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A BEHAVIOURAL MODEL TO EVALUATE THE DELAY ON URBAN TRAFFIC FLOWS AND ANALYSIS OF ENVIRONMENTAL IMPLICATIONS

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ABSTRACT

This paper deals the problem of a road's capacity in presence of perturbations in the vehicular flow. In particular, among the different causes of delay, is here the presence of vehicles parked along the road in relation at their parking activity. Preliminarily is evaluated the delay, caused by each vehicle that leaves its parking position and enters in the traffic flow or by that who slows down the flow to enter in the parking, by introducing these effects in the equations of flow, it is possible to evaluate the modifications that the same curves of down flow suffer. Consequently, it is also possible to evaluate the increase of pollutant emissions.

Keywords: traffic flow, vehicular flow, delay, environmental implication.

INTRODUCTION

The study of the delay on the traffic flow caused by the presence of lateral obstacles along the lane of an urban street presents some aspects uneasy to define.

These studies, even though could explain important effects on the phenomena of congestion especially in those roads in urban areas, which have only one directional lane and are characterized by an intense activity of parking, are neglected.

Despite the considerable influence of the presence of lateral obstacles on the average velocity on the road, no consolidated criteria exist for this kind of evaluation while models, which provide acceptable results for the determination of the running time in function of the flow, or for the delay at the final crossroads, are available [1, 2].

One of the aspects that present greater unknown factors in the determination of delay induced on vehicles that travel on a one-lane road for each direction, without any possibility of overtaking, is about the admissions of vehicles parked on the side of the road or that enter in the flow from secondary accesses (garages, filling stations. etc.).

The probability that the manoeuvres of entering in the flow in a reference time and in a unitary length of the road interfere the traffic on the lane causing delay, must be evaluated.

If all vehicles that wish to carry out the manoeuvres of admission were ready to wait indefinitely for the presentation of favourable conditions for admission. They would not cause delay on the flow.

Really, the drivers of the waiting vehicles, tired of waiting, will try to come out even when the conditions are not favourable, in particu1ar in the absence of an interval of time in the flow sufficient for carrying out the manoeuvre. We assume that the event of the vehicle that comes out in the absence of an interval of time sufficient to make the manoeuvre, and the consequent traffic block, can take place once exceeded a critical waiting time.

This critical time of waiting (or availability to waiting) depends on stochastic factors such as the driver's disposition, reason of the trip, intensity of flow, and so on.

In this paper a criteria for the evaluation of average delay that a single interfering manoeuvre can cause in a unitary time and for a unitary length of arterial road (manoeuvres/h km), is exposed.

Consequently, we can define the modification of the average speed of the trip and of the down flow curves that depend from the width of the lane, besides obviously from the entity of the flow and the average number of interfering manoeuvres.

THE CONDITIONS OF DOWNFLOW IN THE PRESENCE OF LATERAL DISTURBANCES

Generally, it is possible to affirm that in the phenomena of the down flow, on an urban road, different possible causes could produce a decrease in the speed. Among which, we point out, an increase of the entity of flow (and therefore an increase of the traffic density), a reduction of the characteristics of the useful width of the lane and finally the presence of lateral obstacles causing loss of time along the route.

Then, we can express by the following terms the average time of the trip along a generic route:

$$T_C = \sum_{J=1}^{N} T_{rj} + \sum_{J=1}^{N} T_{ij} + \sum_{J=1}^{N} T_{pj} \quad (1)$$

Where:

T_C = total average time of the trip along the route h;
T_{rj} = running time along the generic j^{th} link which is part of the route under study [h.];
T_{ij} = time loss at the final node of the link j [h.];
$T_{pj} = d_j \cdot l_j$ = average loss of time on each vehicle caused by the manoeuvres of parking or, in general, by lateral obstacles [h.];
d_j = average time lost by the vehicle who travels on the link j for the unit of length [h/km];

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l_j = length of link j [km];
N = number of links of the road.

The loss of time added to the running time modifies the relation of down flow [l], increasing the total time of journey.

Some studies have pointed out that in congested urban areas the added loss of time can be prevailing in respect to the running time [2, 3, 4, 5].

The term T_{ij} of (equation (1)), that represents the loss of time localized at the intersection, will not be treated in a direct way, because its effect can be calculated by already known models [6, 7].

The average total time, required to travel along a unitary length of the generic link j, in the absence of intersections, is:

$$t_c = t_r + t_p \qquad (2)$$

Where:

t_c = total time of driving along a unitary length of road considered in the absence of intersections [h/km];
t_r = average running time equal to the inverse of the average speed of flow due only by geometrical characteristics of the road and the volume of traffic [h./km.];
$t_p = d_s$ = average loss of time due to lateral obstacles for unit of length of the road [h./km.].

Therefore, the average speed of the trip on the generic link j is:

$$v_c = v_r / (l + d_s v_r) \qquad (3)$$

where, for the sake of simplicity, the index j is omitted in each term.

We now consider here one experimental model of down flow calibrated for the urban areas of Naples and Cosenza based on about 10.000 speed measurements in different conditions [8]; this model is expressed by:

$$v_r = a_o + a_l L_u + a_2 P + a_3 T^2 + a_4 D + a_5 I + (a_6 + a_7 X)\,(Q/L_u) \qquad (4)$$

Where
v_r = average running speed in the trunk of road j in the absence of the main intersections [km./h.];
L_u = width of the section useful for the down-flow [m.];
P = gradient in percentage (P = 0 assumed for downhill roads);
T = tortuosity;
D = level of disturbance (that implicitly keeps in mind the manoeuvres of admission from lateral parking into the lane);
I = number of secondary lateral accesses;
X = binary variable (0 for the roads with the possibility of overtaking, 1 for the roads with no possibility of overtaking); equivalent flow [vehicle /h.].
Q = equivalent flow [vehicle/h.].

The variables “tortuosity" and “disturbance" have been qualitatively evaluated by four levels of disturbance (null, low, medium, and high) to which the values 0.00, 0.33, 0.66, 1.00 have been attributed, respectively.

Model (4) specified and calibrated in thirteen roads in the urban area of Nap1es has provided the following re1ation:

$$v_r = 30{,}97 + 2{,}91 \bullet L_u - 1{,}34 \bullet P - 14{,}81 \bullet T^2 - 9{,}51 \bullet D - 1{,}46 \bullet I + \\ + (0{,}059 + 0{,}109 \bullet X) \bullet 10\text{-}3 \bullet (Q/L_u)^2 \qquad (5)$$

with the values of R^2 equal to 0.683, the F-Fisher's statistic equal to 2,002.9 and t-Student equal to 2.31.

The model (5), even if obtained on the basis of on1y 6, 523 measured times of route, is representative of a large spectrum of situations in which useful application can be found; this also in consequence of the fact that the parameters, to which the speed is correlated, are included in ample intervals of values.

In the following conditions, a road without lateral obstacles and tortuosity, with absence of secondary intersections, negligible slopes and width of the section useful for the flow equal respectively to 2, 30 m., 3, 00 m. and 3, 70 m. (only one lane for any direction and without any possibility of overtaking), the model (5) becomes:

$$v_r = 37,\,6653 - 0,\,00003176\,Q^2 \quad \text{per } L_u = 2{,}30\text{m.} \qquad (6.1)$$
$$v_r = 39,\,7030 - 0,\,00001866\,Q^2 \quad \text{per } L_u = 3{,}00\text{m.} \qquad (6,\,2)$$
$$v_r = 41,\,7407 - 0,\,00001227\,Q^2 \quad \text{per } L_u = 3{,}70\text{m.} \qquad (6.3)$$

The equations (6) permit to determine v_r only with reference to the geometrical characteristics of the road and to the entity of flow, having excluded the dependence from the grade of disturbance and from other variables. In fact, the effect of lateral obstacles we can evaluate, in a more explicit way, by means of (3). That permits to determine the average speed of the trip v_c once v_r is known (v_r can be determined, for example, by means of (6) and the average loss of time d_s due to the presence of lateral obstacles, as we will show below).

The lateral obstacles substantially depend on the type of interference generated on the flow; from now on we will refer to the presence of manoeuvres connected with the parking activity or due to secondary accesses as the unique delaying cause.

This does not exclude the possibility to extend the analysis to other causes of delay, the total effect of which can be explicative of the variable "D" included in (4). Incidentally it is noted that besides the experimental model (6) reference can also be made to the relations that express the running speed as function of the flow such as, for example, that of Greenshild [9]:

$$K = \left(v_0 - v_r\right) / b \qquad (7)$$

Where:

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K = average vehicular density (or the average number of vehicles present in a unitary length of the considered lane);
v_o = theoretical basic speed in dependence only on the geometrical characteristics of the road;
v_r = average speed of flow, intended as average of the speeds of the vehicles present, in a unitary length of the lane, in absence of intersections or other obstacles (uninterrupted flow);
b = experimental parameter of reduction of speed with the density of traffic.

From (7) and the equation of traffic flow:

$$Q = K \cdot v_r$$

We obtain

$$v_r = v_0 - bQ / v_r \tag{8}$$

THE HYPOTHESES OF THE MODEL

In order to obtain a greater expositive clearness we propose a list of the assumption as base of the analytic formulation.
The assumptions are:

a) the accesses of vehicles from parking into the traffic flow is similar to a lateral access governed by STOP;
b) the down-flow occurs in a single lane and without the possibility of passing any sudden obstacle represented, in the present case, by occupation of the lane by a vehicle that leaves the parking place;
c) the driver waits for an interval sufficient to make the manoeuvre for an amount of time that depends from some casual factors (personal temperament. reason of the trip. and so on). The average value of this amount of time is called "TMP";
d) the waiting time for admission into the flow (TMM) is a stochastic variable that can be assumed equal to the sum of all the refused intervals and of the critical interval T;
e) the distribution of the stochastic variable "waiting time for admission" is supposed, for simplicity of analytic treatment, to be of a Gaussian type;
f) the average time necessary to carry out the manoeuvre of admission (TMM) is equal to the duration of the critical interval T for admission;
g) the forced admission of a vehicle into the flow causes a blockage analogous to that generated by a red traffic light phase; the entity of the delay induced by every single manoeuvre is evaluated in condition of non-saturation, in the further simplification of constant rate of the arrivals;
h) the forced accesses into the flow can be considered as independent phenomena.

EVALUATION OF THE DELAY PROVOKED INTO THE TRAFFIC FLOW BY THE MANOEUVRES OF EXIT FROM A PARKING SPACE

The manoeuvre of exiting from the state of parking of a vehicle parked on the side of a carriageway and its consequent admission into the flow of the lane occurs according to a mechanism analogous to that of admission from a lateral access.

The driver of the vehicle who intends to carry out the manoeuvre observes the vehicles that arrive along the road, and as he finds a sufficient interval, then he makes the manoeuvre.

Is understood to be, in the hereafter, for critical interval T [sec.] that such that all ranges below it are rejected, while those equal to or greater than are accepted; You can then give a representation of the critical frequencies observed experimentally the behaviour of motorists.

Numerous experimental findings in correspondence with admission governed by STOP have permitted to evaluate the average value of the critical intervals between 6 and 8 sec.

The waiting time v [sec.], which in the case here considered coincides with the interval of time that passes between the moment in which it could theoretically carry out the manoeuvre of admission in the absence of flow and the moment in which it has effectively carried out, depends essentially:

- on the characteristics of distribution of the intervals of flow in the lane;

- on the mechanism of manoeuvre, that depends on the typology of parking. The mechanism of manoeuvre substantially determines the time necessary for the vehicle to make the manoeuvre; it is however a stochastic variable, that can be characterized by its average value TMM, and shall consider it as coinciding with the length of the critical interval T.

Regarding the distribution of the temporal intervals into the flow on the lane, it is here hypothesized that the flow itself can be described by Erlang's distribution; with such position, the probability that the interval between two successive passages in a section is equal to the generic time "t", is given by the following probability density function:

$$f(t) = \frac{kQ}{(k-1)!}(kQt)^{(k-1)} e^{-kQt} \tag{9}$$

Where:

k = the parameter of the distribution that assumes entire values included between 1 and 4 related to the intensity of flow:
k = 1 for Q≤500veic./h;
k = 2 for 500<Q<1.000veic./h;
k = 3 for 1.000<Q<1.400veic./h;
k = 4 for Q>1.400veic./h;
Q = the traffic flow on the lane [vehicle./h].

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The v waiting time is equal to the sum of all refused intervals and of the critical interval T.

Called F_v (t) the distribution function of the stochastic variable v, it can be shown that if t < T, results F (t) = 0 why, for definition, the waiting time cannot be inferior to the critical interval.

In the case of t> T two possibilities exist:

a) the first interval, between the vehicles of the flow, useful for the manoeuvres, is greater or equal to the critical interval T, and therefore sufficient to carry out the manoeuvre.

In such case, the interval is accepted whatever is its amount and therefore results v=T, and v ≤ t too. The probability that the is v ≤ t coincides whit the probability F that an interval of time in the flow is greater or equal to the critical interval T, that is:

$$F = \int_T^{\infty} f(t)dt = e^{-kQt}\sum_{i=0}^{k-1}\frac{(kQt)^i}{i!} \tag{10}$$

In this case the manoeuvre doesn't produce interference on the flow.

b) the first interval that occurs has length of y<T, is however refused by the vehicle that wants to enter into the flow, and the waiting process continues. The conditioned probability that the first interval is inferior to T and the service time is still less or equal to it is expressed by F_v (t-y), while the unconditioned probability is given by the product of F_v (T-y) and of the probability that an interval occurs in the neighbourhood dy of y:

$$F_v(t-y)\frac{kQ}{(k-1)!}(k\cdot Q\cdot y)^{(k-1)}e^{-kQy}\,dy \tag{11}$$

The probability that v≤t is obtained by summing the probability expressed by (10) and the integral sum of (11):

$$\begin{aligned} F_v(t) &= F + \int_0^T F_v(t-y) = \\ &= \frac{kQ}{(k-1)!}(k\cdot Q\cdot y)^{(k-1)}e^{-kQy}\,dy \end{aligned} \tag{12}$$

The probability density function f (t), of the stochastic variable v. corresponding to the distribution function F (t), is:

$$\begin{aligned} f_v(t) &= f(t) + \int_0^T F_v(t-y) = \\ &= \frac{kQ}{(k-1)!}(k\cdot Q\cdot y)^{(k-1)}e^{-kQy}\,dy \end{aligned} \tag{13}$$

Operating the Laplace transform of both members of (13), and utilizing two of the properties of the transformed functions of stochastic variable [10], we obtain:

$$E[v] = T + \frac{e^{kQT} - \sum_{i=0}^{k}(k\cdot Q\cdot T)^i}{Q\cdot\sum_{i=0}^{k-1}\frac{(k\cdot Q\cdot T)^i}{i!}} \tag{14}$$

$$Var[v] = (E[v]-T)^2 + \frac{(k+1)\cdot[e^{kQT} - \sum_{i=0}^{k-1}\frac{(k\cdot Q\cdot T)^i}{i!}]}{k\cdot Q^2\sum_{i=0}^{k-1}\frac{(k\cdot Q\cdot T)^i}{i!}} \tag{15}$$

Known the average and the variance of the stochastic variable "waiting time for admission", we can assume a normal distribution for that stochastic variable.

For the way in which we defined the stochastic variable v, the function of distribution is limited on the left in correspondence of the lower value of the waiting time for admission (that for hypotheses is equal to the critical time T).

The relative probability function, with the constraint that the integral sum between TMM and ∞ must be one, analytically is:

$$g_v(t) = \frac{1}{(1-G(TMM))\sqrt{(2\pi Var[v])}}\cdot e^{-\frac{1}{2}\left[\frac{t-E[v]}{\sqrt{Var[v]}}\right]^2} \tag{16}$$

where G(TMM) is the value assumed by normal distribution (of average value and dispersion given respectively by (14) and (15) and unlimited on both side) at the point t = TMM.

The Figure-1 shows the curves of density of probability expressed by (16) by varying the intensity of traffic flow; it is possible to evaluate that, by increasing the flow, the average waiting time and the dispersion of stochastic variable have also an increase.

We suppose that the driver, who wants to enter into the flow, has a limited availability to wait; this is equivalent to admit the existence of a range of time of patience defined by means of its average values, which we shall indicate with TMP, beyond which, the manoeuvre of admission is however, carried out.

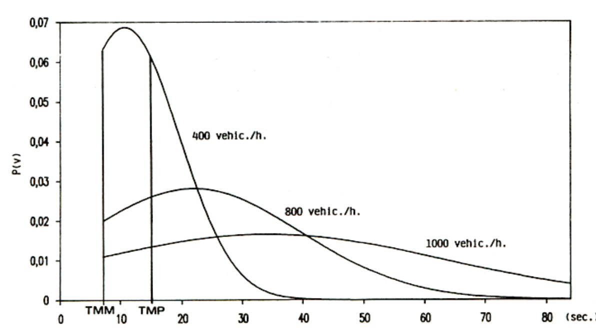

Figure-1. Curves of density of probability (TMM = 7s.).

With reference to Figure-l, the percentage of manoeuvres that cause delay onto the flow, therefore

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called interfering, is the area subtended by the curve of density on the right of the value TMP.

Also, if the flow increases, the average of waiting times approach the point of passing the TMP value, with the consequent increase of the percentages of manoeuvres that interfere with flow.

Analytically the percentage of the manoeuvres interfering (that is also the probability that a certain manoeuvre interferes) is:

$$p(v > TMP) = \int_{TMP}^{\infty} g_v(t)dt \tag{17}$$

We assume that the blockage, provoked by a manoeuvre that interferes with the flow, is analogous to that one generated by a red traffic light phase which has a duration equal to TMM. In consequence, the total delay on the flow, caused by each manoeuvre, with the added hypothesis of constant arrivals and in conditions of not saturated flow, is expressed by:

$$w = \frac{TMM^2 \cdot Q}{2 \cdot (1 - Q/S)} \tag{18}$$

Where:

w = total delay on the flow due to the single interfering manoeuvre of admission with duration w equal to TMM.
S = lane capacity, computable with the relation S = 525. L_u.

The number of vehicles of the flow that suffer delay for a single interfering manoeuvre is:

$$m = TMM \cdot \frac{S \cdot Q}{S - Q} \tag{19}$$

In the hypothesis of independence of the phenomena, the total delay, that a number n manoeuvres generate on the flow has the relation:

$$d_t = n \cdot P(v > TMP) \cdot w \tag{20}$$

where n is the number of manoeuvres per unit of length of the road and of the time [manoeuvre/h km].

The specific delay, per unit of length of the road, endured by the generic vehicle belonging to the flow, is in an explicit way:

$$d_s = \frac{n \cdot P(v > TMP) \cdot w}{Q} \tag{21}$$

and in an implicit form is a function of the type:

$$d_s = d_s(Q, n, T, TMP) \tag{22}$$

The equations (20) and (21), in reference with the flow Q are represented, respectively in Figures 2 and 3; where it is assumed L_u = 2, 30 m., TMP = 15 sec. and n = 100 manoeuvres/h km, while for TMM the values 6, 7 and 8 sec. are chosen.

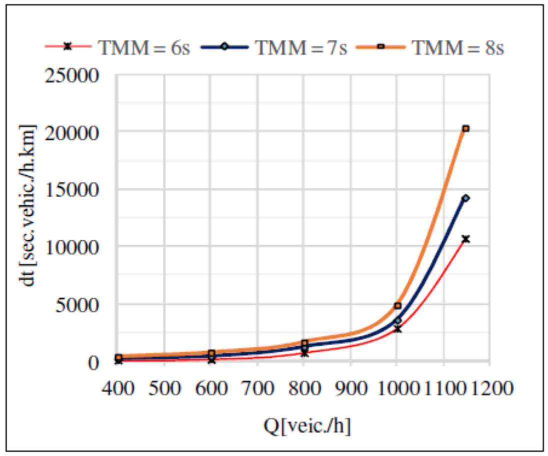

Figure-2. Total delay (L_u=2,30m. TMP=15 s. n=100 man./h. Km).

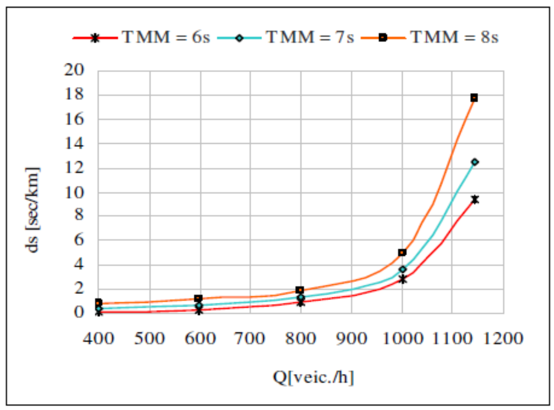

Figure-3. Specific delay (L_u=2,30m. TMP=15 s. n=100 man./h. Km).

THE DELAY PROVOKED BY THE MANOEUVRES OF DIVERSION FROM THE FLOW

In the case of a manoeuvre of diversion from the flow (access to parking), the carrying out of the manoeuvre is essentially conditioned by the availability of the free place. When the manoeuvre is carried out, the modality of its execution generally does not depend on the fact that the service time exceeds a TMP value; so, marking the relative variables to the manoeuvre of diversion from the flow with an apex, the specific delay is given by:

$$d_s' = \frac{n' \cdot w'}{Q} \tag{23}$$

Or, in implicit form:

$$d_s' = d_s'(Q, n', T') \tag{24}$$

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and therefore generally the determination of d_s’ is simpler than that one of d_s.

To the effect previously described we must add the slowing down of the flow caused by low speed, normally maintained by vehicles in the phase of searching for a parking place.

The total entity of delay, and therefore of the contraction of the curves of down - flow, can be evaluated in real conditions once are known the average number n of admission’s manoeuvres in the vehicular flow and n' of diversion’s from the flow (in the further hypothesis of the sum of the effects).

SOME RESULTS OF THE PROPOSED MODEL

The evaluation of the average specific delay, described in an explicit way by (21) and by (23), and in a synthetic way by (22) and (24), also permits to express the relations of the down-flow (6), by means of (3), in function of the number of manoeuvres (per unit of time and length) of the exiting or the entering to the parking places distributed along the sides of the lane.

Some experimental measurements, in the urban area of Reggio Calabria, have permitted to determine, for TMM, a range of values between 6 sec., for parking in line, and 8 sec. for parking in a comb line; while the average value of waiting time for admission (TMP) has been estimated in a range of values between 11 sec. and 15 sec.

In particular, for parking in line, is obtained:

TMM = 2,285 + 0,006862• Q with R^2 = 80, 52% and F a lot superior of critical value;

TMP = 7, 789 + 0, 005766• Q with R^2 = 79, 92% and F a lot superior of critical value; in this case the percentage of interfering manoeuvres is:

P = - 0, 051 + 1, 118Exp-3Q

Instead, for parking in comb, the linear regression becomes:

TMM = 3, 862 + 0, 006872• Q with R^2 = 73, 83% and F a lot superior of critical value;

TMP = 9, 955 + 0,004028• Q

With

R^2 = 79, 13% and F a lot superior of critical value; in this case the percentage of interfering manoeuvres is:

P = - 0, 056 + 1, 124Exp-3Q

From now on, we look at the relation V_c (Q) as function of the specific delay distributed along the road caused by the manoeuvres of exiting from the state of parking. The expression of the model:

$$v_c = \frac{v_r}{1 + d_s(Q, n, T, TMP) \cdot v_r} \tag{25}$$

We have utilized, to describe the function v_c (Q), same prefixed values of L_u, T, TMP with different numbers n of manoeuvres in the unit of time.

In particular the Figures 4, 5 describe a representation of (25) referring to the values of useful width considered in the model (6) and to the function of delay (21) with n; 130, 260 and 400 [manoeuvres/h. km.] having assumed TMM = 8 sec. and TMP = 15 sec.

A CASE OF STUDY: EXPERIMENTAL RESULTS

In the following Tables (1, 2 and 3) are shown the results obtained in terms of v_r-v_c [Km/h].

The values of TMM and TMM’ are derived from the experimental analysis carried out for the three cases considered, in correspondence of several levels of traffic flow and the value of lost time (in addition to manoeuvre) was assumed equal to 7 sec.

The values, experimentally obtained and processed by means of the interpretative model (25), show that, in correspondence to a given value of flow, the functional decay can be displayed as the "vertical leap" between two down-flow curves in correspondence of two different values of n, or in correspondence of two different situations of width of the roadway (Figure-4 and Figure-5).

This decrease of the speed also depends by the values of experimental parameters TMM and TMP.

Table-1. Calculation of specific delay and consequent reduction of speed [Km/h] to vary the flow for n = n’ = 130 [man./h ·km] (low degree of disturbance).

Q [veic/h]	**v_r**	**P**	**TMM** [s]	**Re** [s]	**d_s** [h/Km]	**TMM'** [s]	**Re'**[s]	**d_s'** [h/Km]	**v_r-v_c** [Km/h]
400	39,66	0,50	5,03	12,03	8,05E-5	3,75	10,75	7,36E-4	1,25
600	37,07	0,62	6,40	13,40	8,18E-4	3,75	10,75	8,50E-4	2,16
800	33,45	0,95	7,77	14,77	1,81E-3	3,75	10,75	1,01E-3	2,88
1000	28,78	1 ,00	9,15	16,15	2,78E-3	3,75	10,75	1,24E-3	3,00
1200	23,07	1,00	9,15	16,15	3,59E-3	3,75	10,75	1,59E-3	2,47

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Table-2. Calculation of specific delay and consequent reduction of speed [Km/h] to vary the flow for n = n' = 260 [man./h ·Miles] (intermediate level of disturbance).

Q [veic/h]	$\mathbf{v_r}$	**P**	**TMM** [s]	**Re** [s]	$\mathbf{d_s}$ [h/Km]	**TMM'** [s]	**Re'** [s]	$\mathbf{d_s}$' [h/Km]	$\mathbf{v_r}$-$\mathbf{v_c}$ [Km/h]
400	39,66	0,50	5,03	12,03	9,21E-4	3,75	10,75	1,47E-3	3,45
600	37,07	0,62	6,40	13,40	1,64E-3	3,75	10,75	1,70E-3	4,09
800	33,45	0,95	7,77	14,77	3.63E-3	3,75	10,75	2,01E-3	5,31
1000	28,78	1,00	9,15	16,15	5,56E-3	3,75	10,75	2,47E-3	5,41
1200	23,07	1,00	9,15	16,15	7,71E-3	3,75	10,75	3,18E-3	4,64

Table-3. Calculation of specific delay and consequent reduction of speed [Km/h] to vary the flow, for n = n' = 400 [man./h ·Miles] (high degree of disturbance).

Q [veic/h]	$\mathbf{v_r}$	**P**	**TMM** [s]	**Re** [s]	$\mathbf{d_s}$ [h/Km]	**TMM'** [s]	**Re'** [s]	$\mathbf{d_s}$' [h/Km]	$\mathbf{v_r}$-$\mathbf{v_c}$ [Km/h]
400	39,66	0,50	5,03	12,03	1,42E-3	3,75	10,75	2,27E-3	5,06
600	37,07	0,62	6,40	13,40	2,52E-3	3,75	10,75	2,62E-3	5,94
800	33.45	0,95	7,77	14,77	5.58E-3	3,75	10,75	3,10E-3	7,53
1000	28,78	1,00	9,15	16,15	8,55E-3	3,75	10,75	3,79E-3	7,54
1200	23,07	1,00	9,15	16,15	1,11E-2	3,75	10,75	4,89E-3	6,22

With reference to the Figure-5, at a level of flow equal to 800 veic/h, there is a reduction of speed, compared to the condition of absence of interference, in conditions of low-level of interference (n = n = 130 m/h. km) equal to 2.88 Km/h.

At average level (n = n = 260 m/h. km) the reduction of speed is equal to 5.31 Km/h and, finally, at high level (n = n = 400 man/h. km) it is equal to 7.53 Km/h.

The analysis may be generalized, with respect to other causes of circulatory flow disturbances that can affect the urban road network such as:

- Presence of access to remittances or garages;
- Crosswalks non- adequately signalized;
- Presence of tramway in non-exclusive or protected spaces;
- Excessive heterogeneity in vehicular flow for a non-functional classification and regulation of streets;
- Defects in the regulation, in signalling and in sizing of road venues;

These elements contribute to the functional decay of security and, in some cases, even to that of environmental quality.

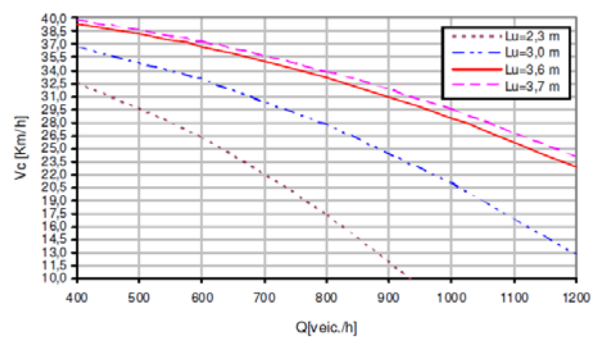

Figure-4. Down-flow curves validate urban roads for several useful width of the lane in the absence of disturbance due to presence of interfering with flow manoeuvres.

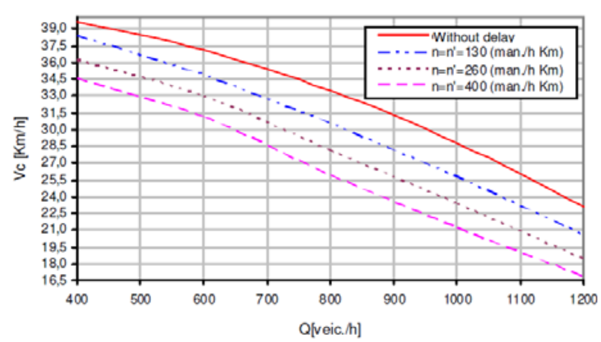

Figure-5. Downflow curves for Lu = 3, 60 m, TMM = sec, TMP = 15 sec. in the presence of different levels of delay due to number of manoeuvres per hour and per kilometre.

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This fact points out that for increasing flows of traffic the duration of the average time of patience would not have any importance.

From the comparisons of those curves and the curves represented in Figure-4 it is possible to evaluate the larger effect, being equal the other conditions, due to the parking accesses with respect to that ones of admission into the flow.

In the same light some authors [12, 13, 14, 15] have already pointed out the importance of the effect that different functions of congestion of the links can produce on the equilibrium trip assignment.

However, the proposed model can already find useful application in many urban roads and intersections characterized by elevated phenomena of congestion caused also by the presence of lateral obstacle distributed along the route [16, 17, 18 and 19].

ENVIRONMENTAL IMPLICATIONS

Parking activities and delays in traffic flows directly result in environmental drawbacks, essentially consisting in an increasing of pollutant emissions, due to the extra time during which engines run while vehicle is standing.

The evaluation of the average specific delay, expressed in an explicit form by Equation (21) and by Equation (23), also permits to express the characteristics of the down flow as a function of the number of involved manoeuvres per unit of time and length. In other words, v_c (Q) is expressed as a function of the specific delay distributed along the arterial road by Equation (25).

Figure-5 reports a sketch of different times involved respectively in covering a line without and with flow disturbances.

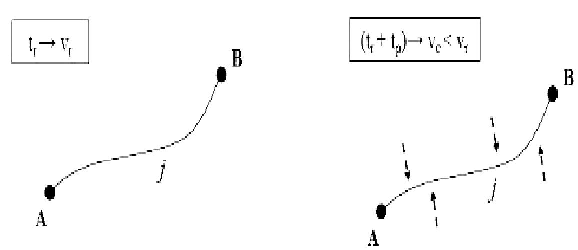

Figure-6. Running Times for line without (left) and with flow disturbances.

In the scientific literature this problem has been widely approached [20, 21, 22], especially in the urban contexts. Generally, the specific pollutant emissions of a vehicular emissive class are expressed by means of the emission factors that represent the amount of pollutants emitted by the average vehicle representative of a given class for a unitary length of journey. For example, in the EMEP/EEA air pollutant emission inventory guidebook 2009 [23], vehicles are classified by type (cars, heavy vehicle, motorcycles, etc.), fuel feeding the engine, age and engine capacity (with regard to commercial vehicles, only differences in weight are considered).

Therefore, for each homogeneous emissive category and for each pollutant, emission factors assume the following form:

$$EF_{ijhkl} = \frac{a_{ijhkl} + c_{ijhkl}\, v + e_{ijhkl}\, v^2}{1 + b_{ijhkl}\, v + d_{ijhkl}\, v^2} \tag{26}$$

Where v is the journey average speed [m/s] of vehicle, i represents the i-th pollutant, j the vehicle type, h the age (assessed with respect to the European Emissions Standards), k the fuel and l the engine volume (or vehicle weight).

The emission factor is expressed in grams of pollutant per vehicle and per kilometre (g vehicle^{-1} km^{-1}) while the values of the coefficients a, b, c, d, and e are derived from EEA [23].

Thus, pollutant emissions of a given class of the vehicle fleet circulating in a given context, E_{ijhkl} (g), is expressed by means of the following equation:

$$E_{jihkl} = EF_{jihkl} \times N_{jihkl} \times L_{jihkl} \tag{27}$$

Where:

EF_{ijhkl} (g vehicle^{-1} km^{-1}) is the pertinent emission factor, N_{ijhkl} (vehicle) is the number of vehicles belonging to each homogeneous emitting class of the considered fleet and L_{ijhkl} (km) is the average length of the typical journey [24, 25, 26, 27, 28].

CONCLUSIONS

The purpose of this study is an interpretative model, which would permit to evaluate, in a quantitative form, the effect of lateral disturbances distributed along a route on the average speed of the trip.

Therefore, a stochastic type of model, as a function of the number of manoeuvres of admission into the flow, or diversion from the flow, carried out in a unit of length and time, is developed to evaluate the entity of total and specific delay that vehicles cope with by running on a lane adjacent to parking places.

The entity of the delay met by each vehicle on account of the effect of a manoeuvre of admission into the flow is evaluated in function of the probability that the waiting time of the driver coming out from a parking place exceeds a limit denominated "time of patience".

In fact, beyond that time, the same driver will however come into the flow causing a slowing down or a blockage on the lane for a duration equal to the time of the manoeuvre.

The formulation of the model has required some explanatory hypotheses among which, for instance, the assumption that the stochastic variables "waiting time of admission" is of a Gaussian type.

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The possibility of using other distributions such as, for example, the Gamma in its figurative form, known as Pearson of the 3th type, has been evaluated.

However, in this phase, the evaluation of the entity of delay met by the vehicles of the flow would seem to be quite closer to that one obtainable by means of the Gaussian type, at least for the values of the parameter considered in the present paper. That even if the mentioned Pearson distribution is more in keeping with the nature of the phenomenon and more adherent to the distribution of the waiting time frequencies obtained by means of computer simulations,.

On the other hand, the environmental implications of the delay times, induced by such flow disturbances, are related to composition of the running vehicular fleet in a given urban context.

Further development of the study will permit to better verify even the validity of the other hypotheses underlying the model and above all the experimental findings of TMM and of TMP for a correct applicability of the model itself.

Moreover, the suggested methodology may be useful for computing another term of the function of cost of a road link, and may intervene in the determination of the equilibrium trip assignment in a transport network.

Further, the model can be useful applied to traffic policy in order to evaluate the opportunity to permit the parking along the road, especially in congested central areas.

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