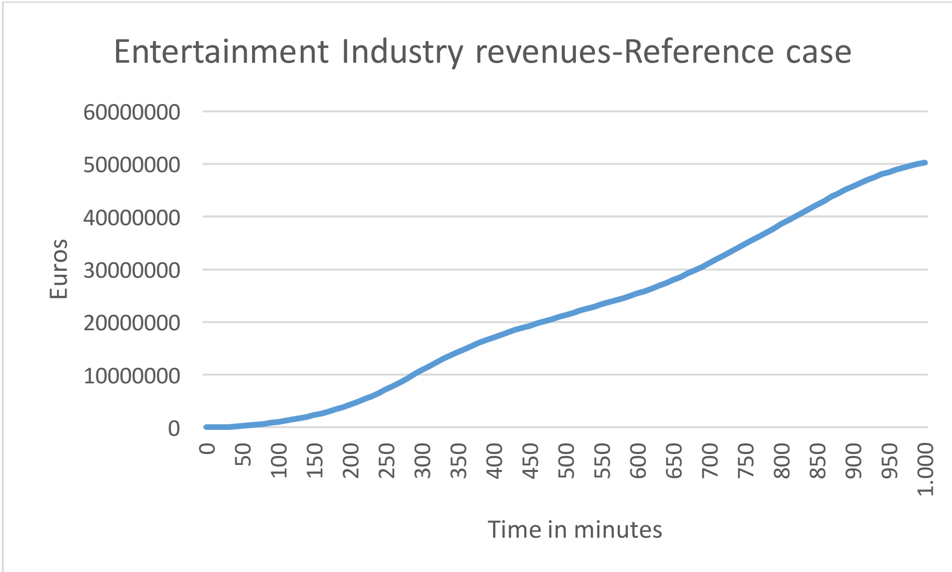

Figure 10 Entertainment industry revenues for zone 6- reference case

Finally, one other indicator that can facilitate the studying of the effects of the different scenarios is the total number of passengers that used the metro for the simulation time. Figure 11 illustrates that in a normal day (off-peak season without critical events), the number of passengers that were serviced by the metro are almost 500000. ATAC S.r.l. also corroborated this number.

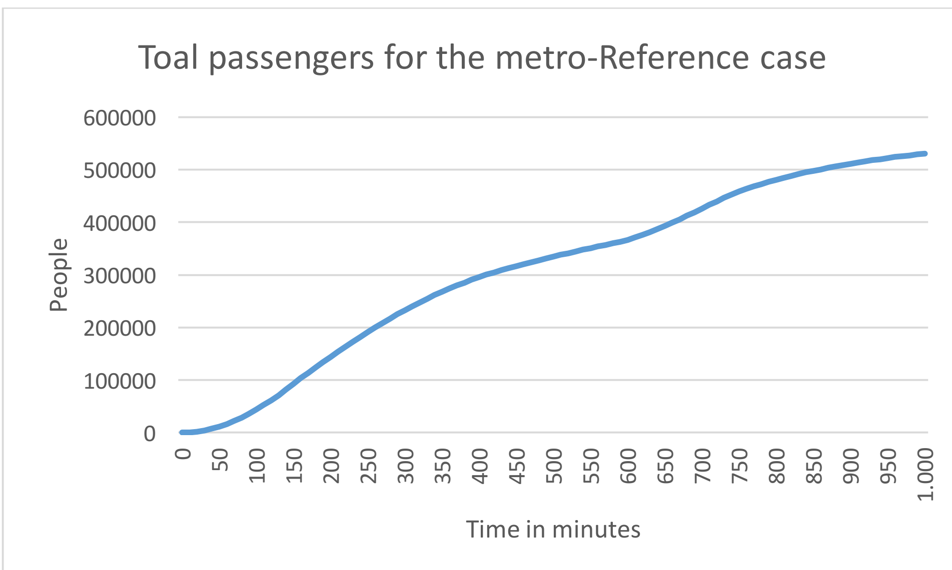

Figure 11 Total passengers for the metro- Reference case

4.2 Scenarios

The simulation of the various scenarios results in a change in the figures that demonstrates the change in the travel patterns that can be observed in real life.

Zone 1

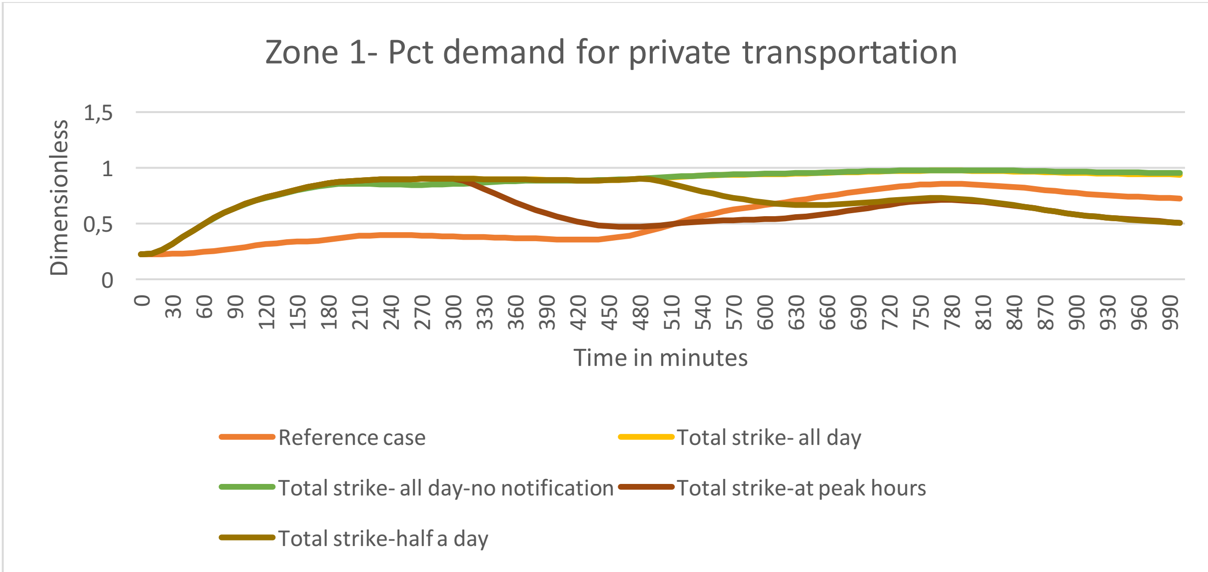

Figure 12 Pct demand for private transportation for zone 1

For zone 1 (Figure 12), the first effect is that the demand for private transportation increases from the beginning of the simulation time. However, for the scenarios, where the extent of the strike is not for a full day, the demand falls below the reference case. Since public transportation starts operating later in the day, when people have - to some extent- already used private transportation, its attractiveness remains relatively high at the end of the working day. The model accounts for carpooling and –implicitly- the use of taxis, thus the excess number of passengers that used public transportation in the morning, turn to the more attractive public transportation in the afternoon.

The choice for private transportation is translated to an increase demand for all the scenarios.

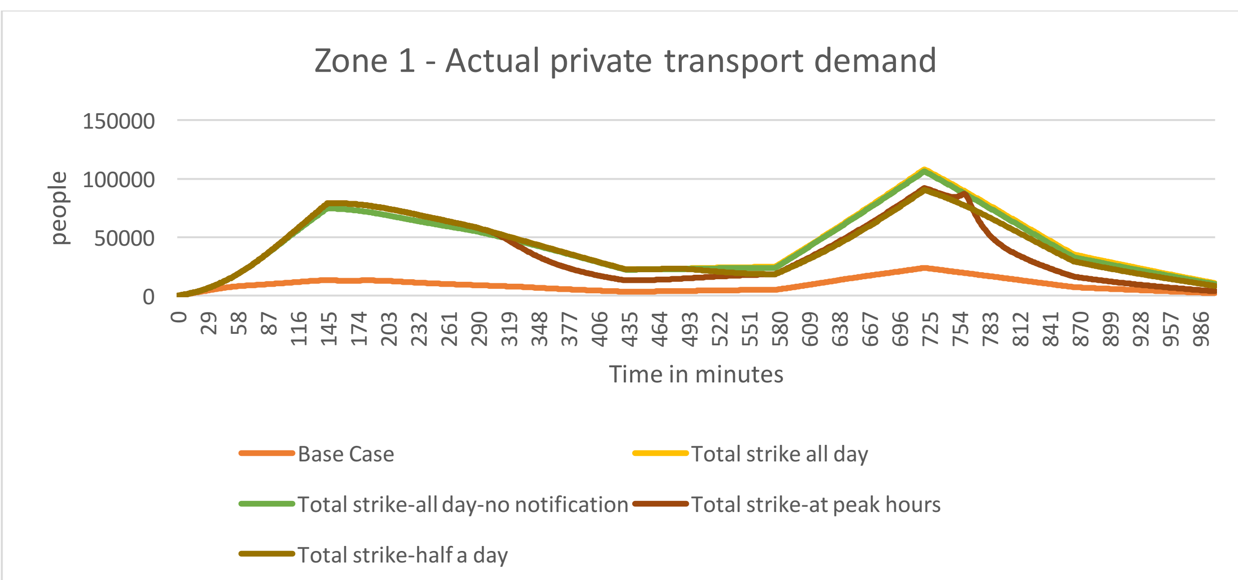

Figure 13 Actual private transport demand

However, at the end of the simulation day, the option of a functional railway that has worked for many hours without an incident forces passengers to turn to private transportation, thus reducing demand for private transportation (Total strike at peak hours Scenario).

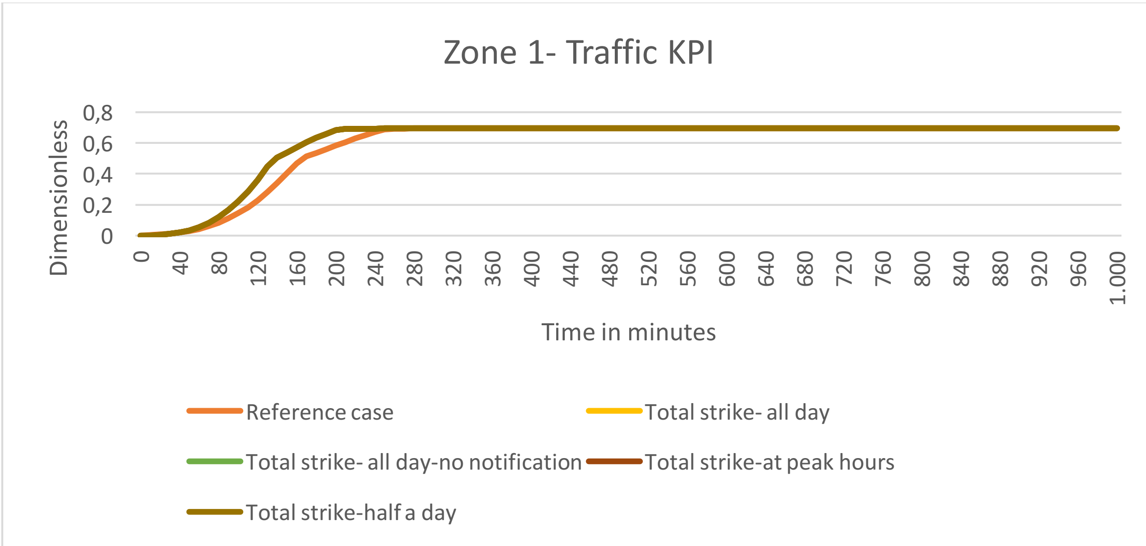

Figure 14 Traffic KPI for zone 1

As a result, the traffic KPI of zone 1 (Figure 14) shows the same behavior as the reference case, with the only difference that its peak level is reached earlier in the simulation time. Consequently, traffic in the city center is not affected greatly by a strike, because it is very high to begin with.

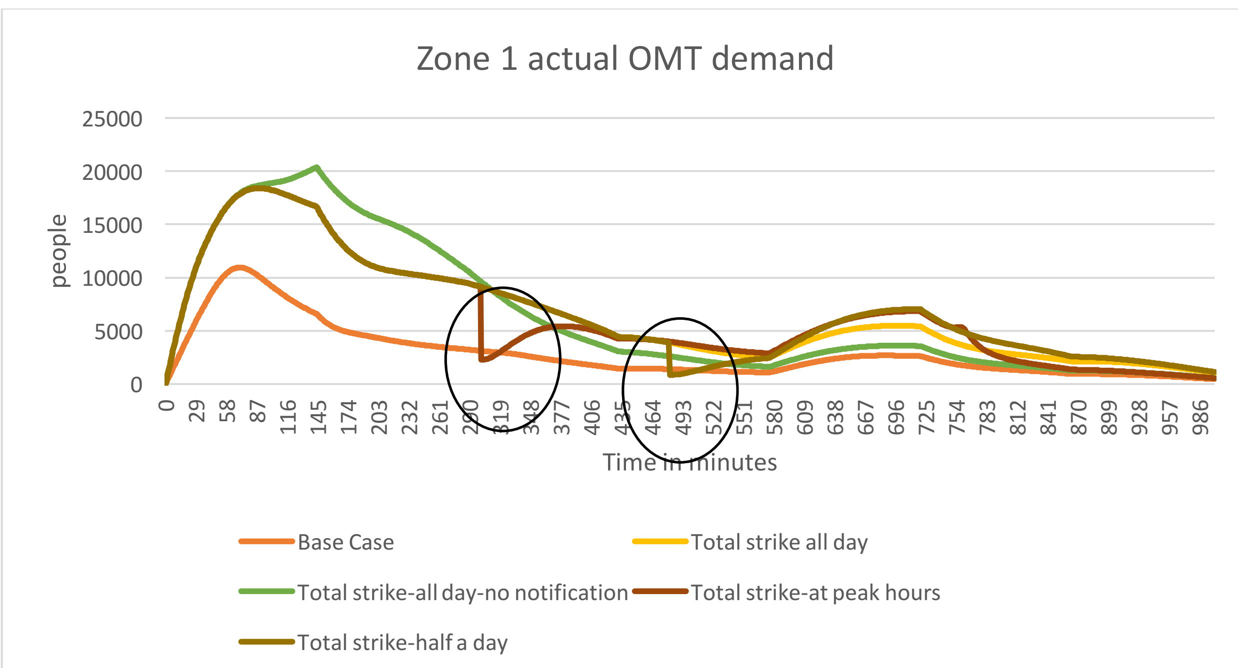

Figure 15 Actual OMT demand for the various scenarios

As expected, the demand for OMT transportation increases for all the scenarios. However, in the figure it can be observed how important is the notification of a strike to the public; without one the OMT demand is higher compared to the other scenarios, but as the (simulation) time progresses it falls to the levels of the Base Case, because no information results in passengers increased fear, which turns them to private transportation.

The two circles show the scenarios where the railway sector re-opens. As the railway sector re-opens, OMT loses some of its attractiveness, which is directed towards the railway. However, as more passengers use the railway, its attractiveness is reduced driving passengers again to the OMT and the system to an equilibrium.

As for the revenues of the entertainment industry, from Figure 16 it can be observed that the level of revenues is decreased for all scenarios. The worst case occurs when there is no notification for the strike. Searching for a means of transportation to return home in an environment with limited alternatives, takes a toll on the urban businesses, with the revenues amounting to 1/3 of the revenues in the reference case.

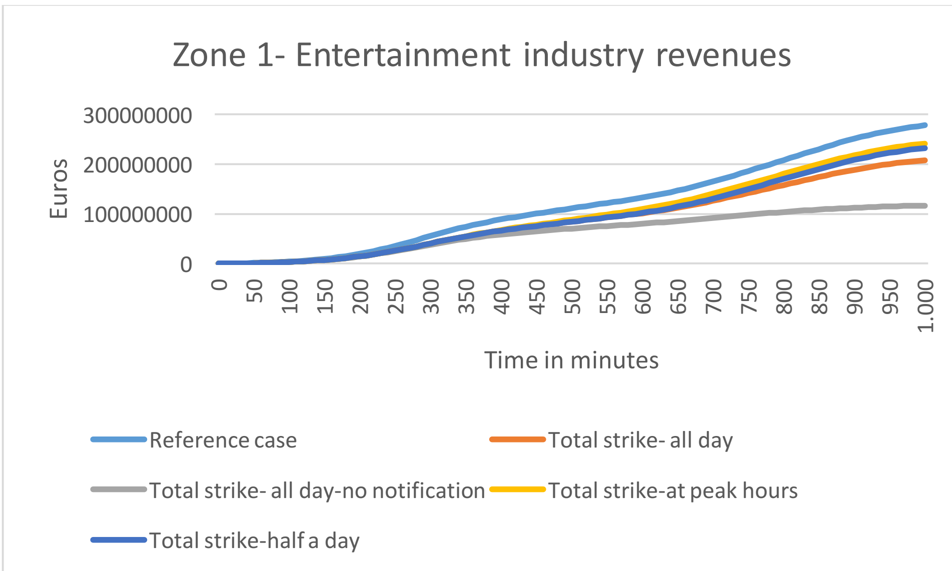

Figure 16 Zone 1 - Revenues of the entertainment industry

Zone 6

For zone 6, the demand for private transportation does not change its behavior; the lack of a metro network in the zone and the absence of the OMT alternative, forces passengers to seek private transportation in larger numbers (Figure 17).

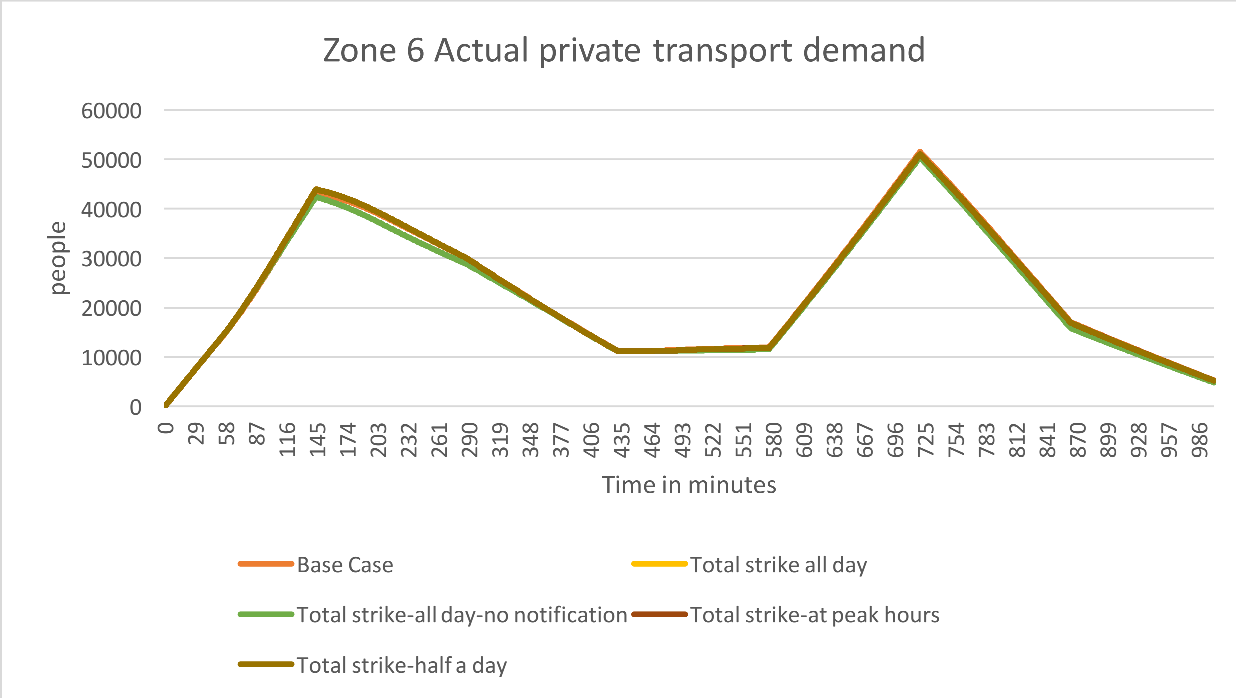

Figure 17 Actual demand for private transportation - zone 6

However, contrary to zone 1, the demand for private transportation does not decrease at the end of the simulation time; it increases and it reaches its maximum value of 1. The lack of a metro network results in people traveling back and forth with their cars (carpooling or using taxis) for the entire day.

As a result, the traffic in the zone is increased compared to the reference case (Figure 16). Comparing them as absolute numbers, traffic in zone 6 is still lower than zone 1, which is attributed to the larger area and the smaller population of the zone. However, the increase for all the scenarios ii almost 50% higher than the reference case, hence the effects of any type of strike will be more visible to zone 6.

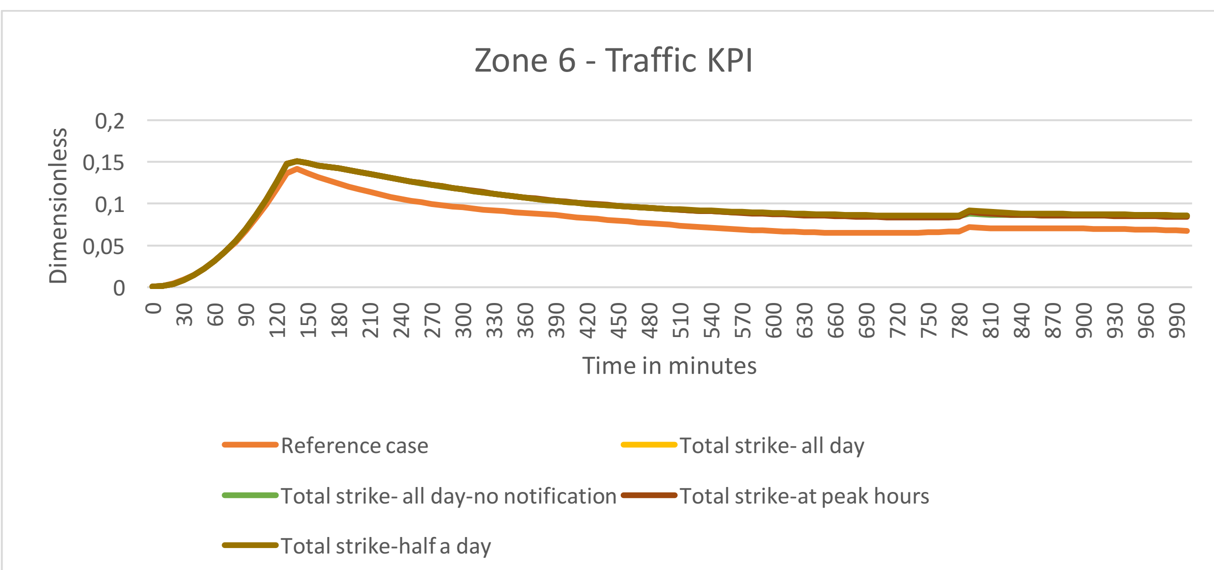

Figure 18 Traffic KPI - zone 6

For zone 6 since there is no railway structure, the OMT transportation is the only option of public transportation. Thus, the demand is absorbed by OMT. However, when there is no notification of an imminent strike, fear increases and passengers turn away even from the OMT mode.

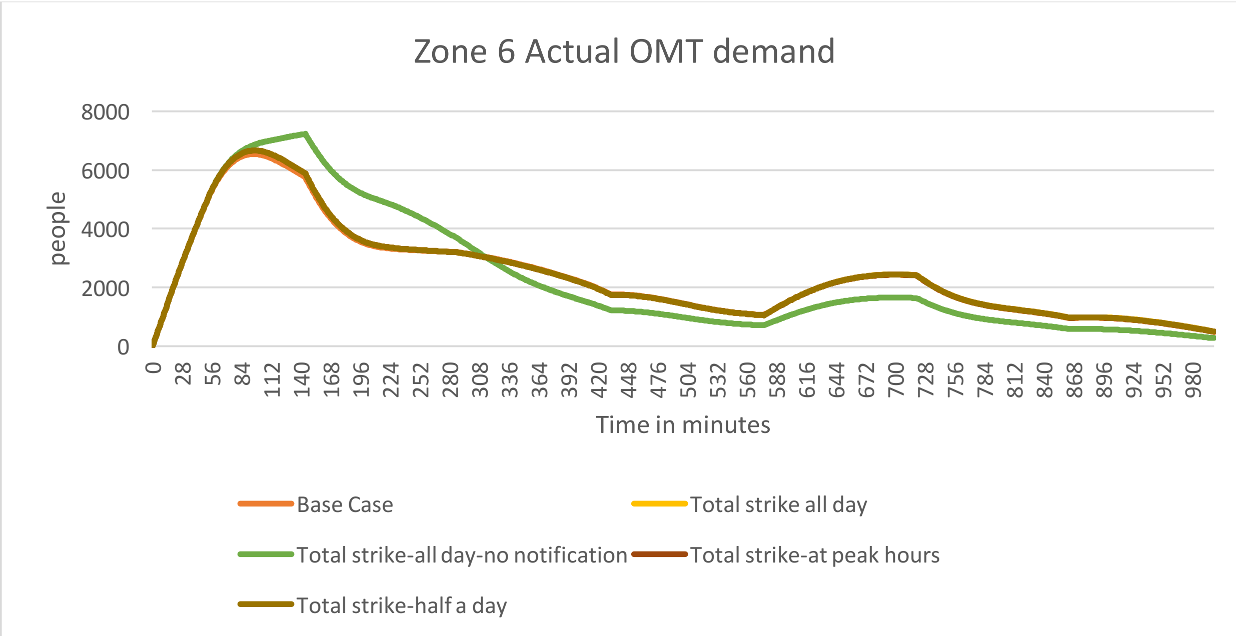

Figure 19 Actual OMT demand for zone 6

Similarly to zone 1, the revenues for the entertainment industry do not change their behavior and are lower than the reference case. Once again, the worst scenario occurs in the case of a strike without a prior notification. Finally, a public transit strike is expected to reduce the number of total passengers of the metro that have been serviced. Figure 20 confirms the expectation, and demonstrates that even a strike for a few hours will reduced the total metro passengers to 50% of the reference case.

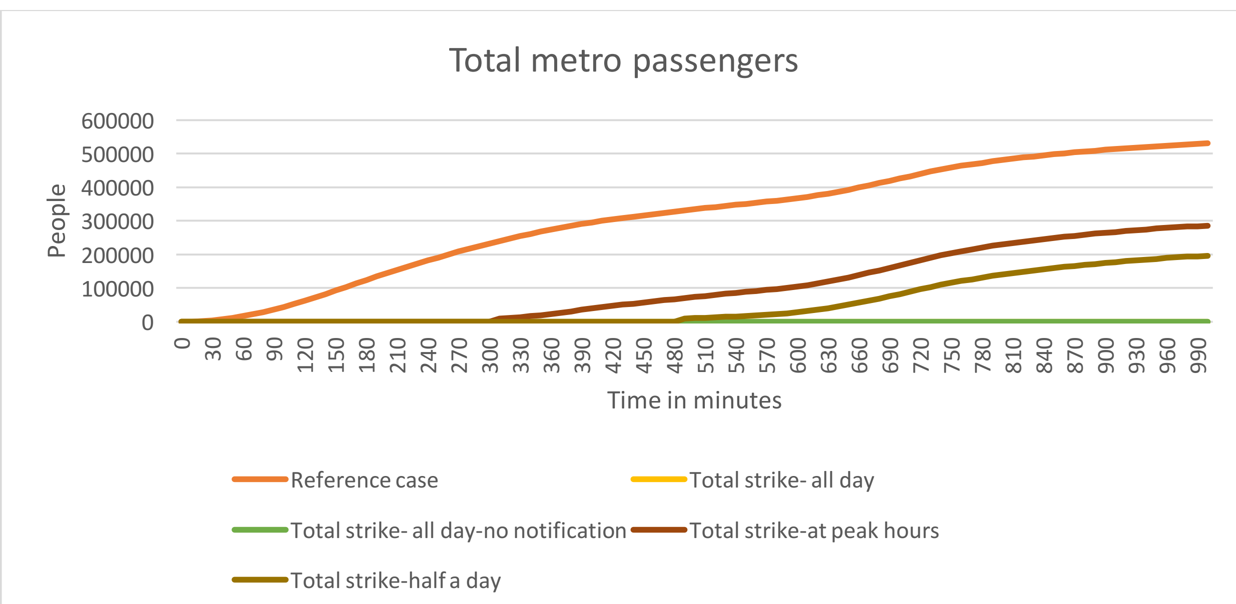

Figure 20 Total passengers served by the metro for all scenario

5. Conclusions

The purpose of this paper was to investigate the effects of a public transit strike – under different scenarios- in the city of Rome, Italy. The study can be considered a "spin-off" from the ATTACS project whose aim is to investigate the economic effects that a transportation closedown, due to a terrorist attack, could have on an urban environment. However, the developed model offer the opportunity to study the effects of a public transit strike (a disruptive event of a different nature) on passengers' behavior.

Despite their significance for the transportation sector, public transit strikes have not been extensively studied in the literature. In the System Dynamics field, although transportation has been a fertile ground for research, to our knowledge no model has been developed to study the effects of public transit strikes on passengers' behavior and on the transportation system itself.

The city of Rome, Italy was used as a reference case. The main effect of the strikes are the increase in the demand for private transportation. However, the greater demand does not translate to an excess of traffic for the city center, because the traffic is already high under the reference case. On the other hand, for outside zones, a public transit strike could result in an increase in traffic as high as 50% of the reference case. Thus, the change in travel patterns that is observed with public transit strikes might be more visible in peripheral zones than central ones.

Furthermore, the most important aspects for the behavior of the passengers (and subsequently the operation of the transportation system) are the duration of the strike and whether there has been any type of notification for and about it or not. Lack of notification and extended hours of strike increase the fear of passengers forcing them to avoid all modes of public transportation. Furthermore, the zones that do not have a railway structure face greater levels of impact compared to the city center (where there is an extensive railway network).

Finally, the model has shown that a change in travel patterns results in a change in consumption habits, thus outlining how important is the function of the transportation system to the economic activity of an urban environment.

Future directions of the research include the simulations of public transit strikes for different European cities and further, the comparison of the results among those different cities. Common travel patterns (and how passengers react to strikes) could help decision-makers to assess the strengths and weaknesses of their respective transportation infrastructures.

Furthermore, both terrorist attacks and public transit strikes are disruptive events. By simulating both under different scenarios, those aspects of the effects that are common for both events could be investigated. The simulations could result in a framework of robust operational design that would help the appropriate authorities to develop contingency plans for extreme situations.

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