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AN ANALYSIS OF LATERAL SUPPORT SYSTEMS TO INCREASE SAFETY AT CROSSROADS

Abstract:
The paper aims at reporting the simulation activities planned in order to investigate on the lateral accident severity and on the possibility of reducing the number of accidents by means of on board systems in case of crossing of roads or crossroads. The problem of collision at intersections is surely very important for the number of accidents and very difficult to tackle from the technological point of view. At this moment several European research projects, like LACOS funded by EC within the 4th framework of the European Research, PROTECTOR and CHAMELEON, two projects funded within the 5th Framework Research Programme, investigate on potential benefits which can be introduced by the use of electronic on board devices both for active and passive safety. The simulations developed in the research are a useful mean to understand in which direction is more convenient to work; in particular a special study has been done about the crossing of unprotected road users (such as pedestrians). The equipment envisaged for the simulations derived from an analysis of the state of the art of technologies for object sensing and actuation as well as defined within the already mentioned projects. These features will be implemented in an existing accident simulator in order to perform simulation runs.

Presenter: Gianguido SALA

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1. INTRODUCTION TO TECHNOLOGIES FOR ROAD CROSSING

In this chapter a brief description of automotive technology today available or in late developing is presented, considering the major concerns of the already mentioned projects. The project LACOS (ended in September 2000) allowed to develop several demonstrator vehicles equipped basically by warning strategy aiming to help the driver in the following two tasks:

1) Lane Keeping (a system warns the driver when the vehicle is running out from the present lane marks);
2) Lane Change Support (a system warns the driver when he is going to overtake with a car coming from the rear or lateral side).

Technologies in LACOS were computer vision for low range sensors (blind spot areas and lane mark detection) and radar for longer range system. Main objective of CHAMELEON project, is to support, to guide and to validate the development (including integration and adaptation concept) of a pre-crash sensorial system necessary for near impending crash detection in all scenarios (city, urban, rural and motorway).

The aim of the project is to minimise the accident consequences investigating the optimal sensorial system for both reversible and irreversible approach to be considered respectively intermediary and final steps of the system development, where:

- Reversible means that the action of the safety system is a reversible action and does not produce any damage to the system itself (for example the pre-tensioning of safety belts);
- Irreversible means that the safety system after its activation has to be substituted (a classic example is Air Bag).

Technologies which are developed in CHAMELEON are:

- Radar technologies (24 GHz and 63 GHz)
- Laser (scanning laser and fixed laser)
- Computer vision

The signals of those different sensors are complementary or overlapped, for that reason a sensor fusion procedure will be developed in order to increase the overall level of the performance of the sensorial system.

PROTECTOR proposes the definition/specification, development/adaptation and validation of a system capable of detecting in urban environment unprotected road users (pedestrians, children, elderly as well as cyclists and motorcyclists) which are very often subjected to accidents and more often excluded from the detected object classification due to the poor performance of the available sensors and processing techniques for an urban scenario.

Technologies envisaged for the PROTECTOR purposes are:

- Radar technologies
- Laser technologies
- Computer vision technologies
- Communication (active and passive links)

From this analysis emerges a wide set of technologies available for crossroads protection, both considering the visible part of the crossroad and the not visible one.Furthermore, recent development of application with digital road makes possible the use of this technology especially for the monitoring of the non visible part of crossroad.

2. THE ENVIRONMENT OF APPLICATION

2.1 The crossroad

Accident statistics show that every year a high number of accidents (35.6%) occurred at crossroads and intersections, nearly one third of the total number of collisions and a huge number of pedestrians are knocked out (table 1).

Non mi convincono molto questi dati; I totali (per avere il 100%) come andrebbero fatti?

Table 1: Accident classification in Italy (mettere una fonte).

		Accident rate %	Fatal accident rate %	Fatal accidents per 100 accidents
At crossroads	Urban	31.2	9.3	9.8
	Extra urban	4.4	5.8	3.5
Not at crossroads	Urban	25.4	15.0	1.6
	Extra urban	12.6	26.0	5.5
Pedestrian	Urban	6.6	10.4	4.2
knocking down	Extra urban	0.5	2.8	14.8
Isolated vehicles	Urban	11.0	10.5	2.5
	Extra urban	8.2	20.1	6.5

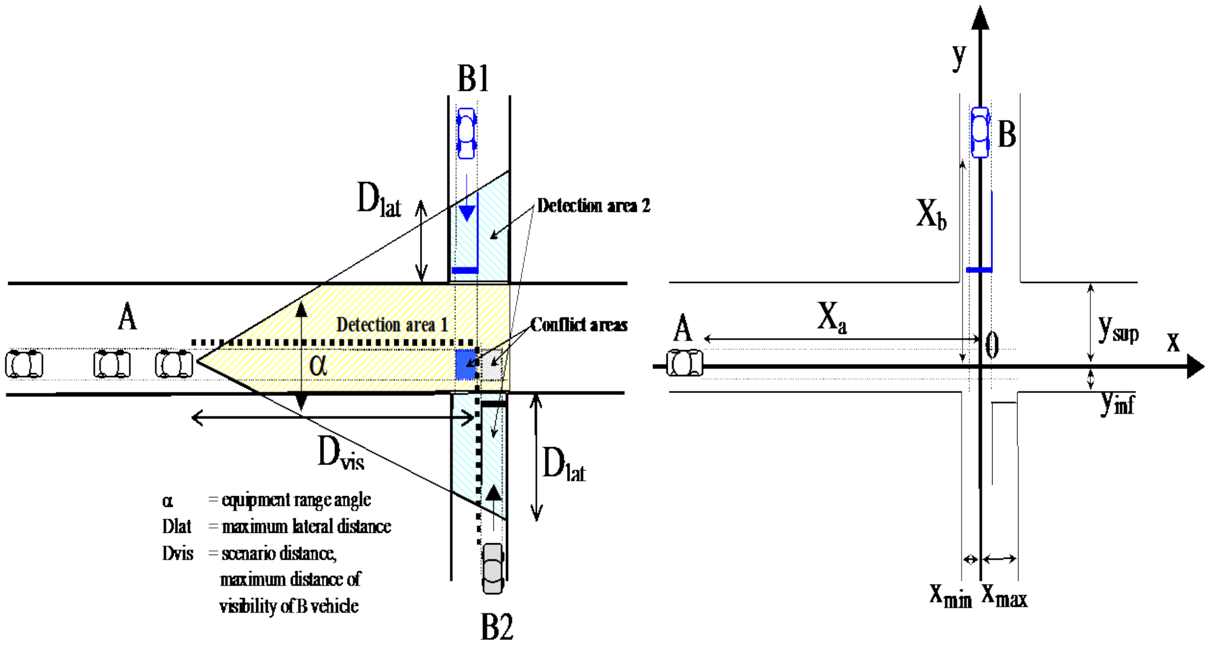

Figure 1: Crossroad description.

Before simulation we have first defined a standard accident configuration for crossroads (fig. 1). In the right side of figure 1 the reference system used in the simulations is shown and in the left side the parameters used in the simulation are described. The size of the crossroad can be fixed according to the number of lanes chosen for the experiment. However the possibility to increase the traffic safety at the intersection is strongly related to the possibility to detect objects (moving or not) which can interact in a road crossing phase.

In the left side of figure 1 the areas of interaction between vehicles when approaching the crossroad are shown. These areas can be divided into two sub-areas, coloured in the figure, and they can be classified as “visible area” or detection area 1 and “non visible area” or detection area 2. Within detection area 1 (the visible one) there are also the conflict areas (shown with a darker zone) where the collision between vehicles can occur. During simulation we consider that a collision occurs when two intersecting vehicles occupies contemporary the conflict area.

At this moment the greatest efforts have been devoted by car manufacturers to equip cars with an autonomous system capable of working especially in longitudinal direction, and in general without considering the vehicle coming from orthogonal direction. The study aims to investigate the effect of longitudinal systems and of system which consider also the “non visible” part of the cross roads.

2.2 Strategies for lateral protection at crossroads

From the wide set of possibilities, we have selected the two vehicle control strategies.

The first one, called late intervention, is based on the assumption that the system must intervene as late as possible in agreement with the maximum brake possibility of the car when the crossing car is detected in the visible area. The car brakes only when the situation is becoming definitely dangerous and should avoid the possibility to have many false alarms. This approach, derived from that used by the EU funded AC-Assist project (1996-98), has given good results in the experimentation done within the project and it is based on the following formula for the spacing between two vehicles:

$$\text{spacing} = v_f^2 \,/\, 2\, a_f \;-\; v_f^2 \,/\, 2\, a_l \;+\; \textit{offset} \qquad (1)$$

where v and a are speed and acceleration respectively of leader (subscript l) vehicle or of following (subscript f) vehicle. The addition of the “offset”, a constant term , makes this formulation more conservative in order to increase the safety of the system. The calibration of offset allows to the simulator to estimate a different level of risk perception of drivers.

The second control strategy considers the possibility to track the crossing vehicle even in the non visible area. This paper does not take care of the technology used to achieve the detection of the non visible area. What is not possible to do easily is the communication of the driver/pedestrian intentions who have to consider the traffic rules and traffic signals.
The basic concept is based on a reduction of the speed of equipped cars when another car (or a pedestrian) is potentially dangerous. This of course reduce the kinetic energy in case of impact.

Two formulas allow us to calculate if a collision can be predicted or not:

$$\frac{X_b + L_b + {}^{W_a}\!/_{2}}{V_b} < 0.9\,\frac{X_a + L_a + {}^{W_b}\!/_{2}}{V_a} \qquad (2)$$

$$\frac{X_a + L_a + W_b/2}{V_a} < 0.9 \frac{X_b - W_a/2}{V_b} \tag{3}$$

Both formulas consider the speed of vehicles stationary. This means the prediction is the more accurate the more close are the two vehicles; the coefficient of 0.9 increases the correctness of prediction.

The control strategy follows the following three rules:

1) If both inequalities are satisfied, then a collision is not predictable, hence the car are free to continue without limitation of its own dynamic,
2) If a collision is predictable, but vehicles are not interacting in the visible part of the crossroads, the equipped car becomes to brake with a quite soft deceleration (0.5 m/s^2) in order to achieve a speed which would allow, in the worst conditions, a crash with fatal consequences (for the experimentation we set this speed to 50 km/h),
3) If a collision can be predicted and the car is visible, the car starts braking with the highest brake capability.

The system does not take into consideration the possible right of way in the road crossing and the equipped car is sure about the movement of the target car only when it is in the own trajectory.

3. SIMULATION CONCEPTS

3.1 Vehicle dynamic simulation

A simulator to study the effect of CAS system was already developed (Sala and Mussone, 1998; 1999) in order to study the evolution of a perturbation within a platoon when an unsafe manoeuvre occurs. The paper includes a short description of simulator features, in particular of those aspects, which allowed simulating some accident types in a crossroad.

Roads are often characterised by the formation of clusters of vehicles interacting between themselves, called platoons, whose safety conditions are depending much on driver (or system) capabilities to react to vehicular flow perturbation. Therefore knowledge of dynamic inside platoons is of great importance to understand which improvements in vehicular safety can be achieved.

Unsafe manoeuvres are studied by the simulation of a crossroad through which a platoon of vehicles is running. When the platoon leader achieves a distance to the crossing road (scenario distance in figure 1), a car running in the crossing road engages the crossroad at constant speed without giving the right of way to the platoon leader.

An algorithm based on the two strategies above described allows the system (the activation is automatic but the simulator can allow warning system also) to choice the best strategy between the following possibilities:

a) disengagement of crossroad at constant speed,
b) soft brake,
c) hard brake.

The other vehicles of the platoon must adapt their behaviour to the new situation in two ways: the first one is to brake after a reaction time by using the maximum braking capability allowed by vehicle mechanics, the second is to follow the leader if it does not brake.

In the case of accident, a follower brakes by using its maximum braking capability. A calculation of secondary effects of these manoeuvres is also worked out. The simulator allows us, through a statistical approach, to calculate the probability of collision of vehicles in platoons. A different probability can be calculated whether we consider or less the possibility to disengagement the crossroad at constant speed. A Monte Carlo procedure is applied to guarantee that the numerous combinations of vehicle features were actually used. For the same platoon, one simulation is repeated a number of times to reach a sufficient statistical significance.

The overall vehicle set is divided into vehicle classes and when necessary, in engine size classes and "cars" class. As regards the efficiency of braking system, since generally it does not depend on the class of vehicle, it is assumed it can vary uniformly between the range 0.8 and 1 of its nominal value.

3.2 The module of vehicular dynamic

If we consider a flat road without additional hooked up weight, the predominant contribution to braking forces is due to the brake system limited by friction between tires and asphalt. Besides friction many other parameters affect and limit the braking force of a vehicle, they depend on mechanical status of brake system, tire condition, anti-lock system availability, ability of driver to brake, and so on.

An additional parameter "k" is inserted in the calculation of maximum brake force in order to introduce some perturbation in braking manoeuvres. This parameter is constant, related to the "quality" of driver and to the state of conventional mechanical equipment; it generally ranges from 0.85 to 1. A module simulates for each vehicle the dynamics of motion (braking on a straight or curved stretch) (Gillespie, 1992) according to the following system of two differential equations:

$$dx_{2/}dt = x_1(t) \tag{4}$$

$$dx1/dt = a(t) \tag{5}$$

in which $x_2(t)$ indicates the position of the vehicle, $x_1(t)$ its speed and a(t) its acceleration function of the coefficient of adherence, $\mu = \mu (x_1)$, which is assumed function of speed.

What's more, a generic relationship between adherence and non-constant velocity of a hyperbolic type is hypothesised:

$$\mu (x_1) = (a\, x_1 + b) / (c\, x_1 + d) \tag{6}$$

which, in the case of a dry surface, becomes a straight line and on a wet surface a hyperbole (Bauer, 1996). The value of the coefficient of adherence is recalculated at every step of integration h. which is set to 0.1 second. It must be remembered that higher resolutions are not necessary when speed is already low, due to its reduction by the braking manoeuvre.

3.3 Reaction times and system delay

The reaction time of drivers for not equipped vehicles was the subject of a particular survey (Allen et al., 1996; Palmertz et al., 1998; Ray, 1996; Gordon et al, 1984); these papers reports about driver reaction times and specifically in a braking manoeuvre but unfortunately only the paper of (Gordon et al., 1984) proposes a distribution of reaction time according to driver characteristics. Because other papers don't deal with this aspect in such a detail but they are consistent with the average values, we use data proposed by (Gordon et al., 1984) as reported below.

Table 2: Braking reaction time distribution

Percentile %	**50**	**75**	**90**	**95**	**97**	**99**
Braking reaction time [s]	**0.85**	**1.11**	**1.24**	**1.42**	**1.63**	**2.16**

In equipped vehicles the control strategy is assumed to work in the range 0.150 ÷ 0.250 seconds the requested braking as explained above in the paper. This time consider also the time spent to activate the brake.

3.4 Simulation scenarios

By varying the conditions of road, of equipped vehicle rate, of the composition of vehicle park, of initial conditions, we are able to define different scenarios.

Platoon conditions are generated by an automatic procedure which "produces" the vehicles which are passing on the cross roads with distances singled out randomly according to a suitable "spacing" distribution derived from the real ones.

Scenarios take into account the following main aspects:

- The different braking levels of vehicles,
- The different traffic flow and the different "spacing law",
- The different percentage of equipment,
- The different speed of the target car (the vehicle B in the figure 1); by selecting an appropriate speed and dimension, the target B can be used to simulate a person.

The different braking level concerns the capability and habit of drivers seldom accustomed to face a vehicle which is not giving the right of way. A coefficient is applied to the maximum performance of leading vehicle to take into account this aspect. For each scenario the percentage of equipment is varied with a distribution amongst classes following the principle that the luxury car will probably be the first to be equipped with new devices. The total equipment rate is set to 10%, 25% and 50% in order to study the evolution of market introduction and to ensure a good sensitivity analysis.

The simulations investigates the number of accidents produced by the simulator for different scenarios as described earlier. Special scenarios have been designed in order to simulate also pedestrian circulation.

To achieve a good stability of the results, the number of iterations for each scenario has been set to 10.000. This value, singled out empirically, guarantees an estimated error less than 3 per thousand and it is not too much time consuming. Parameters considered in the result analysis are:

- Number of collisions,
- Equipment rate,
- Collision speed and mass of vehicle A, mass of vehicle B,
- Traffic Flow,
- Average speed and spacing of vehicles inside the platoon after an accident,
- Type of vehicles (in some scenarios pedestrians have been used instead of a vehicles),
- Type of collision (that is, vehicle A collides vehicle B, a→b, or vice versa, b→a).

4. SIMULATION RUNS

4.1 Collisions between vehicles

Simulations are conducted by using equipped cars with lateral support strategy; the behaviour of a late intervention strategy has been already studied in previous studies as quoted in the reference list (Sala and Mussone, 1998; 1999).

Table 3: Percentage of collisions (10000 cases each scenario).

			Percentage of equipment							
			0%		10%		25%		50%	
		Vehicle B Speed [km/h]	Collision type		Collision type		Collision type		Collision type	
vehicle A speed	Flow A		b->a %	a->b %	b->a %	a->b %	b->a %	a->b %	b->a %	a->b %
90 km/h	200 veh/h	90	2	2	2	2	2	2	2	2
		50	2	4	2	3	2	3	2	3
		15	3	8	3	8	3	7	3	6
	400 veh/h	90	4	4	4	3	4	3	4	4
		50	4	6	4	6	4	6	4	6
		15	6	15	5	14	5	12	6	12
	800 veh/h	90	6	7	7	7	6	7	7	7
		50	8	12	7	12	7	11	7	11
		15	10	26	10	24	10	21	10	19
	1200 veh/h	90	10	8	10	9	10	8	10	8
		50	12	14	12	14	11	14	11	13
		15	14	32	14	31	13	27	13	25
50 km/h	200 veh/h	90	3	2	3	2	3	2	3	2
		50	3	3	4	3	3	3	4	3
		15	4	7	4	6	4	5	4	4
	400 veh/h	90	6	4	6	4	6	4	6	4
		50	6	6	6	6	6	6	7	6
		15	8	13	7	11	7	9	7	7
	800 veh/h	90	16	8	16	8	16	8	15	8
		50	16	12	16	12	16	11	15	12
		15	21	19	21	17	20	15	18	11
	1200 veh/h	90	21	12	21	12	21	11	21	11
		50	21	19	21	19	22	18	21	18
		15	25	25	24	23	23	18	20	14

4.1.1 Number of Collisions

Collisions have been calculated and results are reported in table 3; in figure 2 results for some scenarios are drawn. Clearly, the lower the speed of vehicle B (and therefore the higher the time spent inside the conflict area of the crossroad) the higher the number of accidents, the lower, of course, the severity of these accidents. This result may appear paradoxical but it doesn't take into account the severity of accidents: it reflects only the condition that collisions may occur inside the conflict area which is a limited area, therefore the shorter the presence of a vehicle the higher its speed. For this reason, results obtained with a different speed of vehicles should not be compared and only the effect of equipment for the same scenario must be considered.

The efficacy of the system depends strongly on the speed of vehicle B, and it ranges from few percentage points for higher speed up to 30% in case of 50% of equipped vehicles (figure 2). The reduction of speed A increases the efficacy of the system only when the speed of vehicle B is low. The main reason of this behaviour is the fact that equipped vehicles are not capable of foreseeing whether vehicle B stops or not. Better results could be achieved when also vehicle B is equipped. In this case the interference between vehicles could be avoided at all; nevertheless this implies to have the totality of vehicles equipped. However, the control strategy selected allows a reduction of accident severity by the reduction of speed and the potential kinetic energy of the impact.

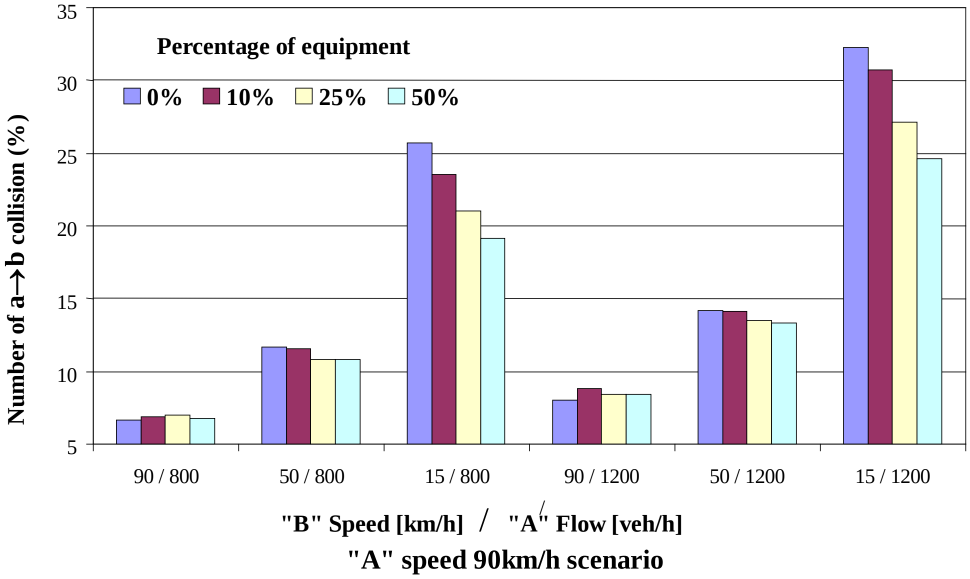

Figure 2: Analysis of the number of collisions for some simulated scenarios.

4.1.2 Collision Speed

An important parameter to estimate accident consequences (and their severity) is collision speed. It is directly joined with the calculation of kinetic energy during the impact and the estimation of post crash damages.

Figures 3 and 4 summarized some results for a reference traffic flow of 800 veh/h. The first one considers the calculation made for a speed of 90 km/h for both vehicle A and B, while the figure 4 reports the results for a speed of vehicle B equal to 15 km/h.

The analysis of figures 3 and 4 allows to identify two main aspects. The first concerns the equipment rate, that is whether the effect of the system is linear with the percentage of equipment or not; in other words if the system is capable of working independently by the behaviour of other vehicles. The second aspect concerns the efficacy of the system. The system is very effective when the speed of vehicle B is low: in this case the collision speed of equipped vehicles can be lower of about a half than that of non equipped vehicles.

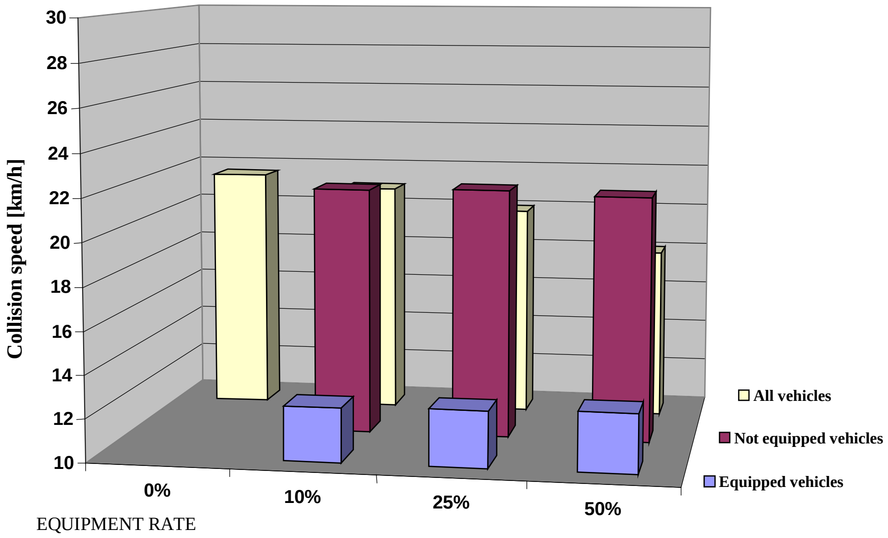

Figure 3: Average speed of collision with speed of vehicle A = 90 km/h and B = 90 km/h.

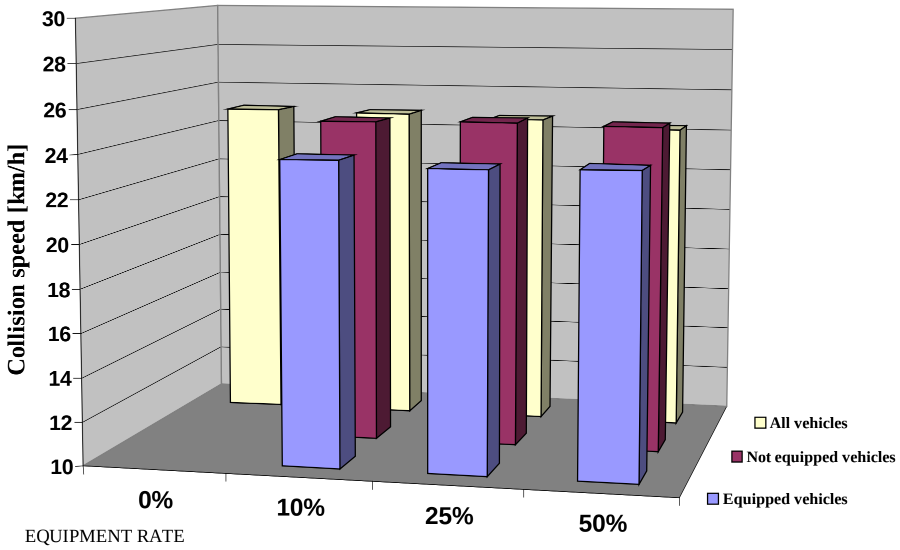

Figure 4: Average speed of collision with speed of vehicle A = 90 km/h and B = 90 km/h.

4.1.3 Lateral distance

A sensitivity analysis on lateral distance is also done. The aim is to understand how the width of lateral distance could affect the efficacy of the lateral control system. The results are summarised in table 4.

It seems evident that a wide distance does not affect too much the performance of the system. In many cases differences are not present at all. This result seems to be very important and it is a valuable contribution in the design of the sensorial system of future. The lateral range of the sensor can be limited to the space needed to understand if the approaching car is giving or not the right of way. This range is in general very close to the visible field.

Table 4: Sensitivity analysis for lateral range of sensors.

Lateral distance of visibility	Vehicle A and B speed	A flow	Percentage of equipment 0%				10%				50%			
			Collision type % collision		vehicle A spacing [m]	vehicle A speed [m/s]	Collision type % collision		vehicle A spacing [m]	vehicle A speed [m/s]	Collision type % collision		vehicle A spacing [m]	vehicle A speed [m/s]
			b->a	a->b			b->a	a->b			b->a	a->b		
40 m	90 km/h	200 veh/h	1.8	2.0	468.45	25.01	2.0	2.0	469.29	24.95	2.1	1.8	468.03	24.79
		800 veh/h	6.4	6.6	132.18	25.01	6.9	6.8	132.35	24.85	6.9	6.5	132.1	24.3
	50 km/h	200 veh/h	3.4	3.4	262.42	14.01	3.6	3.4	262.76	13.87	3.6	2.9	262.03	13.36
		800 veh/h	15.8	12.0	74.03	14	16.0	11.7	74.01	13.5	15.9	11.2	73.7	11.58
60 m	90 km/h	200 veh/h	1.8	2.0	468.45	25.01	2.0	2.0	469.27	24.9	2.0	1.8	468.02	24.54
		800 veh/h	6.4	6.6	132.18	25.01	6.8	6.8	132.33	24.69	6.6	6.4	132.01	23.44
	50 km/h	200 veh/h	3.4	3.4	262.42	14.01	3.6	3.3	262.73	13.82	3.2	2.7	262	13.16
		800 veh/h	15.8	12.0	74.03	14	15.9	11.6	73.94	13.31	15.0	10.0	73.36	10.74
80 m	90 km/h	200 veh/h	1.8	2.0	468.45	25.01	2.0	2.0	469.26	24.84	2.0	1.7	467.98	24.26
		800 veh/h	6.4	6.6	132.18	25.01	6.8	6.8	132.31	24.49	6.4	6.2	131.89	22.49
	50 km/h	200 veh/h	3.4	3.4	262.42	14.01	3.4	3.3	262.69	13.79	2.4	2.2	261.86	12.99
		800 veh/h	15.8	12.0	74.03	14	15.0	11.2	73.83	13.17	10.6	8.2	72.78	10.11

4.2 Collisions involving pedestrians

The analysis of collisions between intersecting vehicles suggests to test the system also when vehicle B is substituted by a pedestrian. The scenario slightly differs from the others used before. Instead of a crossing vehicles there is a pedestrian walking on the roadside (a sidewalk or a shoulder) and suddenly he becomes to cross the road.

The driver can understand the intention of the pedestrian only when he is leaving the roadside. It is a very dangerous situation, but quite often it occurs in urban roads. This scenario does not consider crossing priority.

The control strategy of equipped cars consider only the visible part of the road and recognizes the pedestrian as dangerous just when he is leaving the roadside. The simulation is led in a similar way of previous experiments. The set of vehicles B has been substituted by a group of pedestrians which is classified according to their crossing speeds. These speeds, ranging from 0.5 to 5 m/s, are selected considering the age of Italian citizens and their composition (ISTAT, the Italian statistic Institute, public web site).

The simulation is carried out considering two levels of traffic flow for vehicles A (800 and 1600 v/h) and two different speeds (about 50 and 70 km/h).

4.2.1 Number of Collisions

The results are summarised in table 5. The table is subdivided into two parts according to the speed of vehicle A (50 and 70km/h). The two sub-tables show a substantial inefficacy of the system. The number of collisions depends on the number of dangerous situations which are in relationship with traffic flow and the speed of vehicles. The system seems to be not capable of avoiding accidents, whatever percentage of equipment is applied.

The same table reports the number of side effects, that means the number of secondary accidents occurred inside the platoon and caused by the primary accident, that is the collision with the pedestrian. Side effects are very low and their number remains constant with a little increase in case of a higher equipment rate.

Table 5: Percentage of cases in the pedestrian scenarios.

		Equipment rate			
		0 %	10 %	25 %	50 %
Flow = 1600 v/h	No Collision	75.5	75.4	74.7	75.6
	Collision	23.3	23.4	23.8	23.0
	Side Effect	1.2	1.3	1.5	1.4
		0 %	10 %	25 %	50 %
Flow = 800 v/h	No Collision	72.8	73.1	72.4	73.5
	Collision	26.4	26.1	26.5	25.5
	Side Effect	0.8	0.8	1.1	1.0
Speed of the vehicle A= 50 km/h					

		Equipment rate			
		0 %	10 %	25 %	50 %
Flow = 1600 v/h	No Collision	65.2	65.1	63.6	63.5
	Collision	33.7	33.6	35.0	34.7
	Side Effect	1.2	1.3	1.4	1.8
		0 %	10 %	25 %	50 %
Flow = 800 v/h	No Collision	60.4	60.8	59.6	60.0
	Collision	38.9	38.4	39.4	39.0
	Side Effect	0.7	0.8	1.1	1.0
Speed of the vehicle A= 70 km/h					

4.2.2 Collisions Speed

The second parameter considered for this set of scenarios is speed of impact, that is the speed the vehicle A has when it knocks out the pedestrian (if any). The average collision speed calculated for equipped vehicles has been compared with the average collision speed calculated for not equipped vehicles. This comparison is enclosed in table 6.

Da rivedere se i calcoli sono giusti sia per la tab 6 che 7. Tieni conto che in tab 5 (ora corretta) era invertito il flusso (4s di headway corrispondono circa a 800 e non 1600 v/h).

Basically the lateral control does not introduce any appreciable effect; the system should introduce a reduction of speed but really in some scenarios the average collision speed increases instead of decreasing.

However the number of accidents depends mainly on the speed of pedestrians, as the higher the speed the lower the probability of accident. The speed of pedestrians ranges in a very wide interval: the most slow pedestrian moves 10 times less fast than the fastest one. This high variability of speed can explain the difficulty of interpreting results.

Table 6: Percentage reduction of collision speed.

Vehicle A	Speed	50 km/h	70 km/h	50 km/h	70 km/h
	Flow	800 v/h		1600 v/h	
Equipment rate	10 %	1.0	1.2	-3.0	-1.7
	25 %	0.8	1.8	3.9	3.4
	50 %	0.7	1.8	-3.2	-1.5

To achieve a better understanding of the problem we have led a second analysis concerning the speed of vehicles which did not collide calculated just in the section where the pedestrian crossed (table 7). The equipped vehicles have an evident reduction of their average speed, up to 20%. This reduction is mainly due to the high performance of electronic braking. This result means that the cases leading to knocking out the pedestrian are very difficult to avoid because of the too short distance (in space and time) between vehicle and pedestrian.

Besides the scenarios have been built up supposing a constant speed for pedestrians who cannot avoid the obstacle represented by the vehicle.

Table 7: Percentage reduction of speed for not collided vehicles.

Vehicle A	**Speed**	50 km/h	70 km/h	50 km/h	70 km/h
	Flow	800 v/h		1600 v/h	
Equipment rate	10 %	13.3	6.2	15.0	7.6
	25 %	20.2	12.1	15.4	10.2
	50 %	11.5	7.7	16.3	9.4

5. CONCLUSIONS

The simulation has allowed to study the problem of collisions at crossroads between vehicles equipped with advanced electronic system.

At the moment appears more crucial the development of a suitable control strategy which allows to operate in an efficient way the electronic devices which are today available, even if at prototype level.

The simulations carried out highlights a substantial efficacy of the system in order to avoid, or at least to mitigate, the collision between vehicles. This is particularly true in case of low speed of the crossing vehicle. Nevertheless this efficacy is lower if compared with the efficacy of longitudinal systems as experimented in previous simulation work. While the control strategy adopted does not give sufficient results to avoid pedestrian collisions.

The study demonstrated also that the knowledge of the lateral position of the target may be useless and sometimes dangerous if the dynamic of vehicle B or pedestrian cannot be forecast. In this sense a coordination between vehicles could be more effective to improve safety at crossroads.

Vanno associati biunivocamente tutti i riferimenti nel testo

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