Operating Platoons On Public Motorways:

An Introduction To The SARTRE Platooning Programme

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ABSTRACT

SARTRE [4] is a European Commission Co-Funded FP7 project that seeks to support a step change in transport utilization. The project vision is to develop and integrate solutions that allow vehicles to drive in platoons resulting in a reduction in fuel consumption (potentially up to 20%), improvement in safety (anticipated 10% reduction in fatalities) and increased driver convenience (autonomous systems for following vehicles). The project is exploring the issues around operating platoons on public motorways and the integration of technologies necessary to achieve this as well as a potential charging mechanism that supports the business case. Where possible the project will use existing vehicle technologies to provide the enhanced platooning functions. These will be demonstrated in a platoon of up to 5 vehicles.

SARTRE is a three year programme with 7 partners and not only addresses the integration and development of technology necessary to implement a platooning system but also the human factors that are relevant in the operation of the system. These human factors broadly fall into three categories: driver of the lead vehicle, drivers of the following vehicles and drivers of other vehicles on the motorway. The project aims to encourage a step change in personal transport usage through the development of safe environmental road trains (platoons). Project progress may be monitored via the project website [4].

This paper provides an overview of the SARTRE project and the specific approach taken by the partners that will result in a prototype platoon being available for demonstration in 2012. The paper also presents some of the initial results identified in the programme.

INTRODUCTION

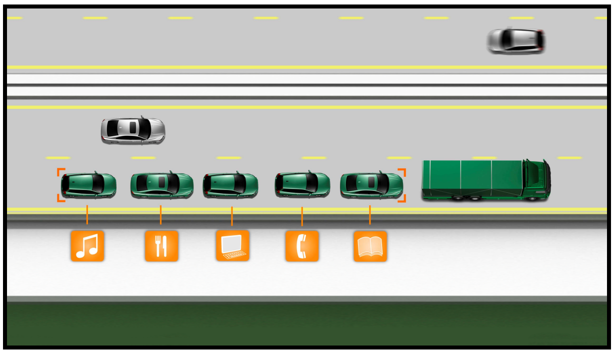

Figure 1 Platoon Illustration

Work has been undertaken on platooning for several years with various scenarios being proposed, however these solutions have typically required significant modification to the roadside infrastructure or even dedicated lanes. With the increased reliability and reduced cost of electronics and communications over the last 10 years it is becoming viable to develop a safe and reliable platooning system, however there are still significant challenges with platoons interacting with conventional traffic on public motorways. There are also significant acceptability issues that mean the adoption of platoons on public motorways is not likely to be a near term reality even with the understood environmental, safety and convenience benefits. The SARTRE project will more fully understand the issues around platooning on public motorways and develop solutions that help address the acceptability issues thus encouraging the modal shift towards vehicle platoons.

The overall concept of a SARTRE platoon is that the lead vehicle will be driven as normal by a trained, professional driver, and the following vehicles will be driven fully automatically by the system, allowing the drivers to perform tasks other than driving their vehicles

THE BENEFITS

The project addresses three cornerstones of transportation issues: environment, safety and congestion while also encouraging driver acceptance through increased “driver comfort”.

In the "Partners for Advanced Transit and Highways (PATH) program" in the US during the 1990s an average benefit of about 20 % improvement in fuel consumption has been estimated for highway (= high speed) driving in platoons [2]. This benefit varies with the number of vehicles, the vehicle spacing and the aerodynamic geometry of vehicles.

A TRL report [3] states that 18% of road fatalities are the result of driver inattention. 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. Suitable scenarios for platoon operation that may lead to improved road safety will be identified on the project.

For the congestion benefits of platooning, SARTRE will reduce the speed variability of vehicles thus improving the overall traffic flow. It is necessary to discriminate between different traffic conditions [1] (free traffic, collapsing traffic, synchronic inhomogeneous traffic and stop&go traffic) with potential benefits from all but free traffic. For collapsing traffic it is expected that the highest benefits will be reached with platoons where vehicle gaps are reduced to a minimum. For "synchronic inhomogeneous traffic" (characterised by both varying traffic flow and average velocity) a significant improvement can be expected through autonomous guidance which helps to reduce these fluctuations. For stop&go, traffic platoon vehicles will leave traffic jams faster than a human driver, leading to a more rapid reduction in congestion.

THE TECHNICAL APPROACH

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

In order to address the above objectives SARTRE has drawn on a number of systems engineering techniques that are being used to define project assumptions and requirements. This paper will discuss the tasks and approach undertaken and how the results are being reviewed and consolidated to derive the project assumptions and requirements, examples include: Defining Terminology, Use Case Analysis, Traffic Modelling, Driver Simulation, Safety and Vulnerability Analysis.

Figure 2 shows the work packages being undertaken on the programme.

Each work package is focussing on a particular set of activities, some of which occur in parallel and some that are distinctly sequential. The complexity of platooning systems and the number of engineering dimensions that needs to be considered lead to a high degree of parallelism in the methodology. This parallelism is often being undertaken by several partners at once, requiring regular, quality focussed communication. The approach taken by SARTRE is to hold frequent task specific conference calls that are supported by face to face meetings when appropriate.

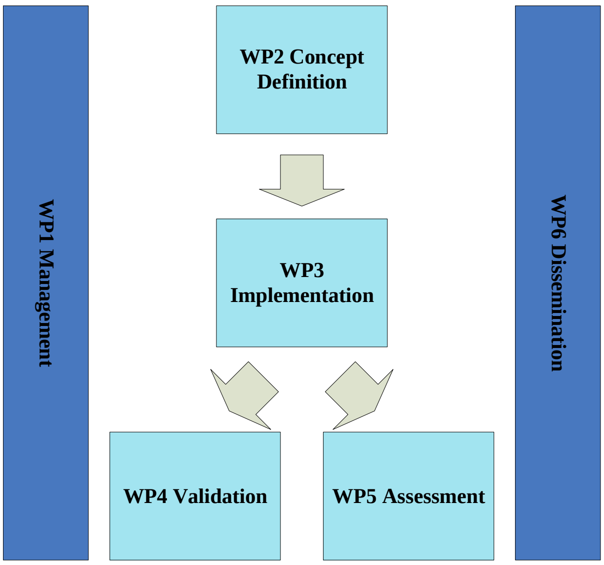

Figure 2 SARTRE Work Packages

For example, there are a number of options to undertake a “join” manoeuvre (whereby a potential following vehicle – PFV – joins the platoon and becomes a following vehicle - FV). One option is where the FV approaches the platoon and fully automated driving is engaged in one step, an alternative would be where semi-autonomous driving is engaged prior to full automated driving. The criterion for deciding which approach should be taken is dependent on a number of factors and the task force allows experts from each research area to contribute towards the decision.

Concept Definition Phase

The specific challenges that are being faced on SARTRE can be highlighted through a brief explanation of the tasks undertaken in the Concept Phase to determine requirements and system architecture. The requirements may be categorised as follows:

- Commercial Requirements - Potential new business model, Financial transaction mechanisms, System security (e.g. data privacy, data theft prevention...), Acceptability (e.g. availability and access to platoons)
- User Requirements - Platoon users (e.g. driver convenience, system usability, driver readiness), Other road users (e.g. avoid disruption, enhance traffic flow)
- Safety Requirements -Platoon users (e.g. neutral or positive impact on safety), Other road users
- Pre-Requisites - Technical Requirements (e.g. use of existing sensor technology)
- Legislative Requirements - Compliance with existing legislation (e.g. applicability of the Vienna Convention), consideration of potential new or revised legislation (e.g. new lead vehicle driver training)

The above list highlights some of the categories that platoon requirements may fall into and also hints at the complex criteria that will lead to agreed Platoon System Requirements.

A number of systems engineering activities have been undertaken in the Concept Definition phase:

- Use Cases Analysis – capturing the use cases for platoon vehicles, non-platoon vehicles and back office systems, considering “normal”, “alternative” and “exception” use cases
- Traffic Simulation – modelling platoon use cases in PELOPS to assess the impact on, and impact of, other road users
- Human Factors Study – simulating platoon manoeuvres to assess the likely human reactions and perceptions given a number of different use cases and platoon parameters, see [5]
- Safety Analysis – defining an initial functional architecture and assessing this for safety issues as well as important non-safety issues (e.g. privacy protection & financial security)
- System Design & Requirements Definition – considering available sensors and actuators, defining conceptual requirements, implementation requirements and an architecture to be implemented

A core objective of the Concept Definition is to identify which use cases should be demonstrated as part of the programme. One example of this is whether to demonstrate one or more non-platoon vehicles interacting with the platoon. Given that a significant number of challenges can be demonstrated with a single interaction the programme will initially cater for only one "other vehicle" interaction.

Implementation Phase

The implementation phase will develop a platooning system with two trucks and three cars. Particular tasks undertaken in this phase are:

- Update safety analysis – as the architecture develops update the safety analysis using AutoFMEA™ to insert faults into the model and assess system safety
- Develop lead vehicle systems (Truck) – develop and integrate new truck systems, includes sensor (including location) and sensor fusion system, platoon management function and HMI
- Develop following vehicle systems (Truck and Car) – develop and integrate following vehicle systems, includes sensor (including location) and sensor fusion system, actuator systems, automated driving systems and HMI
- Develop communication systems – develop vehicle to vehicle communications that allows lead vehicle to communicate with and control following vehicles
- Develop remote systems – develop simple back office system to demonstrate some back office use cases (e.g. find platoon), includes the telematics module for V2I communications
- Integration testing of systems – define an integration test plan that allows individual system elements to be tested and any issues fixed with minimal complication

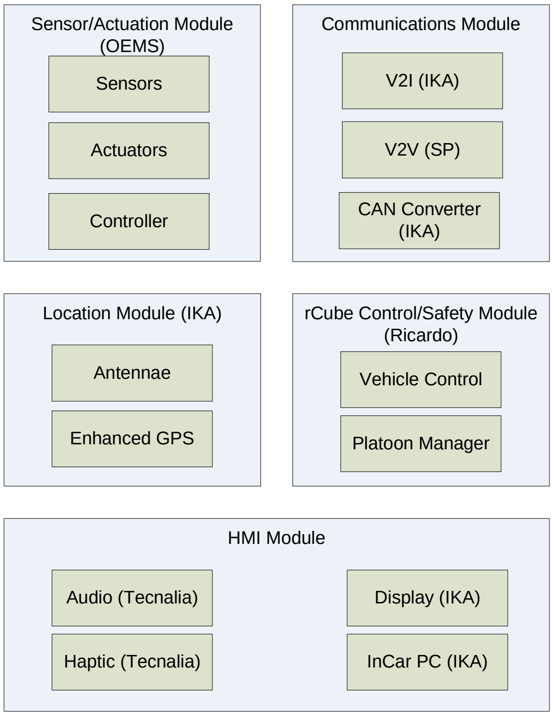

Figure 3 Assumed Physical Architecture

Key functional elements that have been defined are: sensing, sensor fusion, actuation, vehicle automation, platoon management, safety monitoring, human machine interface, communications.

It is anticipated that the high level architecture for the demonstrator will be as in Figure 3.

Validation Phase

The validation phase will test the platoon system to ensure it performs as designed.

Activities include:

- Validate on-vehicle systems – test vehicle systems work to the defined prototype safety requirements, test functionality works at the required reliability
- Validate end-to-end system – test the complete platooning system works to the defined prototype safety requirements, test functionality works at the required reliability
- Assess fuel consumption performance improvements – define and instigate a test plan and to allow actual fuel savings to be measured when platooning

Assessment Phase

The assessment phase is focuses on assessing the non-technical issues relating to platooning, activities include:

- Assess commercial viability – consider the business case and issues around this such as system cost, perceived value for users and potential liability issues
- Analyse net impact on infrastructure and environment – based on test results, platoon conceptual requirements and demonstration results report on potential impact on infrastructure and the environment
- Assess potential policy impacts – explore implications and constraints of existing legislation on platooning including the potential for new legislation
- Undertake stakeholder assessments – undertake a number of stakeholder workshops to obtain external (to the project) feedback on the programme and results (including demonstration of the operating platoon)

INITIAL RESULTS

During the concept phase it was necessary to refine a set of programme assumptions and pre-requisites, both from a platoon concept perspective and also from a project perspective. The following list illustrates some of the assumptions defined, not all of these assumptions will be implemented in the demonstrator:

- There are no changes to road infrastructure
- … limitations and requirements for motorways… from guidelines for the construction of motorways in Germany “RAS-L Richtliniezur Anlage von Straßen – Teil Linienführung”….
- Emergency is defined as a possible violation of platooning principles in order to avoid an accident. The result can either be maintaining the platoon or dissolving it. The following emergency situations will be considered:
    - Emergency obstacle avoidance (all vehicles to follow the leader’s trajectory)
    - Emergency lane change (vehicles don’t follow the exact trajectory)
    - A vehicle driving sideways towards a platoon vehicle
    - Emergency stop (driver in LV braking maximally)
    - LV mistakes (e.g. LV leaving the road, colliding with another object)

    - Radio contact lost within platoon
- A minimal platoon is one LV and one FV.
- A platoon has a maximum size. If a PPV wants to join a platoon of maximum size, join will not be allowed.
- A platoon is not explicitly rearranged i.e. if no change of number of vehicles occurs then the order of FVs is the same.
- Dynamically varying size of gaps between vehicles in a platoon is allowed i.e. there is no requirement for maintaining a fixed distance.
- A truck/bus is not allowed to follow a car.
- An FV can run at any speed from zero up to maximum speed without any driver involvement (thus automatic gearbox is required).
- If required response time is shorter than possible for a human to achieve then autonomous driving handles the situation.

In addition to pre-requisites a number of terms have been defined to minimise confusion over actors during participant discussions. Key definitions are as follows:

BO (Back Office)	Back office is an infrastructure unit supporting platooning.
FV (Following Vehicle)	A vehicle, truck, bus or car, in a platoon behind an LV.
LV (Lead Vehicle)	LV is the lead vehicle of a platoon and is a truck or bus.
OV (Other Vehicle)	A vehicle that will never join a platoon but may affect it.
PFV (Potential Following Vehicle)	A PPV that in a platoon becomes a FV.
PLV (Potential Lead Vehicle)	A PPV that in a platoon becomes an LV.

Given the pre-requisites, a number of use cases have been defined to represent how actors will interact with and within the platoon. The high level use cases have been identified as follows: Create Platoon, Join Platoon, Maintain Platoon, Leave Platoon, Dissolve Platoon, Register, Guide to Platoon, Handle Platoon Status, Charge Platooning vehicle. Further explanation of these may be found in a separate paper [6].

Each use case has been defined for “normal” modes with refinement for “alternative” and “exception” use cases, e.g. Join could have three alternative use cases:

- A PFV joins a platoon via Back office.
- A PFV joins a platoon directly (without Back office assistance).
- A PLV in front of a platoon wants to join the platoon

An example “Exception” Use Case for Join would be if a PFV experiences an emergency resulting in the PFV not joining the platoon.

The use case analysis has enabled a simple state diagram Figure 5 to be defined illustrating the various platoon states and transitions. Figure 5 was subsequently used as the basis for a Platoon Vehicle state transition diagram and an Other Vehicle state transition diagram. From this simple state diagram it can be seen that the number of vehicles is an important factor that illustrates the complexity.

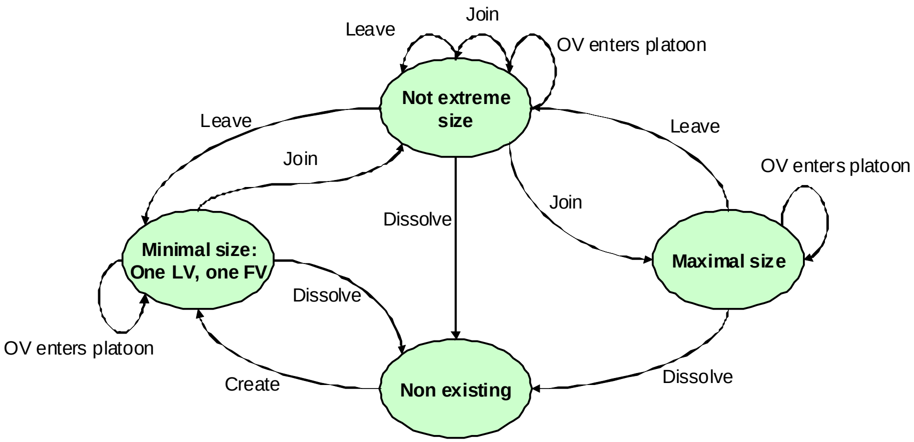

Figure 5 Platoon States

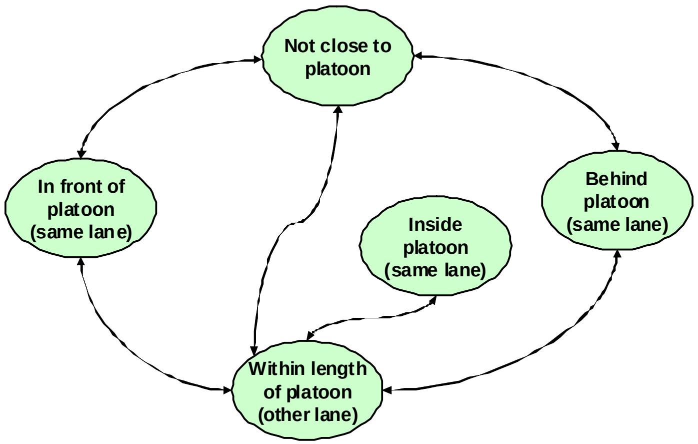

Figure 6 Other Vehicle States

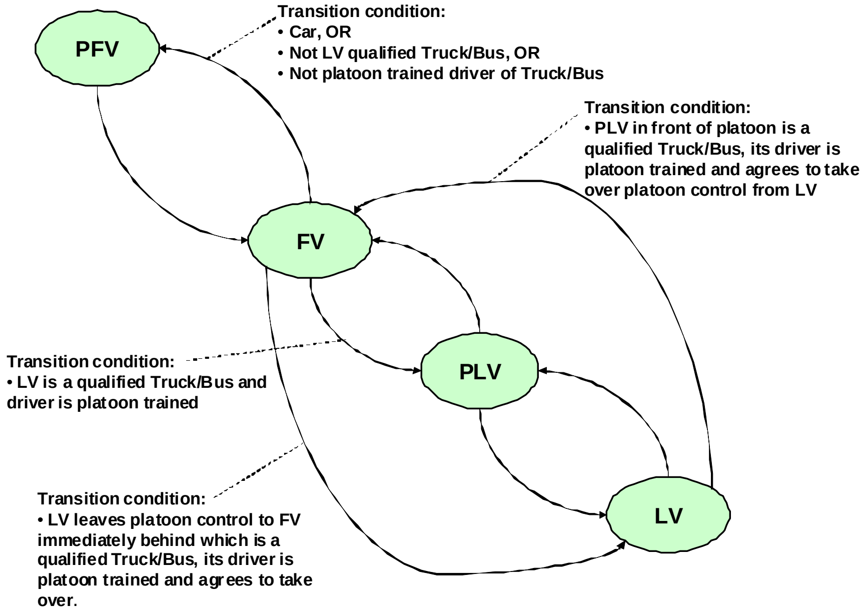

Figure 4 Platoon Vehicle States

Table 1 highlights the relative complexity in resolving issues raised with some of the closing decisions made. As each question is considered a number of dependencies become highlighted, for example, the answer to “1” in Table 1 is dependent on a number of other questions:

- What is the likely relative speed of the PFV when trying to join?

- What is the best method of transitioning between manual and automated control?
- When does the LV "take control" of the PFV?

Item	Issue	Relative Complexity	Inputs	Closing Decision
1	What is the maximum number of vehicles allowed in the Platoon?	Medium	Human Factors Traffic Modelling	No final decision but likely to recommend platoon is no more than 15 vehicles
2	Should a Join/Leave be allowed from the Front and Side?	Low	Human Factors Traffic Modelling	Join and leave should be allowed from front, side and rear.
3	Should the programme consider platoon operation in all environmental conditions?	Medium	Safety Analysis & Human Factors	Consider all environmental conditions
4	Does the platoon need to consider overtaking by the platoon?	Low	Use Case analysis Human Factors & Traffic Modelling	We have to consider overtaking.
5	Should the platoon operate on a single lane restriction motorway	Medium	Traffic Modelling & Human Factors	We will only consider operation on two or more lanes.
6	Should a platoon join/leave manoeuvre transition via a semi-automated (longitudinal control only) state?	High	Safety Analysis Human Factors Traffic Modelling Business Case	Join and Leave will include a semi-autonomous state.
9	How does the platoon have to react to an OV that forces itself into the platoon?	High	Safety Analysis Human Factors Traffic Modelling Business Case	Safely maintain the platoon around the OV for a short period of time then dissolve all FV behind the OV.

Item	Issue	Relative Complexity	Inputs	Closing Decision
10	What frequency of dissolve and reform of platoons (temporary dissolve) is acceptable concerning the business case	Medium	Human Factors Business Case Traffic Modelling	People are ok with up to 3 dissolves in a period of 20 minutes.
11	Driver not obeying platooning rules	High	Business Case Safety Analysis Human Factors	When the driver does not respond to requests from the system, after suitable warnings, consider imposing a financial penalty on that driver. This will vary for each scenario. In the most extreme case, consider stopping the platoon close to when the LV will leave the motorway, then carrying out a dissolve
12	Should a driver in an FV be allowed to take control of the brakes, accelerator pedal and steering	High	Business Case Safety Analysis Human Factors	We should generally allow overrides but there may be cases when overrides are not allowed. Need to differentiate between overrides due to emergency or due to driver wanting to leave. If an FV does a lateral override, other FVs behind it should aim to follow the LV and not the overridden FV. Other FVs need to be told that an FV has gone into manual override mode. For "Longitudinal control overridden" state, if gap becomes too big, dissolve following FVs. Sound alarm when in manual override mode.

Table 1 Sample Platoon Issue

CONCLUSION

A number of technical, economic, social and legal issues have been identified on SARTRE. To resolve these and reach key decisions, a sophisticated set of tools and activities have been utilized to better understand the issues and options. To be able to understand the platoon concept and also define what will be implemented as a demonstrator, it is necessary to analyse the various task results, consider the implications and tradeoffs of certain decisions and reach a consensus on a "closing decision". Each of these steps are enabled through the application of regular "Task Force Discussions" where programme members can each contribute to discussions and support the final agreement.

From the work undertaken to date, there remain a considerable number of complex issues to resolve and these may lead to decisions that could be seen as controversial. Once the SARTRE team has completed the analysis it may therefore be appropriate to discuss the potentially controversial decisions with a wider audience during one of the planned stakeholder workshops.

As well as identifying these complex issues, a number of platoon strategies have been defined that will be further developed, tested and demonstrated on the SARTRE programme. These strategies will be implemented on a platoon with two trucks and three cars. These vehicles will be equipped with existing sensors and actuators (though there may be additional units installed) to demonstrate the relative maturity of some of the key platooning components.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 233683.

Project Partners: Institut Für Kraftfahrzeuge (IKA), Idiada, Ricardo, SP Sweden, Tecnalia-Rbtk, Volvo Cars, Volvo Technology.

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