SPEED ANALYSIS ON URBAN ROADS

Capaldo Francesco Saverio
Researcher and assistant professor – University Federico II of Naples, Department of Transportation Engineering – fcapaldo@unina.it

ABSTRACT

Speed analysis on urban roads sections start from need tied up to traffic assignment models in urban networks: to calculate the average running time in a road section it is necessary to have a good evaluation of average running speed for that road section. First experimentations for the study of drivers «realized» speed (for rural roads) have been published already in 1988. In 1997 it has been published a first expression for «realized» speed in function of curvature (1/R) and of absolute value of the longitudinal road gradient for some typologies of common rural roads.

Most greater number of road accidents occurs in city and the gravity of these, often also for urban roads, comes from transit speed. The transit speed in road safety study cannot be the average speed (like for traffic assignment models) but be «realized» one, defined as the 85° percentile of the speed data distribution.

In this work it has been considered a number of urban roads with definite characteristics and the effected measurements have allowed to define coefficients for an interpolating speed function. It is carry out, besides, spot speed measurements and, for the same location, average speed measurements (measuring the running time on the whole road) in order to value differences for both methodologies.

The significant, even if partial results, will show in the paper.

Keywords: road safety, driver behaviour, running speed, realized speed.

1. INTRODUCTION AND AIM OF WORK

The speeds analysis on sections of urban road rises from needs tied to assignment models of transportation demand for the urban networks. Time used from a vehicle to go through a stretch between two intersections is function, more than by the traffic flows, also by geometric road characteristics and by the presence of possible noise factors for circulation (Davidson, 1966). In order to calculate the average running time for the road stretch, excluding time lost one at intersections, it is necessary have a good evaluation of the average running speed. They are, then, an evaluations of the average value of the measured speed (Greenshields, 1934; Festa e Nuzzolo, 1990).

For rural and highway road, instead, study of speeds of the drivers on stretch of road has seen the publication of the first experimentations, in Italy, already in the 1988 (Capaldo et al., 1988) and, in the 1997 (Capaldo et al., 1997) it has let the determination of a first expression for the calculus of the speed «realized» for drivers in operation only of any geometric characteristics of the layout what the road element curvature (1/ R) and the absolute value of longitudinal gradient in percentage (|i%|). This relationship was, and remain, valid for rural roads kinds very diffused. In this case it is a correlation on the 85° percentile for the distributions of the surveyed speeds.

Great number of roads accidents verifies in city and the gravity of consequences, in town like in extraurban situation, is tied up to transit speed. More elevated speeds are reached in city when the conditions of flows «seem to authorize» (especially low flows, nighttime etc.). Also in city, then, the determination of the stretch speed, if considered for study of road safety, it could not be the relative one to the average value (like in assignment models) but, rather, it must be that «realized» before definite.

In this work, departing from a study for average running speed and traffic flows (Festa and Nuzzolo, 1990), have been considered some urban roads (in city of Naples and Salerno province) with define characteristics and the measurement of speed have allowed to calibrate an interpolating function for the averages transit speeds and regards the road stretch characteristics.

For the same roads has been derived and calibrated even an interpolating function for the «realized» speeds (85° percentile of speeds distribution).

For some locations, besides, it has been led a double measurements series with spot measure (on a section of road stretch) and of average type (measuring the time of transit average on the whole road length) to estimate differences between the two relief methodologies.

Results of this great number of experimentations could be illustrated only partially in this work.

2. TRAFFIC FLOW DATA ACQUISITION METHODOLOGIES

Relief of the circulation characteristics with a human operator be valid when it is necessary short preventive studies in a road sections in which different survey systems will be installed later, systems whose installation costs not would justify a temporary employment. Considered limits imposed by the acquisition with observer, it have developed various automatic systems for the acquisition of flows parameters. Today no one of used methods could be compared for versatility and quantity of information processes to a direct observation, but, opposite, the automatic systems don't present disadvantages due to the operator fatigue.

Different systems could distinguish themselves in three categories for the principal characteristics of the used transducers, intending as transducer an any able device of change a form of energy in an other. Three categories include transducers of presence (or proximity), of movement and of image. In Figure 1 some traducers more used, according to the suggested categories, have showed.

For all kinds of illustrated devices, to exclusion of the systems to images recording, exist some problems to installation and limits tied up to survey technology. They could not be used in those cases in which it is not proposable an flow interruption, not even limited to installation period, or when doesn't exist authorization to breaking road infrastructure or results difficulty provide to supply, to protection from human and meteorological agents of recording devices. It is a good standard that sensors have hide more carefully to avoid that the drivers, realizing the point of measure, they could alter the behaviour that would adopt naturally in the same environmental conditions (in practice slow down).

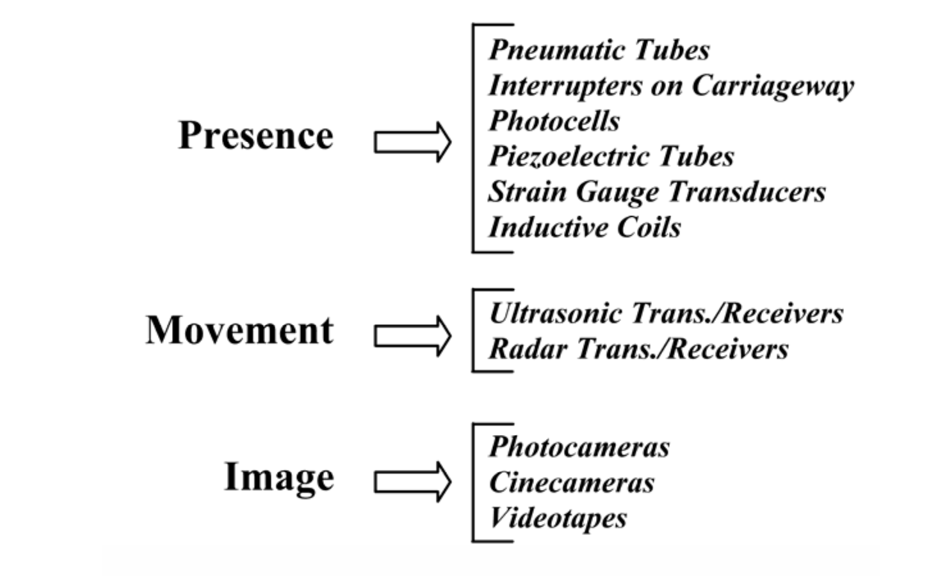

Figure 1 Some categories of transducers

Suitable systems have an elevated reliability if collocated at roads sections with uninterrupted traffic flows. Control of vehicular flows at intersections has greater difficulty of installation, directly proportional to number of manoeuvres that want have under control. It in this case becomes fundamental plan with extreme attention both the choice of the intersection and the location of the single transducers.

Finally the illustrated systems produce, as result, a numerical value that expresses the greatness measure in examination but once gotten this value it is not more possible know if it has been or less result of a correct event (a vehicular passage or an interference).

At end, shown two Tables in which have resumed the kinds of possible surveys with described transducers. The Table 1 furnishes indications on the kind of placing and on the kind of surveying presences. The Table 2 resumes kinds of practicable measurements in a direct and in an indirect way.

The adopted classification is only one of the all possible. At the inside of the same transducers family (for instance those ultrasonic or radar) it would be possible divide transducers in fixed or mobile. Those fixed, still, could be classified in above ground and under ground. The kind mobile and above ground, for instance are the videotapes used for greater part of data acquisitions for this work.

Table 1 Kind of measure point and detectable presences

Measure for	***Vehicle presence***			***Vehicle kind***		
Survey kind	***Area***	***Section***	***Lane***	***Area***	***Section***	***Lane***
Manual recording	**X**	**X**	**X**	**X**	**X**	**X**
Pneumatic tubes		**X**				
Interrupters on carriageway		**X**				
Capacity		**X**	**X**		**X**	**X**
Induttance		**X**	**X**		**X**	**X**
Photocells		**X**				
Ultrasonic		**X**				
Photocameras	**X**	**X**	**X**	**X**	**X**	**X**
Videotapes	**X**	**X**	**X**	**X**	**X**	**X**
Images treatment	**X**	**X**	**X**	**X**	**X**	**X**

Area: measured on area
Section: measured on section
Lane: measured for separate lanes

Table 2 Kind of measure take in direct or in indirect way

Survey kind	***Density***	***Speed***	***Acceleration***	***Gap***
Manual recording	**I**	**I**		**I**
Pneumatic tubes	**I**	**I**		**I**
Interrupters on carriageway	**I**	**I**		**I**
Capacity		**D**		
Induttance		**D**		
Photocells		**I**		
Ultrasonic	**I**	**D**		**D**
Photocameras	**D**	**D**	**D**	**D**
Videotapes	**D**	**D**	**D**	**D**
Images treatment	**D**	**D**	**D**	**D**

D: direct measure
I: indirect or derivate measure

3. UTILIZED METHODOLOGIES

A lot of the experimental data acquisition has been realized using, as it have advanced at point 1, for the most part apparatuses recording images sequences (videotapes or videorecorder) and in second order, and only for a control, human operators provided with transceivers.

Installation and use of a camera, today, don't present no particular problem. Being, however, a video recording that must furnish measures it is necessary take some simple precautions. It have been always necessary a some care for selection of the place where position the videorecorder: there it was the possibility of have a good point of view to the measure and, at the same time, the apparatus was few visible from the road to avoid to alter the drivers behaviour if they notice the apparatuses (Capaldo et al., 1998). In the recording scene, that has been kept fixed with help of a stand, it is been definite a base of measure (different for the different survey sites) with lengths about from the 30 to 40 meters that has been divided in elementary stretch with four sights at measured distance on which have been read the transit times for single vehicles, superimposed on recording, with seconds and cents of second. The data extraction phase remains, still with this particularly economic and versatile technique, the more expensive one.

The different finishing line it has been used for the recording the transit vehicles time that, with next elaborations, have furnished: number of transit vehicles, gaps, speeds and accelerations. The measured speeds on stretch so short it could be considered instantaneous speeds. The measures of acceleration have helped as control: an average value of acceleration next to the zero has guaranteed measurements of speeds at positions sufficiently with low noise.

As these precaution, how the taken one for the accelerations control is really effective, it could have established only with a direct comparison between the same measured greatness with different methodology.

Definition of the second measure methodology has been done for steps. It has been thought that is possible proceed to a control with manuals traffic flows recording. This way to operate has furnished partial results. The operators must recognize every single vehicle (at least for manufacturer, model and color) in entrance and gotten out at the road section on examination, they must be communicated the information by radio reciprocally and record transit times, so the data collectors have worked only with low traffic flows; with higher flows operators have begun to «lose» some and then too many vehicles.

For obtain effective results it has been decided to work with synchronized videorecorders placed at the beginning and at the end of stretch to control. In this way the same operations could have made with the due calm and it has been possible get ulterior measurements for the flows also. Clearly the problems that exist for the correct positioning of an only videotape has been multiplied with the consequent necessity of maintain synchronizations through recordings.

4. EXPERIMENTAL STUDY

Experimental investigation, departing from the cited work, has examined in all nine survey sites. The analysis has been concentrated over road stretch for which the vehicular flow has not influenced with vehicles march in opposite way. It have been examine roads with only way and an only lane.

4.1 Running speed model

For determine the running speed it has been proceeded to calibration of relationship among the running speed (*Vr*) and the variables that more have seemed to influence the determination of the speed. Applying the least square method to the experimental base data (described to the following point 4.3) it has been derived coefficient for a relationship like:

$$V_r = V_r(Q, Lu, P, T, D, I) \qquad \text{(Eq. 1)}$$

with:

V_r = running speed (km/h);
Q = traffic flow equivalent in passenger cars (pc/h);
L_u = section available width (m);
P = average longitudinal slope (i%) in absolute value;
T = stretch tortuosity grade (from 0 to 1 in four steps);
D = stretch trouble grade (from 0 to 1 in four steps);
I = minor intersection number for km.

The stretch tortuosity grade (T) has been definite with four steps from 0 to 1 in function of the existing curvature radiuses on the stretch: a rectilinear road has a tortuosity grade equal to 0, a road with curvature radiuses of about 25 - 30 m has a tortuosity grade of equal to 1. Also the trouble grade (D) has been definite with four values from 0 to 1. It has connected to the presence or less of factors that could cause trouble to the normal vehicles flow as: vehicles paused or frequently halted (for agreed to shops or other), presence of bus stops, pedestrians on the roadway, lateral accesses to blocks of houses etc. It is a factor rather subjective and has been valued with caution and, possibly, in a homogeneous way for all the experimented roads.

For each road it have been calculated coefficients for the model that interpolates the speed data with the flows (the superior part of the flow diagram for each roadstretch):

$$V_r = V_0 + bQ^2 \qquad \text{(Eq. 2)}$$

with:

V_r = average spot speed variable with flow (km/h);
V_0 = average spot speed with zero flow (km/h);
b = regression coefficient
Q = traffic flow equivalent in passenger cars (pc/h).

It have been utilized the flows (intensity of traffic) for intervals of 5 minutes to keep control with the reference work. The equivalent traffic flows have been calculate assigning to heavy vehicles a equivalence coefficient equal to 2.

Successively it has been gone to definition and to calibration of the model pointed out with Eq. 1.

4.2 «Realized» speed model

To determine the «realized » speed it have been calibrated a funtional relationship like as:

$$V_{85} = V_{85}(V_0, Lu, P, T, D, I) \qquad \text{(Eq. 3)}$$

with:

V_{85} = realized speed: 85° percentile of spot speed (km/h);
V_0 = average spot speed with zero flow (km/h);
L_u = section available width (m);
P = average longitudinal slope (i%);
T = stretch tortuosity grade (from 0 to 1 in four steps);
D = stretch trouble grade (from 0 to 1 in four steps);
I = minor intersection number for km.

The expression of the Eq. 3 is similar to the Eq. 1 but less factors that concern the variation of circulation flows on road. The wanted speed is, as remembered already, a value that could be realized prevalently with low flows conditions.

Also the values adopted for the other factors remain unchanged.

4.3 Experimental data base

The experimental data base now concerns eight stretch of roads with only lane, for a total of more than 10,000 speed determinations with the spot method. For two roads it has been led also an investigation to determine average speed on road with cameras and videotape synchronized for a total of 1,000 transit. The Table 3 refers to the geometric characteristics in order to the analyzed roads.

Table 3 Roads characteristics

Road		***La***	***P***	***T***	***D***	***I***
		m	i%			
1	Nicotera	2,5	-5,4	0,00	1,00	2
2	Arenella	3,0	0,0	0,33	0,33	1
3	M. C. di Savoia	3,0	-6,8	0,33	0,33	1
4	Innamorati	3,5	0,0	1,00	0,33	2
5	M. Polo	3,5	1,5	0,00	0,66	0
6	Indipendenza	3,5	0,0	0,33	1,00	1
7	Arpino	4,0	1,0	0,00	1,00	1
8	Lepanto	4,5	0,0	0,00	0,66	0
9	Bernini	4,0	1,7	0,00	0,33	0

4.4 Statistical value for distribution and flow diagrams

For calculations it has been necessary use any statistical determinations of speed distributions recorded for each experimentation site, particularly have been use the average speeds (as average of the spot speeds) derived from the transit times of the vehicles over sight. As control parameter, having more than finishing line for each relief, it have also been derived from speed differences values of average acceleration that have been compared.

In the Table 4 has reported, in the columns from 2 to 5, the average speed value, the standard deviation, the coefficient of variation (ratio between the standard deviation and the average) and the V_{85}, calculated as the 85° percentile of the speeds distribution supposed like normal (*Vm*+ 1.04 *Std. Dev.*). In the same Table 4, to the columns 6 and 7, it have been shown also the relative coefficients of the quadratic regressions for the Eq. 2.

For any sites average speeds results greater than speed with zero flows (V_0) calculate with the Eq. 2. Similarly for other places it is been calculate the 85° percentile of speed distributions greater than V_0. For this the coefficients of the correlation relationship for the running speed have been calculated using an *Vm* equal to the speed for a traffic flow of 600 pc/h. For the «realized» speed the used value, as control, for the V_{85} is that of the speed calculated for a traffic flow of 200 pc/h.

Table 4 Characteristics values of distributions and coefficients for Eq. 2

Road	***Vm*** km/h	***St. Dev.*** km/h	***C. var.***	***V_{85}*** km/h	***V_0*** km/h	***b***
Nicotera	14,50	4,40	0,30	19,08	16,10	9,81100E-06
Arenella	19,18	5,51	0,29	24,91	19,51	9,00000E-06
M. C. di Savoia	18,10	4,40	0,24	22,68	17,60	6,09000E-07
Innamorati	23,35	6,44	0,28	30,04	26,38	1,24940E-05
M. Polo	24,97	6,02	0,24	31,23	25,57	3,74680E-06
Indipendenza	23,56	5,84	0,25	29,64	24,63	9,47150E-06
Arpino	36,46	9,72	0,27	46,57	40,08	6,08190E-06
Lepanto	32,68	9,05	0,28	42,10	37,69	5,16680E-06
Bernini	34,73	14,17	0,41	49,46	39,65	3,63120E-06

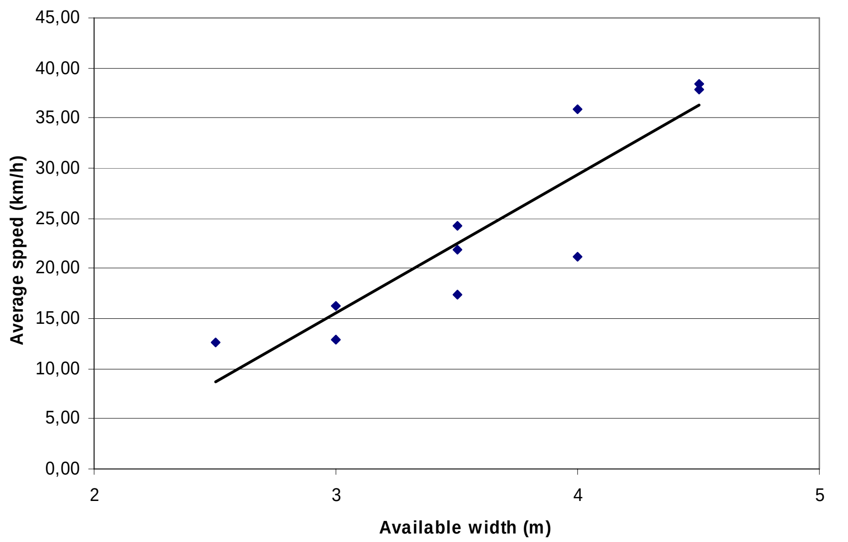

Figure 2 Influence of available width on average speed

4.5 Factors that influence the speed

The speed with which an user decides to run an road stretch is a random value that depends on many behavioural factors not all controllable with mechanical or technical methods. His study (speed as vector the speed could have a direction and an intensity) could help in the understanding of the complex phenomenon of the road flow. In this work the vehicles trajectories are not considered but only the determinations of the speed values. The speed held from a driver in city is, considered the low maximum values recorded, few conditioned from the vehicles characteristics and more from those of the road environment. In the Figures 2 and 3 have reported, for example, the influence of two of the chosen parameters (available width of the road in meters and the absolute value of the longitudinal slope expressed in percentage) on the determinations of the average speeds for different experimental location.

The influence of the first parameter on the speed is positive: it to an increase of the road section width corresponds, basically, an increase of the average speed. The second parameter, instead, has a negative influence on the speed, both the road run with positive slope and with negative slope. The choice of the absolute value of the longitudinal slope appears appropriate. Similarly it is possible appreciate the influence or less of the other chosen parameters on the variation of the average running speed for experimental roads.

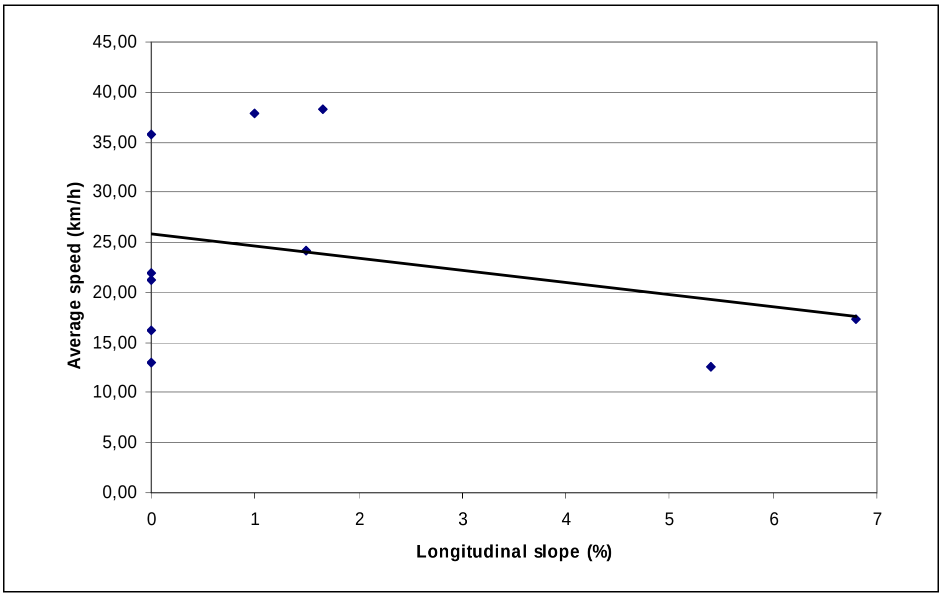

Figure 3 Influence of longitudinal slope on average speed

5. RESULTS

The final relationship for running speed utilized for the analyzed roads is:

$$V_r = a_0 + a_1 \cdot La + a_2 \cdot P + a_3 \cdot T^2 + a_4 \cdot D + a_5 \cdot I + a_6 (Q/La)^2 \qquad \text{(Eq. 4)}$$

and coefficients obtained with a correlation coefficient (R^2) greater than 0,9 are:

a_0	=	3,021146465	a_1	=	9,65729781
a_2	=	2,449831001	a_3	=	-20,67041357
a_4	=	-9,235356125	a_5	=	-2,645026975
a_6	=	-0,000221207			

In the Figure 4 has reported the variation of speeds with traffic flows for the two different suitable models with the Eq. 4 (*Vr(i)*) ed Eq. 2 (*V(i)*). The models behave in a congruent way also if they are much influenced by variations of traffic flows: they are roads with only carriageway and single lane for only way for which the possibility of overtaking doesn't exist and for those with measured lower speed (also with section of lower available width) the phenomenon is most accentuated. The indexes for the examples (i) refer to roads reported3 in the Table 3. It is possible to note, finally, as the Eq. 4 estimates the V_0 higher than models of Eq. 2.

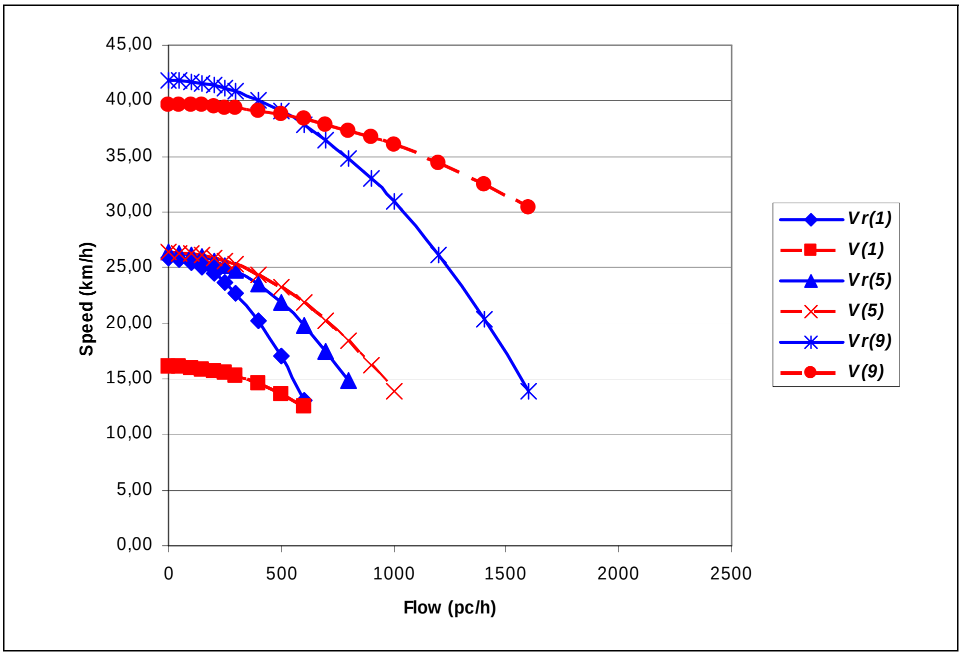

Figure 4 Variation for speeds with flows for the two models in Eq. 2 and Eq. 4 and for three experimental roads (1, 5 and 9)

The final relationship for «realized» speed utilized for the analyzed roads is:

$$V_{85} = a_0 + a_1 \cdot T + a_2 \cdot La + a_3 \cdot P + a_4 \cdot D + a_5 \cdot I \qquad \text{(Eq. 5)}$$

and coefficients obtained with a correlation coefficient (R^2) greater than 0,9 are:

a_0	=	3,211063764	a_1	=	-21,88519444
a_2	=	9,66039288	a_3	=	0,297450472
a_4	=	-13,93836462	a_5	=	1,15842973

Coefficients also in this case are congruent: particularly the coefficient relative to the longitudinal slope, used now in value and sign, with positive slope (a downhill road) increase the speed.

In the Table 5, have reported, for each experimentation, the both values of V_{85} calculated with the relationship Eq. 5, and those relative to the models Eq. 2 with a equivalent vehicles flow of 200 pc/h. Absolute differences (fourth column of the Table 4) aree very low, and not more than 4.82 km/h (Average 1,61; Std. Dev. 9,97); those relative (fifth column) don't exceed the 20% (Average 0,27; Std. Dev. 2,38).

Table 5 Comparison among «realized» speed for experimental roads

Road	V_{85}	V_{200}	ΔV	$\Delta\%$
	km/h	km/h	km/h	%
Nicotera	14,13	15,71	-1,57	-10,02
Arenella	21,53	19,15	2,38	12,42
M. C. di Savoia	18,27	17,58	0,70	3,97
Innamorati	27,82	25,88	1,94	7,51
M. Polo	22,21	25,42	-3,21	-12,65
Indipendenza	29,07	24,25	4,82	19,88
Arpino	37,48	39,84	-2,35	-5,91
Lepanto	37,55	37,48	0,07	0,18
Bernini	39,14	39,50	-0,37	-0,93

5.1 Differences between two kind of measurement

It has been supposed of can use the speed spot measures on a short stretch instead of those on all the road or, however on a relatively long stretch. That's why stretch has been chosen far from intersections and it have been check that the accelerations, in the next experimental sections, are next to zero. In order to compare speed values it have been repeated the investigations for Arenella road and for Lepanto road.

In the first case measures have been take with operators and transceivers. The continues communications between operators has allowed only measurements with very low traffic flows. In the second case, after a test without results with the same equipment and methodology, it has been preferred realize the analysis with videotapes spaced and synchronized.

In both cases the comparison with the measures effects in two different way has underlined differences inferior at 10 %. This value, considered the speed values in the urban flows, could be certainly considered acceptable.

6. REMARKS AND DEVELOPMENTS OF RESEARCH

In this work have been presented the preliminary results of a large sample survey that have been started already from some time. These results have allowed to elaborate, with a good, first approximation, two relationships. The first concerns the running speed of the vehicles on stretch of urban road, for roads to single lane and an only way. The seconds relationship, evidently for the same kind of roads, concerns the «realized» speed for vehicles in city when the traffic flows are very low and the drivers behaviour tied, essentially, to geometric factors.

For the running speed it has resulted that, in a different way from other works, is preferable calibrate more functions and formulas if the characteristics through roads are really different. Among the factors that influence the speed it has appeared correct use the absolute value of the longitudinal slope and not only the positive value of this.

The relationship for the «realized» speed is sufficiently accurate and will be used, as help in the study of the roads safety, to relate the speeds with the damages, as dead and injured, that the urban roads urban accidents cause to control the accidents severity tied to speed.

The comparison through different investigation methodology uses has demonstrated as the difference between the averages speed values measured, for the same location (smaller than 10 %), also for low value of recorded speed, could not justify the additional costs for a detailed sample survey for get more accurate result.

Both relationship are certainly improvable and the sample investigation will be wide for get more values for data base, both the urban roads with same features and for other.

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