A SIMULATOR FOR THE EVALUATION OF THE IMPACT ON TRAFFIC SAFETY OF INNOVATIVE COLLISION AVOIDANCE SYSTEMS

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Abstract
The paper analyses the outcome of a generic automatic anti-collision equipment (or Collision Avoidance Systems, CAS) on accident avoiding in a motor-way environment by using a specific accident simulation software. Basic concept of the simulator is to reproduce in laboratory hypothetical unsafe manoeuvres within a platoon of vehicles. Starting from real situations, a set of "realistic" platoons was built and used as initial point to test whether collisions happen when particularly unsafe manoeuvres are simulated. A database of about 76,100 platoons related to three days (a Sunday, a Monday and a Thursday) was built starting from loop based data collected in a three lane motor-way.

INTRODUCTION

Collision Avoidance Systems (CAS) are related to vehicular safety in the longitudinal movements of the vehicles, mainly in motor-way environment. A CAS system must be effective in avoiding rear end collisions (frontal collision are in general seldom in motor-way environment) both within a dense traffic in which vehicles are interacting between themselves (platoons of vehicles) and in case of approaching situation. This problem was already tackled by (Farber and Paley, 1993; Farber and Huang, 1995) through an analytical study of rear-end collisions by application of the Ford Reamacs model; by (Takubo, 1995) who applied a semi-statistical method to calculate the probability of collision and driver injury. In (Tomioka *et al.*, 1995) a description of performance and features of a rear-end collision system can be found.

However knowledge of dynamic inside platoons is of great importance to understand which improvements in vehicular safety are more desirable. A simulator to study the effect of CAS system has been developed in order to study the evolution of the perturbation within a platoon when an unsafe manoeuvre occurs. Figure 1 shows well as the simulator works. The data of passages detected on a section of a real motor-ways are analysed and platoons of vehicles are identified (a vehicle belongs to a platoon if its time clearance, in the continuation of the paper called "headway", with the car ahead is less than 4 seconds). With the knowledge of the time of the passages, the speed and the length of the vehicles of a platoon it is possible to space them using the basic formula :

distance = speed x headway time - vehicle length (1)

Next step is to assign to each vehicle of the platoon a dynamic and driver behavioural features aiming at reproducing as well as possible a realistic couple driver-vehicle.

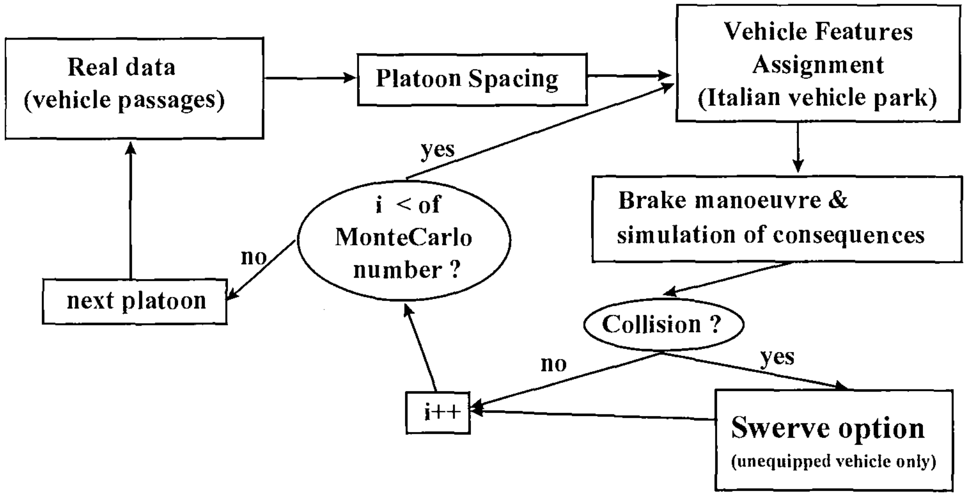

Figure 1 - flow diagram of the simulator

When all the couples driver-vehicle has a own assignment, the simulator perturbs the platoon with a sudden hard brake manoeuvre (at max brake capabilities) of the platoon leader. By using normal kinematic and dynamic formulas (Bauer, 1996; AA.VV., 1996), the simulator reproduces the behaviour of each vehicle of the platoon up to the last vehicle is stopped. In case of collision of an unequipped vehicle, equipped vehicles don't allow this manoeuvre, the simulator allows to repeat the manoeuvre with the possibility of a swerve manoeuvre in a free lane ; secondary effect of this manoeuvre are studied. At the end of the first simulation a new assignment phase is applied to the same platoon up to reach a desired number of iterations. This Monte Carlo procedure ensures that the various combinations of vehicle features were used in order to achieve a sufficient statistical significance. For our simulation this number was set to 10.

SIMULATOR DESCRIPTION

As mentioned in the previous paragraph basic modules of simulator are :
- definition of starting conditions (platoon spacing)
- assignment of vehicle features
- vehicle dynamics simulation
- recording module

For each module we provide a short description:

- Platoon spacing : the sources of initial conditions are data of passages of vehicles collected by static sensors on a freeway section (in our case inductive loop based measurements). These recordings should contain for each passage the measure of speed, time, lane and vehicle length. To have a good reality of situations, a resolution of about 0.01-0.05 sec and 10-30 cm is required. After the identification of the platoon and its spacing , we have a description of a platoon of unequipped platoon as in reality. To simulate equipped vehicles is necessary a further step: the distance of the vehicles which has been defined has equipped is re-calculated using the control law formula as described below.

- Vehicle assignment: this module assigns to each vehicle the following parameters according to suitable distributions :
* reaction time (in case of equipped vehicles the reaction time is estimated to be 120 milliseconds,
* max breaking capability,
* brake quality index

The last parameter ranges from 0 to 1 and reduces the brake capability of the vehicle, it aims to reproduce, even roughly, some aspects joint to ability, tiredness or careless of the driver. Key parameters of this assignment are vehicle length and number of rows belonging to the same class (or sub-class) of vehicles.

Vehicle dynamic: since the vehicles perform only braking, we consider that a car can runs only in deceleration mode. If we consider a flat road without additional hooked up weight, the predominant contribution to the braking forces is due to the brake system limited by the friction between tires and road. Besides friction, many other parameters affect and limit the braking force of a vehicle and they depend on mechanical status of the brake system, tire condition, anti-lock system availability, ability of the driver to brake, and so on.

An additional parameter "k" (brake quality index) is used in the calculation of the maximum brake force in order to introduce a sort of perturbation in the breaking manoeuvre. This parameter is constant for each driver and it expresses the capability of a driver to use its vehicle and the state of mechanical equipment; in general it ranges from 0.85 to 1.

Friction curves, $\mu(v)$, have been derived from curves reported in literature and using a least square procedure we extracted families of curves for dry and wet asphalt.
At the end the formula to calculate the maximum brake is :

$$Dec = \mu(v) * G * k \qquad (2)$$

Where G is the gravitational acceleration, while the curve adopted for friction calculation is

$$\mu(v) = -0.0069\ v + 0.85 \qquad (3)$$

The simulation is based on motion equations and all vehicles brake at their maximum capability with a time delay for the following vehicles depending on driver reaction. The sample time of the simulator is programmable, for our simulations is set to 0.2 seconds.
Recording module: a recording module allows us to record the data at the end of each simulation in ASCII format. Any further analysis of data is done with MS Excel 7.0 or Access.

Platoon database

By varying the conditions of the road, the equipped vehicle rate, the composition of vehicle park and the initial conditions, we are able to define different scenarios. As above-mentioned, three days of data have been used in order to have a critical mass of data needed to produce results with a good statistical significance. The days chosen for test are one Monday, one Thursday and one Sunday in order to guarantee a huge set of different traffic condition. The following table shows figures related to the number of platoons defined for each lane and the average size of platoons (in vehicles).

Control strategies

The program simulates the effects of anti collision systems by using different rules for "spacing" the vehicles within the platoon when needed, and a reaction time equal to 120 milliseconds for all the equipped vehicles. Two control law are used: the first one fulfils an early intervention of the system and helps the driver even in the normal cruise, this law follow a constant headway approach which is set to 1.0 seconds. In this case the vehicles equipped belonging to a platoon are always spaced with this headway. The second one performs a late intervention, the system reacts only as late as possible to avoid a collision. The vehicle maintains the "unequipped distance" till it becomes less than a distance, calculated by the control law algorithm, which is the lowest distance at which the vehicle can avoid a collision by a breaking at max deceleration capability.

Table 1: number of platoons (into bracket the mean number of vehicle each platoon)

Day	Number of platoons		
	slow lane	middle lane	Fast lane
3/10/94	2358	12443	9067
(Monday)	(2.7)	(4.9)	(5.1)
4/5/95	2921	13779	9858
(Thursday)	(2.7)	(4.8)	(5.1)
26/4/95	2686	13082	10351
(Sunday)	(2.6)	(4.7)	(5.2)

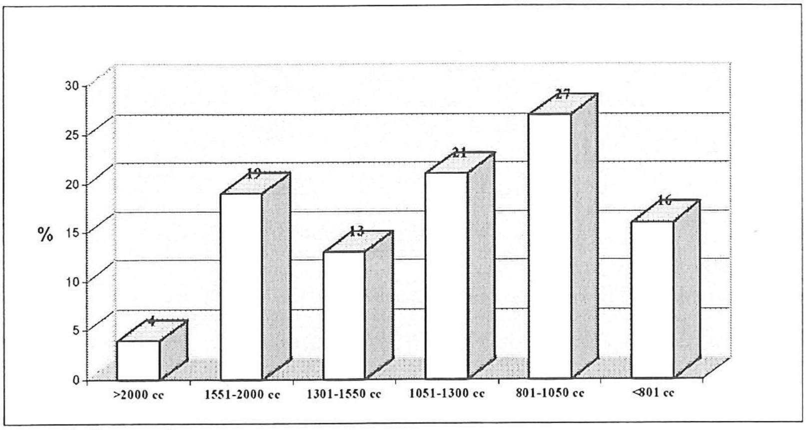

Figure 2: cars Italian park

Vehicle park and equipped vehicle rate

A qualifying characteristics of the simulator is, as mentioned above, the possibility to assign for each vehicle different figures. These values have been given after a careful study of the characteristics of the vehicle park. The real composition of Italian vehicle park has been done starting from the data of 1993 reported by ACI (Automobil Club Italia : the Italian Driver Association).

In bullets in 1993 they were on the Italian roads 29,652,024 passengers cars, 2,645,982 HGV (amongst 76,974 Buses and 254,866 special HGV), 2,526,761 motorcycles, for a total of 39,420,905 registered vehicles (it comprises also vehicles not matriculated for motor ways). The class "cars" which contains all passengers vehicles and the equipped vehicles has been simulated with 100 different rows, each one containing information stratified according to the engine size of the vehicle. This division in engine power classes is done following the ACI report 1993 concerning Italian vehicle park, the distribution in engine size classes is shown in figure 1. The equipment have been distributed amongst classes following the principle that the luxury car will be the first to be equipped with new devices. The total equipment rate is fixed in 10%, 25% and 50% in order to study the evolution of market introduction and to ensure a good sensitivity analysis.

ANALYSIS OF COLLISIONS

This section concerns the analysis of the number of rear end collisions occurred in the experiments. Tables 2, 3,4 report on the number of collisions encountered in the simulations both for equipped and unequipped vehicles. For a better understanding of data notice that the total number of simulated vehicles is equal to the sum of collided and not collided vehicles and it is given by the number of platoons multiplied by the number of vehicles of the platoon (minus the platoon leader) and by the number of Monte Carlo iterations (here assumed ten).

Unequipped vehicles

Table 2 shows figures concerning the absolute number of collisions, the share of collisions vs the not collisions, the share of collisions vs the vehicles collided and not collided (which is called collision rate) and the number of collisions per platoon.

Table 2: Collisions figures for unequipped platoons

Lane		Monday	Thursday	Sunday
Slow	Collisions	9936	12959	8751
	not Collisions	30708	38468	35832
	Platoons	2358	2921	2686
	Collision rate[%]	24.4	25.2	19.6
	Collisions/Platoon	0.4	0.4	0.3
Middle	Collisions	173582	198084	151496
	not Collisions	306008	326636	336924
	Platoons	12443	13779	13082
	Collision rate[%]	36.2	37.8	31.0
	Collisions/Platoon	1.4	1.4	1.2
Fast	Collisions	177428	198551	178523
	not Collisions	198302	204449	257727
	Platoons	9067	9858	13051
	Collision rate[%]	47.2	49.3	40.9
	Collisions/Platoon	2.0	2.0	1.4
Total	Collisions	360946	409594	338770
	not Collisions	534204	568566	629790
	Platoons	23868	26558	28819
	Collision rate[%]	40.3	41.9	35.0
	Collisions/Platoon	1.5	1.5	1.2

Table 3: Accident speeds and spacing for not colliding vehicles

Lane		Monday	Thursday	Sunday
slow	Absolute collision speed [km/h]	35.3	35.4	31.6
	Relative collision speed [km/h]	28.2	27.8	25.6
	Spacing [m]	31.3	30.5	29.8
middle	Absolute collision speed [km/h]	44.5	45.9	40.7
	Relative collision speed [km/h]	33.2	34.2	31.4
	Spacing [m]	31.1	32.0	30.8
fast	Absolute collision speed [km/h]	53.6	54.7	46.9
	Relative collision speed [km/h]	38.5	39.0	34.8
	Spacing [m]	32.3	32.5	29.9
Total	Absolute collision speed [km/h]	48.7	49.8	43.7
	Relative collision speed [km/h]	35.6	36.4	33.1
	Spacing [m]	31.7	32.2	30.3

One general comment concerns distribution of collisions for lanes and days of week. It is evident that the number of collisions in the slowest lane is very reduced in respect of the fast lane in which it is about the 50% of the total, even if the number of platoons in the fast lane does not go over about the 37% of the total. It must be underlined the difference of results between holiday figures and working days. A reduction of the 20% in the average number of accidents is calculated and a notable higher percentage of platoons in the fast lane is found, this is easily explainable with the very limited number of HGV circulating on Sunday.

Another analysis concerns the effects of collisions on vehicles involved. The simulator calculates the average value for the absolute and relative speed of collisions together with the "spacing" which is the stop distance for not collided vehicles. Table 3 shows these figures; if we don't consider the mass of the vehicle involved the data indicates the fast lane as the most dangerous one both in terms of absolute collision speed and in terms of relative speed. About spacing, it is interesting to note that the absolute value is practically the same for the three lanes.

Equipped vehicles

The first analysis considers how the number of collisions changes when different shares of equipped vehicles are put within the traffic. Table 4 and 5 report the collisions data both related to the carriageway and the three lanes. The first finding is that an AC equipment can avoid a very big number of collisions; in the case of 10% of equipped vehicles, there is a decrease of about 8-9% of the collisions; this decrease reaches the 40-42% with an equipment rate of 50% which is in line with a constant decrease of collisions reduction equal to the 8% each 10% of vehicle equipped. These percentages are very impressive if compared with real accident data. In 1995, only in Italian motorways, the accidents were 10,680 with 725 fatal accidents and 19,116 injured people; a reduction even only of 10% of collisions surely would have a big social and economic impact. The figures of the columns "Incremental Decrease of Collision" (Table 4) is an alternative view to read the same data; in this case we calculated the share of decrease of the collisions number starting always from the previous one. That means that the decrease introduced by 25% of equipped vehicles in respect to the 10% of equipped vehicles is equal to 14.5%.

The reading of these two tables underlines two further findings:
- the reduction of collisions depends on the day of week: in Sunday, when traffic is less heavy, there is a greater decrease of collisions and this seems to indicate that "easier" starting conditions improve the efficacy of the system;
- the AC system seems to be more effective in the fast lane, when reaction time is a very crucial factor.

Table 4: Effect of Anti collision equipment on collisions reduction (Overall carriageway)
Legend : CTH : Constant Time Headway strategy LT : Late Intervention strategy.

Equipped vehicle rate	Collision rate			Incremental Decrease of Collisions		
	Sunday	Monday	Thursday	Sunday	Monday	Thursday
10% CTH	8.9	8.4	8.2	8.9	8.4	8.2
25% CTH	22.7	21.7	20.9	15.1	14.5	13.8
50% CTH	42.8	41.8	40.8	26.0	25.6	25.2
10% LT	8.5	7.7	7.4	8.5	7.7	7.4
25% LT	21.5	19.7	19.3	14.2	13.1	12.9
50% LT	41.0	39.0	37.5	24.8	24.0	22.6

Table 5: Effect of Anti collision equipment on collisions reduction (divided by lane).

Equip vehicle rate	Collision rate									Incremental Decrease of Collisions								
	Sunday			Monday			Thursday			Sunday			Monday			Thursday		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
10% CTH	7.9	8.5	9.3	8.2	8.5	8.3	7.6	8.2	8.2	7.9	8.5	9.3	8.2	8.5	8.3	7.6	8.2	8.2
25% CTH	22.0	21.9	23.4	21.2	21.6	21.8	21.1	20.4	21.4	15.3	14.7	15.5	14.2	14.2	14.7	14.5	13.3	14.3
50% CTH	41.3	40.8	44.6	39.0	40.7	42.9	40.4	39.3	42.3	24.7	24.2	27.7	22.6	24.4	27.0	24.5	23.8	26.7
10% LT	8.9	8.2	8.7	7.6	7.7	7.6	7.4	7.5	7.3	8.9	8.2	8.7	7.6	7.7	7.6	7.4	7.5	7.3
25% LT	21.6	21.0	21.9	19.9	20.1	19.4	20.0	19.4	19.2	13.9	13.9	14.4	13.2	13.4	12.7	13.6	12.8	12.9
50% LT	39.2	39.6	42.2	37.8	38.8	39.3	38.1	36.7	38.3	22.4	23.6	26.1	22.4	23.4	24.7	22.6	21.6	23.6

note : (lane 1 : slow lane, lane 2 : middle lane, lane 3 : fast lane)

Table 6: Effect of Anti collision equipment on collisions speed and spacing (divided by lane)

Lane	Eq. Rate	Absolute collision speed [km/h] Mon	Thur	Sun	Relative collision speed [km/h] Mon	Thur	Sun	Spacing [m] Mon	Thur	Sun
Slow	10%	35.0	35.6	31.6	27.8	28.0	25.6	32.8	31.9	31.5
	25%	35.2	35.1	31.4	28.0	27.7	25.5	35.1	34.0	33.6
	50%	35.1	35.8	32.2	28.1	28.2	26.1	38.6	37.6	37.4
Middle	10%	44.1	45.4	40.4	32.9	33.7	31.2	32.3	33.0	32.0
	25%	43.2	44.4	39.7	32.2	32.9	30.7	33.9	34.5	33.7
	50%	42.5	43.4	38.9	31.7	32.2	30.2	37.0	37.2	36.8
Fast	10%	52.5	53.7	46.3	37.4	38.0	34.1	34.0	34.1	31.8
	25%	51.4	52.7	45.4	36.0	36.7	33.3	36.1	36.3	34.2
	50%	50.2	51.2	44.6	34.5	34.9	32.4	39.9	39.9	38.3
Total	10%	48.0	49.1	43.2	34.9	35.6	32.6	33.1	33.5	31.9
	25%	47.0	48.1	42.4	34.0	34.5	31.9	35.0	35.3	34.0
	50%	46.0	46.8	41.6	32.9	33.4	31.2	38.4	38.5	37.6

Table 7: Percentage effect of Anti collision equipment on collision speed and spacing reduction (divided by lane).

Lane	Eq. rate	Absolute collision speed [km/h] Mon	Thur	Sun	Relative collision speed [km/h] Mon	Thur	Sun	Spacing [m] Mon	Thur	Sun
slow	10%	0.9	-0.7	0.0	1.2	-0.7	0.0	4.4	4.6	5.4
	25%	0.4	0.8	0.7	0.5	0.5	0.3	10.7	10.5	11.3
	50%	0.5	-1.0	-1.7	0.2	-1.2	-2.0	18.9	18.9	20.4
middle	10%	0.8	1.1	0.9	1.0	1.4	0.7	3.5	3.1	3.8
	25%	2.8	3.3	2.6	3.0	3.8	2.4	8.1	7.2	8.7
	50%	4.4	5.5	4.5	4.5	5.8	3.8	15.9	14.0	16.3
fast	10%	2.0	1.8	1.3	2.8	2.7	2.0	4.7	4.7	5.9
	25%	4.0	3.7	3.2	6.3	6.1	4.5	10.4	10.4	12.5
	50%	6.4	6.4	4.9	10.3	10.5	6.9	18.8	18.6	21.8
Total	10%	1.5	1.5	1.2	2.0	2.0	1.4	4.1	4.0	4.9
	25%	3.5	3.6	3.0	4.8	5.0	3.5	9.3	8.9	10.8
	50%	5.7	6.1	4.9	7.6	8.2	5.5	17.4	16.4	19.3

But the effect of the Anti Collision system is not only on the number of avoided collisions, but also on reduction of collision speed and consequently on damages due to the collision.
Two main outcomes emerge from tables 6 and 7. Considering the average value calculated on all data, the reduction of absolute and relative speed is quite small; it becomes significant only when using a higher equipment rate.

This has one main reason: the collisions are due for the greatest part to the collisions of unequipped vehicles; in fact, the figures of collision speed are calculated considering only the speed of vehicles which had a collision. A further step consists in calculating the collision speed for accidents caused by equipped vehicles: in these cases better results are obtained.

Spacing increases up to the 20% in the case of a 50% of equipment rate. The reason is the same of the previous point: the average value is calculated on the overall simulations which had no collisions, in this case the main contribution is given by equipped vehicles. The points above-mentioned suggest us to investigate on the number of collisions of equipped and unequipped vehicles considered as two distinct groups. It is clear that in some cases even the equipped vehicles are not capable of avoiding completely the accident. The control strategy in general does not consider the effect of friction and extreme dangerous conditions which can be avoided only by a dramatic reduction of speed and spacing between vehicles but, on the other hand, a too conservative control strategy could be not acceptable because of a notable decrease of road capacity. Even "late intervention" approach, if used near the limit features of vehicles is not capable of avoiding all the collisions, even if results are very close to the constant headway approach (which is set to 1.1 seconds, a little bit low than the average value calculated for platoon of engaged vehicles). But anyway, figures of table 8, particulalry columns related to equipped vehicles, are good advertising messages for a potential user of the system. Probability to have a collision without the system is ranging from 20% in the slow lane up to about 50% in fast lane, while, with AC systems, these limits become from 1% up to 11% in fast lane. Moreover we noted a general decrease of these percentages going towards more higher equipment rate. This improvement is due mainly to stabilisation effect of platoon inside the sequence of equipped vehicles which obviously are present in a higher number in traffic with a high equipment rate. Further analysis on collisions probability is described in the next paragraph.

Table 8: Percentage of collisions of equipped and unequipped vehicles for CTH (divided by lane)

		Collision rate Unequipped vehicles			Collision rate Equipped vehicles		
Lane		**Monday**	**Thursday**	**Sunday**	**Monday**	**Thursday**	**Sunday**
Slow	0%	24.9	25.7	19.9	0.0	0.0	0.0
	10%	24.9	25.8	20.1	2.6	2.3	0.7
	25%	24.7	25.5	19.9	2.4	2.4	0.6
	50%	26.0	26.5	21.0	1.7	1.5	0.5
Middle	0%	36.2	37.8	31.0	0.0	0.0	0.0
	10%	35.6	37.1	30.6	7.0	8.4	4.9
	25%	34.9	36.3	29.8	5.7	7.2	4.1
	50%	35.6	36.4	30.3	4.0	5.1	2.7
Fast	0%	47.2	49.3	40.9	0.0	0.0	0.0
	10%	46.8	48.8	40.4	10.9	11.7	6.7
	25%	46.1	48.2	39.9	8.8	9.6	5.3
	50%	47.7	49.7	41.6	5.5	6.2	3.2
Total	0%	40.3	41.9	35.0	0.0	0.0	0.0
	10%	39.8	41.3	34.5	8.6	9.5	5.6
	25%	39.1	40.5	33.8	7.0	8.0	4.5
	50%	40.0	41.0	34.6	4.6	5.4	2.8

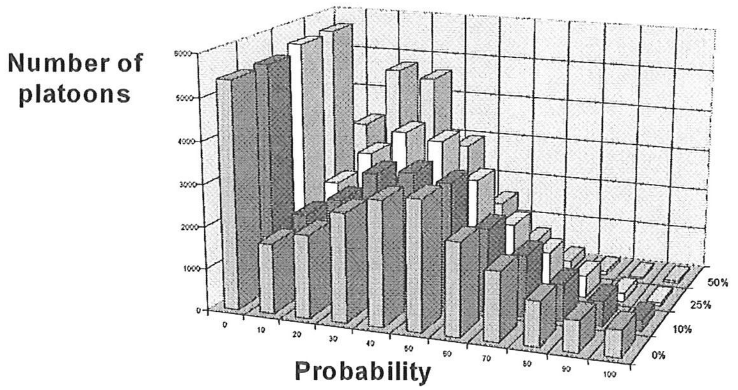

Figure 3: Accident probability

Analysis of collision probability

The statistical approach used in these experiments allows us to calculate the collision probabilities and to associate them to platoon composition and position. The following figures report histograms of accident probability related to the number of platoons.

Collision probability is reduced in the highest values with a steady progression, while it is interesting to note that the number of platoons with zero accident probability remains practically constant varying the equipment rate. The accumulation of platoons with a low collision probability seems to be a not linear process, a bias effect to this behaviour can be surely caused by the Monte Carlo procedure which "favours" the platoons with high numerousity in the sense that, for example, a platoon with 2 vehicles would have 10 potential collisions, while a platoon of 10 vehicles would have up to 90 collisions, it is easy to understand how it is very difficult to increase the number of platoons with zero accident probability because of the low probability to have always equipped vehicles in the platoon. This remark is confirmed by the figure 4 in which the numerousity of platoons is added to the collision probability. To limit the number of figures, only one example related one lane (the middle one), one day and one equipment rate is drawn.

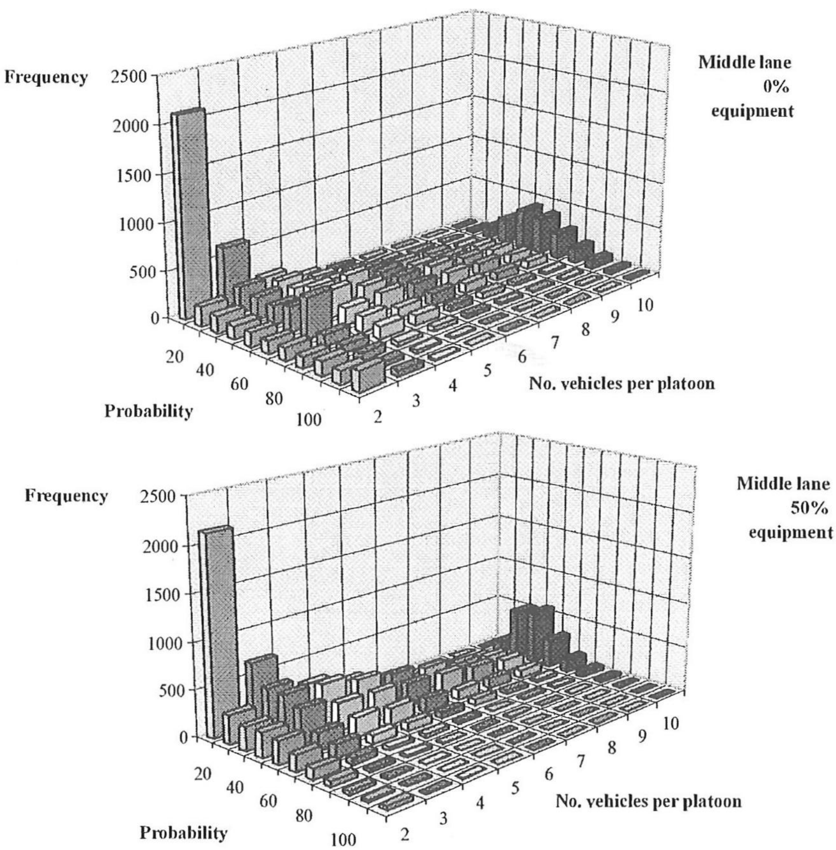

Figure 4 : Accident probability frequency for number of vehicles per platoon for two percentages of equipped vehicles.

Relationship accident-flow

One important analysis concerns the distribution of the collisions along the day and its relations with traffic flow. Figure 5 shows the histograms of collisions and the indication of the vehicular flow calculated each 15 minutes. A direct connection between flow and number of collisions is note; of course this relationship is biased by the effect of the Monte Carlo procedure on the longer platoon as explained in the previous chapter, but anyway the diagrams highlight this relationship and also the high number of collisions happened during the evening hours. This behaviour is confirmed by data on accidents collected by ACI (the Italian Automobile Club) and ISTAT (the Italian Institute of Statistics) for extraurban networks as described by figure 6.

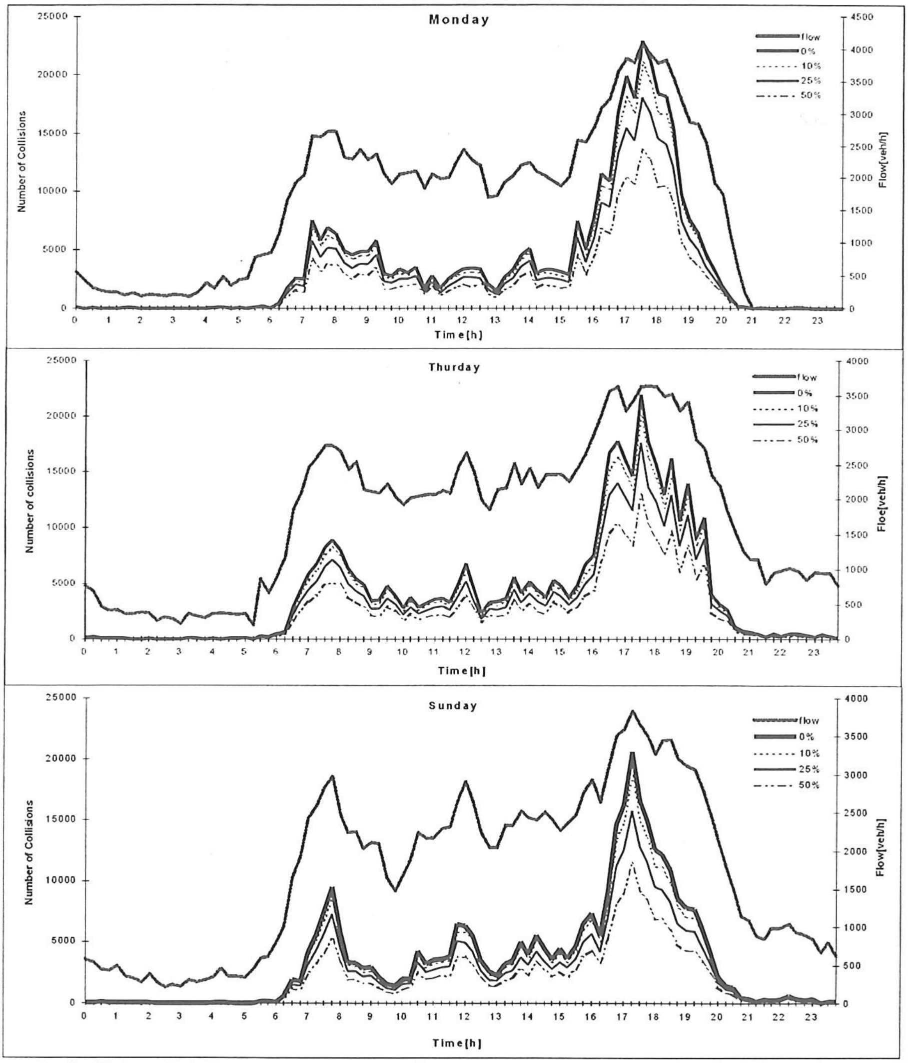

Figure 5 : Collision distribution per time and flow

Hourly Accident Distribution in Italy (1995)

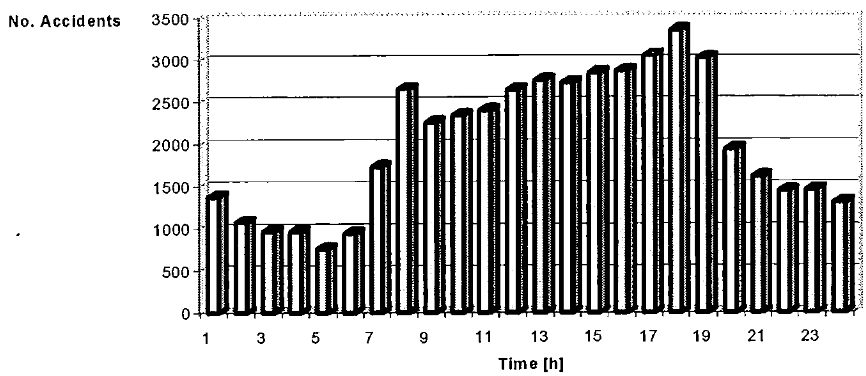

Figure 6: Histogram of accidents occurred in the freeway Italian Network

In this case the accident comprises all the possible causes, such as tiredness, sleepiness, imprudence or distraction and are not only caused by effectively dangerous traffic conditions, even if a roughly estimation of distraction or tiredness is achieved varying the reaction time in brake manoeuvres.

SWERVE MANOEUVRE EFFECTS

The manoevre of swerve is analysed in each case a vehicle cannot avoid collision only by braking. Whether spacing between vehicles in the lateral lane is greater than a fixed value (here it is assumed 30m) the manoevre is allowed. No test on speed or driver capability is carried out. Therefore because middle lane has two lateral lanes it has also a value of probability double in respect of slow and fast lanes.

The experiments found a high number of potential rear end collisions which can be avoided by a swerve manoeuvre but this result could be reduced whether the real capabilities of drivers are kept into account. Table 9 reports figures related to this phenomenon. Because of the higher possibility to swerve, the middle lane has the best improvement in safety when the swerve opportunity is considered.

Table 9: Collisions data with swerve possibility (divided by lane)

Lane		Longitudinal collisions	Swerve	Side Effects	Total collision	Collision rate
Slow	Monday	9936	4898	143	5181	14.8
	Thursday	12959	5652	105	7412	16.5
	Sunday	8751	4228	120	4643	11.7
Middle	Monday	173582	148742	5011	29851	8.9
	Thursday	198084	172567	5546	31063	8.7
	Sunday	151496	133157	4866	23205	6.4
Fast	Monday	177428	67427	6091	116092	36.9
	Thursday	198551	72832	7068	132787	39.4
	Sunday	178523	67196	5293	116620	31.2
Total	Monday	360946	221067	11245	151124	22.1
	Thursday	409594	251051	12719	171262	23.1
	Sunday	338770	204581	10279	144468	18.7

Table 10: Collision rate and collisions decrease when swerve is allowed (divided by lane)

	Equipment rate	10%			25%			50%		
Lane		**Mon**	**Thur**	**Sun**	**Mon**	**Thur**	**Sun**	**Mon**	**Thur**	**Sun**
slow	Collision rate	13.4	15.3	10.8	11.6	12.9	9.1	8.6	9.7	6.8
	Coll. decrease	8.2	7.6	7.9	21.2	21.1	22.0	39.0	40.4	41.3
middle	Collision rate	7.9	7.9	5.8	6.6	6.7	4.9	4.7	4.9	3.6
	coll. decrease	8.5	8.2	8.5	21.6	20.4	21.9	40.7	39.3	40.8
fast	collision rate	33.5	35.6	27.9	28.0	30.0	23.1	19.9	21.3	16.3
	coll. decrease	8.3	8.2	9.3	21.8	21.4	23.4	42.9	42.3	44.6
Total	collision rate	19.8	20.9	16.7	16.4	17.4	13.7	11.6	12.3	9.7
	coll. decrease	8.4	8.2	8.9	21.7	20.9	22.7	41.8	40.8	42.8

But, since no dynamic formula for motion equation in swerve manoeuvres was applied, these figures (especially for the high speed range) can be considered as an upper limit, when the number of swerves is as great as possible. Probably certain dedicated electronic devices could make the number of swerves closer to this theoretic value. Considering the effect of control laws on collision avoidance, the same figures of the longitudinal case are carried out. The only difference is given by the higher space left to the following vehicle by "swerved" vehicles. Figures of table 10 concern only the CTH strategy, but LT strategy had similar results

CONCLUSIONS

The experiments with the accident simulator suggest some main results. A Collision Avoidance System, used alone, is capable of avoiding a wide share of rear end collisions, 8%, 20% and 40% for an equipment rate of 10%, 25% and 50% respectively. No relevant differences are noted for the two examined control laws: late intervention and constant time headway. Micro simulation highlighted some critical aspects of the behaviour of control law in the real traffic, in the following we summarise the items which could have an impact in the design of a control law. Experiments with a TH equal to 1.0 seconds highlighted a good potential traffic efficiency due mainly to the reduced average value of the time headway and emphasised by the traffic harmonisation effect (Less unstable traffic conditions).

The control law must be operative also in case of high relative speed approach, that means that it is crucial to know the speed of the car in front with a good precision level. From a safety point of view, the CTH approach works better with an high number of equipped vehicles. On the other hand, an automatic intervention (by LT strategy), set to maximise brake capabilities, is not sufficient to avoid all accidents, even if efficacy is comparable to the CTH approach set to 1.0 seconds. The collision rate (Collision/(Collision+Not Collision)) of equipped vehicles is ranging from 1% to 10% according to the equipment rate. More conservative control law parameters could be used in simulations to improve these figures with the aim of bettering the most degraded vehicle features (like brake and mechanical efficiency, system reaction time, short time headway, ...) or performance of the equipment (RADAR range). In equipped vehicles the accident probability reduces sharply.

It is extremely difficult to reduce to zero the collision probability both in big and also in smaller platoons because of the presence of unequipped vehicles which statistically can produces a few but not nil number of accidents. The histogram of the hourly collision distribution follows nearly the flow curve with a peak in the evening hours.

The swerve possibility does not decrease the efficacy of the collision avoidance system. Another remark is that an equipped vehicle improves a lot the personal safety and it avoids many accidents to other vehicles (even if does not avoid collisions of unequipped following vehicles) with undoubted benefit also to unequipped vehicles. These experiments have not found unsafe side effects of the system.

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