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THE INSERT OF A REDUCED-GAUGE TUNNEL IN A CROWDED INTERSECTION IN IASI

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Abstract: *In the past two decades, Iasi City had an accelerated pace of development on the number of inhabitants, the number and complexity of some industrial and commercial units, and also on the higher education institutions. Although there has been made several street network modifications and the modernization of some traffic arteries, the explosive growth in the number of vehicles made the urban roads to not face the traffic flows requests.*

Key words: *vehicle, traffic light, phases, access, lane.*

1. Introduction

Under the present traffic conditions, considering the huge number of vehicles and the actual street configuration whose movement capacity cannot be increased, the traffic problems will be amplified.

The image of traffic in an intersection at a given moment, perceived globally, shows us: groups of various vehicles moving at variable speeds, groups of stationary vehicles, groups of moving pedestrians.

Vehicles and pedestrians have permanent tendencies to change their direction of travel and their position at a given moment.

To study the phenomenon of urban traffic, it must be broken down and analyzed as follows: traffic generation areas, traffic destination areas, traffic flows and their movements, traffic participants.

Urban traffic has a cyclical nature, forming in the morning, when people's activities begin, and interrupting late in the evening, when they enter a nocturnal activity regime, starting again the next day.

The materialization of the urban traffic phenomenon on the street network is achieved through traffic flows, with well-determined volume, direction and meaning.

The traffic that strains a street intersection is influenced (both in intensity and frequency of arrivals at the intersection) by the general traffic in that city.

Among the factors that influence traffic generation, one can mention population density.

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Thus, the number of trips and the density decrease exponentially as the distance from the center increases [1]. In addition to density, traffic generation is also influenced by the purpose of the trip made and the physical and administrative structure of the city [2].

Street intersections, as main elements in the development of urban traffic, reduce the flow of traffic on the arteries that converge at intersections, they condition the traffic capacity of the entire street network. A judiciously designed traffic scheme on the major street network of the city is based on the impeccable functioning of its intersections.

In other words, the modern arrangement of street intersections, appropriate to traffic, is a primary necessity in the efforts to solve the traffic difficulties existing in the urban network. Hence the need to study traffic at intersections, calculate capacity and complete their arrangements, to obtain good results in the optimal organization of traffic.

The imposing measures for eliminating these drawbacks can be:

- immediately, having as result an improvement of driving conditions, by requiring minimal expenses;
- of perspective, these allow the solving of difficulties, but by requiring very large investment funds.

One of the of perspective measures would be the making of reduced-gauge tunnels in the crowded intersections, with the role of underground passages for cars, which would help to relieve congestion of crossroads by separating the grades of main traffic flows.

These tunnels will create continuous circulation lanes, free of traffic light stops, having effects upon the traffic flow and ease, and reducing the risks of accidents.

Such tunnels with reduced gauge acting as underground passages have been built, especially in urban areas in various cities in Europe, to address the problems of flow where an extension of the surface arteries is not possible. We mention some examples of tunnels: the A86 tunnel in Paris with a length of 10 km and a gauge of 2.00 m; the “Les Halles” tunnel in Paris with a gauge of 2.30 m; the Paillon tunnel in the city of Nice with a gauge of 2.60 m and two lanes; the “Courrier” tunnel in Annecy with two lanes in each direction and a gauge of 2.50 m; the “Jenner” tunnel in Havre with a gauge of 3.12 m; the set of tunnels in Marseille with a gauge of 2.50 m (Prado Carénage tunnel, Vieux-Port tunnel, Major tunnel and Axe littoral Nord-Sud tunnel).

2. The use of a reduced-gauge tunnel in a busy intersection in Iasi

A difficult problem is the servicing of queues of vehicles accumulated on traffic-lighted accesses of street intersections, by the traffic light cycle, under conditions of oversaturation of the access.

If the period of regressive vehicle queues is resolved in a few traffic light cycles, vehicles are waiting for more than one period before being able to cross the intersection. If the intersection oversaturation is prolonged, then the situation becomes unacceptable for the drivers involved, resulting in additional waiting times and long traffic delays for vehicles in the columns accumulated at the traffic light, a situation that is found in the analyzed intersection.

Therefore, an important conclusion was reached: knowing the process of these queues arriving at the intersection (during peak periods of the day) can be an effective means of analyzing the situation and can allow for taking measures regarding traffic lights that reduce congestion and vehicle delays at traffic light intersections [5].

Analyzing the data from the measurements taken at the analyzed intersection, presented in the table below (measurements taken for one hour, between July and August 2024), some observations can be made:

- due to the electric traffic light control of the intersection, where heavy vehicles also have access, long waiting times for columns to cross the intersection space are observed;
- Greater time losses are observed for left-turning vehicles compared to right-turning vehicles (approx. 70% greater), confirming the difficulties of solving left turns at intersections.

Traffic measurements Table 1

Intersec-tion	Min. no. of vehi-cles in the queue /lane	Max. no. of vehicles in the queue / lane	Medium no. of vehicles in the queue /lane	No. of queue s/h	Total vehi-cles/h	Min. waiting time in queue	Max. waiting time in queue	Med. waiting time in queue	Wait-ing time/ veh	Max. waiting time/ veh
Artery 1 Artery 2	6	15	11,23	43	471	135	503	393	36	103

As a result, large regressive queues of vehicles are observed at traffic lights during the red-light cycle, which cannot be resolved in a single cycle, some vehicles in the queue are stationing for 2 or 3 traffic light cycles before entering the intersection. These very long waiting times, in some cases several minutes, are unacceptable in modern traffic.

Expanding the traffic light cycle, which has been done several times in recent years, cannot solve the problems because, by increasing the free passage time (green) in one direction, the stationary times (red) in the crossing directions also increase, at the same time increasing the number of vehicles accumulated at the traffic light.

The existence of a tunnel at the intersection, located in an area with intense traffic transited by light vehicles, public transport vehicles (bus and tram), as well as heavy vehicles, removes one of the important flows from the traffic pattern of the intersection, namely that on artery 1 and artery 2 in the forward direction.

The intersection is a symmetrical one with four branches (arteries).

The four arteries that converge at the intersection have the following characteristics:

- Artery 1 and artery 2 are provided with 3 lanes per direction and a road width of 20.00 m;
- Artery 3 and artery 4 are provided with 3 lanes per direction, as well as a lane at the street axis intended for the tram line, the road width being 21.00 m.

The dispose of this flow would remove the conflict points between it and the left-steering ones from the other directions, making the crossing of the intersection to the later mentioned flows to be done safely [3], [4].

Also, the heavy vehicles that usually transit this intersection will benefit from larger crossing times, and the traffic light cycle will be able to solve the crossing of the queues from all the arteries of this intersection, dramatically reducing waiting times [5].

These reduced-gauge road tunnels can be used only by normal vehicles, being inaccessible by means of public transport (buses and trams), because of the lack of the urban space for this type of work [3].

The advantage of reduced-gauge tunnels (having a smaller gauge compared to normal tunnels) is that they can be added to the intersection plane without occupying too much from the existing intersection space, and without having to modify the intersection limits [4].

Intersection in which the tunnel can be placed on the artery 1 (photo 1), (figure 1). In the case of placing the access ramps 50 m away from the crosswalk (towards artery 2 and respectively to artery 1), this space can be used for storing vehicles which turn left. We mention that the left turn flows from artery 1 to artery 3 are composed of heavy and very heavy vehicles and they require long times for cranking and for crossing the intersection.

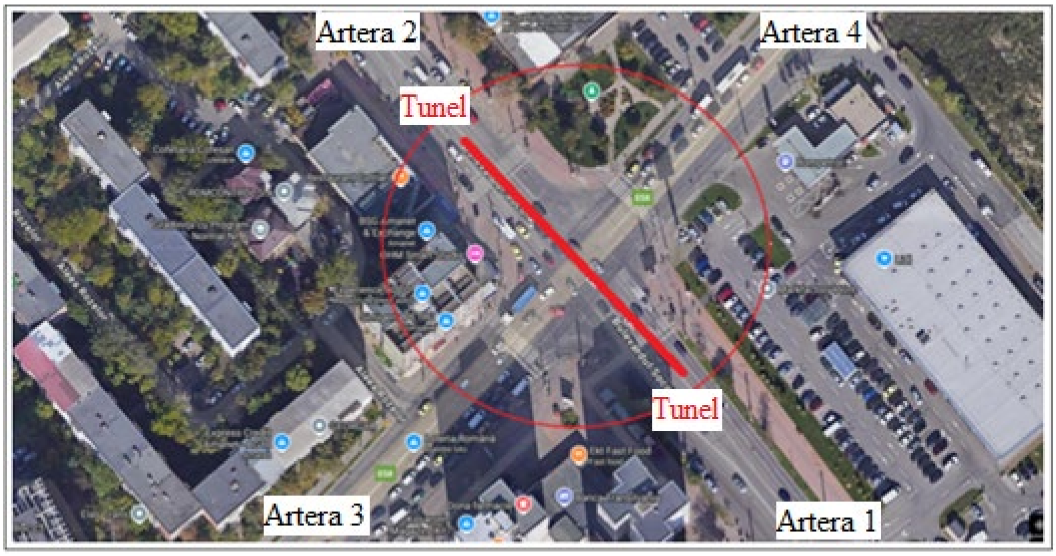

Photo 1. Intersection (artery 1 and artery 2 – Socola Blvd., artery 3 – N. Iorga Blvd., artery 4 – Primăverii Blvd.)

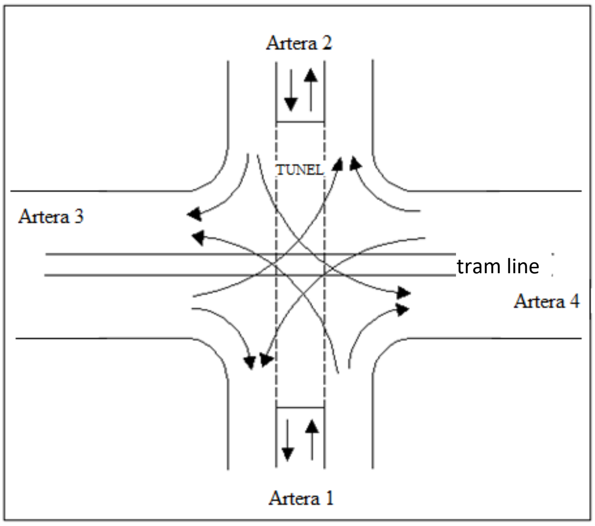

Fig. 1. *Tunnel placement*

The exit ramp towards artery 1 can be placed after roundabout, this way avoiding making the exit in close proximity of the roundabout and gaining the advantage that the tunnel flows would not affect the adjacent streets, however this can lead to an increased length of the tunnel.

3. Traffic capacity calculus of the intersection, with and without tunnel

A case study was conducted on the method of traffic diagnosis, prognosis and therapy [4] in a busy intersection located in an industrial area in Iasi, as well as a case study on the location of a narrow-gauge tunnel, acting as an underground passage in the same street intersection and the comparison of their traffic capacities in the current version (without tunnel) and in the version with the introduction of the tunnel.

The traffic capacity of this kind of intersection is calculated cumulating, in the same way the access capacities with traffic lights, to which it adds the lanes traffic capacities available in the tunnel, computed of a continuous flow and only during green light, of free passing of the traffic light [6-10].

This intersection is directed with a 2 phase traffic light cycle, figure 2, as follows:

- Phase I: artery 3 – artery 4

  tv = 60 sec., tg = 5 sec., tR = 55 sec.
- Phase II: artery 2 – artery 1

  tv = 35 sec., tg = 5 sec., tR = 80 sec.

  artery 1 – artery 2

  tv = 45 sec., tg = 5 sec., tR = 70 sec.

where: tv - green time; tg - yellow time; tR - red time.

The traffic light cycle has a time of T = 120 seconds, yellow light times being included in green light time.

The traffic light phases (figure 2) are:

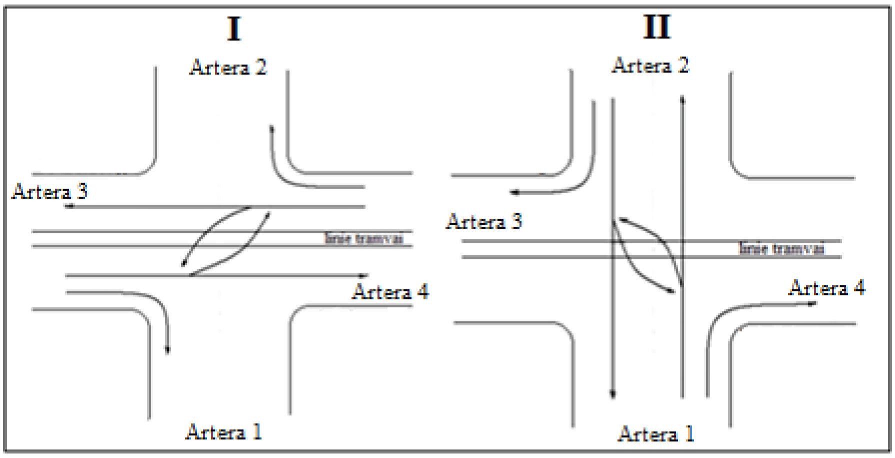

Fig. 2. *Traffic light phases*

The intersection crossing times depending on crossing distances (figure 3):

$$t_2 = \frac{D - 4x7m/s}{8m/s} \tag{1}$$

$$t_2^{I} = \frac{50 - 4x7m/s}{8m/s} = 3sec. \tag{2}$$

$$t_2^{II} = \frac{65 - 4x7m/s}{8m/s} = 5sec. \tag{3}$$

where: t_2 - crossing time; t_2^{I} - crossing time in phase I; t_2^{II} - crossing time in phase II;
D - crossing distance (m).

3.1. Traffic capacity without tunnel

The calculation of the traffic capacity of street intersections was based on the STAS 10144/6-89 method, which was improved by using the Greenshilds graph to determine the time to cross the STOP line (t1).

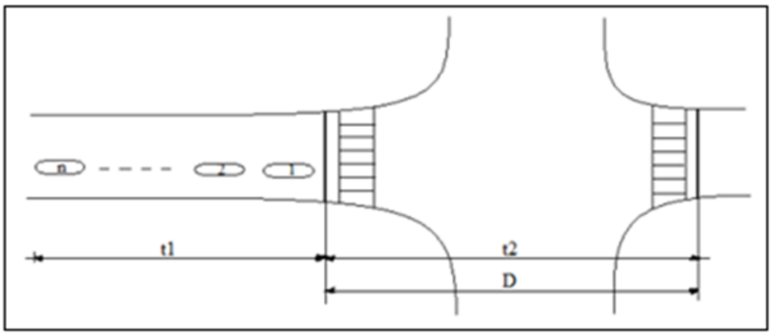

Fig. 3. *Required times for crossing the intersection space*

The intersection capacity formula is:

$$Cap^{intersection} = Cap^{FI} + Cap^{FII} \tag{4}$$

where: Cap^{FI} - phase 1 intersection capacity; Cap^{FII} - phase 1 intersection capacity.

To calculate the traffic capacity of an artery entering an intersection, the Greenshields graph is used to determine how many vehicles can enter the respective lane at the intersection at time t1. The traffic capacity of an artery at the intersection is equal to the number of vehicles, n(t1), multiplied by the number of lanes the artery has.

Finally, the traffic capacity of the entire intersection is obtained by summing the capacity of all traffic arteries (figure 3).

$$t_1 = t_v - t_2 \tag{5}$$

$$\text{Artery 3}: \quad t_1^{I} = 57\,\text{sec.} \tag{6}$$

$$\text{Artery 2}: \quad t_1^{II} = 30\,\text{sec.} \tag{7}$$

$$\text{Artery 1}: \quad t_1^{II} = 40\,\text{sec.} \tag{8}$$

where: t_1^{I}, t_1^{II} - time taken for vehicles in each lane to enter the intersection (phase I, phase II)

Since, in the case of the intersection without tunnel, the left turn flows are not fixed, with no special left cornering storage lanes, from direct observations there are found big delays in fixing the cornerings.

In this case, the entry of vehicles stopped at a light is being made with reduced speed, so we must consider a delay of ca. 20%.

On another note, the traffic flows composition is heterogenous, with a lot of heavy and very heavy vehicles (transit traffic). In this situation from Greenshileds graphic, we will accept the curve with 30% heavy traffic [4]:

$$\text{For phase I}: t_1 = 57\,\text{sec., we have}: n_{t_1}^{FI} = 15\,\text{veh/T} \tag{9}$$

$$\text{For phase II}: t_1 = 30\,\text{sec. and } t_1 = 40\,\text{sec., we have}: n_{t_1}^{FII} = 8\,\text{veh/T} \text{ respectively } 11\,\text{veh/T} \tag{9a}$$

$$\begin{aligned} Cap^{intersection} &= Cap^{FI} + Cap^{FII} = \\ &= \left(4\,\text{lanes x } 15\,\text{veh/T}\right) + \left(3\,\text{lanes x } 8\,\text{veh/T} + 3\,\text{lanes x } 11\,\text{veh/T}\right) = \\ &= 117\,\text{veh/T} \end{aligned} \tag{10}$$

Considering the cycle number:

$$N = \frac{3600}{T} = \frac{3600}{120} = 30\,\text{cycle/h} \tag{11}$$

$$Cap^{TOTAL} = 117\,\text{veh/T x } 30\,\text{cycle/h} = 3510\,\text{veh/h} \tag{12}$$

where: N - number of cycles; T - traffic light period; Cap^{TOTAL} - total capacity.

3.2. Traffic capacity with tunnel

In the case of introducing the 2 lane tunnel on the artery 1-2 route (one lane for each direction), the traffic capacity contains: the traffic capacity of the two lanes in the tunnel on continuous basis, according to STAS 10144/5-89, adding the capacity of the other of intersection accesses, computed in the same way as without the tunnel [8], [9].

Tunnel lanes traffic capacity formula:

$$N^{c} = \frac{1000\,v}{\frac{V^{2}}{26\,g\,f} + \frac{V\,t}{3{,}6} + S} = 300{,}1 \text{ veh. et/h} \tag{13}$$

where: N^c - traffic capacity for one lane;

V – traffic speed, in km/h (40 Km/h);

v – traffic speed, in m/s (11,11 m/s);

f – 0,3 the coefficient of friction between the tire and the road surface;

t – 1 sec., average perception-reaction time;

S – 4 m, safety distance between vehicles.

Tunnel traffic capacity, for its both lanes will be:

$$Cap_{TUNNEL} = 2\,\text{lanes}\,x\,N^{c} = 600\,\text{veh. et/h} \tag{14}$$

To the traffic capacity of the two lanes (equal with the ones computed previously), it adds the capacity of the traffic light accesses.

Since that on the artery 1-2 will remain only the cornering flows (the forward flows being resolved by the tunnel), the traffic light cycle can be reduced as follows:

- Phase I: t_v = 60 sec., same as in without the tunnel case, with t_1 = 57 sec. and number of vehicles per period in phase I - $n_{t_1}^{FI} = 15\,\text{veh/T}$
- Phase II: tv = 45 sec.

For the left cornering from artery 1-2, the crossing distance being 68 meters, we will have t2 = 5 sec., t1 = 40 sec. and number of vehicles per period in phase II - $n_{t_1}^{FII} = 11\,\text{veh/T}$

This way resulting a traffic light cycle of 105 sec. and a number of 34 cycles/hour.

The traffic capacity of such an intersection is calculated by aggregating, in the same way, the capacities of the traffic-lighted arteries, to which is added the traffic capacities of the lanes available in the tunnel, calculated for a continuous flow and only during the green, free passage time of the traffic light phase.

$$\begin{aligned} Cap^{\text{traffic lighth accesses}} &= C^{I} + C^{II} = \\ &= 4\,\text{lanes x } 15\,\text{veh/T x } 34\,\text{cycles/h} + \\ &+ 6\,\text{lanes x } 11\,\text{veh/T x } 34\,\text{cycles/h} = \\ &= 4284\,\text{veh/h} \end{aligned} \quad (15)$$

To this capacity it adds the 600 veh.et./h, the two tunnel lanes capacity, so that the total capacity is 4884 veh.et/h.

It results an addition of 1374 veh.et./h for the adoption of the tunnel, which represents a capacity increase of ca. 39%.

The tunnel located on artery 1 and artery 2 bd. will have a length of 238 meters (168m + 2x35m access ramps) in the case if there will be left a 50m distance from the stop line of the traffic light, for storing the vehicles that turn left and for easing the traffic flow.

The tunnel location is introduced in (figure 4):

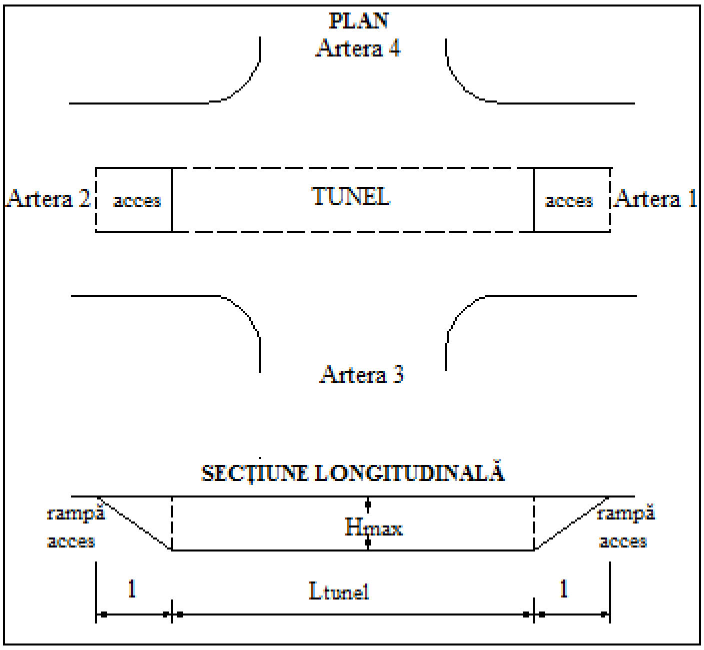

Fig. 4. *Tunnel route in plan view and in longitudinal section*

Because of artery 1 and artery 2 having 6 lanes, there is the necessary space for placing the tunnel in this intersection. The tunnel width will be 6.40 m and the access ramps width will be 5.40 m.

4. Comments and conclusions

- The presentation of the characteristics of urban traffic, the traffic problems and accidents encountered at street intersections, as well as the pollution produced by vehicles stationing at traffic lights, highlight the adoption of narrow-gauge tunnels as a radical solution to solve them.

- The reduced gauge tunnel acting as underground passage in the analysed intersection situated in the transit zone of Iasi city, helps on growing the crossroad capacity with 39%.
- The designing and building of new underground passages in crowded intersections, where are found at least two very intense flows, would lead to increased vehicle traffic fluency, safety and comfort, to the growth of the respective intersections traffic capacity and to the creation of some traffic "paths" without stopping restrictions at traffic lights.
- Also, heavy vehicles that normally transit this intersection will benefit from longer crossing times, and the traffic light cycle will be able to resolve the crossing of queues on all arteries in this intersection, substantially reducing waiting times.

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