Speed management in the freeway. Models for the esteem of V_{85} and FFS.

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ABSTRACT

Lately the conviction that for planning road elements it is more convenient, in terms of safety, to consider $\mathbf{V_{85}}$ is more consolidated. In fact $\mathbf{V_{85}}$ compared with theoretical project speeds , allows to render many verifications that are the basis of correct planning more effective. In technical literature various models for the estimation of $\mathbf{V_{85}}$ are present but they only regard highways and they are not extendable, less than remarkable approximations, in the freeway field. In this study we resume, in part, the contribution presented to XIII convention SIIV. An estimation model of $\mathbf{V_{85}}$ in freeway within conditions of not-conditioned flow was proposed. The database for the study was acquired through a series of speed and capacity surveys on a stretches of the A3 freeway by means of a fixed survey system. In particular, the surveys were carried out in 12 different sections placed in various geometric conditions.
The obtained model turned out to be very reliable one in the local area. In fact, the found maximum error in the estimation of A3 resulted as being within 4%.
Furthermore, with the same modalities used in order to construct the $\mathbf{V_{85}}$ estimation model, a second model was obtained that permits the estimation of speed to free flow (FFS) in various circulation conditions. The latter can be very useful in studies regarding freeway service levels.

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INTRODUCTION

The road user, when driving, demonstrates variable behaviour that is always a compromise between conditioning due to a series of external factors (road conditions, environmental conditions, etc.) and a series of personal factors [1] (prudence, driving ability, psycho-physical state, etc). The result of this compromise is the speed that he puts into effect. In some particularly favourable conditions, the speed put into effect coincides with that wanted. In other cases, where such conditions are less favourable, it is impossible to put into effect the speed desired and therefore he must proceed at a lower speed.
In this work different driving modalities when some external situations change have been studied. In particular, a series of surveys in various geometric conditions were carried out, thus permitting the identification of the sizes that influence $\mathbf{V_{85}}$ and FFS. With this information the models for the estimation of $\mathbf{V_{85}}$and **FFS** were built .

1. DATA USED IN THE STUDY

Data used in the study were found on an stretches of the A3 freeway (Salerno - Reggio Calabria) comprising between progressive 195,00 (Castrovillari - CS -motorway-exit) and 253,000 (Cosenza North – CS- motorway-exit). The geometric sizes measured in each section are represented in table 1.

Table 1

Route section N.	Date	Progressive road distance [km]	Direction	Longitudinal Grade [%]	Section-Lane width [m]	Curving (1/R) [1/m]	Tortuousness. ($\sum\alpha i/3$)* [grad/km]	State of paving	Transverse grade [%]	Distance of motorway-exit [km]
1	21/03/03	246,000	N	-2,0	10,7	0,0000	5,3	Dry	2,5	2,5
2	14/04/03	236,000	S	1,0	10,7	0,0000	5,3	Dry	2,5	2,0
3	30/05/03	236,600	S	1,5	10,7	0,0000	5,3	Dry	2,5	2,6
4	05/06/03	207,000	N	-0,5	8,7	0,0000	23,7	Dry	2,5	1,5
5	11/06/03	205,000	N	4,5	8,7	0,0000	24,7	Dry	2,5	2,1
6	18/06/03	205,000	N	4,5	8,7	0,0000	26,0	Dry	2,6	2,1
7	18/06/03	205,200	N	-4,0	8,7	0,0000	26,0	Dry	2,4	1,9
8	27/06/03	243,200	N	-1,0	10,7	0,0012	12,0	Dry	5,0	2,0
9	20/02/04	195,700	N	3,5	8,7	0,0014	28,0	Dry	5,5	1,2
10	21/02/04	209,500	N	0,1	8,7	0,0010	22,0	Dry	6,0	1,4
11	22/02/04	204,500	S	-4,5	8,7	0,0029	22,0	Dry	7,0	2,6
12	28/02/04	204,600	N	4,5	8,7	0,0029	29,0	Dry	7,0	2,7

* The meaning of this variable is showed in the paragraph 2.1

1.1 System for the survey of the vehicle speeds and flows

In every section in the first column of table 1 the survey station by means from which the capacities and speed of vehicles which passed in the interval "T" were placed. The survey station outline is represented in figure1. It is constituted by a digital television camera connected to a portable PC that permits the visualisation of images captured by the television camera. The system placed across the freeway section, as in figure 1, at a distance always greater than 25 meters, permits the filming of vehicles that pass in the chosen section. Knowing the distance between the three vertices, A,B and C represented in figure 1, it is possible to characterize "fundamental 1" that joins points 1 and 2 and "fundamental 2" that joins points 1' and 2'. With such information, under the hypothesis that along the two "fundamentals" there is uniform motion , it is possible to obtain the speed of the vehicles that pass along "fundamental 1" and " fundamental 2".

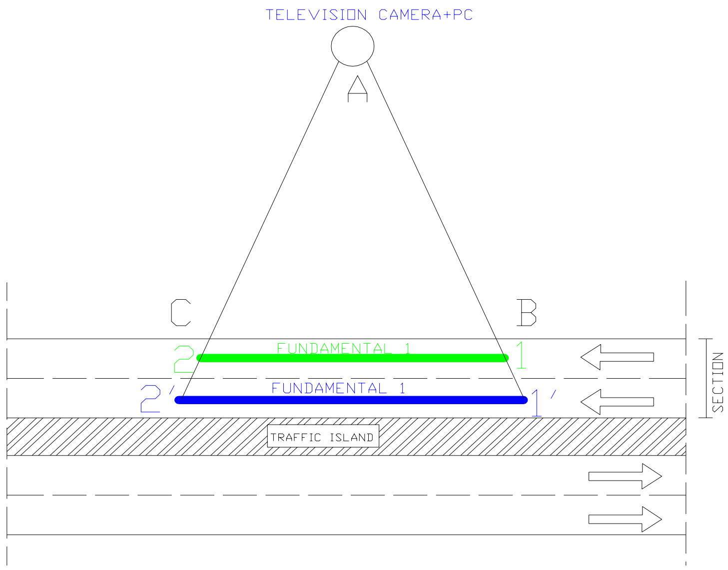

Figure 1

In fact, the PC is endowed with a card for the acquisition and elaboration of images that permits the reading of images with an advance of 1 frame for time (1 frame=1/25 of second). It is possible to count the number of frames necessary for the vehicle in order to cover one of the two "fundamentals". From the relationship between "fundamental" and the number of frames, the vehicle speed is obtained. For confirmation of the validity of the system and its calibration in each survey many controls were carried out. Three vehicles were made to cover one of the two fundamentals and their speed was noted. From the comparison between the speed measured with a tachometer and those measured by the system, the reliability of the latter was checked and the results were always acceptable.

1.2 Organization and elaboration of the data

The data acquired from the survey station has been organized according to the sequence represented in table 2.

Table 2

Vehicle label	Vehicle Type	T1 [sec+frame]	T2 [sec+frame]	Xi (Fundamental) [m]	ΔT=(T1-T2) [frame]	Speed =ΔT/ Xi [Km/h]	Gap label "i"	N. Vehicle in the "i" Gap [veic/min]	Avarage speed in the "i" gap (car only) [km/h]
1	Trailer lorry	9,18	10,19	23,85	26,00	82,56	1		
2	Car	21,12	22,10	23,85	23,00	93,33	1		
3	Car	36,9	37,03	23,85	19,00	112,97	1		
4	Car	38,23	39,12	26,29	14,00	169,01	1		
5	Lorry	49,17	50,17	23,85	25,00	85,86	1	5	125,10
6	Car	105,06	105,22	23,85	16,00	134,16	2		
7	Lorry	124,09	125,13	23,85	29,00	74,02	2		
8	Car	133,21	134,20	26,29	24,00	98,59	2		
9	Car	147,24	148,16	26,29	17,25	137,17	2		
10	Car	150,07	151,14	23,85	32,00	67,08	2	5	109,25

Subsequently the capacity of vehicles/minutes has been transformed into vehicles/hour. Furthermore, in order to take into account the presence of vehicles other than cars, the hour capacity has been transformed into an equivalent capacity. In order to obtain the equivalent capacity it was necessary to determine the coefficient of equivalence **ET** for each various grade condition. It was determined starting from the assumption that if two different vehicle capacities, calculated at two different intervals, determine the same average speed, then the relative equivalent capacities are the same. Therefore, characterizing the intervals that satisfy such a condition, ET was determined. Obviously both negative values and values inferior to one were discarded for obvious contrast with the ET mean. **ET** values are represented in table 3.

Table 3

Date	**Progressive of survey section [Km+m]**	**Longitudinal Grade [%]**	**Et**
21/03/03	246,000	-2,00	**1,70**
14/04/03	236,800	1,00	**2,25**
30/05/03	236,600	1,50	**1,85**
05/06/03	207,000	0,50	**1,92**
11/06/03	204,600	+4,00	**3,7**
18/06/03	204,000	+4,00	**3,7**
18/06/03	203,200	-4,00	**3,5**
27/06/03	243,200	-1,00	**1,96**
20/02/04	195,700	3,5	**3,5**
21/02/04	209,500	1,00	**1,9**
22/02/04	204,500	-4,5	**3,8**
28/02/04	204,600	4,5	**3,7**

Knowing the equivalent capacity and the average speed in each interval capacity classes capacity with an amplitude of 100 vehic/h were constructed; for each of these a second speed average, Vm2, was calculated, (table 4).

Table 4

Class	**Qeq [car/h]**	**Vm1 [km/h]**	**"i" Gap label**	**Vm2 [km/h]**
1400-1300	1400	106,96	36	113,91
	1380	120,87	10	
1300-1200	1200	100,68	44	100,68
1200-1100	1140	115,61	6	115,61
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200-300	240	122,19	46	122,75
	180	123,32	9	

With the data represented in table and in particular with Qeq and Vm2, for all 12 surveys, "speed-capacity" diagrams were created, and, in particular, the relations that connect Qeq with Vm2 were identified. Table 5, represents the equations that connect Qeq and Vm2 for every one of the 12 "speed-capacity" diagrams. Such equations have been used to calculate the FFS represented in the last column of table 5. The value of the intercept of these equations represents the free flow speed (FFS). However considering the shortage of relative points at low capacities and doubts on the linearity of the flow diagram, the value of the speed calculated in correspondence of one Qeq 300Veic/h was assigned to the FFS. In this way the speed can still be considered as free flow conditions and the flow diagram can be considered as a linear course.

Table 5

Progressive road distance [km]	Direction	Longitudinal Grade [%]	Section-Lane width [m]	Curving (1/R) [1/m]	Tortuousness ($\sum\alpha i/3$)* [grad/km]	T [minuts]	N. Vehicle in T	Et	Connection between Qeq and Vm2	FFS (Free Flowspees) [km/h]
246,000	N	-2,0	10,7	0,0000	**5,3**	60	656	2,00	Vm= - 0,0137*Qeq +134,31	**130,2**
236,000	S	1,0	10,7	0,0000	**5,3**	100	1210	2,25	Vm = -0,0104*Qeq +134,74	**131,6**
236,600	S	1,5	10,7	0,0000	**5,3**	60	653	1,85	Vm = -0,0117*Qeq +133,08	**130,0**
207,000	N	-0,5	8,7	0,0000	**23,7**	83	473	1,92	Vm = -0,0073*Qeq + 129,29	**127,1**
205,000	N	4,5	8,7	0,0000	**24,7**	40	263	3,60	Vm = -0,0003*Qeq + 105,53	**105,1**
205,000	N	4,5	8,7	0,0000	**26,0**	50	341	3,70	Vm = -0,0054*Qeq + 106,47	**105,0**
205,200	N	-4,0	8,7	0,0000	**26,0**	56	400	3,50	Vm = -0,0032*Qeq + 112,14	**111,1**
243,200	N	-1,0	10,7	0,0012	**12,0**	45	720	1,96	Vm = -0,0030*Qeq + 126,01	**125,1**
195,700	N	3,5	8,7	0,0014	**28,0**	46	262	3,60	Vm = -0,0069*Qeq + 117,60	**115,5**
209,500	N	0,1	8,7	0,0010	**22,0**	58	379	1,90	Vm = -0,0035*Qeq + 128,41	**127,3**
204,500	S	-4,5	8,7	0,0029	**22,0**	45	187	3,80	Vm = -0,0008*Qeq + 109,50	**109,2**
204,600	N	4,5	8,7	0,0029	**29,0**	45	187	3,70	Vm = -0,0134*Qeq + 97,38	**93,3**

1.2.1 Identification of average speed distribution law

The distribution that best represents average car speed is normal distribution. In order to verify if the data used in the present study is compatible with normal distribution, the χ^2 test was carried out for each of the 12 studies. In order to carry out this test, first speed data in amplitude classes of 10km/h was organised. Then, absolute frequencies and expected frequencies were calculated and the value was determined as being χ^2. In table 6 the χ^2 values and values of many sizes that were used for the determination of the test are represented.

Table 6

Date	Progressive road distance [km]	Direction	N. vehicle	N. cars	Average speed of cars [km/h]	Standard deviation [km/h]	N. class	ν (Degree of freedom)	Fi (Total absolute frequency cars only)	fi (Total expected frequency cars only)	χ^2 ($\sum$((Fi-fi)^2)/fi))	Result Test
21/03/03	246,000	N	656	512	122,7	22,20	14	11	512	510,67	11,56	Ok
14/04/03	236,000	S	1210	1002	124,5	21,00	14	11	1002	1000,80	24,14	Ok
30/05/03	236,600	S	653	515	125,9	21,97	14	11	515	513,80	26,88	Ok
05/06/03	207,000	N	473	305	124,0	20,70	14	11	305	302,10	19,79	Ok
11/06/03	205,000	N	263	192	105,6	17,28	11	8	192	191,60	7,02	Ok
18/06/03	205,000	N	341	281	107,3	17,98	12	9	281	280,72	23,50	Ok
18/06/03	205,200	N	400	318	109,0	18,00	13	10	318	317,81	14,14	Ok
27/06/03	243,200	N	720	589	122,5	18,09	14	11	589	588,94	18,68	Ok
20/02/04	195,700	N	262	195	110,0	19,20	10	7	195	192,8	6,58	Ok
21/02/04	209,500	N	379	306	124,3	18,52	13	10	306	304,89	12,73	Ok
22/02/04	204,500	S	187	116	107,9	18,60	9	6	116	114,4	3,39	Ok
28/02/04	204,600	N	187	168	98,69	17,23	9	6	168	166,23	8,33	Ok

Given that the normal distribution comes near to the observed phenomenon, for each of the 12 surveys carried out, $\mathbf{V_{85}}$ was calculated as:

$$V_{85} = V_{average} + 1,04 * St.dev. \qquad (1)$$

$V_{average}$, standard deviation and $\mathbf{V_{85}}$ determined with (1) are represented in table 7. In the last column the observed $\mathbf{V_{85}}$ is represented , that is the speed exceeded by 15% of the cases in each survey. The observed $\mathbf{V_{85}}$ and the $\mathbf{V_{85}}$ calculated with (1) are very near; therefore there is a further confirmation of good adaptation of normal distribution regarding the observed speeds.

Table 7

Progressive road distance [km]	$V_{average}$ [km/h]	Standard deviation [km/h]	V_{85} observed [km/h]	V_{85} Calculated with Normal distribution law [km/h]
246,000	122,7	22,20	147,6	145,8
236,000	124,5	21,00	145,3	146,3
236,600	125,9	21,97	146,7	149,0
207,000	124,0	20,70	147,3	145,5
205,000	105,6	17,28	124,6	123,5
205,000	107,3	17,98	124,7	126,0
205,200	109,0	18,00	124,1	127,7
243,200	122,5	18,09	140,9	141,3
195,700	110,0	19,20	130,1	129,9
209,500	124,3	18,52	143,0	143,4
204,500	107,9	18,60	128,5	127,2
204,600	98,69	17,23	117,9	117,0

2. MODELS FOR THE ESTEEM OF SPEED

2.1 Model for the esteem of V_{85}

The $\mathbf{V_{85}}$ estimation model was obtained by means of multiple regression between $\mathbf{V_{85}}$, obtained in various surveys, and the other sizes indicated in table 1.

The (variable) sizes that best characterize $\mathbf{V_{85}}$ are represented in blue in table 8. The *Longitudinal grade* was taken as an absolute value, in that there is insufficient variability regarding climb and descent conditions. In particular, such viability appeared as being weaker in features with no planimetrical curving (straight stretch); *tortuousness*, characterized by the shape represented in table 1, is introduced in order to take into account the modalities used by the driver to approach the element on which speed is measured. In short, with such a term we can differentiate situations of two straight stretch (or other elements), as in the example indicated in figure 2, where the elements that are in the same condition (same length, same section width, same grade etc.) but are preceded and succeeded by a stretch of different tortuousness. In order to take this situation into account the following relationship (Σi /3) was constructed, that represents the inclination variation of section elements of the polygonal support, with respect to a horizontal reference axis, in a stretch of 3 km in which the survey section was placed at 2,5 km from the beginning of the stretch.

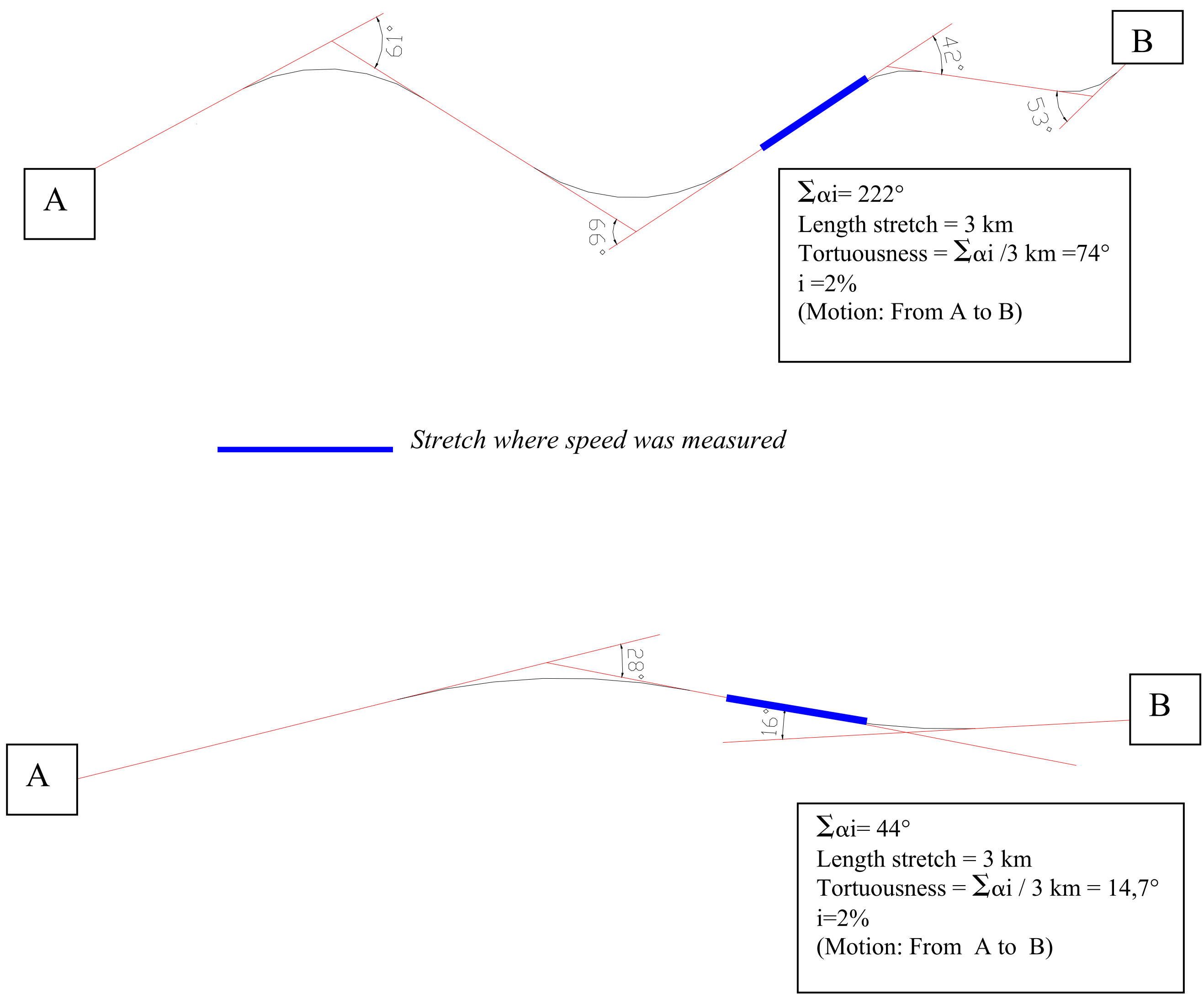

Figure 2

In table 8 the sizes used in multiple regression are represented; in particular independent variables are indicated in blue.

Table 8

Progressive road distance [km+m]	Direction	Longitudinal Grade [%]	Curving (1/R) [1/m]	Tortuousness. ($\sum \alpha i/3$) [grad/km]	V_{85} Calculated with Normal distribution law [km/h]
246,000	N	-2,0	0,0000	5,3	145,8
236,000	S	1,0	0,0000	5,3	146,3
236,600	S	1,5	0,0000	5,3	149,0
207,000	N	-0,5	0,0000	23,7	145,5
205,000	N	4,5	0,0000	24,7	123,5
205,000	N	4,5	0,0000	26,0	126,0
205,200	N	-4,0	0,0000	26,0	127,7
243,200	N	-1,0	0,0012	12,0	141,3
195,700	N	3,5	0,0014	28,0	129,9
209,500	N	0,1	0,0010	22,0	143,4
204,500	S	-4,5	0,0029	22,0	127,2
204,600	N	4,5	0,0029	29,0	117,0

The result obtained with multiple regression is the following:

$$V_{85} = 155{,}13 - 1319 * (\mathbf{1/R}) - 0{,}41 * (\textstyle\sum_i \alpha \mathbf{i/3}) - 4{,}1 * \mathbf{|i|} \qquad \mathbf{(2)}$$

Coefficient ρ^2 turned out as being equal to **0,95**. Such a result confirms the strong relationship between the three independent variables and V_{85}. Moreover the t-Student test carried out in order to check the significance of the variables used in regression further confirmed the validity of relation (2) (table 9).

Table 9

	Coefficient	standard Deviation	t-student	significance *
Constant	155,13	1,97	78,40	0,000
curving	1319,63	842,89	-1,56	0,156
tortuousness	0,41	0,12	-3,53	0,008
Longitudinal Grade	4,10	0,66	-6,90	0,000

*Hypothesis checked with the test is the following: establish the probability that the coefficients are casual and do not belong to the population whose characters we are studying.

Model (2) was verified comparing the speed values observed with those obtained with the aforementioned model. In table 10 and figure 3 the comparison results are shown.

Table 10

Date	Progressive road distance [km]	V_{85} calculate with the (2) model [km/h]	V_{85} observed [km/]	V_{85} Calculated with Normal distribution law	Error found between V_{85} Observed and V_{85} calculate with the (2) model [%]
21/03/03	246,000	**144,8**	**147,6**	**145,8**	**1,2**
14/04/03	236,000	**148,9**	**145,3**	**146,3**	**0,7**
30/05/03	236,600	**146,8**	**146,7**	**149,0**	**1,6**
05/06/03	207,000	**143,4**	**147,3**	**145,2**	**1,4**
11/06/03	205,000	**126,6**	**124,6**	**123,5**	**0,9**
18/06/03	205,000	**126,0**	**124,7**	**126,0**	**1,0**
18/06/03	205,200	**128,1**	**124,1**	**127,7**	**2,9**
27/06/03	243,200	**144,6**	**140,9**	**141,3**	**0,3**
20/02/04	195,700	**127,4**	**130,1**	**129,4**	**0,5**
21/02/04	209,500	**144,4**	**143,0**	**144,3**	**0,9**
22/02/04	204,5 sud	**123,9**	**128,5**	**127,2**	**1,0**
23/02/04	204,5nord	**121,0**	**117,9**	**117,0**	**0,8**

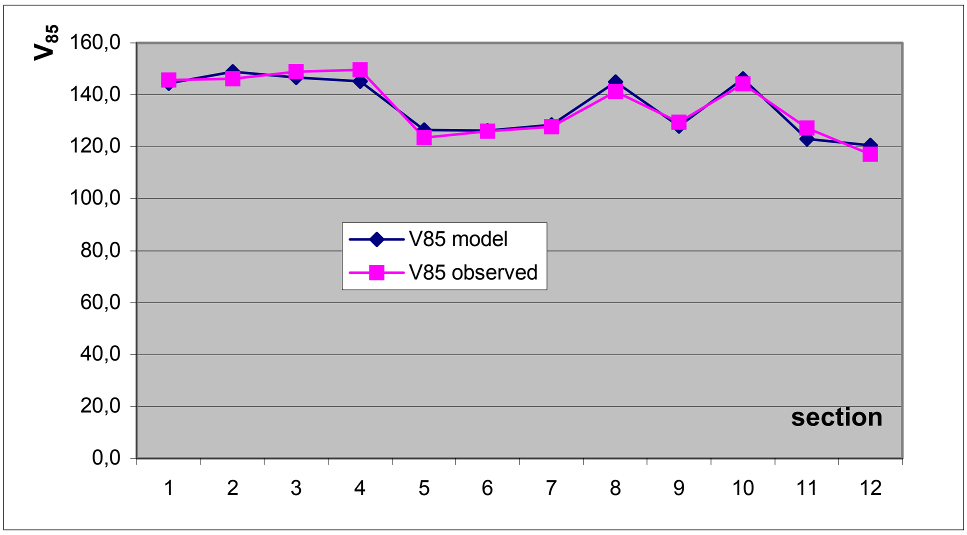

Figure 3

2.2 Model for the esteem of FFS

The estimation model for FFS was obtained following the same procedures as illustrated in paragraph 2.1. In table 11 sizes regarding multiple regression are represented. Independent variables are marked in blue.

Table 11

Progressive road distance [km+m]	Direction	Longitudinal Grade [%]	Curving (1/R) [1/m]	Tortuousness ($\sum \alpha i/3$) [grad/km]	**FFS** [km/h]
246,000	N	-2,0	0,0000	5,3	130,20
236,000	S	1,0	0,0000	5,3	131,62
236,600	S	1,5	0,0000	5,3	130,08
207,000	N	-0,5	0,0000	23,7	126,50
205,000	N	4,5	0,0000	24,7	105,12
205,000	N	4,5	0,0000	26,0	105,44
205,200	N	-4,0	0,0000	26,0	111,18
243,200	N	-1,0	0,0012	12,0	125,11
195,700	N	3,5	0,0014	28,0	115,53
209,500	N	0,1	0,0010	22,0	127,36
204,500	S	-4,5	0,0029	22,0	109,26
204,600	N	4,5	0,0029	29,0	93,36

The result obtained with multiple regression is the following:

$$\mathbf{FFS} = 139{,}7-1703{,}3*\mathbf{1/R}-0{,}47*\sum_i \alpha \mathbf{i/3}-4{,}5*\mathbf{|i|} \qquad \mathbf{(3)}$$

The determination coefficient ρ^2 turned out equal to **0,91.** Such a result confirms the strong relationship between the three independent variables and FFS. Futhermore the t-Student test carried out in order to control the significance of the variables used in the regression further confirmed the validity of the relationship (3) (table 12).

	Coefficient	standard Deviation	t-student	Significance*
Costante	139,75	3,06	45,6	0,000
curving	1703,38	1307,98	-1,3	0,229
tortuousness	0,470	0,18	-2,6	0,032
Longitudinal Grade	4,50	0,94	-4,8	0,01

*Hypothesis checked with the test is the following: establish the probability that the coefficients are casual and do not belong to the population whose characters we are studying.

Tabella 12

Model (3) has been verified comparing the speed values observed with those obtained with the aforementioned model. In table 13 and figure 4 the comparison results are shown.

Table 13

Date	Progressive road distance [km+m]	FFS observed [km/h]	FFS calculate with the (2) model [km/h]	Error found between FFS observed and FFS calculate with the (3) model [%]
21/03/03	246,000	**130,2**	**128,2**	**1,5**
14/04/03	236,000	**131,6**	**132,8**	**0,9**
30/05/03	236,600	**130,0**	**130,5**	**0,3**
05/06/03	207,000	**126,5**	**126,4**	**0,1**
11/06/03	205,000	**105,1**	**107,8**	**2,5**
18/06/03	205,000	**105,4**	**107,2**	**1,7**
18/06/03	205,200	**111,1**	**109,5**	**1,5**
27/06/03	243,200	**125,1**	**127,6**	**1,9**
20/02/04	195,700	**115,5**	**108,4**	**6,6**
21/02/04	209,500	**127,3**	**127,3**	**0,1**
22/02/04	204,5 sud	**109,2**	**104,2**	**4,9**
23/02/04	204,5nord	**93,3**	**100,9**	**7,5**

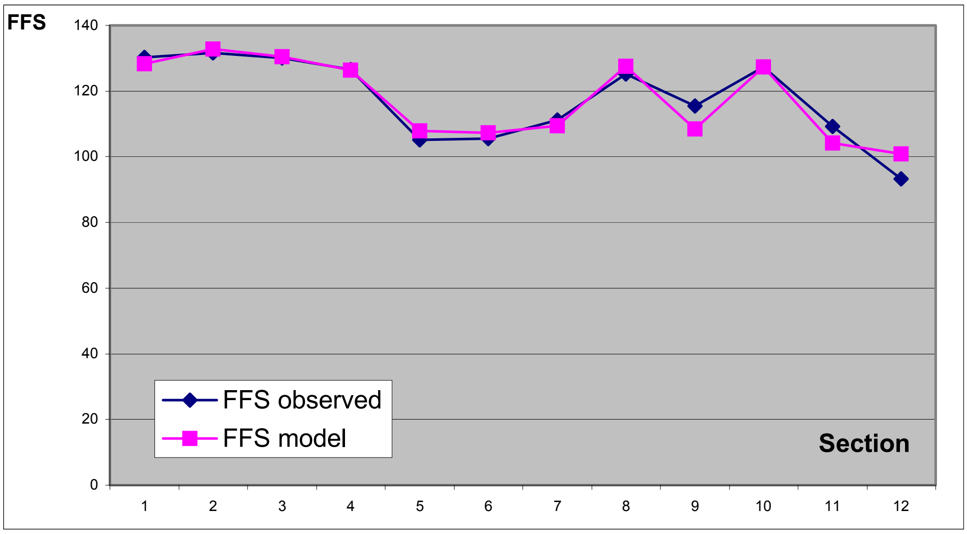

Figure 4

Conclusions

In this study we have shown how the drivers' speed, in the freeway field, systematically varies according to several geometric sizes. Therefore, observing the speed of drivers relating to the previously mentioned situations models (2) and (3) were obtained which respectively permit the obtainment of **V_{85}** and **FFS**.
The sizes that influence **V_{85}** and **FFS** in a meaningful way are *curving*, *the longitudinal grade* and *tortuousness*. In particular the last term was introduced in order to take into account the modalities with which the driver approaches the element on which speed is measured. With this term it is possible to differentiate between, for example, situations of two straight stretches (or other elements) in the same conditions (same length, same section width, same grade etc.) but which are preceded and succeeded by stretches of different tortuousness. In short, this term represents the analytic shape of " memory function" already introduced in studies similar to the present one.
In conclusion, the two models found have shown a good reliability in the research area. In fact the maximum error found in experimental checks was, in the case of **V_{85}**, within 4% and in the case of **FFS** within 8%. Therefore, given the good reliability found, the two models can be used for every type of study and for application in which it is necessary to know these two sizes. However, some perplexity remains regarding the use of the two models in other freeway, in that verification experiences have not been carried on other freeways. For this reason the following stages of the study will regard sample increase with other surveys on the A3 stretch, the experimentation of models (2) and (3) on an other freeway with characteristics homologous to the A3. In particular this experimentation is being organized on a section of the A14 freeway (Pescara - Taranto) and on some sections of the Naples-Salerno freeway.

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