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DEVELOPMENT OF A TRAFFIC DECONGESTION MODEL AT CONSTANTINE CITY TO IMPROVE URBAN MOBILITY: CASE OF THE ZOUAGHI SLIMANE CROSSROAD (ALGERIA)

The object of the study is modeling traffic congestion. For modeling traffic congestion in the aim to get better fluidity of road traffic mainly in urban areas, it is necessary to use powerful computers, ahead the complexity of the task. Because, road traffic is a complex phenomenon especially at crossroads, firstly due to the high number of users who use it, secondly the nature of the crossroads which have a complex mesh network. In this paper, a mathematical approach based on the Greenshield model who interested in the study of traffic performance at crossroads is developed. This model permit to control and regulate traffic urban which must meet various objectives like: minimizing wait times for vehicles at crossroads, optimization of traffic flows on the road network. The application treated in this papier is the Zouaghi Slimane crossroads of Constantine city (Algeria). According obtained results, the time spent at crossroads Zouaghi Slimane can reach more than 45 minutes and more for day. This situation brings to asking the following question: how to reduce the travel time lost at this crossroads? To give the answer at this last question, the first step is to considering the different variables that characterize the progressive movement of vehicles on a road. In the objective to give a mathematical formulation, which links, the number of vehicles present at time t over a length L of the road. Speed is one of the basic parameters of traffic flow, the relationship between the fundamental parameters of traffic considers the different variables that characterize the progressive movement of vehicles on a road permit to give a mathematical formulation which links the number of vehicles present at time "t" over a length "L" of the road. The main objective is to bring out indicators such as speeds, density and critical flows allowing to set up a dynamic management of the traffic, for a decongestion the crossroads Zouaghi Slimane.

Keywords: *traffic road, modelling traffic congestion, critical flows, traffic dynamic management, regulate traffic urban.*

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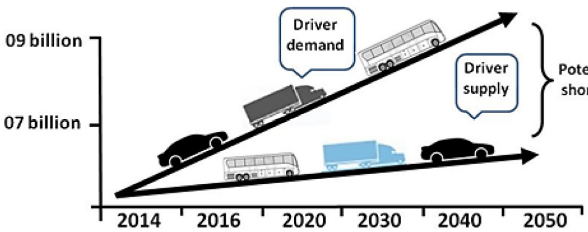
1. Introduction

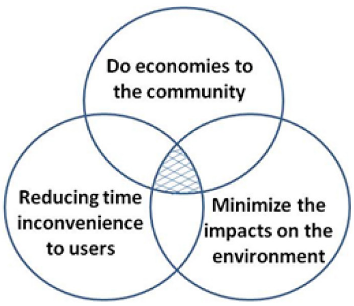
The transports systems will have to face a major challenge in the coming decades, to ensure sustainable mobility and movement of people (Fig. 1). The importance of transport systems in these different forms continues to grow in Algeria, because they are the key factor in the development of modern economies. However, the Algerian transport system must cope with the request for a young population increasingly more demanding of mobility and a public opinion, which do not support the level of services quality offered. For that, is imperative today that the transport infrastructures making the switch to sustainable construction and less energy costly with less environmental pollution [1, 2].

Currently, due to a continuous increase of the vehicle fleet estimated at 5.6 million in 2018 [2], the great Algerian's cities have experienced: congestion problems, air pollution, noise and road safety, which are generating the dysfunctions in the man-agreement of their utilities, roads and means of transport. For this reason, the public authorities encourage transport companies to increase efforts to maintain and improve the quality of services proposed [3]. This development is expected to be continued to meet the common objectives of decongestion of the cities and the asphyxiated effect by traffic, to open up the outlying areas and improving environmental quality. It is importance to point-out, that to decongest the roads, it is very important to take into account: make savings at the community, reduce the time of inconvenience, as well as minimizing impacts of pollution on the environmental.

The congestion characterization consists in making an analysis of the density generally at a particular point where measurements of the flow and density are available. The diagram flow – density plot makes it possible to determine a critical density beyond which the traffic is congested. The value of these thresholds varies greatly from one locality to one another; it can be alternate by multiple factors such as the presence of heavyweight.



a



b

Fig. 1. Demand transport evolution and impacts: *a* – sustainable mobility; *b* – imperative transport system today

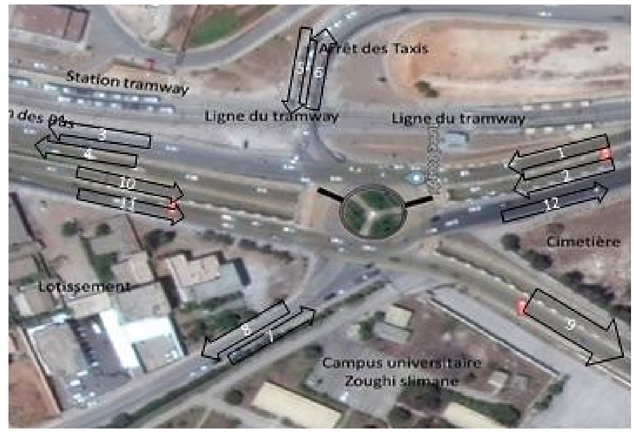
The congestion definition on a network of crossroads is too complex to allow an easy local characterization. At similarly, the congestion volume indicators are difficult to be calculate in this type of environment. On the other hand, time spent and time lost at crossroads are more easily calculated.

Thus, *the aim of paper* is to study the phenomenon of congestion at the Zouaghi Slimane crossroads in Constantine city (Algeria). The main objective is to determinate the indicators speeds, densities and critical flows, for set up a dynamic management of the traffic, in order to decongestion the crossroads Zouaghi Slimane. These last make it possible to assess the impact of an operating action on traffic conditions, and thus to implement effective traffic management strategies

2. Materials and Methods

The Constantine city is the capital of east of Algeria, despite the competition from other cities. It occupies a central location in the region, being a pivotal city between the crossroads of major routes north-south and west-east. It is also the metropolis of the East and the largest inland city in Algeria. The Constantine city has nine suburban areas. A suburban agglomeration is a nearby area of habitat, representing the extension in terms of habitat and sometimes activities of the Constantine city. Like most major Algerian cities, the Constantine agglomeration is known a strong urbanization over the last decade. For this rapid urbanization, result an increase of population movement.

The Zouaghi Slimane crossroads is a case study for its very important geographical position near the airport and the university of the Mentouri Constantine brothers, it is also the crossroads of a set of destinations such as the new city Ali Mendjeli, towards El khroub, the entrance and exit of the east-west highway etc. By its particularity, the urban transport network at this crossroads is very dense and sometimes it has low fluidity for long periods of the day, as shown by the black points in Fig. 2.



a

b

c

Fig. 2. Identification of entry and exit locations of the Zoughi Slimane crossroads: *a* – aerial view of the intersection; *b* – entrance to the crossroads; *c* – exit to the crossroads

The phenomenon of congestion is present at this crossroads, for this the travel time (past or lost) of the latter was measured. According obtained results, the time spent at crossroads Zouaghi Slimane can reach more than 45 minutes; but on average, the time spent is around 20 to 40 minutes for day. This situation brings to asking the following question: how to reduce the travel time lost at this crossroads? In addition, how to solve the problem of congestion knowing that there are multimodal traffic and a lot of interaction between the different modes?

The approach bat not the best solution, is to decongest the traffic in the crossroads Zouaghi Slimane in the aim to increase road capacity. This solution certainly is very expensive, but it has the advantage of sustainably improve traffic flow. Another solution would be to develop regulation tool and management of the road traffic. This means, modeless the evolution of cars density in time and space [4–6]. To establish models, some researchers use partial differential equations, that describe physical phenomena like fluid mechanics [7, 8], which informs that the flow debit is equal to the product of the density with the speed of the flow $Q=K \cdot V$ (Fig. 3).

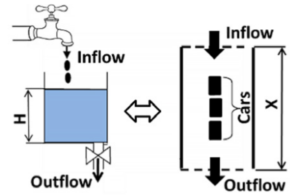


Fig. 3. Analyzing of unidirectional flow

The flow speed V is given by the equation:

$$V = Q / K, \quad (1)$$

where Q – flow; K – density.

This relationship is widely used in traffic theory for analyzing unidirectional flow [9, 10].

All efforts in research and development have resulted in the development tools for control and management traffic road; bat the problem of traffic congestion is not resolved completely [11–13].

3. Results and Discussion

The approach in the mathematical model developed by [3] will enable to relate $Q_{\max}$ traffic flow and optimal speed V_{opt} that should be allowed to ensure fluidity in traffic. Consider a test road with single traffic lane and having a rectilinear section. Let's put in this rectilinear section N identical car of length L and the conductors are the automatons [3]. By definition, the flow Q of trail section is the number of vehicles N divided per time t then obtain:

$$Q = \frac{N}{t} = \frac{V \cdot t}{L} \cdot \frac{1}{t} = \frac{1}{L} V, \quad (2)$$

where Q – flow (cars/hour); V – speed (m/s); L – length of the car (m); N – numbers of vehicles (cars); t – time (hour).

Now let's replace automatons by humans [2]. The driver's cars observe a safe distance from the vehicle that precedes it and which corresponds to the distance L_r (m) would have the vehicle traveled during the reaction time t_r=2 s medium of the conductors:

$$L_r = V \cdot t_r = \frac{5}{9} \cdot V \left(\frac{\text{km}}{\text{h}}\right). \quad (3)$$

The expression of the flow Q, is given by the following formulation:

$$Q = N \cdot \frac{1}{t} = \frac{V}{L + \frac{5}{9} \cdot V}. \quad (4)$$

For stopping the vehicles, the brakes need an average distance L_C proportional to the kinetic energy:

$$L_C = k \cdot E_C = k\left(\frac{1}{2} \cdot M \cdot V^2\right),$$

where $C_f = 1/2 k \cdot M$ (M – masse of cars).

Each driver must maintain a safe distance dS from the vehicle which precedes it. This distance is equal to $d_s = L_r + L_c$ that are travels the vehicle during a medium time $t = t_r + t_c$. The expression of the flow Q in this case is:

$$Q = \frac{V}{L + t_r \cdot V + \frac{1}{2} k \cdot M \cdot V^2} = \frac{V}{L + \frac{5}{9} \cdot V + C_f \cdot V^2}. \quad (5)$$

According to the equation (5) the flow Q, in situation of traffic saturation varies depending on the speed V as a hyperbolic function. Then, the relationship between the speed and flow can be observe as follows. The flow is equal to zero because there are no vehicles or there are too many vehicles so that they cannot move. At maximum flow, the speed will be in between zero and free flow speed. The maximum flow $Q_{\max}$ is obtained when the derived function $Q = f(V)$ is equal to zero:

$$\frac{dQ}{dV} = 0,$$

then

$$Q_{\max} = \frac{\sqrt{\frac{2L}{(k \cdot M)}}}{\left(L + \left(\frac{5}{9}\right) \cdot \sqrt{\frac{2L}{(k \cdot M)}} + \frac{1}{2}(k \cdot M) \cdot \frac{2L}{(k \cdot M)}\right)} = \frac{\sqrt{\frac{2L}{(k \cdot M)}}}{\left(2L + \left(\frac{5}{9}\right) \cdot \sqrt{\frac{2L}{(k \cdot M)}}\right)}. \quad (6)$$

The relation between flow and speed can be representing with the help of some curves. They are referrers to as the fundamental diagrams of traffic flow. It should be noted that flow and density vary with time and location. However, using the model given in equation (6), it is not possible to give any information on the time mean speed v_t, which is the average of all the speeds of vehicles passing through a point over a given period (average speed of the flow), nor on space mean speed v_s, who is the spot speed, but spatial weightage is given instead of temporal. Time mean speed v_t and space mean speed v_s are two important measures of speed, that should be allowed to ensure fluidity in traffic:

$$v_t = \frac{\sum_{i=1}^{n} q_i v_i}{\sum_{i=1}^{n} q_i}, \quad (7)$$

$$v_s = \frac{\sum_{i=1}^{n} q_i}{\sum_{i=1}^{n} \frac{q_i}{v_i}}, \quad (8)$$

where q_i – the number of vehicles having speed v_i, and n – the number of such speed categories.

The fundamental diagrams of traffic flow are vital tools which enables analysis of fundamental relationships. There are three diagrams – speed-density, speed-flow and flow-density [14–20]. The theoretical studies on road traffic try to describe using the fluid mechanics approach, in the aim to understand the interactions between vehicles and drivers. All these studies carried out lead to the development of models and tools for the modeling and construction of streets, roads and highways. Bruce D. Greenshields of the Yale Bureau of Highway Traffic studied models of density and speed [10]. He was also interested in the study of traffic performance at crossroads [21]. For this reason and in the rest of the present paper let's use the Greenshields model to assess the level of fluidity at the Zouaghi Slimane crossroads.

The first step consists to identify of entry and exit locations of the Zouaghi Slimane crossroads. For this, it is possible to a measure collection program spread over the whole day at different periods as illustrated in Table 1.

Table 1

Measurement collection program spread over the whole day

Link	Period of days	Time interval
Link i i=1 to 12	First period	7 h 45 min to 8 h 00 min
		8 h 05 min to 8 h 20 min
		8 h 25 min to 8 h 40 min
	Second period	11 h 30 min to 11 h 45 min
		11 h 50 min to 12 h 05 min
		12 h 10 min to 12 h 25 min
	Third period	14 h 00 min to 14 h 15 min
		14 h 20 min to 14 h 35 min
		14 h 40 min to 14 h 55 min
	Last period	16 h 30 min to 16 h 45 min
		16 h 50 min to 17 h 05 min
		17 h 10 min to 17 h 25 min

In many studies, the speeds measured are represents in the form of a frequency table "where well in class of the same frequency q_i". Our statistical data are numerous, for that, it is useful to group our measurements into speed classes to facilitate their reading and treatments.

In the second step, let's calculate time mean speed v_t and space mean speed v_s according to all periods of the day and on all 12 links, as can be seen on the processing of the first link *1* and the last link *12* for example (Fig. 4). The first link is composed by 1 lane and the last link by two-lane respectively speed and rapid lanes.

The third step consist to calculate the density K (cars/km) according the counting of flow Q (cars/hour) which is obtained from counting data.

After data processing, let's calculate time mean speed v_t and space mean speed v_s according to all periods of the day and on all 12 links, as it is possible to on the data processing of the first link and the last link (Tables 2, 3).

The relation flow – density, density – speed, speed – flow can be represented with the curves (Fig. 5). They are referred to as the fundamental diagrams of traffic flow. It should be noted that, the flow and density vary with location and time [20].

On a given stretch of road the relation between the density and the corresponding flow is referred to as one of the fundamental diagrams of traffic flow. Similar to the flow-density relationship, speed will be maximum, referred to as the free flow speed, and when the density is maximum, the speed will be zero.

The relationship between the speed and flow can be postulated as follows. The flow is zero either because there are no vehicles or there are too many vehicles so that they cannot move. At maximum flow, the speed will be in between zero and free flow speed [20].

Let's consider now the relationship between the speed and flow, the maximum flow $Q_{\max}$ is obtain after differentiating q with respect to $\overline{V}_s$:

$$\frac{d}{d\overline{V}_s}\left[\overline{V}_s^{\,2}\right]=\frac{d}{d\overline{V}_s}\left[V_f\cdot\overline{V}_s-\frac{V_f}{K_j}\cdot q\right]=0,\ \overline{V}_s, \quad (9)$$

$$\frac{dq}{d\overline{V}_s}=\left[K_j-2\cdot\overline{V}_s\cdot\frac{K_j}{V_f}\right]=0\ , \quad (10)$$

$$K_j=2\cdot\overline{V}_s\cdot\frac{K_j}{V_f}\ . \quad (11)$$

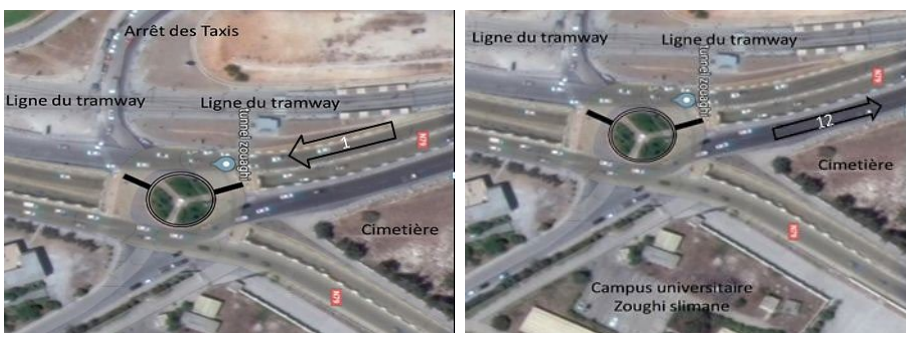


Fig. 4. First and last links of Zouaghi Slimane crossroads

Table 2

Result of first link

Link	Period of days	V_t (km/h)	V_s (km/h)	Density K (cars/km)
Link *1*	First period	17.71	13.91	215
		25.25	20.52	179
		27.62	21.64	169
	Second period	26.46	21.44	211
		27.28	20.83	196
		26.78	22.45	108
	Third period	29.93	25.13	95
		34.47	32.00	106
		30.54	24.83	97
	Last period	36.81	32.64	96
		20.10	15.87	176
		30.47	26.81	120

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Table 3

Result of the last link by two-lane

Link	Period of days	V_{f1} (km/h)	V_{s1} (km/h)	Density K_1 (cars/km)	V_{f2} (km/h)	V_{s2} (km/h)	Density K_2 (cars/km)	Total $K=K_1+K_2$
Link *12*	First period	55.96	43.65	98	46.66	32.03	155	253
		34.93	29.59	151	22.33	13.54	292	443
		46.07	38.51	114	23.73	14.83	283	397
	Second period	45.3	36.7	91	19.42	11.02	359	450
		41.85	36.87	98	26.02	12.81	273	372
		52.7	44.1	72	20.63	11.05	319	391
	Third period	56.4	46.72	79	33.31	19.58	217	296
		38.83	31.49	113	22.54	13.22	341	453
		45.39	39.68	90	29.81	18.47	206	295
	Last period	53.85	45.53	77	22.59	12.03	304	380
		47.65	41.42	92	24.66	12.56	333	425
		46.96	42.48	87	23.71	11.42	359	445

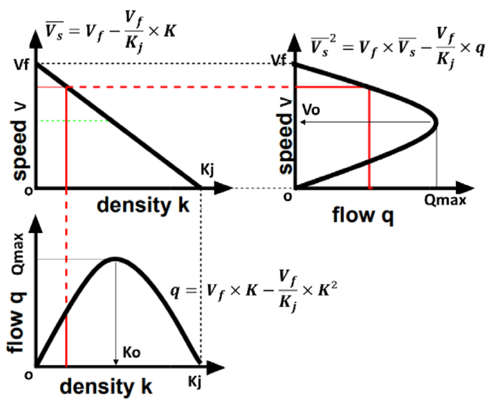

Fig. 5. Illustration of fundamental diagram of "Greenshields model" traffic flow

Thus, the space mean speed V_0 (Fig. 5) at which the flow is maximum is equal to half the free mean speed $V_0 = V_f/2$.

In the same, let's consider now the relationship between the flow and density, the maximum flow $Q_{\max}$ is obtain after differentiating q with respect to K. Then the density K_0 is half the jam density:

$$\frac{dq}{dK} = \frac{d}{dK}\left(V_f \cdot K - \frac{V_f}{K_j} \cdot K^2\right) = 0 \rightarrow K_0 = \frac{K_j}{2}. \quad (12)$$

To substitute K by K_0 in the relationship between the flow let's obtain:

$$Q_{\max} = \frac{V_f \cdot K_j}{4}. \quad (13)$$

The free mean speed V_f corresponding to maximum speed that can be attained on the highway and the jam density K_j are obtains using the method of regression analysis in fitting speed and density data to the macroscopic models. A measure commonly used to determine the suitability of an estimated regression function is the coefficient of determination (or square of the estimated correlation coefficient) R^2. The closer R^2 is to *1*, the better the regression fits:

The results in Table 4 show that links *2*, *9* and *12* have a regression coefficient R^2 very close to *1* compared to the other links where the dispersion is too great.

Table 4

Compilation result at twelve links

Link	$Q_{\max}$ (cars/h)	V_0 (Km/h)	K_0 (cars/km)	R^2
1	3714.36	18.28	203.15	0.601
2	5666.81	22.58	250.93	**0.892**
3	4453.84	24.06	185.51	0.563
4	8906.78	26.69	333.67	0.567
5	1848.75	8.6	214.99	0.642
6	2424.84	11.02	220.04	0.305
7	3378.04	15.38	219.68	0.61
8	897.00	13.39	66.965	0.05
9	2219.91	24.48	90.67	**0.756**
10	4746.91	18.23	260.41	0.8
11	5627.91	7.5	750.19	0.565
12	10301.94	24.86	414.37	**0.764**

Fig. 6 illustrates the geographical location of the three links *2*, *9* and *12*, and clearly shows the existence of Junction points (JP1, JP2, JP3 and JP4 Junction point) which obstruct the flow of traffic at the level of the Zouaghi Slimane crossroads practically at daytime languor.

Fig. 6. The links *2*, *9* and *12* in the map of Zouaghi Slimane crossroads

One of the solutions consisted in moving the bus stop after the tram station; this will decongest the junction point JP1. To decongest the junction, point JP2, it's important to put up a removable beacon which will ensure fluidity at the junction point JP2. The free cars movement in the crossroads will be free up traffic at the junction point JP3. Decongest the junction point JP4 requires a widening of the road due to heavy traffic at the exit of Zouaghi Slimane university campus.

Urban traffic congestion significantly impacts commute times, air quality, and overall city efficiency. The most critical phenomenon in the road traffic is the congestion [15, 16]. Although the technical and technological progress realized by the humans in all domains. The road traffic remains a victim of increasing congestion when demand exceeds the capacity of the road infrastructure [17]. In this case, the vehicle will slow down to the entrance of the road infrastructure, thereby forming a bottling in traffic.

The Constantine city, like all the major cities of the country, is faced with urban growth problems characterized by very significant spatial sprawl which has arrived at saturation. Among the areas that have experienced dense and rapid urbanization in Constantine city is Zouaghi Slimane, Ain El Bey and Airport zone. This urbanization has created dispersed urban fabrics corresponding to habitat collective and individual. Then, the need for displacement is felt more and more and phenomenon of congestion is present at this locality, principle at the Zouaghi Slimane crossroads.

Urban traffic congestion modeling enables better understanding and prediction of traffic patterns, aiding in the development of efficient management strategies.

4. Conclusions

In this work, the first step involves identifying the various variables that characterize the progressive movement of vehicles on a road, with the goal of establishing a mathematical formulation that relates the number of vehicles at time t to a specific road segment of length L. Traffic modeling by analyzing vehicle speeds provides valuable insights into flow dynamics and helps optimize traffic management strategies.

This enabled to use a Greenshields model to regulate the traffic speed in real time. The main objective is to set up a dynamic management of the traffic, for a decongestion the crossroads Zouaghi Slimane. It should be note here that implementing measures such as improved public transportation, carpooling incentives, and traffic signal optimization can help regulate road traffic effectively in the crossroads Zouaghi Slimane.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating this work.

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