A Zero Headway System on Automated Highways

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Introduction

Beyond fascination it has always created, speed is looked at as the most significant progress indicator in the transportation field. A rapid overview of speed evolution since one hundred years throughout transportation means shows that car, train, shipping and air transport speed has doubled every forty or fifty years. This tendency is likely to last for the coming years. In this general tendency, riding cars appears to be an exception : it is the only mode for which speed doesn't follow the transportation vector capabilities. The reason of this relative car mobility failure is not to be found in owners' will or on road infrastructure characteristics or on car technology but in the fact that society is not ready to bear the increase of fatalities which grows with speed of private cars.

Car ownership has been, for mostly all developed countries, a major progress factor in the field of individual mobility and freedom. Is it natural that this trend should stop ? It is at least our technical responsibility to examine why this transportation mode is facing a problem that was imagined years ago for rail. The main reason of this relative failure is that « individual » cars are driven by « individuals ». The marvellous tool of freedom may not be in the position of facing a basic conflict : individual freedom to move does not mean individual possibility to kill !!!

One way of overcoming this difficulty may be to switch, each time it is possible, from individual driving to automatic driving. But questions remain.

Has technics enough arguments to convince individuals to accept automatic driving and operators to assume the responsibility of controlling individual cars of a traffic flow ? Is there a progressive way to move from complete individual control and responsibility to fully automatic systems and its corollary consequence, : Operator responsibility ? Is the technical solution socio-economically acceptable ? This paper tries to give a first partial answer to those questions.

A technical solution

A framework with...

The hereafter briefly described technical solution is a rough scenario only given so as to propose a sensible framework to give efficiency orders of magnitude and judgements on automation concepts.

The idea is to build or to fit out automatic driving dedicated smart motorways. Cars driven automatically in platoons may be running on these. infrastructures.

... sensible outputs...

To be convenient and offer door to door car journeys, the number of switches between individual and automatic driving must be as little and as simple as possible. To be sensible, it must also comply with some basic ideas :

- keeping individual driving in places where automatic driving is not technically possible (automation cannot handle the « struggle for life » that drivers have to face while they are entering an busy express way or when they cross the Place de la Concorde in Paris at 6 p.m.) or where it is not economically viable (automation can hardly find its economical justification in low density areas) and implement fully automatic driving in places where utility and economy are strong. It is noticeable that those places often coincides with a strong lack of interest in driving,
- implementing automatic driving on road network links where the combination of the flow density and the very few degrees of liberty left to the drivers make it acceptable (or convenient) and economically viable,

and

- insure a high level of service in the switching from one way of behaving to an other.

... and doubts on progressive evolution

In most developed countries effort has been put on the solution of the equation « liberty », « speed », « safety », « capacity », « comfort ». Until now, most proposed actions have focused on driving helps where the driver keeps the driving tasks control, that is to say the driving responsibility. The two most well known PROMETHEUS[1] functions : AICC[2] and DMRG[3] stand as the best example. Available bibliography[4] shows that, if noticeable gains on motorways in terms of « comforts », « safety », « liberty » and « capacity » can be foreseen, these progresses may be balanced by losses in terms of capacity on busy freeways and motorways.

... but automatic driving is possible even in hostile environment...

Some military programmes such as DARDS have tried for easily understandable reasons to automate driving in situations where the driven vehicle environment was hostile. Those programmes showed that, even in a non dedicated infrastructure, it was possible to automatically drive a car to a target through an unknown environment. Another example of driving automation is given by the use of fully automatic sweeping machines in the Paris underground.

Back to private cars, among European, Japanese or north American Programmes dealing with driving helps (PROMETHEUS, DRIVE[5], RACS[6], CACS[7], AMTICS[8], VICS[9] and V.H.S[10] and IVHS-PATH[11]), only IVHS has shown the real ambition to open on fully automatic driving. In fact only certain IVHS programmes go further than simulation or scientific curiosity. In France, two interesting studies from Yves David INRETS[12] December 1991[13] and May 1994[14] show the balance between the interest and the difficulty of such a challenge.

... and needs to appear sensitive ...

Moreover, the sociological and technical difficulties of driving automation, the corresponding investment will have to face that driving automation is not going to be market driven before long. Even institutional research may hesitate to support automatic driving : recently the UE 4th PCRD did not retain automatic driving because it was not « user driven ». To be user driven, and more precisely, final user driven, a facility must be imagined by its beneficiary : « what you never had, you never miss ! ». It is mostly unlikely that any reasonable person can imagine that he could go where and when he wants, automatically driven by a system which would not be « Big Brother ».

In fact, the way French TGV came from research to be operational can give some ideas on research for future automated highways. This is the guideline this paper will follow.

... to be founded for research and experimented

Two major reasons support automatic driving : **Safety and Capacity**, several other reasons may exist in favour of automatic driving : speed, comfort, energy saving, space saving, noise reduction, and environmental reasons.

As automatic driving has not been implemented and as techniques are not decided yet, it is not possible, at this stage, to give any reliable figure on benefit of automatic driving in terms of injuries and fatalities.

It can, nevertheless be foreseen that automatic driving introduction should have the same results on safety that other guided transport. An hypothesis of safety increased by a factor of ten seems reasonable. In any case it is quite clear that if the foreseen improvement by automatic driving systems cannot bring this amelioration where it operates, automatic driving will never exist significantly.

Regarding capacity, automatic driving can simultaneously shorten headways and increase speed. A 50% hypothesis of speed increase and a average reduction of a 4 factor in headways multiplies by six the capacity on one lane which, as a consequence of lateral guidance and absence of overtaking, should be narrower.

In terms of energy saving a factor of two may be envisaged.

Main functions

Guidance

The following rapid overview of available positioning techniques aims at evaluating whether the state of the art in this matter allows a reasonable ambition in solving car positioning which is a basic function required for automatic driving. The problem envisaged here is only to assess if technology is available to host in the vehicle or in the road-side equipment the necessary parameters to transfer to « the command boxes » in charge of platooning control, the position of the vehicles with enough accuracy to elaborate their commands.

Two main types of guidance have to be envisaged, longitudinal guidance and lateral guidance

Lateral guidance

Regarding **lateral guidance**, some careful studies have been carried out on this subject, more particularly on the behalf of the FHWA[15] since 1970, they have proven that it was possible to keep a lateral position with an accuracy better than 4 cm.[16] for speed up to 130 km./hour.

We will consider in the following that this problem has already enough reliable solutions to be considered as solved or easily solvable.

Longitudinal position

Regarding **longitudinal position**, two major types of modes can be envisaged :

- the « vehicle follower » mode, this mode implies a relative car positioning system which may be associated or not with transmission links between cars and/or between cars and ground, in this last case the ground knows all car positions,
- the « point follower » mode, in this mode, the ground calculates all cars position and transmits these positions to all interested cars.

In fact, in the future, implemented systems will probably combine the two system so as to insure fall-back facilities. Point follower mode being the normal operational mode and vehicle follower being the fall back facility.

Critique to the technical solution

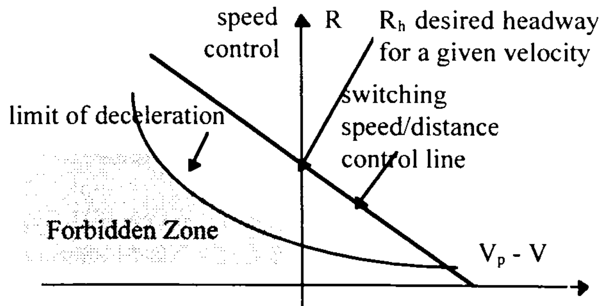
Even if platooning system seem to technically feasible and offer some promising improvement in traffic flows, traffic calming, safety and energy saving, platooning considered as a driving help must keep time headways at values between 1 and 2 seconds. In these conditions, even under the hypothesis of 100% cars equipped lane capacity will not exceed 2,000 to 3,000 vehicle per hour.

If headways fall under 1 second, responsibility must switched from the driver to the Operator as individuals are not in the position of reacting in such a short time.

In these conditions why not going to a :

A 0 headway operating system on Automated Highways

The following diagram[17] gives indications on performances needed by the various cars involved in a platoon so as to guaranty that the platoon is behaving properly. Behaving properly means in this case that safety is guarantied. It does not mean comfort or convenience.



V = velocity of the followed car, P_p = velocity of the preceding vehicle, R = Headway (distance), R_h = Desired headway (distance),

Paul Fancher & Robert Erving Diagram applications of ICC systems for the driver supervisory role. Paris 1994 1st World Congress on ATT

For a given steady velocity of followed car, this diagram shows that as far as the following car stays in the left half where ($V > V_p$) and is in its deceleration capability it can reach the desired headway. That is to say that platoon forming conditions are simple to determine when the platoon is running at a given speed but needs a lot more anticipation when the platoon velocity is not stable.

In this case, phase diagram representation is not sufficient and each vehicle must have also a real time knowledge of :

- its velocity and acceleration, as well as its possible acceleration,
- the distance to the proceeding vehicle (which can be replaced by knowledge of all surrounding vehicle even if in the following vehicles are ignored),
- the velocity and acceleration of the proceeding vehicle,
- the velocity and acceleration of the first of the platoon.

In a platoon vehicles are « bunch riding » that is to say that they can be considered as an unique vehicle (notwithstanding the difficulties of controlling all the vehicles of a platoon).

The relatively simple following command law[18] :

$$C_i = C_p\Delta_i(t) + C_v\dot{\Delta}_i(t) + C_\gamma\ddot{\Delta}(t) + K_v[V_l(t) - V_i(t)] + K_\gamma[\gamma_l(t) - \gamma_i(t)]$$

C_i command applied to the vehicle i

Δ_i distance between the vehicle i and the vehicle i-1

V_i, γ_i speed and acceleration of the vehicle i

V_l, γ_l speed and acceleration of the platoon first vehicle

$C_p, C_v, C_\gamma, K_v, K_\gamma$. parameters to be adjusted

has been tested in simulation for a platoon composed of 4 to 16 vehicles (of 3 different types) with certain perturbations such as delays in communication links and noise in measures. Those simulations have shown that, for a rapid velocity variation from 18m./second to 30m./second with $\gamma = 0.3\text{m./s}^2$ and a jerk of 2m./s^3, the vehicles kept a steady headway (distance) with variations shorter than 1cm. without noise and shorter than 11cm. with perturbation.

This shows clearly that it must be possible (with reasonable vehicles performances) to insure a 0 headway platoon. A 0 headway platoon presents a lot of advantages : control simplified, stability increased, better aerodynamic, ...

But if cars are touching one-another questions arise :

- What is the reasonable number of cars in a platoon ?
- What are the problems to organise and control rendez-vous ?
- How cars share power needed to make the platoon going ?
- What happens in case of car break-down in the middle of a platoon ?
- How where and when a car can join a platoon
- How where and when a car can leave a platoon
- ...

Those questions bring other questions :

- In this kind of systems, car are completely interdependent, how can the operator take the responsibility of operating platoons of « unknown » clients ?
- It will be convenient to insure their physical linkage between cars, how to do it ?

It is not on the purpose of this paper to give consistent answers to all these questions but as automatic driving future is strongly dependent on these answers, the following scenario can be considered as a first tentative to give some guidelines for answers.

Derived proposed scenario

The answer to the first question is basically not technical, platoon sizes are given by the level of risk the Operator is ready to assume. Whatever care is taken all way down the chain from scenarios studies to system building, nobody can say that a bridge will not fall just in front of a platoon provoking a disaster. The only dimensioning factor which can be taken is the capacity of a train or a jumbo jet : some 600 persons. In this condition 500 cars platoons seem reasonable.

Once platoons are dimensioned, the gap between platoons can be estimated as twice the stooping distance in case of crash of the previous platoon. If a velocity of 180km./hour is taken and a possible deceleration of 1 g is retained this gives a gap of d = _ Vt (average speed during deceleration) with V = 50m./s V = γt d = 500 m.

In this case the theoretical maximum flow is 12,000 vehicles/hour/lane (some 5 to 10 times over an ordinary motorway lane capacity).

Regarding rendez-vous, one possible solution is to group cars waiting on the access ramp in a platoon and adjust speed of the platoon as shown on the R_h diagram. It is well understood that prior admitting a car on the access ramp to the dedicated motorway, performance checks are made and undesirable cars are rejected.

It is well understood that, cars allowed for automatic driving, are especially designed and equipped (whether they are cars of the operator fleet or they belong to individuals). Part of the equipment is the « electro-magnet » insuring vehicle coupling and pressure sensor for power sharing. The strong connection is a security in case of car break-down (in this case the whole platoon exits the automatic lane as soon as possible).

Regarding the ability of leaving a platoon it must be noticed that entering ramps and exit ramps are parallel to automatic lanes for a distance of 1,500m. (length of a platoon and its headway). The first thing checked is the ability of the exit ramp to admit the vehicles wanting to exit. Once admittance is given, the platoon splits in as many parts as required, starting from the end of the platoon. while the separate platoons move to the parallel lane the end of the platoon sticks back to the main platoon. In the same way small platoon on the parallel lane stick together so as to form a unique platoon.

[1] Programme for a European Traffic System with Highest Efficiency and Unprecedent Safety

[2] Automatic Intelligent Cruise Control

[3] Dual Mode Route Guidance

[4] [PRO-GEN Review, Conclusion and Future needs {Vito Mauro, Pierre-Yves Texier} Paris December 1994 1st World Congress on ATT]

[5] Dedicated Road Infrastructure for Vehicle Efficiency and Safety

[6] Road Automobile Communication System

[7] Centralised Automobile Communication System

[8] Advance Mobile Traffic Information and Communication System

[9] Vehicle Information and Communication System

[10] Vehicle Highway System

[11] Program on Advanced Technology for the Highway

[12] Institut National de Recherche sur les Transports et leur Sécurité

[13] [Considérations sur l'Intérêt et la Faisabilité de l'Autoroute Automatique {Yves David}décembre 1991].

[14] [Compte rendu des travaux de l'atelier AHS-PSA (Automated Highway Systems / Precursor System Analysis) Washington 5-8 April 1994.]

[15] Federal Highway Administration

[16] [Automated Highway Studies at the Ohio State University. An overview {R.E. Fenton R.F Mayhan} IEEE Transaction on Vehicular Technology vol.40 n°1 February 1991]

[17] [{Paul Fancher & Robert Erving} Diagram Applications of ICC Systems for the Driver Supervisory Role. Paris December 1994 1st World Congress on ATT]

[18] [longitudinal Control of a platoon of vehicles {S. Sheikholeslam - C.A. Desoer} Proc. 1990 Am Control Conference San Diego May 1990