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The Influence of Road Congestion on Urban Mobility

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Abstract

Urban mobility is defined by all the travel possibilities within a city and their spatial arrangement. In recent times, the world's major cities are changing their infrastructure to accommodate alternative and public transport modes and are also developing car-free policies as they increase mobility and pursue a sustainable future. Congestion in road traffic is defined as the phenomenon of the reduction of vehicle flow speed to the point of zero due to so-called sensitive areas on the road. This scientific paper has been developed by the authors in a logical and elegant manner, which deals with the influence of road vehicle traffic congestion on urban mobility in cities in the European Union. In this way, those interested can get acquainted with the main factors and conditions favoring the occurrence of road traffic congestion, the deterioration of urban mobility due to road traffic congestion in the European Union and the queues of road vehicles (moving or stationary columns at intersections, pedestrian crossings, railway level crossings, accidents or road events, etc.). The scientific paper also deals with two case studies on waiting wires. At the end the conclusions related to this research area are drawn and some recommendations are made by the authors regarding the field. The paper also contains an annex in which the 30-minute accessibility by car during peak hours in 2012 and 2019 in other EU cities is presented.

Keywords: Road Vehicle, Congestion, Accident, Black Spot, Urban Mobility, Waiting Threads, Graphical Method

1. Introducere

Managing urban mobility is a major challenge for Europe's metropolitan area. In addition to unavoidable financial constraints, planners and policy-makers are faced with numerous, often competing, demands: Maintaining a high quality of life while creating an attractive environment for business; and restricting traffic in sensitive areas without restricting the necessary movement of goods and people [1]. Sustainable urban mobility is one of the main challenges facing EU cities and is a matter of concern for many EU citizens. There are strong links between increased sustainable urban mobility on the one hand and economic growth and reduced environmental pollution on the other. Urban mobility is an issue that affects many EU citizens, who are sensitive to the time they spend traveling and the money they spend on transport. The EU is investing significant sums to help cities improve their mobility and make it more sustainable. Member States and cities need to use the funds more effectively and efficiently to respond to the challenges involved, in particular in the context of the *"Green Deal"* communication. Urban mobility faces many challenges, of which traffic congestion is one of the most difficult. Congestion in road traffic is defined as the phenomenon of the reduction of vehicle flow speed to the point of zero due to so-called sensitive areas on the road. Numerous economic studies show that the cost of congestion to society is high (estimated at €270 billion per year in the EU) [2] and the smoother the traffic in an urban area, the more likely it is that the area's economy will grow. One study has shown that switching to free-flowing traffic could increase worker productivity by up to 30% in regions where traffic is very congested [3]. Many European cities are affected by the impressive number of cars over 15 years old (especially Eastern European cars), forming huge queues at pedestrian crossings, traffic lights at busy intersections and generating toxic, greenhouse gases that affect air quality by regularly exceeding the limit values for the protection of human health set in the Ambient Air Quality Directive [4]. Up to 96% of EU citizens living in urban areas are exposed to levels of air pollutants considered by the World Health Organization (WHO) to be harmful to health. As road traffic congestion in the EU is often found in and around urban areas, this problem affects the majority of EU residents. In 2013, the European Commission estimated that the total health costs of air pollution amount to several hundred billion euros per year. Pollution also has a negative impact on biodiversity. Recent studies also point to lack of physical movement as a serious negative side-effect of driving. In 2018, the EU set current targets to reduce the number of deaths and serious injuries caused by road crashes by half by 2030 compared to 2019 levels, and to almost zero by 2050 [5, p. 5]. However, experience shows that an increase in road capacity in urban areas results in higher levels of traffic and therefore traffic congestion, so other approaches need to be used to find a solution [6, pp. 4-8].

1. Main factors and conditions favoring road traffic congestion

1.1 Road accidents

According to data made available by accidentology specialists, a road accident is an event caused by a violation of traffic rules, involving one or more vehicles on a public road, resulting in damage to health, bodily integrity or even death of one or more passengers, or various material damage.

Road accidents are classified as follows:

- ***Minor accidents*** - are those which result in injury to one or more persons, resulting in individual incapacity for work for up to 30 days or property damage - up to 60% of the value of the automobile;
- ***Serious accidents*** - are those that have one or more of the following consequences:
    - persons who have been fatally injured
    - persons permanently disabilities;
    - an injury to one or more persons resulting in an individual incapacity for work of more than 30 days;
    - property damage exceeding 60% of the value of the vehicle.

Therefore, the following aspects will be taken into account when determining the material damage in order to classify the road accident:

- the value of vehicles that have been destroyed in an accident or the repair of damaged vehicles;
- the value of other goods or merchandise transported, damaged or destroyed.

✓ *Accident involving cars and pedestrians:*

- hitting pedestrians traveling on either the left or right side of the road;
- hitting pedestrians who were on areas designated for pedestrian traffic, e.g. sidewalks;
- hitting pedestrians who were irregularly crossing the road or stationed on the carriageway.

- ***Single vehicle accidents:***
    - an inversion;
    - a collision with an obstacle on or off the road;
    - a collision with an obstacle as a result of skidding;
    - hitting a cyclist or an animal;
    - an accident that occurred when getting in or out of a moving car.
- *Multi-vehicle road accidents:*
    - a collision - front to back;
    - ciocnirea cu a collision with a parked vehicle;
    - a parked vehicle;
    - a head-on collision - driving in opposite directions;
    - a side collision;
    - a tangential collision - as a result of not keeping the lateral distance;
    - o collisions in the column of vehicles.

1.2 Black spots in road traffic. How they are standardized

The determination of black spots will be done using the Kernel Density method applied with GIS technology [7], taking into account one or more attributes of the accidents recorded. The historical time period considered is 5 years [8].

GIS (Geographic Information System) is the framework for collecting, managing and analyzing data. Rooted in the science of geography, GIS integrates many types of data. It analyses spatial locations and organizes layers of information into visualizations using maps and 3D scenes. With this unique capability, GIS reveals a deeper understanding of data such as patterns, relationships and situations - helping users make smarter decisions. Hundreds of thousands of organizations in nearly every field are using GIS to create maps that communicate, perform analysis, distribute information, and solve complex problems that arise in the world. This is changing the way the world works [7].

GIS technology applies the science of geography using tools for understanding and collaboration. It helps people achieve a common goal: Gain actionable intelligence from all kinds of data. Apps provide user-driven experiences to get work done and bring GIS to life for everyone. GIS apps work anywhere: On cell phones, tablets, web browsers, and desktops.

One or more attributes/criteria of the crashes recorded in the EAC (Evidence of Road Traffic Accidents) database will be used to standardize the black spot calculation results, as follows: county/UAT/country; environment of occurrence; road category; road name; road condition; road condition; road lighting; weather conditions at the time of the crash; cause of occurrence; mode of occurrence; number of vehicles involved; consequences of casualties.

According to other authors, a "black spot" on a road map is a road segment or an intersection where accidents occur more frequently than the national or regional average. Essentially, these locations are considered dangerous because of their specific characteristics: Poor visibility, dangerous curves, inadequately signalized intersections, lack of safety infrastructure or heavy traffic [9].

According to general definitions, a black spot is a place where at least 5 serious accidents have occurred within 3 consecutive years, but the exact criteria may vary according to the legislation of each country.

Black spots can result from a combination of factors, including [9]:

1. ***Road design problems:*** Inadequately designed road infrastructure, either due to old standards or lack of funds for modernization, can lead to dangerous spots. For example, tight bends without an extra safety lane or inadequately marked intersections can increase the risk of accidents;
2. ***Traffic conditions:*** Areas where traffic volumes have increased significantly in recent years can become black spots if infrastructure has not been adapted. In addition, frequent congestion and drivers' behavior (excessive

speed or disregard of traffic rules) contribute to an increased risk of accidents;

3. ***Weather and visibility conditions:*** Adverse conditions, such as fog, rain or snow, can amplify dangers in certain road areas, particularly where there is a lack of adequate signage or where roads are not well maintained;
4. ***Lack of road safety features:*** Sometimes the lack of crash barriers, well marked pedestrian crossings or sufficient lighting at night can turn an otherwise ordinary area into a black spot.

To identify and monitor black spots authorities use statistical data and advanced technology to identify them. Among the most important sources of data are: Accidentology data to analyze the frequency and severity of accidents in a given area; traffic studies to monitor traffic and driver behavior under different conditions, including average speed and vehicle flow; GPS and camera analysis as modern technologies that allow real-time traffic monitoring and data collection on road conditions.

In some countries, authorities have also started to use artificial intelligence to predict potential black spots by analyzing traffic patterns and weather conditions.

Identifying black spots is only the first step in improving road safety. Once identified, it is essential to implement measures to reduce the risk of accidents. Among the most effective solutions and measures are [9]:

1. ***Redesigning infrastructure*** by upgrading dangerous roads, intersections and curves can significantly reduce the number of accidents. This can include widening roads, installing crash barriers or introducing deceleration lanes before dangerous areas;
2. ***Improving road*** signage by installing more visible road signs, additional traffic lights or signs warning of hazards can help drivers to be more careful;
3. ***Introducing intelligent traffic systems*** through modern technologies, such as automatic speed detection or weather warning systems, can reduce the risk in dangerous areas;
4. ***Driver education and awareness*** through campaigns to inform and educate drivers about safe behavior on the road can have a significant impact on reducing the number of accidents, especially in areas known as black spots;

Fig 1: Marking the ”black spot” area with a panel [18]

Fig 2: Marking the ”black spot” area with a road sign [12]

Improving public street lighting by properly illuminating intersections and roads with visibility problems can make a huge difference, especially at night.

On the roads of European countries, black spots are marked by signs (Fig 1) and warning road signs (Fig 2), mounted on the right/left side of the road vehicles (depending on the traffic situation in each country).

To reduce deaths and serious injuries, EU Member States can take action in the design and maintenance of their road networks. Investments should be targeted on the road sections where most accidents occur and where there is the greatest potential to reduce accidents [10] (so-called black spots/hotspots) [5, p. 37].

In EU countries, in addition to standard police procedures, road traffic legislation (e.g. Lithuania) provides for a thorough investigation to understand the cause of each fatal accident. Road sections with an incidence of four or more road crashes in the last four years are labeled as "black spots" and identified on a publicly accessible map with recommendations for drivers. In addition, each of these black spots is analyzed in order to identify the measures needed to improve road safety performance. The road operator then has one year to implement these road safety measures. The objective of Lithuania's road safety strategy is to eliminate any black spots by 2030. In Spain, two criteria are used to identify road sections with a relatively higher accident risk. The first is the dangerousness of the road section (based on the number of accidents in the past, the length of the stretch of road concerned and the average traffic volume at different times). The second criterion is the number of accidents in absolute values. Both parameters are assessed against different thresholds which are defined according to the category of road and traffic volume [5, p. 38].

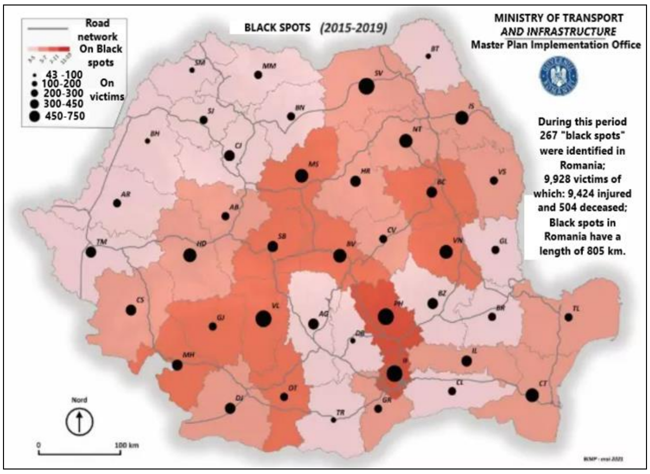

Fig 3: Black spots on Romania's roads between 2015-2019 [19]

In Slovakia, "black spots" are defined as one-kilometer stretches with five or more road accidents recorded in the previous year [5, p. 38].

In 2008, Romania defined a "black spot"/hotspot as a road segment with a higher road accident rate than the average accident rate recorded on that road. This definition was repealed in 2018 and at the time of the audit no other definition had yet been developed. Since then, Romania has launched a project funded by the Recovery and Resilience Mechanism to address the problem of hotspots, using an ad-hoc definition to identify them [5, p. 38]. In Romania, the red triangle with the black dot was introduced in the Highway Code in December 2012 [11], The road indicator is placed in areas considered at risk, i.e. places where there are frequent accidents, some of them very serious, with victims. In Bucharest, the Romanian capital, for example, there were at least 33 such areas this year. For example, such a road sign warning drivers that there is an increased risk of accidents has also been placed at the intersection of Dacia Boulevard and Polonă Street. In the first 7 months of this year, there were 16 accidents here, resulting in 27 fatalities [12].

Teo Peter, bassist of the Romanian classic rock band Compact, also lost his life here. Drivers say vegetation here covers road signs and buildings built very close to the intersection reduce the field of vision.

What is certain is that, in an area signposted by road signs or signposts warning drivers that they are following an area of road where there is a major risk of accident, all drivers must reduce speed and drive carefully to avoid any danger. Slowing down vehicles in these areas, at rush hour or in extremely busy traffic creates major traffic jams.

On March 7, 2013 there were 138 black spots [11] on all roads in Romania, and on March 19, 2024 there were 267 black spots on national roads alone in Romania [13]. They have increased instead of decreased. The increase is due to a large number of vehicles in the fleet, its ageing, but also to the indiscipline of drivers and pedestrians in traffic. In Fig 3 we present a map of the existing black spots in Romania between 2015-2019.

1.3 Signalized and unsignalized intersections in major European metropolitan areas

Intersection of roads or streets may be defined as any junction, junction or bifurcation of roads, including the spaces formed by them.

Traffic jams at undirected or directed intersections can occur as a result of factors disrupting the normal flow of vehicles. These disruptive factors include: change of speed; change of direction of travel; loss of right of way through an intersection; obstacles on the roadway (vehicles, pedestrians, goods or goods falling from other vehicles, etc.) which would imply an imminent collision, stopping at red traffic lights, stop or yield sign, when other vehicles with right of way are on the cross road, etc.

All these contribute to the creation of queues of queues of queuing or waiting vehicles, and the main causes of traffic jams at controlled or uncontrolled intersections according to the Road Traffic Regulations, articles 129 - 135, which we present below [14]:

- ✓ Changing the direction of going to the left, in the case of vehicles entering an intersection traveling on the same road in alignment, but from opposite directions, is done through the left of the center of the intersection, without crossing their paths, and when approaching an intersection the driver of the vehicle must travel at a speed that allows him to stop, to give right of way to traffic participants who have this right;
- ✓ At ***uncontrolled intersections***, the driver of the vehicle is obliged to give way to vehicles coming from the right, under the conditions laid down in the regulations. At intersections, drivers of left-turning vehicles are obliged to give the right of way to vehicles coming from the right-hand side;
- ✓ Only special vehicles (police, rescue, fire brigade) have priority when they are on emergency or emergency missions. In order to have the right of way, these vehicles must have their lights and audible signals in operation and other vehicles will stop and give the right of way regardless of whether they are on a road with priority. To this end, the drivers of other vehicles are obliged to stop immediately, on the pavement or, failing this, as close as possible to the edge of the road or kerb, in the direction of travel, when approaching and passing vehicles with priority traffic rights which have special red warning lights and audible warning devices in operation. Drivers are also obliged to reduce speed, to drive as close as possible to the edge of the road in the direction of travel and to give right of way to priority vehicles with special blue warning lights and audible warning devices;
- ✓ At uncontrolled intersections, the driver is obliged to give right of way to vehicles running on metal rails (trams). They lose the right of way when turning left or when the road signs in the area in question indicate a different traffic rule;
- ✓ ***Traffic controlled intersections*** are divided into: intersections controlled by traffic officers (police officers); intersections controlled by traffic signals (electric traffic lights); intersections controlled by priority signs (this category also includes roundabouts). At traffic signal-controlled intersections, left-turning vehicles give right of way to oncoming vehicles;
- ✓ In intersections with traffic controlled by priority indicators the right priority rule is observed only if two vehicles are to meet, each entering the intersection from a road signalized with an indicator having the same meaning of priority or loss of priority;
- ✓ When approaching a station for public passenger transport vehicles equipped with a bus shelter, from which the driver of such a vehicle signals his intention to exit, the driver of the vehicle in the lane next to the verge or kerb shall be obliged to reduce speed and, if necessary, stop to allow it to re-enter the traffic.
- ✓ Drivers of vehicles are obliged to give right of way to pedestrians on the roadway in order to board the tram or after alighting from the tram, if the tram is stopped at a station without a refuge.
- ✓ The driver of a vehicle whose forward motion is impeded by an obstacle or the presence of other road users which makes it necessary to change into the oncoming lane must reduce speed and, if necessary, stop to allow oncoming vehicles to pass;
- ✓ In the case referred to in Article 51, paragraph 2, drivers of vehicles are obliged to give the right of way to road users with whom they are passing and who are driving according to the meaning of the traffic light signal signal signaling the traffic light to which they are facing;

- ✓ When exiting residential or pedestrian zones, drivers are required to give right of way to all vehicles with which they pass;

The driver of a vehicle is also obliged to give right of way in the following situations:

(a). At an undirected intersection when entering a national road coming from a county, municipal or local road;
(b). At an undirected intersection when entering a county road coming from a communal or local road;
(c). At the undirected intersection when entering a communal road from a local road;
(d). When about to enter a roundabout intersection from one traveling in a roundabout;
(e). When moving downhill in relation to the driver who is climbing, if there is an immovable obstacle in the direction of travel of the driver who is climbing. In this case the maneuver shall not be considered overtaking for the purposes of Article 120(j);
(f). When starting to move or when entering the public road coming from a property adjoining the public road in front of the vehicle traveling on the public road, regardless of the direction of travel;
(g). When making a left or right turn and passing a cyclist riding on a marked cycle path;
(h). A pedestrian crossing the public road in a specially designed, marked and signposted place or at the green traffic light signal at the pedestrian crossing point, when the pedestrian is in the direction of travel of the vehicle.

1.4 Pedestrian crossings

According to the Romanian Road Traffic Code, the driver of a vehicle is obliged to give right of way and come to a complete stop in front of a marked pedestrian crossing when there are pedestrians who wish to cross or are already on the crossing.

As road users, pedestrians have the right of way as a result of crossing through properly signalized areas at the green pedestrian traffic light. In other words, as the driver of a road vehicle, you are obliged to give the right of way to all road users (pedestrians) perpendicular to the axis of the vehicle in places where pedestrians are allowed to cross.

In the countries of the European Union as well as in Romania, a country that has joined the European Union and has fully adapted its road legislation, according to Emergency Ordinance No 195 of December 12, 2002 republished, on traffic on public roads, Article 123 stipulates [14]:

- ✓ The driver of a vehicle is obliged to drive at a speed not exceeding 30 km/h in built-up areas or 50 km/h outside built-up areas in the following situations:

a) When passing through intersections with uncontrolled traffic;
b) On particularly dangerous bends marked as such or where visibility is less than 50 m;
c) When passing organized groups, military columns or corteges, whether they are moving or stationary on the carriageway side of single-lane roads in each direction;
d) When passing animals which are being driven on the carriageway or on the verge;
e) When the carriageway is covered with ice, ice, snow, slush, slush or wet cubic stone;
f) On uneven roads, marked as such;
g) In the area of operation of the "Children" warning sign between the hours of 7:00 a.m. and 10:00 p.m. and of the "Accident" sign;
h) At unmarked pedestrian crossings, signalled by signs and markings, when the public road has not more than one lane in each direction and pedestrians on the pavement in the immediate vicinity of the roadway intend to cross
i) When changing direction through bends;
j) When visibility is less than 100 m in fog, torrential rain, abundant snow.

- ✓ Article 135 of the same Regulation stipulates [14]:

The vehicle driver is also obliged to give right of way in the following situations:

a) At an undirected intersection when entering a national road from a county, municipal or local road;
b) At an undirected intersection when entering a county road coming from a communal or local road;
c) At the undirected intersection when entering a communal road from a local road;
d) When about to enter a roundabout intersection from one traveling in a roundabout;
e) When moving downhill in relation to the driver who is climbing, if there is an immovable obstacle in the direction of travel of the driver who is climbing. In this case the manoeuvre shall not be considered overtaking for the purposes of Article 120(j);
f) When starting to move or when entering the public road coming from a property adjoining the public road in front of the vehicle traveling on the public road, regardless of the direction of travel;
g) When making a left or right turn and passing a cyclist on a marked cycle path;
h) A pedestrian crossing the public road in a specially designed, marked and signposted place or at the green traffic light signal at the pedestrian crossing point, when the pedestrian is in the direction of travel of the vehicle.

Special attention should be paid to pedestrian crossings at the corner of intersections. Here que que queues are combined with the situations imposed on drivers by regulation, with the situations described above for road or street intersections, whether directed or undirected. Also, large queues of queuing or waiting vehicles form for road vehicles at pedestrian crossings crossing major boulevards in urban areas at rush hours, and this aspect becomes even more dangerous on European national roads crossing towns (a specific aspect in Eastern European countries), where pedestrian crossings are located across these categories of roads. In these areas, the danger of a road accident is imminent, as many drivers do not observe the legal speed limit in the localities where such marked and signposted pedestrian crossings are located.

The aspects outlined above require braking of vehicles in traffic, slowing down and stopping as appropriate. These aspects imply que queuing while moving or stationary, which are factors and conditions conducive to congestion.

1.5 Rail level crossings

The railroad crossing is where the public road crosses the railroad. The approach to a railway level crossing shall be signaled with appropriate warning signs and/or additional railway level crossing signs (art. 68 of the Regulation).

According to Article 136 of the Regulation drivers are obliged to [14]:

(1) At the level crossing with the current railroad, the driver of the vehicle is obliged to drive at reduced speed and to make sure that a railway vehicle is not approaching from the left or from the right.
(2) When crossing the railroad, pedestrians are obliged to make sure that a railway vehicle is not approaching from the left or right.

Article 137 of the Regulation provides [14]:

(1) The driver of a vehicle may cross the current railway track with barriers or half-barriers if the barriers or half-barriers are raised and the light and sound signals are not in operation and the slow flashing white light signal is in operation.
(2) When traffic at a level crossing with the current railroad is directed by railway employees, the driver of the vehicle shall obey their signals.

Article 138 of the Regulation provides [14]:

(1) The driver of a vehicle is obliged to stop when:

(a). The barriers or semi-barriers are lowered, being lowered or raised;
(b). The red light signal and/or audible signal are in operation;
(c). It meets the indication 'Level crossing with single track without barriers', 'Level crossing with double track without barriers' or 'Stop'.

(2) Vehicles must stop, in the order of arrival, where there is maximum visibility of the track without passing the signs referred to in paragraph. (1) (c) or, as the case may be, before the stop marker or before the barriers or half-barriers when they are closed, being lowered or raised**.**

The aspects presented above require braking of vehicles in traffic, slowing down and stopping as appropriate. These aspects imply que queuing while moving or stationary, which are factors and conditions conducive to congestion.

2. Deteriorating urban mobility due to road congestion in the European Union

In the absence of a significant shift to other forms of transportation, increasing congestion is an indication that urban mobility is deteriorating for traffic participants. Congestion is both a physical phenomenon related to how vehicles are prevented from moving forward by other vehicles as the demand for road space - which is limited - approaches maximum capacity, and a relative phenomenon related to user expectations of road system performance [15].

The most common indicator of traffic congestion is based on the difference between the average speed under free-flow conditions (usually calculated from data recorded at night) and under observed conditions at different times of the day, converted into an increase (absolute or percentage) in average travel time.

According to data provided by TomTom [16], a provider of road traffic data, between 2013 and 2018, congestion from road vehicle traffic worsened in 25 out of 37 urban nodes for which data was available for this period [6, p. 117].

This trend was observed in all the cities in Europe that Eurostat specialists visited. Eurostat is the statistical office of the European Union. It is the main source of comparable data at the European Union (EU) level. Its main responsibilities are to provide statistical information to the EU institutions and to promote the harmonization of statistical methods in the Member States and the accession and candidate countries, as well as in the EFTA (European Free Trade Association) countries. The organizations in the different countries that cooperate with Eurostat are summarized under the European concept, as the European Court of Auditors.

The map in Fig 4 shows how, in Barcelona, the distance traveled in 30 minutes by car is less than in 2012.

Among the factors to be taken into account are cost and convenience for Europeans using road transport. From the analysis of the figures presented, in seven out of eight cities, it is more time-efficient to use private cars than public passenger transport.

This is also shown in Fig 5, which shows that it takes longer to get to Naples central station by public transport than by private car. Only for Madrid were parts of the city identified where access to Atocha station - one of the two main stations - was faster by public transport (Fig 6).

Quality public transport is essential for sustainable urban mobility, as it provides - together with 'active mobility' (transport based on human physical activity, such as walking and cycling) - an alternative to the use of private cars.

Quality public transport requires, among other things, easy access (a large part of the population should be within a short distance of a public transport infrastructure), frequency and speed, as well as a high degree of connectivity to the network. Cities were able to use EU funds to help expand their public transport networks by investing in metro and tram lines and rolling stock.

The levels in peripheral areas are lower, indicating that significant parts of the population are only to a small extent served by public transport. However, as these cities attract commuters from the surrounding areas, the choice between private car and public transport is based on the public transport on offer in the periphery and the ease of connections to the rest of the network, regardless of how good public transport is within the city.

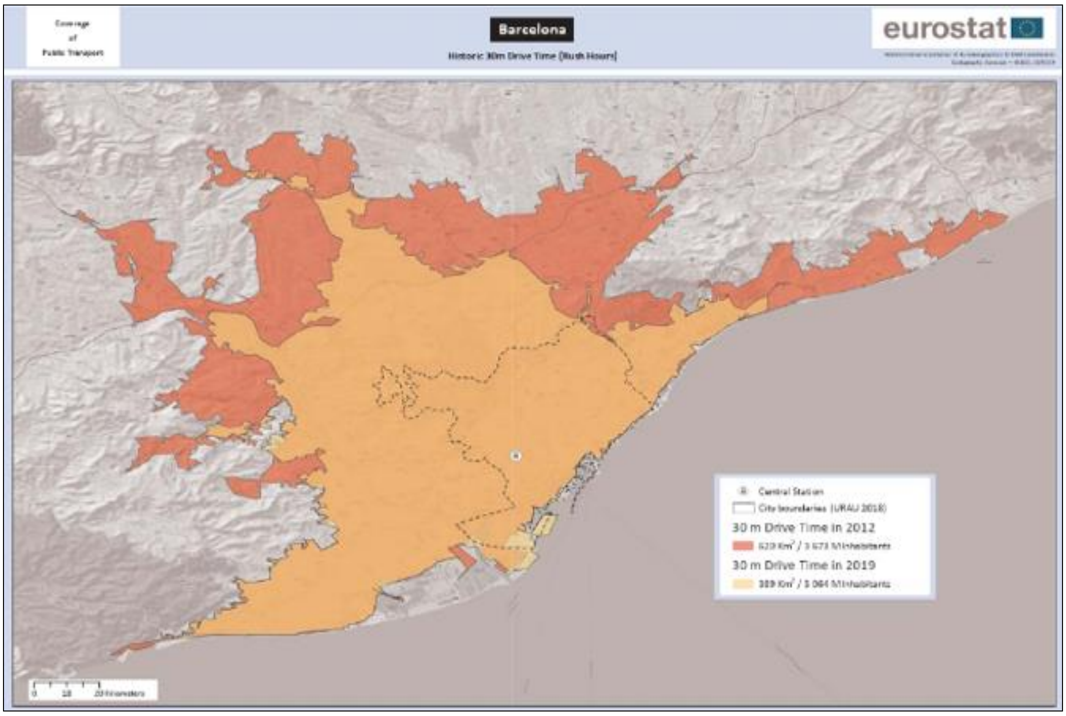

Fig 4: Accessibility within 30 minutes driving time during rush hours in 2012 and in 2019 – Barcelona [6, p. 17]

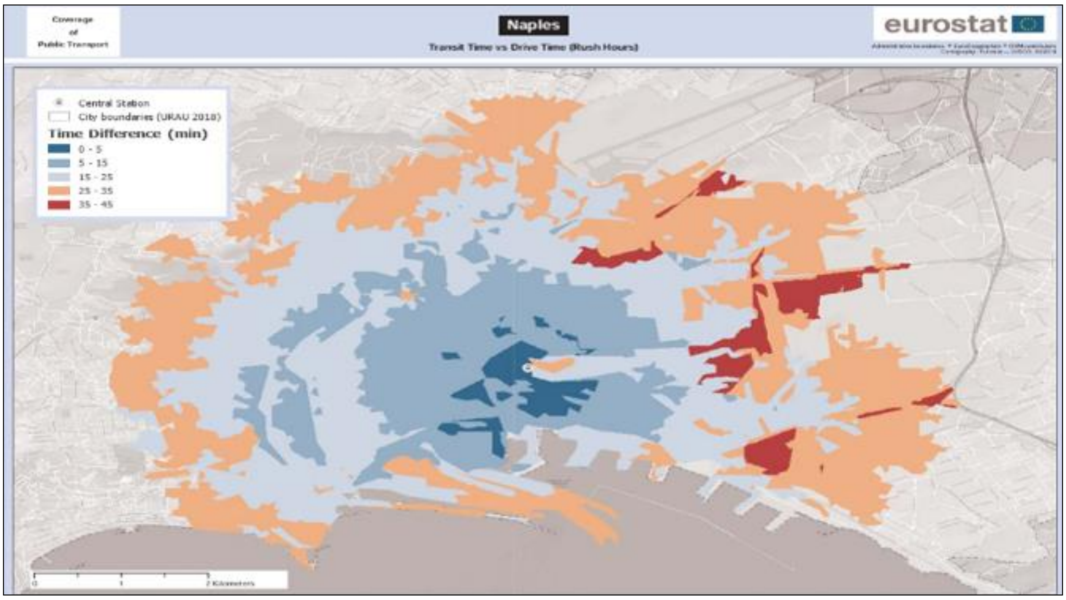

Fig 5: Comparative accessibility of Naples train station by car and by public transport [6, p. 18]

A 2019 report by the Organization for Economic Cooperation and Development (OECD) shows that the percentage of the population living near public transport facilities in some cities is very high. This is shown in Table 1.

Table 1: Public Transportation Coverage [6, p. 20]

Name of city	Inner city	Metropolitan area
Leipzig	99.9%	70.7%
Hamburg	99.9%	99.5%
Naples	53.5%	48.5%
Madrid	99.9%	96.7%
Warszaw	100.0%	84.8%
Average*	95.6%	87.9%

* The average covers the 81 cities that had General Transit Feed Specification (GTFS) [17] data, of the 121 cities covered by the International Transport Forum report.

The lower degree to which peripheral "commuter zones" are served by public transport, as well as the fact that most lines serving the periphery connect to the city center, while an increasing share of trips are between suburbs, contribute to the higher modal share of private vehicles in these areas than in the inner city (Fig 4) [6, p. 20].

The levels in outlying areas are lower - see the example of Palermo in Fig 7, which shows that significant parts of the population are only to a small extent served by public transport.

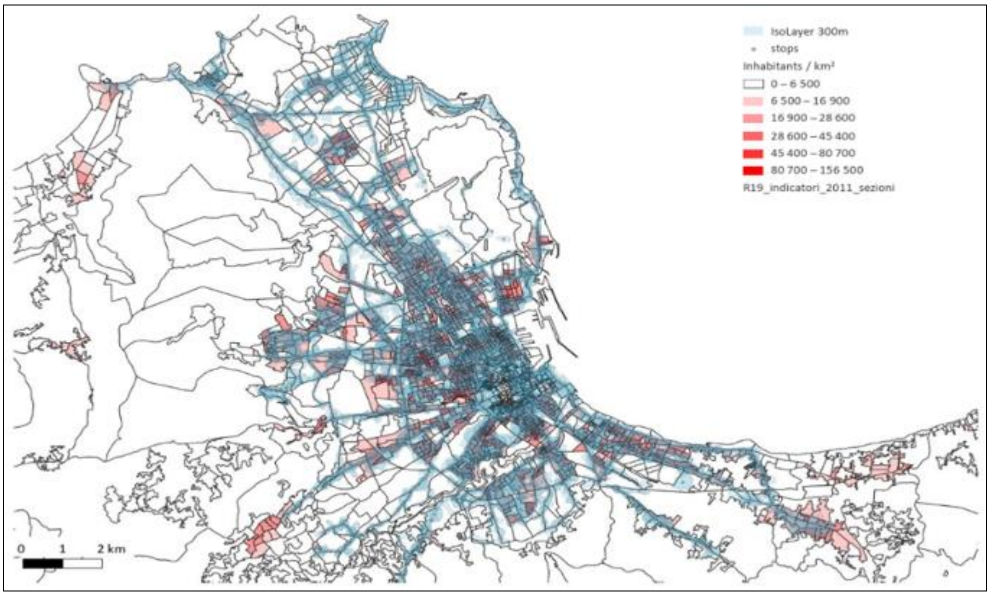

Fig 7: Population density and public transport coverage in Palermo [6, p. 20]

Similar maps for the specific situations of the other cities visited by Eurostat specialists are presented in Annex 1 of this paper.

3. Waiting wires of road vehicles. Case studies

Disturbances can occur in the flow of road vehicles in a given lane at a given time, which can affect the flow of vehicles on different parts of the streets. In urban traffic, such phenomena may occur in the following situations:

- ✓ in the area of intersections, or at pedestrian crossings in the areas between intersections. In these situations, queues or queues of waiting vehicles form in the traffic lane if the flow of arriving vehicles is greater than the through-flow through the area;

in the event of a road traffic event road traffic is stopped and then hindered for a period of time in the area of a road accident.

In these situations, traffic jams with stationary or slow-moving vehicles form in the traffic lane.

These situations cause drivers to lose a lot of time and feel uncomfortable and nervous.

In order to study the appearance, development and disappearance of waiting wires, it is necessary to be able to mathematically model the arrival and departure laws in the area in question.

The mathematical modeling of the waiting wires will take into account the number of arriving road vehicles and the time interval between them, the number of departing road vehicles and the time interval between them. Another important factor in the mathematical modeling of the queueing thread is the mutual respect of the drivers, defined by the *"first come, first gone"* principle.

By mathematical modeling of a queue one can determine the time wasted by parking in the queue, the number of parked vehicles, the start and stop time of the waiting thread.

For a proper modeling of the queue line it is necessary to know the frequency of arrivals and departures, the number of arrival and departure lanes in the queue line area, the respect of the place of each vehicle in the waiting thread.

The following assumptions can be made regarding arrival hypotheses:

1. Equal time intervals between two successive arrivals, thus having a regular distribution of road vehicles over time;
2. Time intervals distributed according to a Poisson distribution, thus having an exponential distribution of vehicles over time.

One or more lanes shall be considered for the number of lanes. The number of lanes in and out is the same.

In mathematical modeling it is assumed that the *"first come, first gone"* principle is respected.

To better understand how the caculus works, here is **an example**:

Consider the case of waiting thread formation for a traffic lane at which the arrival and departure law of road vehicles is with a regular distribution.

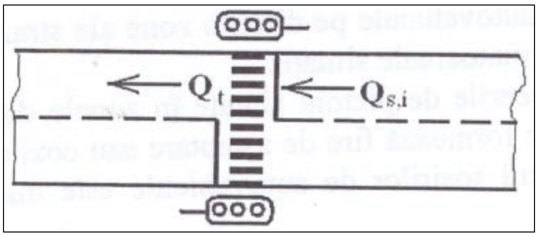

Fig 8: Flow of road vehicles at pedestrian crossings

Consider a section of road with a pedestrian crossing with traffic lights (Fig 8). at the pedestrian crossing the flow of vehicles in one lane has the value Q_t. The flow rate of road vehicles arriving at the pedestrian crossing shall have the value $Q_{s,i}$.

Waiting thread starts when the number of arriving road vehicles is greater than the number of vehicles passing through the pedestrian crossing zone ($Q_{s,i} > Q_t$).

As an example, consider that the green time of the traffic signal cycle allows a throughput of Qt = 380 [vehicles/hour] for the whole hourly interval considered.

The arrival of vehicles at the pedestrian crossing is in accordance with the data shown in Table 2.

Table 2: Vehicle arrival at the pedestrian crossing

Time interval	Number of road vehicles arriving at pedestrian crossings		Number of road vehicles crossing pedestrian crossings	
	[vehicles/hour]	[vehicles/minute]	[vehicles/hour]	[vehicles/minute]
6:30 - 7:00	360	6,00	380	6,33
7:00 – 7:30	400	6,66	380	6,33
7:30 – 8:15	420	7,00	380	6,33
8:15 – 9:30	300	5,00	380	6,33

The graphical method is used to solve the case. A system of axes is chosen in which the time is measured in minutes on the ***x*** axis (and additionally in hours) and the total number of vehicles that have arrived at and left the pedestrian crossing zone is measured on the ***y*** axis.
The dimensional scale chosen is:
- ✓ for time: 1mm = 1 minute;
- ✓ for the number of road vehicles: 1mm = 20 vehicles.

The waiting thread graph is shown in Fig 9.
From the graph shown in Fig 9 the following can be determined:
- ✓ The moment when the queue starts to form. Corresponds to point A (6:15), when the flow of vehicles arriving at the pedestrian crossing area is greater than the flow of vehicles leaving the area;
- ✓ The time at which the queue ends. Corresponds to point B, where the total number of vehicles leaving the pedestrian crossing area is equal to the total number of vehicles arriving at the pedestrian crossing area (121.14 minutes = 2 hours and 14 minutes at 8:01 a.m.);
- ✓ The maximum waiting thread length is determined by the length of the CD segment. For the example in Fig 9 the maximum waiting thread length is (length of CD segment in mm/scar used for the Oy axis results in 112.5 vehicles);
- ✓ The time interval during which the waiting thread was present: 121.14 - 15.00 = 106.14 ≈ 1 hour and 46 minutes;
- ✓ The time at which the length of the waiting thread line is at its maximum corresponds to the abscissa of points C and D. From the diagram, t = 60 minutes (this corresponds to 7:00 p.m.);
- ✓ Surface area ACB is the number of *road vehicles x minutes involved* in the waiting thread line, which is determined by the mathematical relationship:

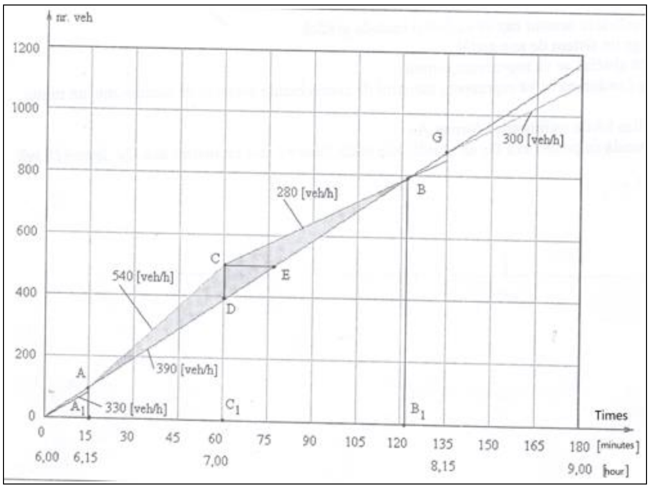

Fig 9: The waiting thread graph

$$S_{ABC} = S_{AA1CC1} + S_{CC1BB1} - S_{AA1BB1} \quad (1)$$

Where,

$$SAA1CC1 = \frac{[(AA1+CC1) * sacale\ axis\ Oy] * [A1C1 * scale\ axis\ Ox]}{2} \quad (2)$$

Similarly, determine the values of the surface areas S_{CC1BB1} și S_{AA1BB1}
The resulting value is S_{AA1CC1} *= 5,983 vehicles/minute.*
- ✓ average waiting time for a vehicle is determined with the mathematical relationship:

$$tm,a = \frac{SAA1CC1}{[(BB1-AA1)*sacara\ axei\ Oy]} \quad (3)$$

The resulting value is: $t_{m,\,a}$ *= 8,67 minutes.*
- ✓ the average number of road vehicles in the queue is determined with the mathematical relationship:

$$Nrm\ veh = \frac{SAA1CC1}{[(A1B1)*sacara\ axei\ Ox]} \quad (4)$$

The resulting value is: $Nr_{m,\,veh}$ *= 56.37 road vehicles.*

- ***Case study 1***

Graph the waiting thread in the following case:
Input data: The green time of the traffic light cycle allows vehicle traffic through pedestrian crossings of Q_L ***= 400 +12 * n [veh/h]*** for the all times 6:30 – 9:15 p.m.; ***n*** is any number and can have any value (in our case ***n = 18***). The arrival of road vehicles at pedestrian crossings is shown in Table 3.

Table 3: Arrival of road vehicles at pedestrian crossings

Time interval	Number of road vehicles arriving at pedestrian crossings
	[vehicles/hour]
6:30 - 7:00	380 + 20 * n
7:00 – 7:30	390 + 30 * n
7:30 – 8:15	410 + 35 * n
8:15 – 9:30	385 + 15 * n

It will be determined:
- ✓ Time of waiting thread formation;
- ✓ The end time of the waiting thread;
- ✓ The time interval during which the waiting thread exists;
- ✓ The maximum number of road vehicles that are involved at any one time in the waiting thread;
- ✓ The time at which there is a maximum number of vehicles in the waiting thread;
- ✓ Average waiting time for a road vehicle;
- ✓ Maximum waiting time for a road vehicle.

The graphical method will be used to solve this case.
A coordinate axis system will be chosen as follows:
- ✓ After the abscissa the time ***t*** will be presented;
- ✓ After the ordinate the number of arriving and departing vehicles (cars) in one minute.

A4 millimetric paper will be used.
It is recommended that for the axis ***Ox*** to use the scale ***2 mm = 1 minute***, and for the axis ***Oy 2mm = 10 vehicles (motor cars).***

Results
Calculating the scale: 165/250 = 0,6;
To fit the A4 format of millimetric paper we have: *1 mm = 1 minute*;

Table 4: Arrival of road vehicles at pedestrian crossings at hourly intervals

Intervalul orar	Număr de vehicule rutiere sosite în dreptul trecerii de pietoni [vehicule/oră]
6:30 - 7:00	374 = (320 + 3 * 18) * 30'
7:00 – 7:30	650 = (560 + 5 * 18) * 30'
7:30 – 8:15	590 = (500 + 5 * 18) * 45'
8:15 – 9:15	370 = (280 + 5 * 18) * 60'

Vehicles/hour = vehicles/60 = vehicles/minute = $\frac{400+4*32}{60} * 165$ = 1,452 vehicles (5)
We have: *Ox = 1mm = 1 minute; Oy = 1 mm = 10 vehicles*.

Qt = 400 + 4 * 18 = 472 vehicles (6)

$\frac{472}{60} * 165$ = 1,298 vehicles (7)

Table 5: Mathematical calculations on hourly intervals

Time interval	Calculate
6:30 - 7:00	320 + 3 * 18 = 374 veh/h; 374/60 = 6.23 veh/min; 6.23 * 30 = **187 vehicles**.
7:00 – 7:30	560 + 5 * 18 = 650 veh/h; 650/60 = 10.83 veh/min; 10.83 * 30 = **325 vehicles**.
7:30 – 8:15	500 + 5 * 18 = 590 veh/h; 590/60 = 9,83 veh/min; 9.83 * 45 = **442 vehicles**.
8:15 – 9:30	280 + 5 * 18 = 370 veh/h 370/60 = 6.16 veh/min; 6.16 * 60 = **370 vehicles.**

- ✓ The moment when the waiting thread starts to form: corresponds to the point **A** (7:15), (Fig 10), where the flow of road vehicles entering the pedestrian crossing zone is greater than the flow of road vehicles leaving the pedestrian crossing zone;
- ✓ The time at which the queue ends: corresponds to point **B**, at which the total number of road vehicles that have left the pedestrian crossing area is equal to the total number of road vehicles that have arrived at the pedestrian crossing area (9:10), (Fig 10);
- ✓ The maximum waiting thread length is determined by the segment length **CD** = 150 road vehicles (Fig 10);
- ✓ The time interval during which the waiting thread exists = 1 hour and 55 minutes (Fig 10);
- ✓ The maximum number of road vehicles that are involved at a given time in the waiting thread ≈ 519 vehicles, (Fig 10);
- ✓ The time at which the waiting thread length reaches its maximum value corresponds to the abscissa at points C and D, i.e. 8:15, (Fig 10);
- ✓ The time at which we have a maximum number of vehicles in the waiting thread = 8:15, (Fig 10);
- ✓ Average waiting time for a road vehicle is calculated according to the mathematical relationship (2), as follows:

$$SAA1CC1 = \frac{(34+97)*\ 10*(60*1)}{2} = 39.300 \text{ minutes} \quad (8)$$

Apply in the mathematical relationship (3) and we get:

$$tm, a = \frac{39.300}{(124-34)*10} = 6.13 \text{ vehicles/minute} \quad (9)$$

- ✓ After the abscissa the time will be presented ***t*** (Fig 10);
- ✓ Will show the number of vehicles (cars) arriving and departing in one minute (Fig 10);
- ✓ Maximum waiting time for a road vehicle = 12.62 minutes, (Fig 10);
- ✓ The graphical method will be used to solve this case (Fig 10);
- ✓ Choose a coordinate axis system as shown in Fig 10.

- ***Case study 2***

Knowing the method of calculation and the mathematical relationships that apply, give the following ***input data:*** $\boldsymbol{Q_t = 800 + 80 * n}$, (where, ***n*** can take any value, and in our case it is still 18), and in this case $\boldsymbol{Q_t = 800 + 80 * 18 = 2.240}$ ***vehicles/hour***, ***(***$\boldsymbol{Q_t = 2.240/60 = 37,33}$ ***vehicles/minute)***; at 12:00 there is a road accident and traffic is interrupted road traffic for $\boldsymbol{t_0 = 10 + 2 * 18 = 46}$ ***minutes***; the circulation of road vehicles is restarted under restrictive conditions, as follows: $\boldsymbol{Q_r = 180 + 15 * 18 = 450}$ ***vehicles/hour***, ***(***$\boldsymbol{Q_r = 450/60 = 7,5}$ ***vehicles/minute)***, for the time period $\boldsymbol{t_r = 30 + 3 * 18 = 84}$ ***minutes***, after which road traffic returns to normal; $\boldsymbol{Q_{sosiri\ (s)} = 300 + 3 * 18 = 354}$ ***vehicules/hour ⇒*** $\boldsymbol{Q_s = 354/60 = 5,9}$ ***vehicules/minute.***
Use A4 millimetre graph paper.
When plotting the graph on millimetric paper take:
- ✓ on axis ***Ox: 1 mm = 1 minute;***
- ✓ on axis ***Oy: 1 mm = 10 vehicles***.

Results
Average time is calculated with the mathematical relationship:

$$tmed = \frac{vehicles * minute}{Vehicle} = \frac{Sabcd}{VD*D1} \quad (10)$$

Apply the input data to the mathematical relationship (10) and we get;

$$tmed = \frac{13,000}{600} = 21.67 \text{ minutes} \quad (11)$$

$$Average\ number\ of\ vehicles = \frac{Vehicles * minute}{MinutE} = \frac{SABCD}{A*D1} \quad (12)$$

Replace the data in the mathematical relationship (12) and we get:

$$Average\ number\ of\ vehicles = \frac{13{,}000}{120} = 108.3\ vehicules \quad (13)$$

37.33 * 46 = 1,717 vehicles/minute.
t_{maxim} = 140 minutes.
Nr. vehicles = 1,000/60 = 16.66 vehicles/minute.

- ✓ The time at which the waiting buffer (dock) at point **D** = 140 minutes ends, (Fig 11);
- ✓ The total number of vehicles that arrived in the accident area, corresponding to the segment **DD1** = 1,000 vehicles and is equal to the number of vehicles that left the accident area = 16.66 vehicles/minute (Fig 11);
- ✓ Total time during which the traffic was interrupted and restricted, segment AD1 = 135 minutes ≈ (140 minutes), (Fig 11);
- ✓ The maximum number of vehicles that are at any given time in the traffic buffer (dock), segmental **FC** ≃ 290 vehicles occurs at t_{max} = 130 minutes after the accident, (Fig 11);
- ✓ Maximum waiting time in the EC segment waiting buffer (dock) = 46 minutes (130 minutes - 84 minutes = 46 minutes, (Fig 11);
- ✓ The number of *vehicles * minutes involved* in the waiting buffer (dock) is determined by the points **ABCD,** as follows:

$$SABCD = \frac{1{,}000 * 140}{2} - \frac{84 * 920}{2} = 70{,}000 - 38{,}640 - 9{,}600 =$$

21,760 vehicles x minute (14)

- ✓ We apply in the mathematical relationship (10) and we get:

$$tmed = \frac{21{,}700}{1{,}000} = 21.76\ minute \quad (15)$$

- ✓ Average number of vehicles in the waiting buffer (dock) = 21,760/140 = 155,42 vehicles;
- ✓ The graphical method will be used to solve this case (Fig 11);
- ✓ Choose a coordinate axis system as shown in Fig 11.

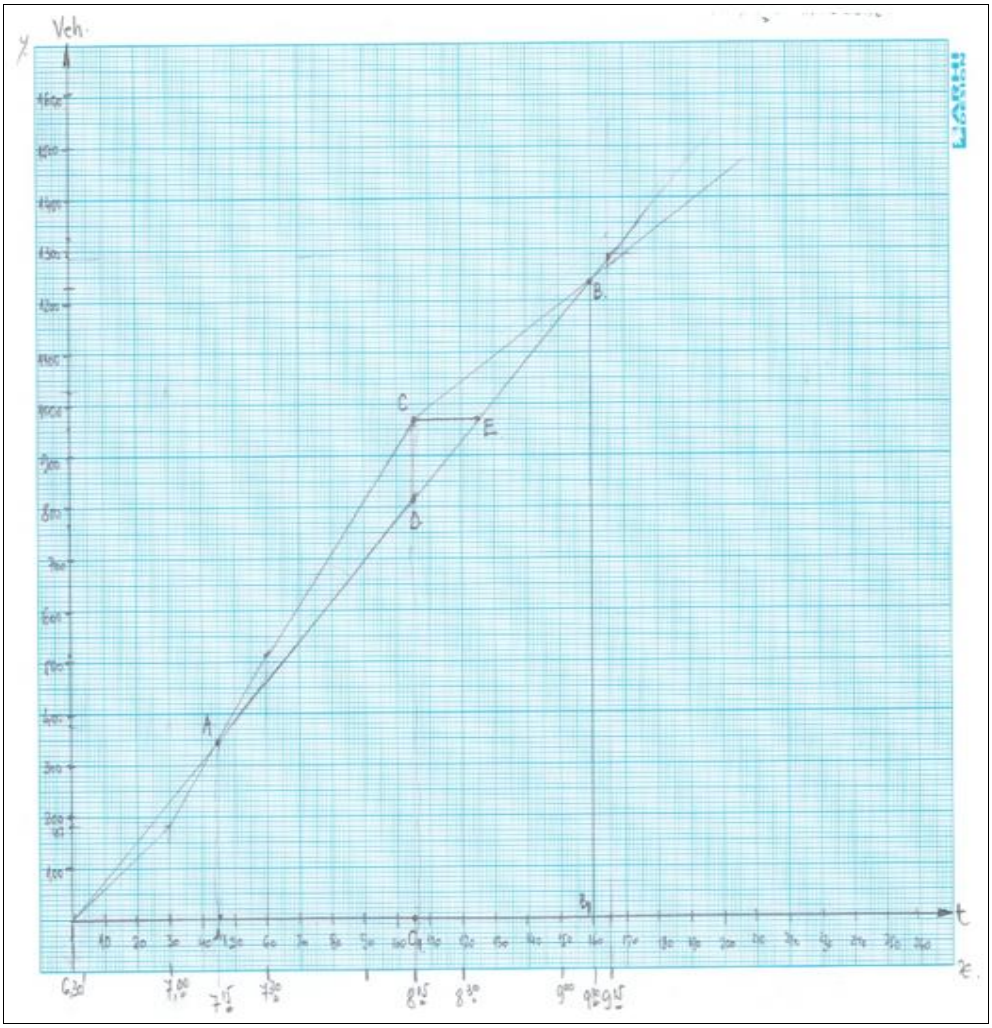

Fig 10: Graphical representation of the result of the obtained waiting thread

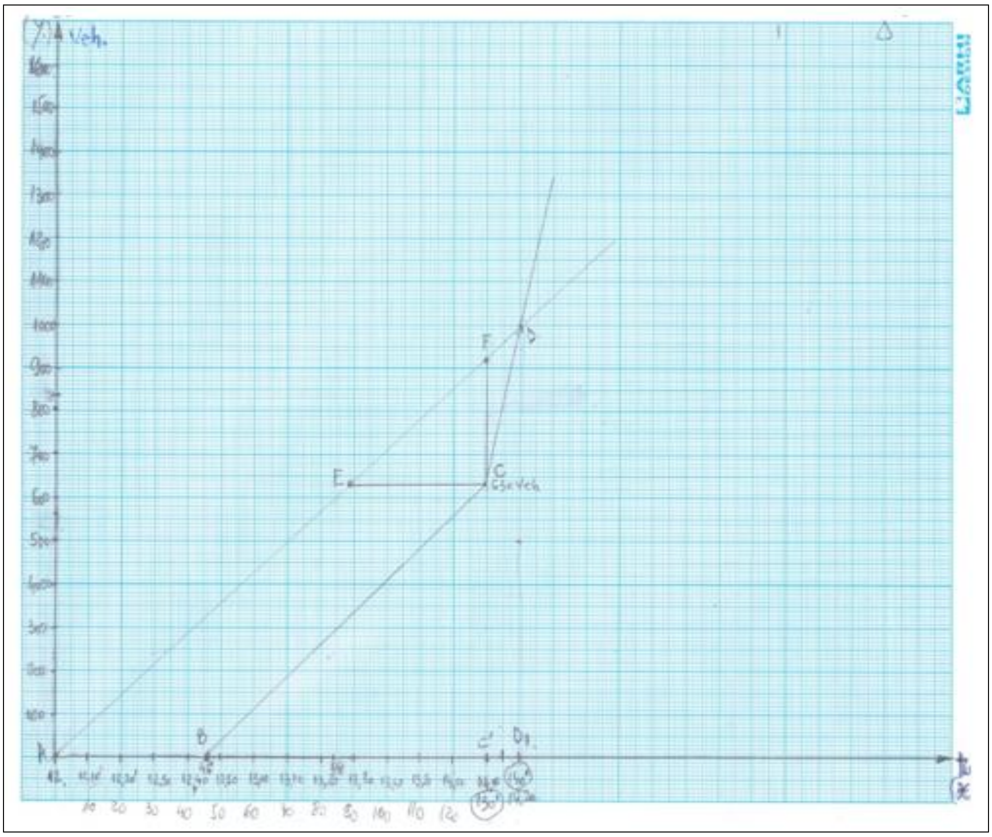

Fig 11: Graphical representation of the result of the obtained waiting thread

5. Conclusions and recommendations from the authors

Intersections congested areas, pedestrian crossings placed close to each other or at the corner of intersections (especially on major urban boulevards), road accidents, vehicle traffic in the area of black spots, railroad crossings and any congested area, obstacle or reason involving speed reduction creates waiting threads and congestion.

Black spots pose a continuous challenge to road safety. While identifying these locations is crucial, success lies in the rapid and effective implementation of prevention and improvement measures. Authorities, road engineers and communities need to work together to make roads safer, thereby reducing accidents and saving lives. In the long term, investments in infrastructure, technology and education can turn black spots into safe areas for all road users.

Most of the time, road accidents can occur due to: technical problems of the vehicle, difficult roads, bad weather conditions or errors made by road users.

Here are some safety measures that can help prevent road accidents:

- ***Respect traffic rules in bad weather conditions:*** In the cold season there are weather phenomena such as snow, sleet or rain, and these can affect traffic safety. Therefore, you will need to drive more cautiously, observing the speed limits, to avoid skidding off the road in unexpected situations;
- ***Respect traffic rules:*** Following traffic rules has been an effective measure to prevent accidents. So observing the speed limit, keeping an optimal distance from vehicles in front or following road signs will help prevent an unwanted accident;
- ***Check the technical condition of your car:*** Many accidents are caused by a technical fault in an automobile. It is therefore necessary to regularly check the condition of your car to avoid any unpleasant events.

Therefore, with increased attention in traffic and a proper check of the car, we will be able to circulate safely and avoid unpleasant events.

There is no clear trend towards more sustainable modes of transport. Although cities have put in place a number of initiatives to increase the supply and quality of public transport, overall, there has been no significant reduction in private car use. Some air quality indicators have improved slightly, but many cities still exceed EU minimum air quality standards. Greenhouse gas emissions from road transport continued to increase steadily. Travel time by public transport is often longer than travel time by private cars.

For urban mobility in the EU to become more sustainable, it is essential that the actions of all stakeholders are coherent. Since the presentation of its 2013 Urban Mobility Package, the European Commission has published a series of policy documents and guidelines and has increased funding for projects in this area. The Court recognizes that significant improvements in sustainable urban mobility need more time to materialize. However, six years after the Commission called for radical change, there are no clear indications that cities would fundamentally change.

Over the last decade, to help cities meet the challenges involved, the European Commission has published a series of policy documents accompanied by guidelines. In line with the principle of subsidiarity, Member States and their cities are not obliged to follow these guidelines and the extent to which they have been taken up has been limited - in particular, in relation to the development of Sustainable

Urban Mobility Plans (SUMPs). To support its policy objectives on sustainable mobility, the EU has made significant funding available. There is no EU-wide requirement to make access to funding conditional on the preparation of a UMEMP, although some Member States have imposed this condition at national level. In recent years, the Commission has increased the political pressure it can exert on sustainable urban mobility through the European Semester process. However, without a clear link between country-specific recommendations and Member States' use of EU funding, this pressure will be limited.

Some Member States and cities have made efforts to complement EU funding with adequate resources to ensure the proper operation and maintenance of their public transport networks; costs can also increase because lines are not always technically interoperable. In addition, several urban mobility practices at local level were not consistent with the objective of more sustainable urban mobility. The Court identified examples of positive initiatives targeting sustainable urban mobility; these generally required strong political leadership and considerable communication efforts to gain public acceptance.

The European Court of Auditors found that the EU-funded projects it analyzed were not as effective as expected due to weaknesses in their design and implementation. These projects were not always based on sound urban mobility strategies, which in many cases lacked adequate baseline data and analysis, relevant targets and coordination with other plans and with neighboring municipalities.

Copenhagen effectively combines urban mobility planning with urban planning. For example, office space and workspaces with a number of employees above a certain threshold can only be established close to a main public transport station.

The scientific paper has achieved the aims and objectives for which it was written.

The case studies presented in this scientific paper can be successfully applied in the development and training of students in the specialization of transportation and traffic engineering in the faculties of transportation and traffic engineering. Also these case studies can be part of the laboratory guidance of the road traffic and urban transport disciplines, or they can be used as practical applications in the seminars of the road transportation engineering training disciplines.

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