SARTRE: SAfe Road TRains for the Environment

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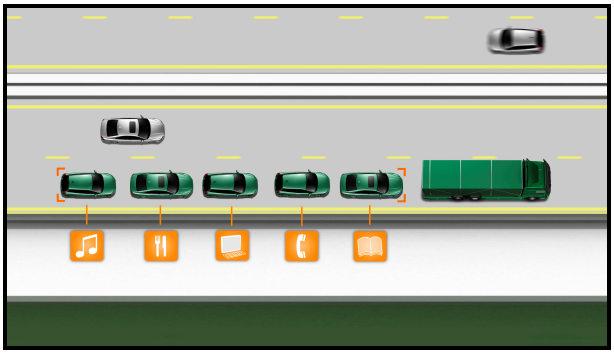
1. Introduction

The SARTRE project aims at encouraging an evolutional change in the use of personal transportation means through the development of safe and environmental road trains (platoons). For the safe adoption of the road trains, systems will be developed and will allow the interaction of the platoon with non-platoon vehicles on un-modified public highways. The project addresses three cornerstones of transportation issues: environment, safety and congestion while also encouraging driver acceptance through increased "driver comfort".



Platoon illustration
Source: VOLVO

SARTRE is a three year project within the 7th Framework Programme in which 7 partners from throughout Europe participate actively. The project will not only address the integration and development of the necessary technology to implement road trains but will also consider the human factors behind the operation of the system in a regular basis. These factors include the driver of the lead vehicles, the drivers of the following vehicles and the drivers of other vehicles along the highway.

The entire requirements of the systems with the added human factors impose a necessity to carry out extensive testing of the systems individually and on a fully integrated demonstrative run. These demonstration tests require simulating as much as possible real life conditions but in a controlled environment to provide the necessary safety conditions for drivers and other users. This paper discusses the approach taken by the SARTRE consortium regarding the system testing and demonstration.

2. The SARTRE project

For several years, work has been done on platoon development with a variety of possible scenarios, in which most of the solutions require a significant amount of modification to the roadside infrastructure or even dedicated lanes.

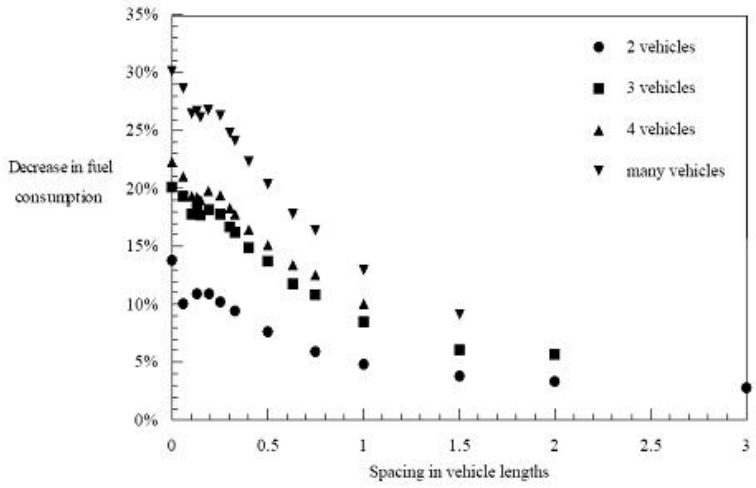
Nowadays, with the increased reliability and the reduced cost of electronic equipment and communication systems, it is viable to develop a safe and reliable platoon system. Nevertheless, and due to the nature of the system, there are still significant challenges with platoons interacting amid conventional traffic on public motorways. Also, acceptability is still an issue that has not been solved, meaning that the adoption of platoons on public motorways is not likely to be a short term reality.

The SARTRE project and its demonstration tasks, through the full understanding of the related issues of platoons on public roads and developing new solutions that help address acceptability issues, aim at showing to the public the environmental, safety and convenience benefits obtained from the use of this system. In this way, the project encourages the modal shift towards vehicle platoons on motorways.

3. Platooning Benefits

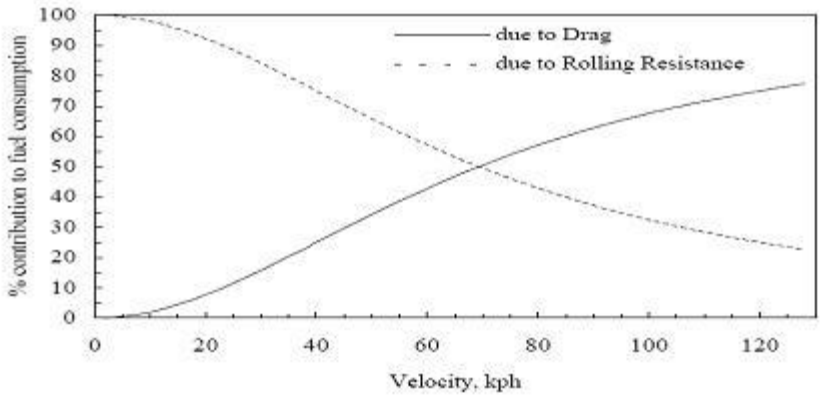
Environmental Benefits

The environmental benefit potential of platooning has been carefully investigated in previous work, for instance in the "Partners for Advanced Transit and Highways (PATH) Program" in the US during the 1990s. In "The Aerodynamic Performance of Platoons - A Final Report" from the PATH Program an average benefit of about 20 % has been estimated for highway (= high speed) driving. This benefit varies with the number of vehicles, the vehicle spacing and the aerodynamic geometry of vehicles.



All geometries average decrease in fuel consumption for platooning vehicles
Source: PATH Project

Generally, a smaller spacing between vehicles gives greater benefit in terms of energy consumption. However, smaller spacing is also more challenging for the control system, so a balance needs to be established. Initially, we should be aiming at a spacing of about 1 meter, which would correspond to about 0.2 vehicle lengths in the diagram above. The speed at which the road train is running is also important for the environmental benefit.



Fuel consumption due to drag and to rolling resistance as a percentage of total fuel consumption
Source: PATH Project

The benefit is also dependent on the aerodynamic geometry of the vehicles that form the platoon. For instance, a small vehicle following a large vehicle will get a greater benefit. Also the opposite situation will occur, and there is reason to believe that the average benefit estimated in the PATH study will be true also for SARTRE. There is one important exception: The SARTRE proposal assumes that the lead vehicle of the road train will be a commercial vehicle. Trucks are taller and wider than cars, and this will likely increase the benefit for the following vehicles that are close to the leader.

Safety Benefits

A road train will perform quite different to normal highway traffic regarding the risk for accidents and injuries. There is a clear challenge in making the road train interaction with drivers and surrounding traffic and its ability to handle exceptional situations safely. There are obvious opportunities with autonomous vehicles following a professional driver. The road train users will benefit safety-wise from having a trained, supervised, professional driver in the lead.

A Department for Transport report (see bibliography) states that 95% of road accidents involve human factor contribution. The platoon incorporates a significant level of driving automation whereby for extended periods “drivers” of following vehicles concede their control to the lead vehicle and local autonomous systems. Thus road train users should benefit safety-wise from having a trained professional driver in the lead vehicle with autonomous control systems while within the platoon.

Traffic Flow Benefits

For the expected traffic flow benefits of platooning it is necessary to discriminate between different traffic conditions and the applicable road train scenarios to each of them. There are 4 principal traffic conditions that can be met: free traffic, collapsing traffic, synchronic inhomogeneous traffic and stop&go traffic. Obviously, the best traffic condition is free traffic, from which, according to the increase in volume and variability of gaps between vehicles and speeds, the other three conditions can be met.

SARTRE platooning may not bring improvements for free traffic yet it will indeed aid in the delay of collapsing traffic, maintaining a constant speed and gap between vehicles on a scenario where high speeds and open spaces are a constant. By the time that collapsing traffic scenario is reached, the road train will provide the most benefits, as the point of the collapse is dependent on the required traffic space of each vehicle and the time gap. The smaller the time gap the more the collapse point is shifted towards higher traffic flows. With platoons, this time gap is reduced to a minimum and by doing so the road capacity can be enhanced and traffic congestions avoided or at least delayed.

A latter condition is the synchronic inhomogeneous traffic, characterised by density waves, where vehicles drive in between 30 and 80 km/h in 100 m distance. In this case, a significant improvement can be expected as the autonomous guidance helps reduce the dynamics. In the case of a further increase of the traffic flow a complete breakdown occurs, and stop&go traffic condition appears. The beneficial effect in this condition is achieved when the platoon leaves the traffic jam, as the acceleration is sufficient enough and controlled, maintaining the space between vehicles thus leading to a faster dissolving of the congestion.

4. Project Activities

The project objectives can therefore be summarised with the following points:

- Define a set of acceptable platooning strategies that will allow road trains to operate on public motorways without changes to the road and roadside infrastructure.
- Enhance, develop and integrate technologies for a prototype platooning system such that a number of the defined strategies can be assessed under real world scenarios.
- Show how platoons can lead to environmental, safety and congestion improvements.
- Illustrate how a new business model can be used to encourage the use of platoons with benefits to both lead vehicle operators and to platoon subscribers.

Following the project objectives, a comprehensive cluster of tests are defined. In order to provide the correct validation for the developed system, both simulation and physical testing will be carried out.

Initially, a simulation on the fuel consumption will be made for subsequently evaluating the entire system on the test track. Afterwards, each partner in charge of developing the subsystems for the project will have the task of testing and evaluating the functionality at its own facilities, so that later, all the systems brought together can be tested at IDIADA's facilities and if possible on the public road. Overall, the testing will include the most important aspects of the platoon system and the fuel consumption benefits.

For the assessment of the fuel consumption improvements, a specific task was created and is focused in the possible benefit obtained from the system in terms of emissions and fuel consumption. One of the objectives of the SARTRE system is to reduce the fuel expenditure of the vehicles while platooning, as a more continuous and soft driving situation is present. Also, the aerodynamics of the entire road train provides extra savings in fuel consumption.

As a first activity, a simulation on the forecasted benefit will be carried out. In order to obtain the relevant data, a software simulation will obtain several aerodynamic coefficients that a whole platoon will have on a highway at the designated speed, to then translate it to single vehicle aerodynamic coefficient. The best advantage of having this simulation, is that a great variety of gap sizes can be tested, resulting in a comparable set of data of which is the best gap to be established so that it provides better fuel efficiency but at the same time maintains a high safety level.

This task comprises one part simple physical testing and one part simulation. First of all, a coast down test of the assigned vehicles has to be done. The coast down test will provide the data related to engine torque and fuel consumption from the real life. Later on, a CAD model of the vehicles is uploaded to a Computational Fluid Dynamics Software (CFD), where the vehicles can be tested individually in order to obtain the drag coefficient (Cd) and the lift coefficient (Cl). Subsequently, a set of two cars (one following the other) will be tested. In this part of the test and using different distances between vehicles, new pairs of drag and lift coefficients will be gathered.

Afterwards, a one-dimensional simulation model of the vehicle to be tested can be generated, using the coast down results to know the work done by the engine and the related fuel consumption. Next, a one-dimensional model of the car using only physical parameters is to be evaluated.

Once the data from the physical and coast down simulations are correlated, the drag and lift coefficients (Cd, Cl) must vary according to the previous figures calculated on the CFD. From here, new engine work data will result. Analysing the applied torque and the rpm rate on the engine's fuel consumption map, for each value of Cd and Cl we would have the fuel consumption comparative.

When the simulated tests have been carried out, it will be important to select the best configuration possible to be tested on the tracks. This configuration should have a good compromise between fuel consumption and safety, so that the most reasonable formation or set of formations and gaps are evaluated. This will be a very important input not only for the physical testing, but also for the conceptual work of the project.

To evaluate the fuel reduction, two methods will be used: tests in track and power benches. Testing in proving grounds provides a realistic value but it is not very robust as boundary conditions are difficult to be controlled. This absence of robustness will be made up by bench testing. The pattern obtained in the tests in proving ground will be implemented in the test benches of power train. Then, the results obtained will be correlated and solid values of the fuel consumption will be generated. These values will then be compared to simulation results to verify that they are correspondent and that the selected spacing was the most favourable.

Continuing with the project, full system testing will be done at the test tracks. Although physical testing is not as repeatable as laboratory testing, it is quite necessary to ensure the correct functionalities and operation of the integrated system. The first tests of the different systems working together will take place at this stage of the project. IDIADA will provide its proving grounds and test equipment for implementing these trials with the lead vehicle (1 truck) and following vehicles (3 cars). Eventually, as the trials go on, an additional following vehicle (1 truck) will be added.

The first group of tests will be performed in dynamic platforms, which are flat open areas where there is no risk of having an accident as they are closed environments, with strict control and with ample enough run-out zones. These platforms have 6 degrees of freedom; will be aided by differential GPS units (accuracy ±20 mm) and to simulate surrounding traffic, rabbit vehicles will be used. These characteristics ensure that the tests are run in a safe and controlled environment.

One of IDIADA's Dynamic Platforms
Source: IDIADA

Following the first group of tests in the dynamic platforms where the entire systems are validated altogether, come the system trials in the high speed track. This high speed track is designed to have several entry/exit areas from the same side as on a regular road. It has a total length of 7560 m, two straights of 2000 m and two bends of 1780 m. It accounts for a total of four lanes, for which the first two lanes will be used in the project. These two lanes were selected because of the velocities and manoeuvres that can be performed.

IDIADA Automotive Technology
Source: IDIADA

During this phase, the system will be tested not only on the functional systems, but also on the operational aspects of the project. The idea of having a test track like these is to be able to control the surrounding traffic, the velocity, ensure high safety standards and count on the support of the personnel and project members. Moreover, the ability to perform highway incorporation and exit brings to the trials a realistic approach for the desired functioning of the system.

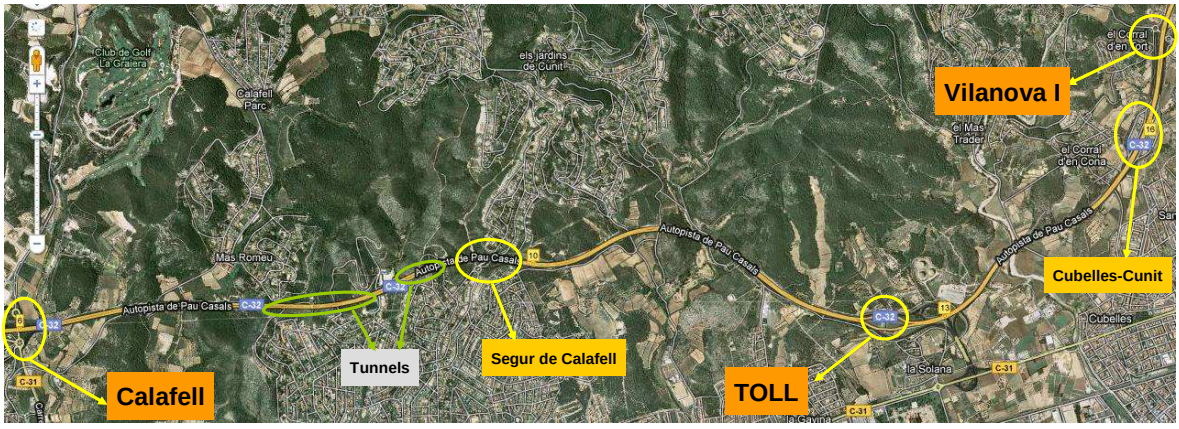
The tests will be carried out using the Driver-in-the-Loop concept, having different drivers with a different distribution of age, sex, size and driving skills. Nevertheless, these trials are carried out under controlled environment, with rabbit vehicles and other involved personnel that know and understand the platooning concept and are aware of any emergencies and hazards that could arise during the test runs. For this reason, evaluating the system in real traffic is considered necessary.

Operating in real traffic is one of the challenges of the platooning system and that is one of the reasons why the system should be tested there. Most of the tests will be executed in proving grounds, which allow extreme driving conditions with safety, but lack of reality at certain points. IDIADA has cooperated with road administrations and highways operators for other research projects. In some cases, tests have been executed in pure real traffic

conditions. In others, when safety has not been fully guaranteed, the roads have been closed for a short period of time and used for the test; always trying to identify a low traffic density zones and off-peak hours.

IDIADA has already proposed a section of a local highway to carry out the tests on real highway. This section of the highway includes many of the most important features that a SARTRE platoon needs to deal with, assuring that real life test conditions prevail.

The proposed section is from the C-32 highway, from Calafell to Vilanova I entrance, which covers approximately 12 km.



Selected test route
Source: Google Maps

This segment was selected due to:

- Its proximity to IDIADA proving grounds.
- Lower traffic density than other C-32 sections.
- Toll booth with low traffic on Cubelles-Cunit exit, both ways, manually controlled barriers.
- Entrance to Calafell is generally low traffic as it only crosses a secondary road from Bellvei to Calafell (TV-2126). North entry and exit.
- Exit Vilanova I is generally low traffic as it only crosses a secondary road from Vilanova to L'Arboç (BV-2115). South entry and exit.
- The path is predictable and enclosed.
- Includes tunnels.
- There are various entry and exit points for vehicles.
- There is enough space for platoon manoeuvres.

The proposed testing sequence is as follows:

1. Entrance by Calafell.
2. Road train created.
3. At Segur de Calafell, new vehicle joins (only entrance direction Vilanova).
4. At Cubelles-Cunit, one vehicle leaves platoon.
5. Toll booth crossing.
6. Exit at Vilanova for direction change.

7. New highway entrance, the platoon is created again.
8. At Cubelles-Cunit, one join and/or leave platoon manoeuvre is made.
9. Toll booth crossing.
10. At Segur de Calafell, one vehicle leaves platoon (only exit direction Calafell).
11. At Calafell, road train exits and changes direction.

This sequence can be repeated as many times as required and can accept modifications in the use cases to be tested. This scenario will also add the input from other vehicle users while facing a platoon on the road for the first time. This input could be very important for the conceptual work as it could help in modifying the length of the platoon and other users' perceptions.

If highway trials are not achieved, IDIADA will propose to use a common proving ground called "General Road". This proving ground is based on the access road to all the proving grounds at IDIADA, with a 5.3 km length and a 300x20 m braking area. It is formed by different types of roads, some of them simulating main roads with two ways and others representing highways. It also has different bends and slopes and speed limits vary depending on the zone. Usually, this track is used for general assessment of the vehicle. The General Road could then be used as a representative track for real traffic conditions. When needed, real traffic could be emulated adding human driven random cars interacting with the platoon.

IDIADA's General Road
Source: IDIADA

5. Conclusion

The importance of carrying out simulation, proving ground testing and real traffic conditions evaluation is that the entire system is validated from the most basic elements and concepts to the complete system operation within controlled and uncontrolled environments. Having the certainty that the elements that conform the system are working properly in a stage by stage evaluation ensure that the outcome of the entire trials is valid, carried out with the best safety standards and complying with all the requirements set by the project developers.

The results obtained from this validation phase of the project will be the three demonstrators for the cornerstones tackled by the project: improving fuel economy and the environmental impact at the same time, adding an extra level of safety for future mobility systems and an improved traffic flow throughout the highway networks. This project will generate new technological advancements and will be a solid base for oncoming research projects that will bring closer the platooning concept to real life.

6. Acknowledgments

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