USE OF CARSIM® FOR THE ASSESSMENT OF THE INFLUENCE OF CHANGE OF SPEED AND VISIBILITY ON ROAD SAFETY.

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ABSTRACT

In this paper the Authors face the theme of road safety through the use of the calculation model CARSIM®. This software is able to show the way the vehicles answer to driving inputs from a dynamic point of view, with respect to the boundary conditions, generating the same results that would spring out from expensive real scale tests carried out with special vehicles equipped with specific instrumentation.

Moving from the analysis of a C1 track designed with respect to the prescription of the new DM 5/11/01 Norms, the specific aspect of the sight distance was analysed, getting to the definition of two alternative proposals for the determination of the overtaking manoeuvre sight distance.

On this matter, different scenarios characterised by dissimilar speed values of the simulation vehicles were considered, both the dimensions and the characteristics of the vehicles themselves being also changed, so as to get to two different formulations for the assessment of the minimum overtaking sight distance, which are complementary and, at the same time, alternative to what proposed by the Norms.

More specifically, the Authors formulated a mathematical models set for the increase of road safety which, thanks to the help of virtual reality, allows the validation of the Italian Prescriptions and, on the other hand, integrates them with a further improvement through computerised simulations, in order to analyse all the possible situations that could be experienced in real driving conditions.

Keywords: *CARSIM, road safety, sight distance, visibility.*

1 FOREWORD

Trying to get to outcomes which could be easily used by road engineers, this research is a contribution to the increase of road safety, by means of an investigation on the sight distance for the overtaking manoeuvre.

The first part of the experimental numerical analysis made use of the software CarSim®, with whom a road track can be virtually assembled and gone through: furthermore, the real situations can be represented with the software, any possible anomaly which could jeopardise the safety of circulation being thus pinpointed.

In the second stage of the research, different simulation scenarios have been evaluated, contemporaneously working out two different proposals of formulation of the minimum overtaking sight distance, so as to allow a completely safe manoeuvre, also in critical situations.

2 THE SOFTWARE CARSIM®

One of the potentialities of the software is to illustrate the way vehicles dynamically answer both the surrounding and driving inputs, yielding to the same results that would come out from tests on vehicles equipped with specific instrumentation.

Generally speaking, CarSim® is composed by four modules closely connected to each other which allow, by means of a graphical database and a model solver, to arrange a surface animation generating some engineering plots.

3 EXPERIMENTAL ANALYSIS

3.1 Definition of the road geometry

The road considered for the investigation, according to the Italian Standards, is a C_1 secondary rural road with a design speed Vp within 60 km/h and 100 km/h; it consists of one carriageway and two opposite 3.75 m lanes, with a 1.50 m lateral shoulder.

From the planimetric point of view eight curves compose the track, the radii values being within 118 m and 437 m (Table 1), along with three straight parts and ten transition curves, for an overall length of 4870 m.

Table 1 Characteristics of the bends of the road track

BEND	RADIUS (m)	LENGTH (m)	ANGLE (°)	CHORD (m)
1	350	220.260	36	216.640
2	320	166.890	30	165.005
3	345	188.245	31	185.920
4	315	696.500	127	563.000
5	350	218.665	36	215.130
6	320	172.500	31	170.650
7	310	318.550	59	304.715
8	310	283.500	52	274.035

From the altimetric standpoint, the road is constituted by five gradients and appropriate vertical connections.

After the assembly, it was possible to virtually drive through the road track on a passenger car.

The starting screen which allows the management of the track properties, is illustrated in Figure 1, while Figure 2 represents the virtual screenshot of the road.

Figure 1 Starting screen of the road geometry management

Figure 2 Virtual screenshot of the track

3.2 Simulation of the overtaking manoeuvre

By means of a specific analysis, CarSim® enables the simulation of the overtaking manoeuvre, on the basis of the real situations experienced on two way rural highways simulation.

Hence, the real overtaking sight distance (D_s) along the road was assessed as function of the design speed deduced from the speed profile, and afterwards the overtake was simulated in the parts were such manoeuvre was allowed by the geometry of the track.

The simulation of the real driver's vision represents the pivotal aspect of this kind of analysis, since the software allowed to locate the user's eye on the dashboard of the car, so as to give the have a feeling of being driving while another car is coming in the opposite direction. Figure 3 shows the scenario of the simulation.

Figure 3 Screenshot of the scenario during the assessment of D_s

3.3 Proposals for the calculation of the overtaking sight distance

Inasmuch the total D_s length of the road was determined, the real vehicle overtake was simulated in order to have an understanding whether or not such minimum distance was sufficient to allow the manoeuvre in safety conditions.

For this purpose, three vehicles were considered for the investigation: overtaking (A), overtaken (B), and running in the opposite direction (C).

For the sake of understanding, according to the Italian Standards, the D_s minimum value is:

$$D_s = 5.5 \text{ x } V \text{ (km/h)}$$

where the speed is the punctual value taken from the speed profile and calculated as function of time t_1 needed by A while cueing in the tale of B, of time t_2 needed by A to get in front of B (equal to the ratio between the average length of the vehicles l_m and their speed variation), and as function of time t_3 which is necessary to allow A to move back into its lane.

Having the chance to simulate an infinite number of simulations, the Authors realised that t_2 is not always the values prescribed by the Standards (2 seconds).

Therefore, the formula was thorough fully analysed by verifying the relations between the average length of the vehicles l_m and their corresponding speed variations.

As a matter of fact, the typologies of vehicles represented in Figure 4 were considered.

Vehicle 7 of Figure 4, from a dimensional point of view, was used to simulate the presence of a heavy vehicle, the software only giving the chance to refer to passenger cars. Thus, the input data were the following:

- V_A from the speed profile, for safety reasons equal to 100 km/h;
- V_B progressively increasing from the lower value of the interval (60km/h);
- V_C for safety reasons equal to the design speed (100km/h);
- t_1 equal to 4 seconds as prescribed by the Standards;
- t_3 equal to 4 seconds as prescribed by the Standards;
- l_m to be calculated according to the vehicles chosen.

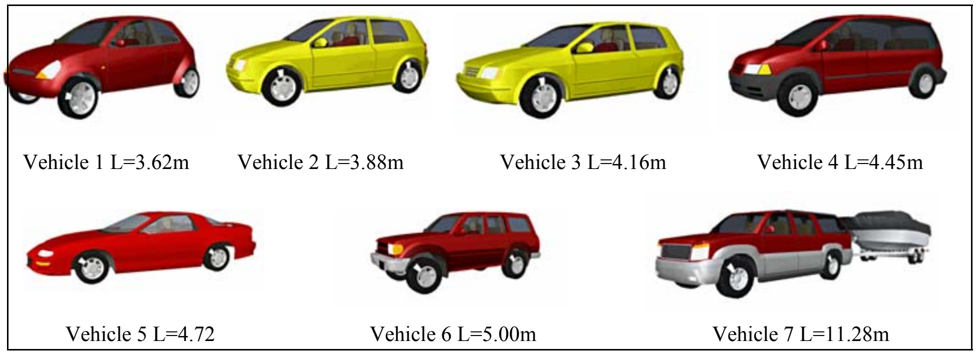

Figure 4 Typologies of vehicles used for the simulation

Starting from these values, the output values were:

- t_2 ;
- the minimum overtaking distance on the basis of the Standard formula $D_s = 2 x V x (t_1 + t_2 + t_3)$.

The t_2 value was detected through CarSim®, by accurately positioning the two vehicles; actually, t_2 could be also calculated in an analytical way by referring to the input data, but the direct assessment with the software allowed the Authors to validate the model and to thorough fully reproduce the overtaking manoeuvre.

From the development of all the possible combinations, it came to the fore that for Δv values within 20 km/h and 10 km/h, the overtake occurred in not complete safety, with consequent potential collision between the overtaking vehicle and the car riding in the opposite direction, this situation being one of the most common experienced on C_1 two lane rural highways.

Hence, one of the most mulled-over musings was the fact that the minimum D_s prescribed by the Norms as function of t_2 = 2 seconds, is not always verified: indeed, during the simulation it was found that there are some safety deficiencies just for such overtaking situations which mainly occur on ordinary roads.

Two different formulations were, thus, proposed, the final proposal being the one which guarantees highest safety standards.

The first formulation provided for the simulation of all the scenarios, by modifying the input data as follows:

- Δv between A and B equal to 10 km/h, so as to consider the most critical, although most common, situation;
- V_A and V_B varying within the range 70÷100 km/h and 60÷90 km/h, respectively, Δv being always equal to 10 km/h;
- l_m calculated as function of A and B dimensions;
- $t_1 = t_3 = 4$ seconds;
- t_2 detected by the simulation with CarSim®;

The output was the following:

- minimum overtaking sight distance, figured out from $D_s = 2 x V x (t_1 + t_2 + t_3)$, with V taken from the speed profile;

For the sake of brevity, in Table 2 and Table 3 the results of only two of the different scenarios analysed have been reported.

From such results the chart of Figure 5 was inferred, where the design speed is reported on the X-axis and D_s on the Y-axis.

This representative chart was added with the left hand side straight line which refers to D_s calculated with the Standard formula for speed values up to 65 km/h, since, up to this value, such value gave result with adequate users safety.

One could notice that some of the speed values were smaller than the lower bound of the speed interval (60÷100 km/h), as some situations might occur when the driver is obliged to drive at reduced speed.

In addition, it is clear that the higher scenario is significantly detached from the others, and the reason for this resides in the fact that it refers to the heavy vehicle overtake, the l_m value being thus larger than the previous situations.

Table 2 Typical output of the simulations carried out (Case n° 5)

CASE n° 5			
V_B (km/h)	**V_A (km/h)**	**D_s calculated (m)**	**D_s Standards (m)**
60	70	***432***	385
65	75	***463***	413
70	80	***493***	440
75	85	***524***	468
80	90	***555***	495
85	95	***586***	523
90	100	***617***	550
A = overtaking vehicle		*l_A = 3.62 m*	*t_1 = 4 seconds*
B = overtaken vehicle		*l_B = 5.00 m*	*t_3 = 4 seconds*
C = vehicle riding in opposite direction		*l_m = 4.31 m*	
ΔV = 10 km/h		***t_2 = 3.10 seconds***	

The mean value of each D_s referred to every speed was worked out, thus obtaining a straight line with the points representing the D_s distances and the speed intervals within 70 and 100 km/h. From such results the chart of Figure 5 was inferred, where the design speed is reported on the X-axis and D_s on the Y-axis.

This representative chart was added with the left hand side straight line which refers to D_s calculated with the Standard formula for speed values up to 65 km/h, since, up to this value, such value gave result with adequate users safety.

Table 3 Typical output of the simulations carried out (Case n° 15)

CASE n° 15			
V_B (km/h)	**V_A (km/h)**	**D_s calculated (m)**	**D_s Standards (m)**
60	70	***535***	385
65	75	***573***	413
70	80	***612***	440
75	85	***650***	468
80	90	***688***	495
85	95	***726***	523
90	100	***764***	550
A = overtaking vehicle		*l_A = 4.72 m*	*t_1 = 4 seconds*
B = overtaken vehicle		*l_B = 11.28 m*	*t_3 = 4 seconds*
C = vehicle riding in opposite direction		*l_m = 8 m*	
ΔV = 10 km/h		***t_2 = 5.76 seconds***	

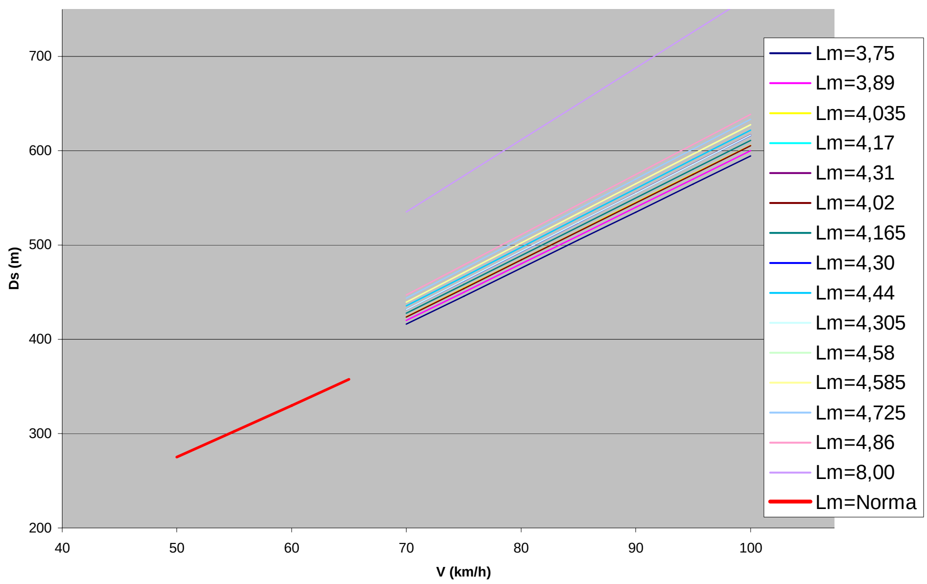

Figure5 Chart with the 15 scenarios and the Standards results (first simulation)

One could notice that some of the speed values were smaller than the lower bound of the speed interval (60÷100 km/h), as some situations might occur when the driver is obliged to drive at reduced speed.

In addition, it is clear that the higher scenario is significantly detached from the others, and the reason for this resides in the fact that it refers to the heavy vehicle overtake, the l_m value being thus larger than the previous situations.

The mean value of each D_s referred to every speed was worked out, thus obtaining a straight line with the points representing the D_s distances and the speed intervals within 70 and 100 km/h.

In the following chart of Figure 6 both the points representing D_s obtained from the Standards and the curve of the just mentioned mean value of D_s are represented as function of the speed.

The equation describing the behaviour of D_s, corresponding to the first formulation proposed for the calculation of the minimum overtaking sight distance, is the following:

$$D_s = -0.0019\,V^3 + 0.416\,V^2 - 21.309\,V + 539.75$$

This formulation is harbinger of far-reaching outcomes: indeed, for each speed, the minimum overtaking sight distance worked out was higher than the values calculated with respect to the Italian Standards.

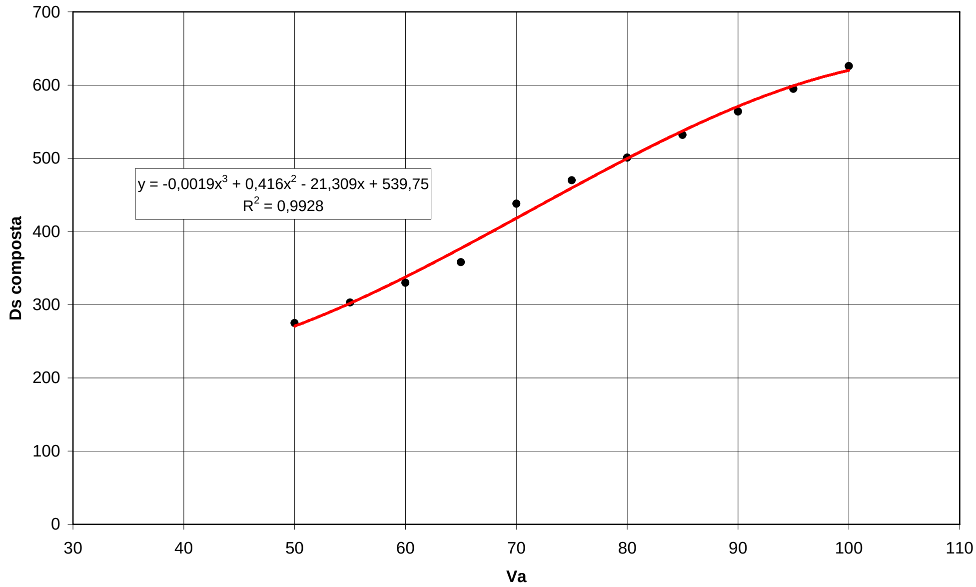

Figure 6 D_s behaviour in the first formulation

The second proposal is still based on the 15 possible scenarios, but with some differences in the input data, which can be summarised as follows:

- Δv between vehicles A and B changing from 10 km/h to 40 km/h, taking into account all the possible situations;
- V_B fixed at 60 km/h, which is the lower bound of design speed;

- V_A varying from 70 km/h to 100 km/h, as a consequence of the fixed Δv;
- l_m worked out as function of l_A and l_B;
- $t_1 = t_3 = 4_s$ seconds
- t_2 found out through CarSim®.

Once again, the output was the following:

- minimum overtaking sight distance, figured out from $D_s = 2 \times V \times (t_1 + t_2 + t_3)$, with V taken from the speed profile;

  Some of the results have been included in the following Table 4 and Table 5.

Table 4 Results of the second virtual analysis (Case n° 3)

CASE n° 3				
V_A (km/h)	**ΔV (km/h)**	**t_2 (sec)**	**D_s calculated (m)**	**D_s Standards (m)**
70	10	2.91	***424***	385
75	15	1.94	***414***	413
80	20	1.45	***420***	440
85	25	1.16	***433***	468
90	30	0.97	***448***	495
95	35	0.83	***466***	523
100	40	0.73	***485***	550
A = overtaking vehicle			*l_A = 3.62 m*	*t_1 = 4 seconds*
B = overtaken vehicle			*l_B = 4.45 m*	*t_3 = 4 seconds*
C = vehicle riding in opposite direction			*l_m = 4.035 m*	*V_B = 60 km/h*

Table 5 Results of the second virtual analysis (Case n° 15)

CASE n° 15				
V_A (km/h)	**ΔV (km/h)**	**t_2 (sec)**	**D_s calculated (m)**	**D_s Standards (m)**
70	10	5.76	***535***	385
75	15	3.84	***493***	413
80	20	2.88	***484***	440
85	25	2.30	***487***	468
90	30	1.92	***496***	495
95	35	1.65	***509***	523
100	40	1.44	***524***	550
A = overtaking vehicle			*l_A = 4.72 m*	*t_1 = 4 seconds*
B = overtaken vehicle			*l_B = 11.28 m*	*t_3 = 4 seconds*
C = vehicle riding in opposite direction			*l_m = 8.00 m*	*V_B = 60 km/h*

Hence, the results have been used to drawn the chart of Figure 7, which includes also the straight line referred to the Italian Standards. The tendency line was thus derived, the consequence being the D_s behaviour represented in Figure 8

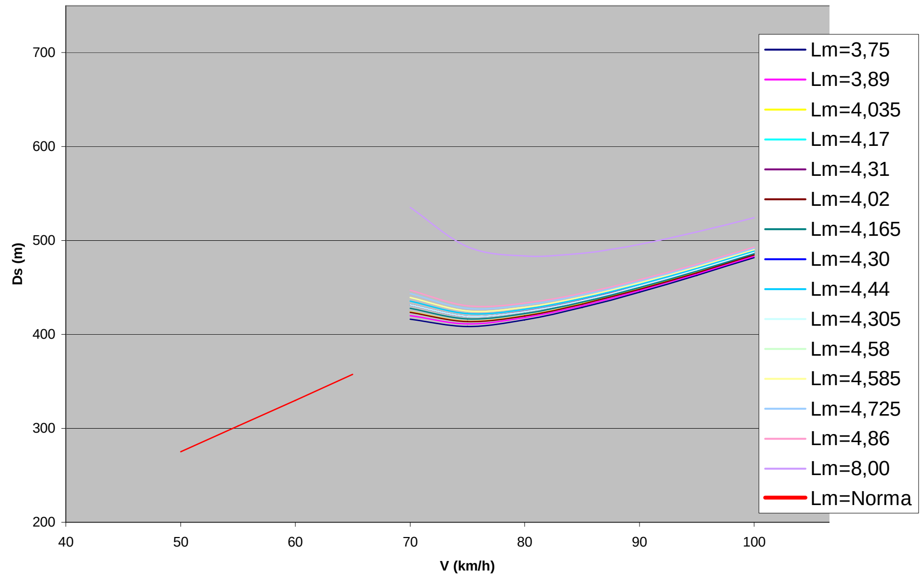

Figure 7 Chart with the 15 scenarios and the Standards results (second simulation)

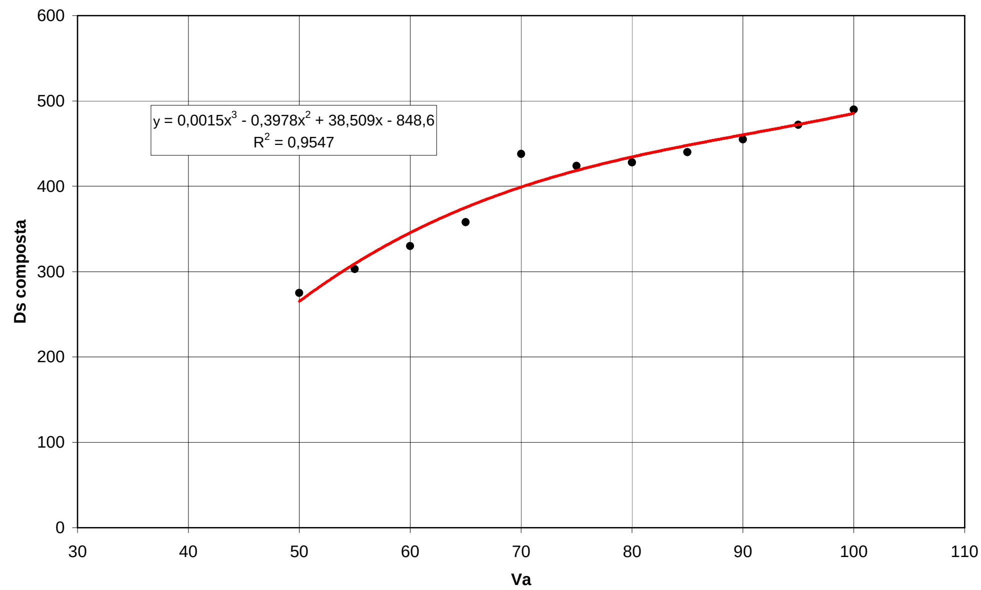

Figure 8 D_s behaviour in the second formulation

The equation representing the chart of Figure 8 is the following:

$$D_s = 0.0015\ V^3 - 0.3978V^2 + 38.509\ V - 848.60$$

With this formulation, for some speed intervals, the minimum overtaking sight distance is smaller than the prescribed value, the model bringing, in this case, some safety drawbacks.

As a matter of fact, for safety reasons, the Authors suggest to refer to the first formulation.

So as to get to a large scale evaluation, the values of such formulation were compared with the minimum overtaking sight distance proposed by both the Italian Standards 5/11/01 and the Swiss Standards SN 640090, as illustrated in Table 6.

Table 6 Comparison of the results of the proposed formulation with the Standards

V (km/h)	D_s (m) Italian Standards	D_s (m) Swiss Standards	D_s (m) Model proposed
60	330	450	346
70	385	500	432
80	440	550	520
90	495	575	600
100	550	625	660

This comparison is a seamless endorsement for the positiveness of the proposed analysis, inasmuch it furnishes different suggestions, according to the speed intervals: indeed, according to the model, the D_s values are larger than the corresponding outcomes of the Italian Standards in force, such results being, on the contrary, smaller than the Swiss Standards suggestions in case of 60 km/h $\leq V_p \leq$ 80 km/h.

4 CONCLUSIONS

This investigation was focused on the analysis of a C1 rural highway after its virtual reconstruction by means of the software CarSim®.

In particular, the pivotal aspect of the overtaking manoeuvre was faced, by defining two alternative proposals for the calculation of the minimum distance which would allow the overtake in safety conditions, these results being compared both with the Italian and Swiss Standards.

The software employed for the simulation enables to reproduce real cases and, thus, to get to reliable results.

Hence, the experimental analysis was concentrated on the verification of the overtaking sight distance along the road track on the basis of the values furnished by the Italian Standards, with the important conclusion that there are some speed intervals for which the manoeuvre is not accomplished in full safety.

Afterwards, several scenarios were simulated, the differences residing in the changes of speed, dimensions and characteristics of the vehicles: as a consequence, two different formulations for the assessment of the above mentioned distance were achieved, both of them being complementary and, for some reasons, alternative to the Standards.

In the first formulations the speed difference between the two vehicles involved in the overtake was fixed (10 km/h), while in the second one the speed of the overtaken vehicle was set equal to the lower bound of the design value (60 km/h), thus the difference of speed between the two vehicles varying with simulations.

Referring to the final results, the Authors found that the first proposal is more accurate from the safety standpoint; indeed, the overtaking manoeuvre can be accomplished with higher safety standards if the proposed formulation is considered, while the Standards, for some speed intervals, appear to furnish inadequate sight distance.

In conclusion, it can be stated that this research drove the Authors to elaborate some interesting analytical formulations for the increase of road safety which, with the help of virtual reality, allow to both validating the Italian Standards and to integrate and further improve them by means of computerised simulations. In this way it is possible to analyse all the possible situations which could be experienced on C1 rural highways, where a severe number of casualties and fatalities occurs.

Having stated this, it would be desirable to further broaden the investigation by analysing all the other road categories, so as to get to an accurate database for the implementation of a generalised mathematical model which would favour the highest safety conditions possible for road users.

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