HEAVY VEHICLE PLATOONS ON UK ROADS

FEASIBILITY STUDY

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EXECUTIVE SUMMARY

In order to have a robust understanding of the benefits and issues of convoying/platooning for heavy vehicles, a road trial is the only practical way to collect or validate all the required information. A trial would provide the opportunity to measure directly the benefits that might be realised in terms of fuel economy and emissions and further investigate commercial viability. A phased trial could also provide information on the interaction between trial vehicles and other road traffic, allow investigation of public perceptions to the technologies, how to provide information to other road users, and allow investigation of how the driving task within the platoon is affected. In the longer term, the potential impacts upon driver's hours rules might also be assessed. Furthermore, a trial would allow the possibility of assessing convoying/platooning technologies in a scientific manner, informing and encouraging effective systems, rather than relying on technology development to dictate types of system and their operator uptake.

Both convoying and platooning systems are both technically feasible today; convoying with vehicle to vehicle communication has been demonstrated and the fundamental technologies which form the basis of the regulation of following distance and lane keeping are fitted to current vehicles. Convoying (where drivers remain 'in control' of the vehicle) could be implemented in the short term (1-2 years) and platooning (where drivers could disengage to a greater extent from the immediate driving task) in the medium term (3-5 years).

However, there is no commercial convoying/platooning system currently available and any system used in a trial would not be a market-ready system. Indeed, it is envisaged that considerable development and testing would be required to produce an effective convoying/platooning system for use in a road trial, even if it is based on an existing prototype platooning system. The likely need to access the Controller Area Network (CAN) bus and to manage the interaction of other safety systems mean that the involvement of an Original Equipment Manufacturer (OEM) and their suppliers would be required. Furthermore, significant modifications to the power steering system are likely to be required to enable the lane-keeping functionality desirable in the case of short following distances, along with an Human Machine Interface (HMI) system to relay information on the status of the convoy/platoon between participating vehicles.

In order to collect statistically significant data for an impact assessment, the effect of variations encountered during daily haulage operations must be accounted for. These variations could include load, weather, seasons, driver and routes, and these are known to have significant effects on, for example, fuel economy. Achieving statistically meaningful results in light of these variations will be an important factor in determining the overall size of the trial in terms of the number of trucks vehicles / drivers and the overall duration of the trial. It should be noted that if the amount of data required to achieve statistical significance is very large, it may be advisable to consider a trial that examines the issues within particular budget and timescale constraints.

Road trial feasibility is heavily dependent on a range of parameters which are as yet difficult to define, including:

- the system functionality (the capability and performance of the prototype system in terms of following distance capability, vehicle to vehicle communication etc.);
- the number of vehicles in the convoy/platoon; and
- the location and timing of any trial.

However, it can be identified that any trial should:

- use the same vehicle type so that mismatches in acceleration and braking performance can be minimised (although it is recognised that vehicle load will have a significant effect on this);
- be limited (initially at least) to a maximum of five vehicles in any one convoy/platoon, in line with previous successful demonstrations so that interactions with infrastructure and the impacts on other traffic could be minimised;
- exclude tankers and any vehicles with hazardous loads;
- avoid network pinch-points, tolls, bridges, road works, and areas with lane width restrictions;
- not take place in extreme weather conditions (e.g. ice, snow), but include commonly occurring conditions (e.g. day/night, rain);
- obtain the necessary legal, insurance and highway operations approvals for the use of the technology;
- train all drivers involved in the prototype system being used, including normal operation, interaction with other traffic (expected and unexpected) and appropriate emergency procedures.

Any trial should be run using a phased approach with a comprehensive stepwise review of all risks and should consist of:

- System development of the on-vehicle systems as well as any off-vehicle systems required to manage the organisation of convoys/platoons (e.g. to help vehicles locate and join a convoy/platoon) as these are not available commercially;
- Track tests to assess the overall system performance and to train drivers in the technologies and system function, and including:
  - tests involving greater number of vehicles; and
  - connect and disconnect procedures “in use” cases (e.g. other vehicles entering the convoy/platoon etc.);
- Road tests on an appropriate stretch of UK motorway in conditions of very low traffic flow, likely to be best achieved by night-time testing;
- Road tests using runs which are part of normal haulage operations. First trials in this stage should investigate the most appropriate and effective way to notify other road users of the vehicles in the trial;
- Road trials using runs which are part of normal haulage operations in greater traffic flow conditions and more complex motorway road layouts.

The initial response received from operators to the questionnaire and further consultation was limited and those that provided feedback did not consider convoying/platooning as the highest priority. However, it was apparent that the benefits that might be achieved were not widely known. The interest shown by operators in being kept informed of trial progress demonstrates that once the technology is proven, and that its application to specific logistics operations is better understood, operators will give the topic greater consideration.

Although UK has not ratified the 1968 Vienna Convention on road traffic, it has ratified the very similar Geneva Convention on road traffic. This is sometimes misquoted as requiring the driver to be permanently in control whereas it actually requires the driver to be capable of controlling the vehicle at all times. The Government's *Pathway to Driverless Cars: A Code of Practice* suggests that a trial in which control is temporarily ceded by the driver could be carried out on UK roads without changes to the existing law.

Insurance cover for any trial (depending on the technology used) is likely to require detailed information on the trial design (e.g. scope, size, location, prevailing weather and traffic conditions) and access to information from pre-trial testing before cover can be put in place. If insurance cover is not provided by an insurance company, any trial would need to rely on self-insurance.

A range of parameters have been identified which should be collected as part of any trial. These will be defined further in the work specification and the types and size of data collected will depend on the specific design aspects of each trial phase and the overall size of the trial.

Using the best information available at the time of writing, a trial of convoying or platooning technologies on an appropriate UK motorway is deemed feasible. However, the safety and key issues should be reviewed at each stage to ensure that the mitigation measures used are appropriate and effective.

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1 INTRODUCTION AND AIMS

The use of vehicle technologies to assist the driver is now widely accepted in passenger cars and commercial trucks. The next step of semi-autonomous and autonomous technologies include combining several vehicles together to form convoys or platoons, which are predicted to bring about significant benefits in terms of safety (casualty reduction), real-world fuel efficiency, emissions (lower CO_2), road capacity and congestion (more efficient use of the road space leading to improved traffic flow), and driver convenience. The relative importance of these benefits will be different for different types of vehicle. For example, with commercial heavy goods vehicles, fuel efficiency will be more important and driver convenience perhaps less important than with passenger cars. While the scale of these benefits can be predicted theoretically, a more accurate measurement will be provided from a road trial, which also provides important information on practical issues and on interactions with existing infrastructure and other vehicles.

In order to have a robust understanding of the benefits and issues of convoying/platooning for heavy vehicles, a trial involving the participation of key stakeholders is the only practical way to collect or validate the required information. In principle, a road trial would generate reliable information for an impact assessment, which will then enable the evaluation of appropriate policies with respect to semi-autonomous or autonomous platooning. However, as well as providing a way of measuring the benefits and investigating logistical issues, carrying out a trial on the public road carries a paramount responsibility to ensure a high level of safety. Consequently, a thorough and independent assessment of issues and risks and their appropriate mitigation actions is essential.

The Department for Transport commissioned this project to produce a feasibility study for a UK road trial of convoying/platooning of heavy vehicles. This feasibility study aims to identify and assess the main issues relating to a road trial of HGV convoying/platooning technology on UK motorways and provide a clear and independent assessment, highlighting the data required to inform an impact assessment, the risks of running a road trial, their appropriate mitigating measures, and to clearly identify any risks or issues that cannot be mitigated or which have residual risk.

1.1 Previous studies

A range of previous studies (for example, PATH, SARTRE, KONVOI, Energy ITS: see Appendix 2) have consistently found a range of benefits for vehicle convoying or platooning. These benefits can be summarised as follows:

- **Benefits in terms of fuel economy** – the PATH project predicted fuel economy savings of 20% for four or more vehicles, and up to 30% for “many vehicles”. The SARTRE project demonstrated benefits of up to 8% for the lead vehicle and up to 16% for following vehicles (Figure 1, [1]) and the Energy ITS project showed benefits of up to 9% for the lead vehicle and up to 22% for the second truck (Figure 2, [2]):
  - Fuel economy benefits with platooning are created by vehicles following in close proximity which affects the aerodynamic drag resistance for both the

- The lead vehicle also benefits from platooning as the low pressure area that is behind that vehicle is not as low when there is another vehicle following closely behind. The vehicle's engine must expend energy to overcome this low pressure zone behind the vehicle.
- Studies have consistently found that the fuel economy benefits generally increase as the following distance reduces.

lead vehicle and particularly the following vehicles. This reduces fuel consumption (and tail pipe emissions). The aerodynamic profile of the vehicles is important to the fuel economy benefits; smaller vehicles following larger vehicles will attain greater benefits.

- **Benefits in terms of reduced emissions** – Aerodynamic improvements lead to improvements in the levels of tail pipe emissions, with all emissions (CO_2, NOx, particulates, etc.) reducing in proportion to the reduction in fuel use.
- **Benefits in terms of improved traffic flow and capacity** – SARTRE and other studies (e.g. [3]) have shown that controlling the following distances between vehicles helps maintain free-running traffic, and in cases of higher density traffic, automatic control reduces unnecessary acceleration and braking, leading to a more efficient, safer use of the road.
- **Benefits in terms of improved safety** – around 90% of accidents [4][5] involve driver error and for this reason, automatic control (or driver assistance) reduces the magnitude of the risk of driver error that contributes to accident causation. This leads to safer driving, provided that all vehicles are controlled in the same way, or that the autonomous vehicles can be integrated safely into the general traffic mix that comprises both automatically and manually controlled vehicles.

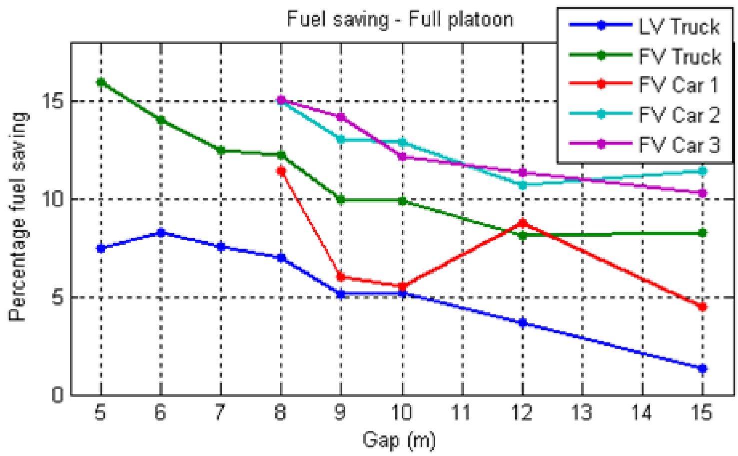

Figure 1: SARTRE fuel economy savings – 2 trucks and 3 cars at 85kph

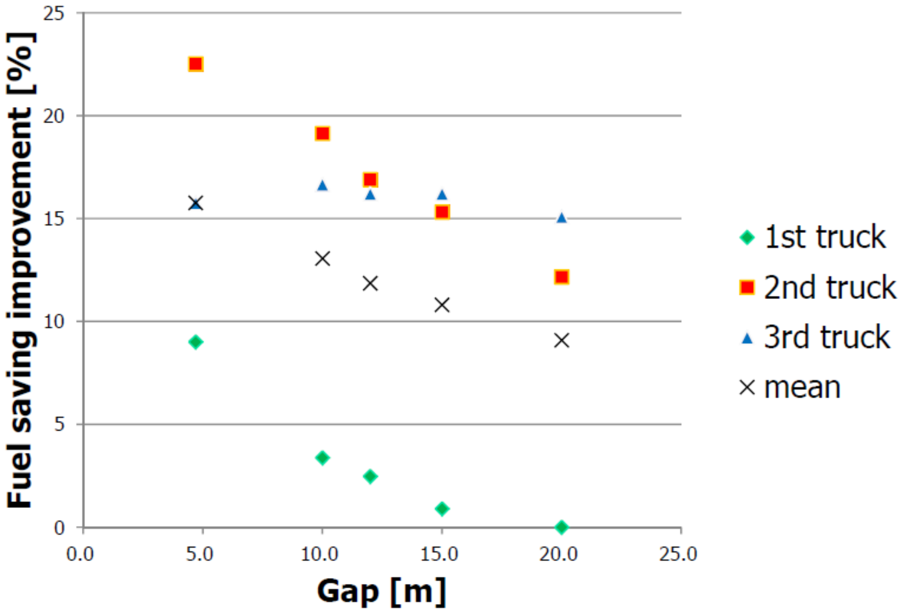

Figure 2: Energy ITS fuel economy savings – 3 trucks at 80kph

1.2 Methodology

This study involved consideration of a large range of issues that must be considered to determine if, and under what conditions, a road trial of convoying/platooning heavy goods vehicles can be carried out on UK roads.

These issues were investigated and assessed by reviewing previous literature and via consultation with a wide variety of stakeholders (see Appendix 3). A questionnaire was sent to 97 stakeholders identified by the project team to provide information pertaining to each of the technical areas identified.

In addition to the descriptive text and information on each of the technical issues, a risk register (Appendix 5) was developed to track each of the issues associated with running a trial of convoying/platooning heavy vehicles on UK roads that formed a way of monitoring and documenting the mitigating actions that could be implemented.

1.3 References

[1] Eric Chan, “Cooperative control of SARTRE automated platoon vehicles”, October 2012, ITS World Congress

[2] Sadayuki Tsugawa, “Final report on automated truck platoon within Energy ITS project”, October 2013, International Task Force on Vehicle Highway Automation

[3] J. Kotte, Q. Huang, A. Zlocki, “Impact of platooning on the traffic efficiency”, in Proceedings of the 19th ITS World Congress, Vienna, Austria, 22-26th October 2012

[4] Arne Bartels, “Automated driving – State of the art and future challenges”, March 2013, iMobility Forum. www.imobilitysupport.eu/.../automation/...3/...auto...automation.../file

[5] Volvo Trucks, “European Accident Research and Safety Report 2013”, January 2013. Available at: http://pnt.volvo.com/pntclient/loadAttachment.aspx?id=27116 [Last accessed February 2014]

2 CONVOYING AND PLATOONING

The main advantage of platooning for heavy goods vehicle operators is that the vehicles can travel closer together which will bring aerodynamic efficiencies and result in improved fuel consumption. Of course, there are other societal and environmental benefits (for example: safety, emissions, and congestion), although these may be more difficult to directly measure during a trial.

There are a range of simpler vehicle technologies that could potentially bring some of the advantages of platooning in a shorter timeframe. These will be referred to as 'convoying' technologies.

Convoying:

Convoying means the formation of groups of heavy vehicles following a manually controlled lead vehicle using technologies to assist the driver. Adaptive Cruise Control (ACC) systems (which may be modified to function at smaller following distances than normal), and possibly combined with Lane Keeping Assist (LKA) systems, to provide automated control of the vehicle headway as well as vehicle steering while cruising at motorway speeds. The drivers in the convoy are required to closely supervise the automatic systems and be ready to take over "instantly", and are still actively in control of their vehicle. For more advanced convoying systems that use Cooperative ACC (CACC) there would be vehicle to vehicle (V2V) communication between participating vehicles.

Platooning:

Platooning means the formation of groups of heavy vehicles following a lead vehicle using technologies so that the following vehicles are controlling themselves (with V2V communication between vehicles). A driver in the platoon is not required to actively control the vehicle. The lead vehicle is manually controlled by a professionally trained driver. When a vehicle is platooning, the automated system will control the distance to the preceding vehicle by automatically controlling the engine, gearbox and the brakes. It will also automatically control the steering so that the vehicle follows the preceding vehicle. The driver must, however, be available to take over control at short notice, usually within a few seconds. It should be noted that platooning technologies would only be enabled by the driver at certain specific times and under certain conditions, and that the rest of the time, the vehicle would be driven manually.

2.1 Levels of Automation

When looking at automated vehicle systems, it is useful to be able to classify these systems depending on the degree of automation. Three organisations have defined classification levels of automation:

- NHTSA (National Highway Traffic Safety Administration) in the US have defined five levels, numbered from 0 to 4.
- SAE (Society of Automotive Engineers) have defined six levels, numbered from 0 to 5.

Level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of *dynamic driving task*	System capability (*driving modes*)	BASt level	NHTSA level
***Human driver* monitors the driving environment**								
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
***Automated driving system* ("system") monitors the driving environment**								
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes	Highly automated	3
4	**High Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	Fully automated	3/4
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**	-	3/4

Figure 3: SAE levels of automation with corresponding NHTSA and BASt levels

- BASt (Bundesanstalt für Straßenwesen) in Germany has defined five levels, from "driver only" to "fully automated".

SAE is the most recent organisation to publish their levels [6] and they have shown how their levels correspond with those of the other organisations in Figure 3.

It can be seen that there is a lot of commonality between the different organisations' definitions. As the BASt definitions are probably the most likely to influence any potential future EU regulation, this report will use the BASt definitions. The different levels of automation (adapted from [7]) are shown in Figure 4.

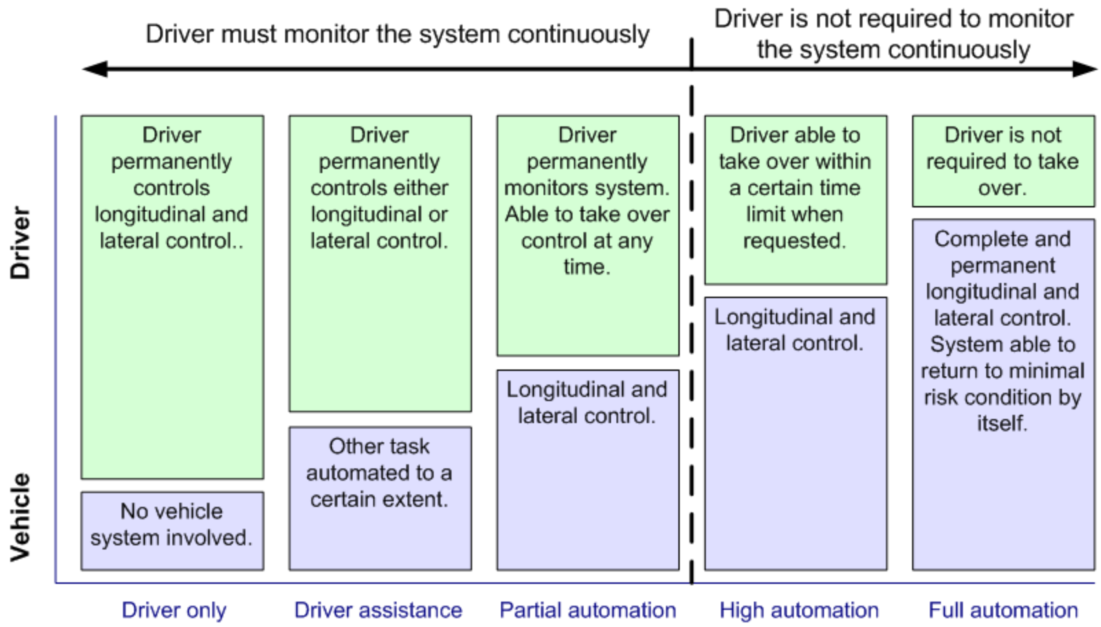

Figure 4: BASt levels of automation

The three lower levels cover systems that exist currently in passenger car production vehicles. In the "partial automation" level, although both the longitudinal (engine & braking) and lateral (steering) motion are fully controlled by the vehicle, the driver is required to permanently monitor the operation of the system, maintain situational awareness of what is happening around the vehicle, and must be able to take over control of the vehicle at any time at short notice.

In the fourth level, "high automation", the vehicle is also controlling the longitudinal and lateral motion of the vehicle, but here the driver is not required to monitor the system continuously. This means that they are able to undertake other tasks such as reading a book or using their smartphone. They are likely to also lose situational awareness and might not be aware of what is happening in the surrounding traffic, or what is coming up on the road ahead. They may decide to take over control, or may be requested by the system to take over control, but it is assumed that this transition to taking over control will not be immediate. None of the organisations have defined the time interval for intervention but this report assumes that the time delay is in the range of several seconds or even several tens of seconds.

In the fifth and highest level, “full automation”, the driver is not required to take over at any time, although they may still choose to do so. This means that the automated vehicle system must be able to handle any situation that it may encounter and if necessary bring the vehicle to a safe state.

The key transition / threshold in the five levels is from “partial automation” to “high automation” where there is a difference in the driver’s responsibilities, moving from the driver being fully responsible, to the driver not being fully responsible. This key transition also appears in the NHTSA and SAE levels between their Level 2 and Level 3. This is also the key transition between our definition of “convoying” and “platooning”, with convoying being a “partial automation” system (or even “driver assistance” depending on the details of the system) and platooning being a “high automation” system.

2.2 Convoying and Platooning Systems

An example of convoying technology is Adaptive Cruise Control (ACC) combined with Lane Keeping Assist (LKA). ACC controls the vehicle’s speed using the engine and the brakes and, by constantly measuring the distance to the preceding vehicle, will automatically slow down if the traffic ahead slows down. LKA senses the lane markings and keeps the vehicle in the lane by controlling the steering. ACC and LKA typically are used when cruising at motorway speeds. These systems are already available on some passenger cars and, in order to comply with current legislation, require the driver to hold the steering wheel, sometimes requiring them to touch the steering wheel every few seconds.

This could in the future be augmented with Cooperative ACC (CACC) where several vehicles travel together and are in constant communication to coordinate their accelerations, decelerations and cruising speeds. This allows them to travel at closer distances than if they only had standard ACC, increasing the fuel economy gains that are achievable. Since the driver will still have to steer the vehicle, there will be a minimum inter-vehicle distance below which the driver will not see enough of the road to be able to control the vehicle comfortably.

With platooning, the lead vehicle in the group is driven normally by the driver and any following vehicles within the group control themselves, with the drivers not required to actively control their vehicles. It should be noted that platooning technologies would only be enabled by the driver at certain specific times and under certain conditions, and that the rest of the time, the vehicle would be driven fully manually. When the vehicle is platooning, the automated system will control the distance to the preceding vehicle by automatically controlling the engine, gearbox and the brakes. It will also automatically control the steering so that the vehicle follows the preceding vehicle. The driver is therefore not actively controlling the vehicle and could carry out another task such as reading a book. The driver must, however, be available to take over control at short notice, usually within a few seconds, or tens of seconds. Platooning is envisaged to allow the vehicles to travel closer together than when convoying, and therefore enables the maximum fuel economy advantage to be obtained.

Both convoying and platooning are technically possible in the near future. Although LKA systems are not widely fitted to HGVs, the European Union General Safety Regulation 661/2009 mandates AEB (Autonomous Emergency Braking) and LDWS (Lane Departure Warning System) for HGVs over 8 tonnes on new types of heavy vehicle from 2013 and new vehicles from 2015, so the technology required in terms of sensing (for lane detection) and system functionality (ACC, AEBS) is available. As neither convoying nor platooning technology are currently available commercially, these systems would have to be developed as prototype systems for a trial. A convoying system not involving vehicle to vehicle communications (V2V) (i.e. one using standard or modified ACC) would be easier and cheaper to develop than a platooning system. Convoying systems with V2V would be more complex and expensive to develop, but less than the cost and complexity of a platooning system.

2.3 Potential Fuel Economy Gains

A number of past projects involving platooning trucks have characterised the fuel economy gains achievable through increased aerodynamic efficiency by running vehicles close together. For convoying vehicles, the need for the drivers to have a view of the road will impose a minimum gap between vehicles, limiting the fuel economy benefit achievable. For platooning vehicles, the drivers do not need such a good view of the road and because the driver is relinquishing responsibility of the driving task to automated systems, a smaller gap will be possible.

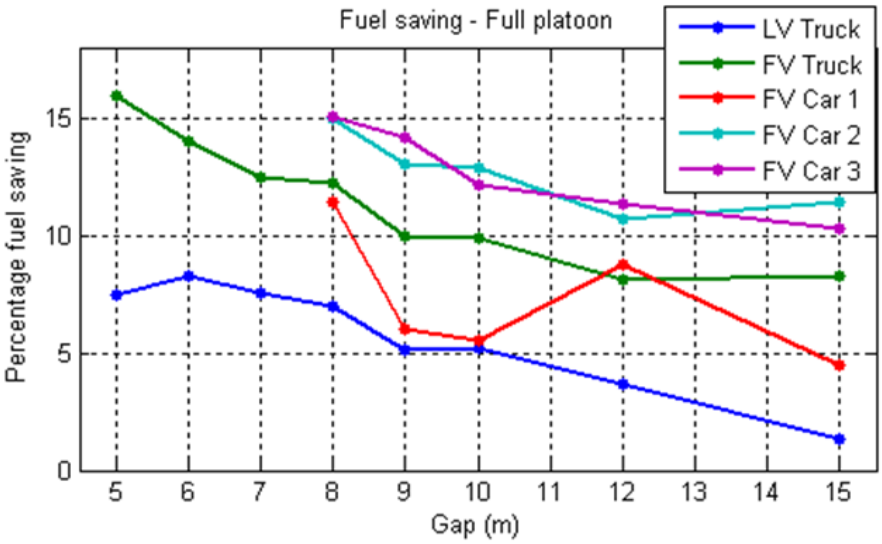

Figure 5: SARTRE fuel economy improvement (85 km/h)

If we assume that the gap between vehicles will be 6m for a platooning vehicle and 12m for a convoying vehicle, the potential gains (based on the SARTRE measurements [8] in Figure 5) are shown in Table 1. The fuel economy gains are almost double for platooning at 6m as they are for convoying at 12m. These results were achieved with platooning vehicles and V2V communication. The following vehicles need to vary their speed continuously to maintain the gap size. In order to allow enough margin for this while remaining strictly within the 90 km/h limit, the nominal speed was set to 85 km/h.

Table 1: Fuel savings (85 km/h) – convoying vs. platooning

	Convoying	Platooning
Lead truck fuel saving (%)	4	8
Following truck fuel saving (%)	8	14

Based on experience from the SARTRE project, having trucks platooning with a 6m gap is quite comfortable for the driver. For convoying, a greater separation would be desirable and these should be investigated as part of any trial (or pre-trial) phases. It is initially proposed that any trial begin with a gap of 12m if convoying.

Neither convoying nor platooning systems are available at present in production. Purely from a technical perspective (i.e. ignoring other aspects such as legislation), vehicle OEMs estimate that convoying systems could be in production in 1-2 years and platooning systems in 3-5 years (see questionnaire responses). For a road trial using vehicles fitted with prototype systems, both types of systems could be developed and installed, although of course platooning systems will be more costly and more time-consuming to develop.

2.4 Questionnaire results

All aspects of this feasibility study have taken into account the use of both convoying and platooning. The stakeholder questionnaire has been formatted so that each question is considered from the perspective of both convoying and platooning systems.

Of the 96 questionnaires sent to stakeholders, 17 (18%) were returned. These stakeholders comprised representatives of a number of groups, namely: vehicle manufacturers, technology providers, network operators, trade associations, regulators, emergency services, road safety groups, research organisations, insurance companies, operators and fleet managers, training providers, data-handling operators and security services.

Due to the response rate, an analysis by stakeholder group was not undertaken. Instead, all responses were considered and the rankings for each stakeholder view on the importance of issues (between 1 and 5; 1 being less important, 5 being more important) for a UK road trial analysed. This showed that when considering the median difference between the score allocated for each issue for convoying and the score allocated by the same stakeholder for platooning, there was no difference overall. Therefore, when the responses were pooled, there was no difference in the importance of issues for convoying compared with the same issues for platooning. However, some individual stakeholders did report a difference in the importance of issues. In these cases, the issues were generally judged as being greater (i.e. more of a potential issue) for platooning, although it was clear from the responses that there was significant variation (see Figure 6). From this information, it is clear that a trial should consider mitigation actions for each of the issues identified.

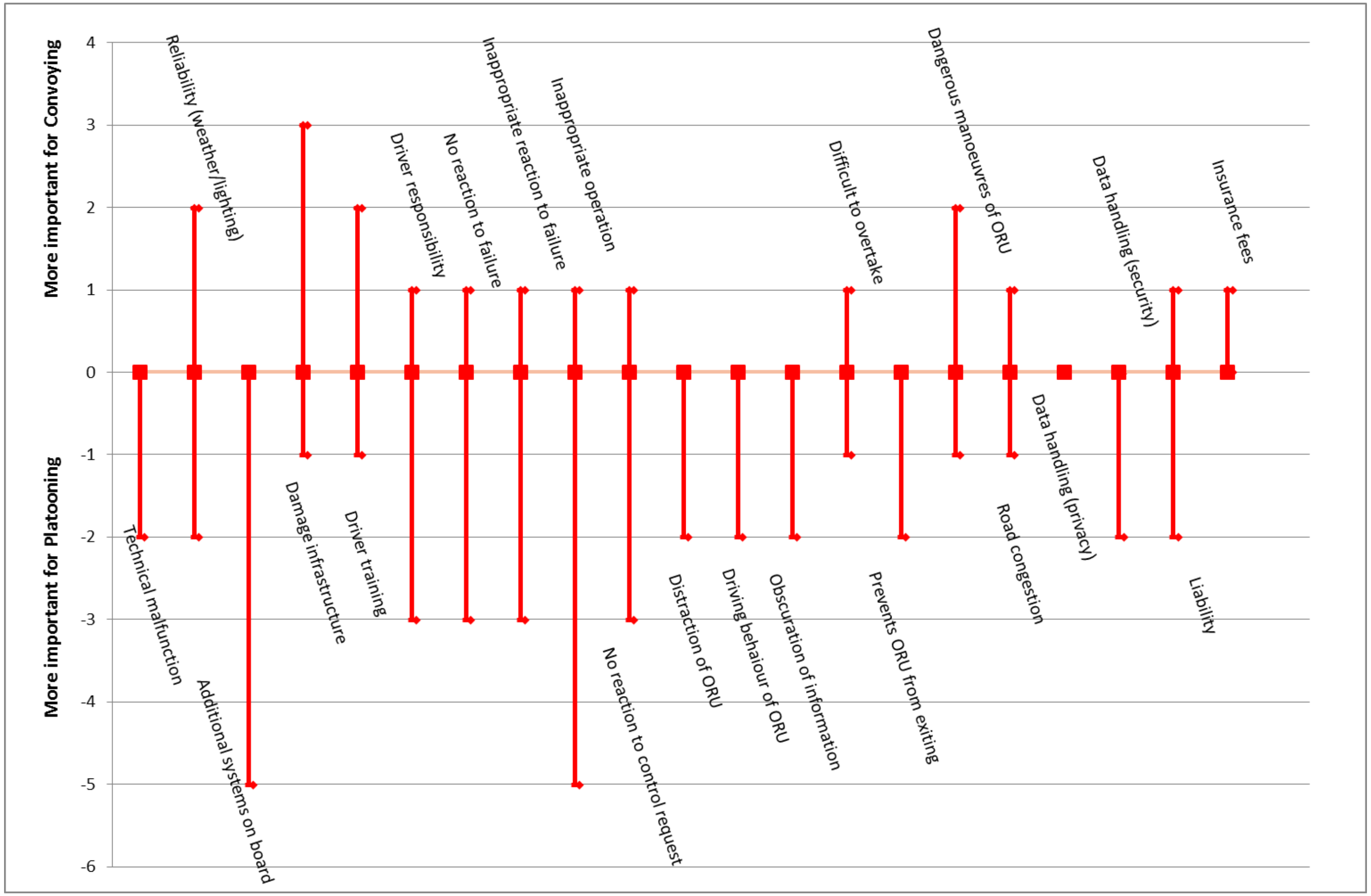

Figure 6: Median difference (with min and max) between scores for issues important to convoying and platooning for each stakeholder response (Key: ORU means Other Road User)

2.5 Key issues and mitigations for convoying and platooning

In terms of assessing feasibility for a trial on UK roads, the key observations on convoying and platooning are:

- Neither convoying nor platooning systems are available at present as a commercial system. Both systems would need development and any system used in a trial in the short-term would be a prototype system.
- From a technical perspective (i.e. ignoring other aspects such as legislation), vehicle OEMs estimate that convoying systems could be in production in 1-2 years and platooning systems in 3-5 years.
- For a road trial using vehicles fitted with prototype systems, both types of systems could be developed and installed, although platooning systems will be more costly and more time-consuming to develop.
- Most of the fundamental functionality and systems required for convoying (i.e. LDW, ACC) exist on current heavy vehicles, although the system would need to be developed to allow the steering to be controlled, as well as other communication and safety functions necessary for the overall convoying system. This is detailed in chapter 4.

2.6 References

[6] SAE levels of driving automation. Available at: http://cyberlaw.stanford.edu/blog/2013/12/sae-levels-driving-automation [Last accessed: 6 January 2014]

[7] Tom Gasser, “Legal issues of platooning”, October 2011, SARTRE workshop

[8] Eric Chan, “Cooperative control of SARTRE automated platoon vehicles”, October 2012, ITS World Congress

3 ROAD INFRASTRUCTURE

SARTRE and other previous studies have trialled convoys of up to five vehicles in length, thereby demonstrating that groups of close-following vehicles of this length are feasible on motorways or roads of motorway standard. Indeed, larger groups of vehicles would also be possible from an infrastructure point of view if the convoy or platoon is formed once on a motorway. This of course, does not include the consideration of the effects of a large group of heavy vehicles would have on surrounding (manually controlled) traffic, in the case of motorways, particularly around junctions. For this issue, the effect on other road users is likely to be dependent on the convoy/platoon length. The platoon in SARTRE consisted of 2 trucks and 3 cars and, when the gap size was 6m (the typical size used in the project), the total length of the platoon was just under 60m.

However, the extent to which the existing infrastructure limits the length of the convoy/platoon is dependent on the locations(s) and part of the road on which convoying or platooning would take place. If this is limited to formation once on the main carriageway, there is no impediment to convoy/platoon length and the main factor affecting the upper limit for length would be the safety effects on surrounding traffic. In particular, the length of the platoon has particular implications at road junctions and how the platoon may affect other vehicles entering or leaving at a junction.

The number of vehicles feasible to be used together in any trial would depend on the location and prevailing road traffic conditions of the trial. If the location for initial trials is considered to be a motorway environment with light traffic (e.g. night-time on a remote motorway) then five vehicles might not be very different to the normal and expected grouping of such vehicles. In this case, each driver would be expected to be able to take control of the vehicle and therefore would utilise the technology to convoy efficiently. In this case, the compatibility of the convoy with road junctions, road geometry and road layout is not considered to be a barrier to feasibility.

Convoys or platoons of heavy vehicles may provide particular benefits for network pinch points. While this would be a target should convoys/platoons become established, this would not be an appropriate location for the initial phases of a trial, although some investigation of these benefits might be possible, should a series of as yet undefined criteria be met. This would need to be considered in the trial specification and monitored as any trial progressed.

3.1 Slip-roads and motorway junctions

For convoying technologies, operation around slip-roads and road junctions would be feasible because each driver is in control of each vehicle and would adapt the convoy to allow surrounding vehicles to exit or enter the motorway junction as required. Convoying should only be implemented when traffic flow is appropriate to allow efficient use of the active technologies. Any trial should clearly define the conditions and circumstances under which the driver should be under full manual control of each vehicle.

For platooning technologies, the drivers in the platoon could be disengaged from the driving task and primary responsibility held by the lead driver. Provided the limit on the number of vehicles in the platoon was appropriate, this situation could be compatible with current infrastructure provided the platoon was formed on section of motorway which met safe criteria for location, weather conditions and traffic flow. This approach would place increased emphasis on interaction with non-platoon vehicles should the non-platoon vehicle wish to exit or enter the motorway at the same time as the platoon. In this case, appropriate mitigation measures would be required to ensure that the presence of the platoon is clearly communicated to other drivers and that the platooning system was capable of coping with vehicles intruding into the platoon. The platoon would normally use gap sizes (e.g. 6m) to discourage non-platoon vehicles intruding into it, but it must still be able to deal with such eventualities. Part way through some of the platoon manoeuvres, for example during a joining manoeuvre, a much larger gap could exist for a certain time so the probability of an intrusion in this circumstance would be much higher.

3.2 Lane restrictions, road works, incidents and conditions affecting traffic flow

Conditions considered here include:

- Toll booths, tunnels, bridges with specific weight limitations
- Lane restrictions: road works, short-term incidents

The conditions and circumstances highlighted above would not be appropriate for the initial phases of any trial. It would be the eventual aim that congestion and traffic flow could be improved in these conditions by using platooning technology, but this would require a fully validated and tested system and significant work would be required to integrate the platoon safely and reliably into normal traffic flow at these features. This cannot be modelled theoretically because the behaviour of the system is unknown, as is the behaviour and reaction of surrounding traffic to the presence of a platoon.

Although the convoying/platooning system has not yet been developed, the sensing system could be impaired in extreme environmental conditions of fog, snow and excessive dust or smoke. Although radar is less affected in such conditions compared with other sensing technologies, these environmental conditions should be excluded from the trial. Any trial should also exclude road conditions of snow/ice or extreme winds which would increase the safety risk of normal driving for large or high-sided vehicles.

A trial should include assessment of the system in a range of expected road conditions, for example: day/night, light-moderate rain, and traffic of varying density and flow. However, any trial should begin with testing off the road (on test tracks) to verify system performance and overall safety before progressing to more challenging traffic flow conditions.

3.3 Convoy/platoon interactions

Conditions considered here include:

- Platoon vehicles joining/leaving from the rear/middle of the platoon

- Interactions with other vehicles: overtaking, non-platoon vehicles entering within the platoon under ‘normal’, ‘exceptional’ and ‘malicious’ conditions

For convoying, these issues pose no larger threat than normal driving because the drivers in the individual vehicles remain in control at all times. For platooning situations, the system must be robust enough to address these issues and to provide an appropriate and safe response. However, the capability and performance of platooning systems are unknown and therefore the inclusion of platooning in a UK trial would require significant track testing to ensure that it could react appropriately and safely to these situations. A convoying or platooning system would be expected to cope effectively with these conditions before it could be safely included in a road trial.

Exceptional situations, such as pedestrians, cyclists or animals on the motorway would require the driver leading the platoon to take action. The convoying/platooning system should, in these extreme conditions, effectively react to the lead vehicle as well as communicating to vehicles in the convoy/platoon to implement appropriate emergency procedures provided that V2V systems are fitted.

3.4 Prioritisation of platoons

In a trial situation, a convoy could be given priority, but this is not considered necessary and might actually create more communication and enforcement requirements and issues. Further into the future, a situation can be envisaged where platoons might be segregated from ‘non-autonomous’ vehicles in dedicated lanes so that the interactions between vehicles with different levels of automation could be controlled. However, a trial in the short-term would not need to segregate convoying vehicles and instead could mitigate the interaction risks by the location and timing of the trial in the initial phases and consider information provided to surrounding traffic via gantry signs for later phases when the traffic density might be greater.

3.5 Key issues and mitigation measures for road infrastructure

The key issues for the infrastructure have been identified as:

- In the future, changes to the infrastructure would be required if the group of vehicle remained under semi or autonomous control off motorways. However, this is not a realistic prospect in the short term and any trial should be carried out on motorways.

- The convoy/platooning system should be expected to function effectively in expected environmental conditions (e.g. day/night, rain) and traffic flows of different densities. System performance should be verified on a test track prior to inclusion in any trial. Extreme environmental conditions should be excluded from any trial.

- The upper limit of the number of vehicles (length) of the convoy or platoon could be greater than the five vehicle length that has been demonstrated by previous projects.

- The factor affecting the upper limit of length is the extent to which surrounding traffic is affected. In particular, the length of the platoon has particular implications for how the platoon may affect other vehicles entering or leaving at motorway junctions. In this context, the effect on surrounding traffic is proportional to convoy/platoon length.

- Based on the evidence from other studies, we believe that there are no feasibility issues for operation of heavy vehicle convoys or platoons on motorways with respect to existing road infrastructure, provided that formation is limited to 'on-motorway' and specific requirements for location, weather conditions and traffic flow are met.

- Later phases of any trial might consider providing information to other road users of presence of the convoy/platoon via gantry signage, although the possibility of changing the behaviour of other drivers requires consideration. Despite this, signage might be particularly advisable in situations of greater traffic density, but inclusion in any trial should be made on the basis of specific criteria and the monitoring of outputs from any initial trial stages.

4 VEHICLE ASPECTS

As platooning and convoying systems are not available in production, the vehicles participating in the trial will have to be fitted with prototype systems to enable operation within convoys or platoons.

One of the differences between prototype and production systems is that a production system will have been extensively validated over a wide range of operating conditions. The prototype systems used in the trial will not have been validated to this level and there will be certain extreme conditions, for example heavy snow, where the trial system might not be usable. System performance may also be degraded in more commonly occurring environmental conditions, although this cannot be assessed before the system is developed.

The prototype systems must be developed to a level to allow safe everyday operation, but it will be recognised that the drivers will require an extra level of training that may not be required when such systems will be deployed commercially. Faults within the system, or any degradation of performance, will have to be detected, logged and, where appropriate, be reported to the driver(s).

Although the prototype system will not be developed to the same extent as a production system, it should be recognised that there will still be a considerable amount of development work that will have to be carried out before the actual trial can take place. There will be an extensive development phase involving driving on test tracks. This will also have to set up scenarios where there is interaction with non-platoon vehicles. The test track will have to be able to allow sustained driving at motorway speeds which means that only the larger test track sites will be suitable. When the system is mature enough, extensive tests on the public motorway network will have to be carried out before the vehicles are ready for the trials to start. It is difficult to provide a time estimate for the development phase as this is dependent on the trial scenario, the type of system developed and its performance.

By definition, any road trials would use systems whose operational safety has not yet been proven. There are likely to be a range of additional risks that may need to be addressed to minimise as far as reasonably practicable any risks of trial vehicles becoming involved in accidents while on trial. Two particular issues seem at this stage worthy of particular consideration; in-convoy/in-platoon collisions and driver protection systems.

4.1 In-convoy/in-platoon collisions

In the event of the lead vehicle having to apply emergency braking, the following vehicles will automatically apply their own brakes to avoid colliding with the rear end of the vehicle immediately in front of them. Therefore, the basic capabilities of the vehicles' braking systems should also be considered, and will be important under such conditions. Differences in tyres, loads, brake temperatures, air pressures, system architectures, etc. will all mean that the vehicles in a convoy/platoon will all have slightly different emergency braking capabilities.

One way to avoid collisions would be to put the poorest performing vehicle at the front, followed by the next worst, etc. until the best braking vehicle brings up the rear. While this might help to ensure that any gaps between vehicles before the braking started are maintained (or even increase), it would restrict the flexibility of the trials and may not be very reliable as any brake performance measured under one set of circumstances (e.g. as part of a periodic technical inspection regime) may not be a good indicator of real world performance, under the specific vehicle loading, road surface and weather conditions applicable at the time of the emergency braking incident. Therefore a more appropriate mitigating measure may be to increase the distance between following vehicles based on calculations that allow for likely variations in braking performance. Another option may be to set each vehicle to have the same braking deceleration, based on that of the worst performing vehicle in the convoy/platoon – this, however, may have liability implications if, for example, the ultimate braking capability of the lead vehicle has been compromised to avoid in-convoy/platoon collisions, but such that it could not avoid its own collision with a non-convoy vehicle in front of it. An alternative approach would be to use similar (or ideally identical) type of vehicles in any trial. This is the preferential option and is considered likely should a large operator be involved in any trial.

When platooning, the vehicles within the platoon will continually share data between themselves so manoeuvres such as emergency braking will be coordinated. As soon as a vehicle brakes, the other platoon vehicles behind it will be informed and will start braking with minimal delay.

Depending on the following distance and the system used, it will also be necessary to deactivate or modify the AEB (Autonomous Emergency Braking) because many systems may pre-charge the brakes at small headways, or even begin to activate the brakes. Provided the brakes were not pre-charged, the use of AEB would be beneficial because this would mitigate collisions between the vehicles. For convoying or platooning systems for which this becomes an issue, AEB system would need to be deactivated when in a convoy/platoon.

The trial could use either articulated or rigid trucks. With an articulated truck, there is the additional risk of jack-knifing during a heavy deceleration. As jack-knifing is mainly affected by the vehicle's own systems, this will be unaffected by being in a convoy or platoon, except that there would be several trucks close together, some of which could jack-knife. Therefore, the effect on surrounding traffic could potentially be higher. Consideration should be given to using articulated trucks which include systems to prevent this, for example Volvo's Stretch Brake system. The type of vehicle being used may depend on the haulage company's operations (assuming that a haulage operator is involved with the trials). However, taking into consideration the safety and technical benefits, careful consideration must be given to using articulated vehicles.

4.2 Driver protection systems

Drivers may be reluctant to be in a following vehicle if they perceive that they are putting themselves at greater risk of colliding with the rear end of a vehicle in front than they would accept in normal driving, through much lower following distances. Consideration should therefore be given to whether additional occupant protection systems are feasible and necessary. Three-point seat belt use and driver airbag systems should be regarded as the minimum required standard, but additional cab strengthening and/or energy absorbing frontal structures may also need to be considered. That said, the vehicle systems necessary for convoying and platooning are likely to reduce the severity of collisions relative to unequipped vehicles. Consequently, such measures may only be required to support driver acceptance of the technology and their initial perception of increased risk.

Other vehicle aspects that should be considered include:

- Regular roadworthiness testing/inspections to ensure all trial vehicles are in optimal operating condition at all times
- The sorts of loads (if any) that are carried, their value, their weight/density, their restraint systems etc. Dangerous goods should be excluded from any trial.
- Vehicle/trailer age and condition, and fitment of enhanced safety systems

4.3 Damage to vehicles from road debris

Previous projects found that travelling at close following distances might result in increased vehicle damage caused by road debris. This should be monitored in any trial by visual (photographic) inspection so that any changes to the vehicle can be recommended for larger scale implementation.

4.4 System performance

The platooning system will broadly have to:

- Guide the vehicle to a nearby platoon
- Manage the process for joining and leaving the platoon
- Maintain the vehicle within the platoon

The condition where the most accuracy is required of the platoon control system is maintaining the vehicle within the platoon as it drives through the varieties of road topologies encountered on the motorway road network, where it will have full control of the vehicle's longitudinal and lateral motion.

The normal motorway lane width is 3.65m and where narrow lanes are used due to road works, the width can reduce to 3.25m [9]. As the width of a truck can be assumed to be 2.5m (cab width from [10]), assuming that the truck is centred in the lane, this leaves a space of 0.57m on either side of the truck on a normal motorway lane and 0.37m either side for a narrow lane.

The entire sensing and control system must therefore be able to maintain the lateral position to a few tens of centimetres, which is a challenging target. It may be decided that, when narrow lanes are encountered, all of the platoon vehicles revert to full manual control. This may be desirable not only due to the narrow widths, but also due to the increased probability of difficult traffic conditions (e.g. lane merging).

The nominal longitudinal gap between the vehicles will be several metres, with a minimum probably in the range of 4-5m at 90 km/h. The requirements on accurate control are therefore not as strict as for the lateral direction.

The previous sections discussed absolute limits imposed on the sensing and control system for safe operation, but it is also important that the driver feels that the system is operating in a stable and accurate manner. As the distance to the preceding vehicle is quite short, non-stable operation (e.g. oscillations) will not provide the driver with a feeling of safety even if the absolute safety limits are fully respected. This is, of course, a subjective judgement and it will have to be evaluated during the course of system development.

4.5 System safety

The prototype systems fitted to the vehicles will have to be developed to a high level of safety. However, it is unlikely to be possible to implement a fully comprehensive safety development process to the same level as a commercialised production system. A safety process will need to be developed, based on industry standards that are suitable for a prototype system used in an extended road trial. There isn't an existing standard to cover platooning vehicles so the safety process is likely to be based on ISO 26262 with extensions to cover multiple HGVs.

The safety process will have to define which safety procedures would have to followed during the development process, and define the level of redundancy that would be acceptable. It will be recognised that the drivers of the vehicles will be typical truck drivers, but with additional training to enable them to operate the platooning systems, participate in the trials, and use prototype-level systems.

4.6 Vehicle type

The scope of any road trial includes only trucks and not, for example, vans or passenger cars. Trucks containing dangerous goods should be excluded from the trials.

It may be necessary to mount equipment to the rear of the trucks to support platooning. This could include for example communications antennae or a shield covering the undercarriage. If the trucks used are rigid trucks, then this equipment can simply be installed once. If the trucks used are articulated, with a separate tractor and trailer, then equipment would have to be mounted on the trailer and it would be necessary to be able to disconnect and reconnect equipment whenever the trailer is swapped over.

In order to maximise the commonality of modifications required, it is recommended that all of the platooning vehicles should be of the same make, model and age. The ideal situation, in terms of system design, would be that the vehicles involved in any trial are identical.

4.7 Platooning/convoying vehicle systems

Additional sensors may be fitted to the vehicles in order for them to detect other vehicles on the road, whether they are platoon vehicles or non-platoon vehicles. It is anticipated that radars and cameras will be sufficient, and that more sophisticated and expensive sensors will not be required. It may be necessary to fit several such sensors in order to measure objects to the side or behind the vehicle.

Some of the vehicle's existing sensors may have to be upgraded. Some vehicles are fitted with a steering wheel sensor to measure the steering wheel rotation angle. For a platooning system, the requirements on this sensor will probably be higher than for the existing system(s), requiring better accuracy and, more importantly, a more accurate determination of the straight-ahead position. The platooning system will require information on the current braking and acceleration effort, which may require additional sensors to be fitted, or access to the vehicle CAN data bus which will likely require the co-operation of the vehicle manufacturer.

In order to control the vehicles, actuators will be required. Many vehicles are already fitted with ACC (Adaptive Cruise Control) which control the speed of the vehicle by controlling the engine power (i.e. accelerator pedal) and the vehicle brakes. The ACC system may only be able to obtain a limited amount of braking effort. Although this is acceptable and sufficient for an ACC system, a higher braking effort may be required from a platooning system, so modifications to the ACC / braking system may be required. It is likely that new vehicles would be equipped with AEB and it may be that modifications to the response of this system would be required.

For platooning and convoying systems using V2V communication or following at following distances less than standard ACC, the steering would be controlled by using the EPAS (Electric Power Assisted System). It should be noted that while EPAS is commonplace on passenger cars, it is not common on HGVs so it is likely that a prototype EPAS will need to be fitted to trial vehicles.

The platoon control system will have to send commands to the vehicle's ACC and EPAS systems, probably by sending messages onto the vehicle's CAN bus. The vehicle OEM will have to be involved in the development of such systems in order to obtain the best performance and safety of the overall system.

Depending on the precise system, the vehicles may have to communicate with each other in order to coordinate their movements, so a form of V2V (Vehicle-to-Vehicle) communications system will be required. This should be based on existing automotive standards, e.g. 802.11p, taking into account developments with Cooperative Intelligent Transport Systems communications in Europe and with NHTSA in the US in this area. The vehicles may additionally require communication with other external systems so a form of V2I (Vehicle-2-Infrastructure) communication might also be required.

When radar is used to detect the preceding vehicle, it is not always known exactly which physical point of the preceding vehicle the radar signal is bouncing off, especially if the road topography is such that the preceding vehicle is higher than the following vehicles. The radar signal, and thus distance measurement, may bounce off the flat rear surface of the truck or on parts of the undercarriage of the truck which may be 1-2m further away than the flat rear of the truck. At long distances, this is a minor insignificant error but if we have, for example, a nominal 5m gap, this error becomes significant. In order to mitigate this effect, a flat shield may need to be fitted at the back of the truck covering the undercarriage.

4.8 Human Machine Interface

The drivers will have to be able to control the vehicle system, and need to be informed of the status of the system so a HMI will be required. This could consist of visual, auditory or haptic HMI. The HMI will have to deal with the normal operation of the system as well as with emergency situations where a safety alert may need to be provided to the driver.

Drivers will also be able to override the system at any time by using the usual controls for example by pressing on the brake or accelerator pedals or by turning the steering wheel. There should also be an easily accessible switch to disable the autonomous functions.

When driving in the platoon as a following vehicle, the driver will have a limited view of the road and may lose a certain amount of situational awareness. For convenience and driver comfort, it may be useful to provide a live video feed of the road ahead, produced by a camera mounted on the lead vehicle.

The system status must be reported to the driver including any faults or degraded operation, for example due to extreme weather conditions.

4.9 Driver-monitoring systems

When a vehicle is platooning, the driver is not required to drive the vehicle. However, at certain times, for example when they are approaching the point where they have to leave the platoon, the driving responsibility will transition from the vehicle to the driver, and the driver will have to resume control as requested by the system.

A driver monitoring system will need to be fitted to allow the response of the driver to be monitored during any trial and to ensure that they are available to take over when required. These normally consist of a camera with suitable image processing software.

The effects of driving close together on the airflow into the cabin need to be investigated, ranging from possible changes to the airflow or to the quality of the air, so additional sensors may be required in the cabin.

4.10 Road trial systems

One of the aims of the trial is to collect data on how the system is used on a day-to-day basis. A large amount of data will therefore need to be collected to allow later analysis. A large capacity data logger will therefore be required and it will have to log the vast majority of the data from the systems outlined in this chapter.

The data collected should also be relevant to investigate any incidents that may occur. In the event of a collision, data should be logged from at least 30 seconds before the event to 15 seconds after the event.

It should be noted that the amount of data to be logged might be quite large, especially if video from cameras needs to be logged permanently. A balance has to be found between reducing the amount of logged data while still providing enough information for all of the analysis that is required.

The logged data must be transferred to a computer server for long term storage and subsequent analysis. This system should automatically do this periodically using a mobile data connection. In the event of a long-term problem with the mobile connection, an alternative means of transferring the data should be provided.

As the trial is also interested in the response of other road users, equipment to monitor these other road users may be required. Although it will be tempting to record a video stream of the surrounding traffic, consideration must be given to the large amount of data that will be produced, and the necessity to be able to analyse and review this data.

4.11 Vehicle inspection

The vehicles will have to be periodically inspected in order to:

- Verify that the convoying / platooning systems are working as intended
- Monitor if there is any additional degradation due to platooning, e.g. increase in stone chips to the front of the vehicle / damage to radiator, etc.

The inspection interval should be defined in the trial plan; it is likely that different aspects of the system/vehicles would require checks at different intervals, with those with safety critical impacts checked more frequently.

4.12 Vehicle tachograph

The trucks will already be fitted with a tachograph to monitor the driver's working, driving and resting hours. If the trial includes evaluation of the issues of drivers' hours, for example by classifying periods following within a platoon as "working time" rather than "driving time", modifications to the tachograph system may be required to enable proper recording of this.

4.13 General

The vehicles will be fitted with additional systems to allow for convoying / platooning. It should be remembered that the vehicles are still working vehicles so these systems will have to be mounted to:

- Be hidden from view as much as possible
- Be as robust to normal procedures as possible including cleaning and maintenance of the vehicles

4.14 Key issues for vehicle aspects

For any UK road trial the key issues for vehicle aspects can be summarised as:

- As platooning and convoying systems are not available in production, the vehicles participating in the trial will have to be fitted with prototype systems to enable operation within convoys or platoons. These prototype systems will require a significant amount of development effort on test tracks and on the road. A safety process will need to be developed that is suitable for a prototype system used in an extended road trial.

- The prototype system will likely utilise existing sensors, although these may require upgrading. Development of power assisted steering system will be required to facilitate lane keeping functionality and sensors to monitor vehicle state and access to the vehicle CAN bus will be required. The latter will necessitate manufacturer involvement in any trial.
- The safety process will have to define which safety procedures would have to be followed during the development process, and define the level of redundancy that would be acceptable
- HMI systems will be required to display the driving responsibility and transition of responsibility for the driving task between the system and driver.
- A driver monitoring system will be required to allow the response of the driver to be monitored and to ensure that they are available to take over when required.
- The effects of driving close together on the airflow into the cabin need to be investigated, ranging from possible changes to the airflow or to the quality of the air, so additional sensors may be required in the cabin.
- Risks associated with collisions between vehicles in a convoy/platoon or other road users should be mitigated by:
  - Developing and testing prototype system performance in a phased manner, starting with tests on a suitable test track and progressing to the road only when performance has met the required performance level
  - Using drivers trained in the system and the functionality of the prototype systems.
  - Ensuring there is appropriate safety margins built in to the prototype system.
  - Ensuring a defined and regular inspection procedure to guarantee the functionality of safety critical systems.
  - Considering additional cab strengthening and/or energy absorbing frontal structures and the use of appropriate secondary safety systems to mitigate perceived safety risk.
- The scope of any road trial should include only trucks and not, for example, vans or passenger cars. Dangerous goods should be excluded from the trials.
- As it may be necessary to mount equipment to the rear of the trucks to support platooning, articulated trucks will have to allow disconnection / reconnection of equipment when the trailer is swapped over. The rear of the trucks may require modifications to improve the radar reflection (depending on vehicle structure of those used in any trial).
- In order to maximise the commonality of modifications required, it is recommended that all of the platooning vehicles should be of the same make, model and age. The ideal situation, in terms of system design, would be that the vehicles involved in any trial are identical.
- A large capacity data logger will be required to record vehicle data (time, velocity, acceleration etc.).
- Considering the amount of modifications required to vehicles, developing the vehicle systems in close partnership with the vehicle manufacturer is highly recommended.

4.15 References

[9] Highways Agency, "Narrow Lane and Tidal Flow Operations at Road Works on Motorways and Dual Carriageway Trunk Roads with Full Width Hard Shoulders", TA 64/94, April 1994

[10] Volvo FH series specifications, website accessed January 2014

5 DRIVER INFORMATION

In platooning/convoying, the lateral and longitudinal controls of the vehicle are transferred from the driver to the vehicle systems. This will only be enabled in situations where certain conditions are met (e.g. certain road types, visibility conditions, presence of other vehicles with the same system in the vicinity). In the automated mode, the nature of the driving task is shifted from decision-making and manoeuvre implementation tasks to monitoring tasks. Even though the technology is taking over the control of the vehicle, drivers are still required to monitor the system state to detect any unforeseen situations (e.g. system failure, road engineering work). In the event of needing to resume control, the driver must have (or be able rapidly to assimilate) an understanding of the current driving situation to resume the control of the vehicle safely. Also, another requirement for automation to work as expected is that drivers need to accept it otherwise they will either refuse or underutilise the system.

Therefore, any impacts of the automation on drivers need careful consideration to maximise the benefits for drivers while minimising the disadvantages to ensure a safe operation of platoons or convoys.

The major aim of this section is to present the scope of influence of autonomous vehicles on drivers' performance, ranging from the expected benefits for drivers to potential risks. A number of risks will need consideration before the implementation of the HGV platoon or convoy road trial in the UK. This section will outline how the human factors issues can be addressed by informing drivers either through effective training method or in tailoring the system design to drivers' requirements.

5.1 Driver information (platoon & other drivers)

5.1.1 Benefits of convoys/platoons for drivers

- Effect on drivers' workload: A driver in a convoy must continuously monitor the status of the system and road conditions but is not required to make continuous inputs to the steering and accelerator/brake controls. Their workload is therefore lower (but sustained monitoring is not a task to which humans are well adapted). For platooning, drivers in the following vehicles may not need to make any inputs nor monitor the driving situation until such time as they are required to do so. Driver workload during this time is therefore greatly reduced.
- Effect on drivers' safety: Automated systems are meant to perform the driving task in a more efficient and reliable way than drivers. Human error is a contributory factor in more than 90% of road collisions [11]. The operation of the vehicle by automated systems reduces the opportunity for human error. Automation therefore promises to enhance safety and convenience of the driving task.
- Effect on drivers' capacity: to maximise the benefits of the technology and because automation reduced drivers' active participation in the driving task, drivers could be able to engage in other tasks, not directly related to the driving

task. For safety reasons, it must be ensured that they will always be able to re-engage in the driving task within a few seconds [12].

- Effect on drivers' comfort: As some of the tasks for safe control of the vehicle are taken over by vehicle systems, platooning/convoying may increase drivers' comfort.

5.1.2 Risks of convoys/platoons for drivers

Convoys/platoons offer potential benefits for drivers in terms of safety and comfort. However, a requirement for the benefits to occur and to avoid risks is that drivers use the system in an appropriate fashion.

- Drivers' 'underload': Automation of the driving task can relieve drivers' workload up to such an extent that drivers experience cognitive 'underload'. Drivers' performance is degraded in 'underload' situation due to a deteriorated attention capacity, resulting in a degraded vigilance and loss of situation awareness. It is particularly important to maintain drivers' situation awareness (in the case of platooning) should drivers have to resume control of the vehicle suddenly.
- Overreliance on vehicle systems: Good (but not perfect) performance of the systems may lead drivers to trust the automation to such an extent that drivers would neglect to monitor system performance. As a result, drivers may fail to notice when systems fail and/or make less effective decisions in response.
- Change in drivers' skill required: Platooning/convoying change the nature of the driving task with the possibility that a driver is required to resume full responsibility for control of the vehicle in infrequent, unexpected situations. Taking over in these situations would require some specific training to be provided to drivers so that they would know how to react in unforeseen circumstances.
- Long-term change in drivers: In the longer term, there is the possibility of de-skilling drivers due to lack of time driving the vehicle manually. However, this is considered a very low risk since the majority of driving skill is related to manoeuvring and operating in more complex traffic; something that would still require manual control.
- Drivers' acceptance of platooning/convoying: Another issue related to the use of vehicle systems in this way is acceptance of the systems by the user. If drivers dislike use of the system or feel that they can do better themselves, it can result in underutilisation of the systems. Drivers' trust can be affected by the systems' perceived reliability. If the system fails or behaves unpredictably, this might affect drivers' perceived reliability (and hence usage) of the system.

Several other factors may also be important in influencing the choice whether to use or not to use the system such as the attitude toward automation, which is shaped by different factors such as the perceived expected benefits (reduced workload, increased comfort, system characteristics, etc.) but also by the reliability of the systems (system errors, amount of false alarms, etc.). System characteristics such as gaps between the vehicles or platoon length can influence drivers' acceptance of the convoys / platoons and poor system design (too much warning or false alarms). The consequence of a poor acceptance by drivers can range from an inappropriate reaction to warnings and feedback up to disengagement of the automation system.

- Behavioural adaptation and risk compensation: Behavioural adaptation is a response of drivers to the introduction of new systems such that their personal needs are achieved as a result. This creates a continuum of effects ranging from a positive increase in safety to a decrease in safety [13]. In the case of vehicle automation systems, it is conceivable that drivers would exhibit behaviours that result in reduced safety as a result of a reduction in workload (e.g. engagement in a distracting task).
- Transition between normal driving and automated driving and vice versa: Resumption of control of the vehicle can either be planned or not as in case of a system failure. Drivers need to have sufficient awareness of the current situation (e.g. traffic, weather, road surface, speed limit etc.) when they regain the control. In addition, recent studies have demonstrated drivers' adaptation to the short gaps kept in a platoon. In a series of simulator studies drivers' time headway before and after driving in a platoon were compared and it was constantly found that drivers kept shorter time headways after the platoon drive than before especially when the time headways were short [14][15]. This effect can be avoided through system design (see section 5.2).

The following section describes simple rules to follow to address each of the issues mentioned above and ensure a safe implementation of the convoys / platoons on UK roads.

5.2 Key issues for driver information

The key issues for driver information can be summarised as:

- A driver in a convoy must continuously monitor the status of the system and road conditions. Their workload is therefore lower, but sustained, continuous monitoring is not a task to which humans are well adapted. Appropriate training and HMI are important to mitigate these effects.
- It is therefore important to design the system so that it provides enough feedback of the system's state to avoid over-reliance or decision errors of drivers in case of a system failure. It is important that the system design supports the formation an appropriate mental model of how the system works.
- The system needs to monitor drivers' attention to ensure they are aware of the driving situation and able to take over control of the vehicle at any time within a few seconds.
- Behavioural adaptation to shorter headways can be tackled by either feedback on drivers' distance or in enlarging distance before drivers leave the platoon.

5.3 References

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6 USER INTERFACE REQUIREMENTS

The user (or human-machine) interface (HMI) represents the conduit through which the user receives information about and can manipulate the status of the vehicle control systems. To minimise collision risk, human factors considerations must be addressed in both convoying and platooning. Firstly, drivers' situation awareness may change when the vehicle takes responsibility for aspects of vehicle control. This may change a driver's understanding of the driving environment and their impression of how the vehicle is likely to behave. If the vehicle performs hazard perception and vehicle control functions, it is possible that a driver's skill in these tasks may degrade over time. An increase in reliance on technology for safe control of the vehicle may at times reduce drivers' workload to the extent that they may become inattentive or potentially fall asleep. Alternatively, in order to manage the potentially complex systems, the HMI may create excess workload that becomes distracting for the driver. All these factors must be considered in the HMI design to ensure that the overall driving task is not more difficult, more risky or more unpleasant than driving unaided.

The HMI must ensure that a driver is aware of the current mode of system operation but transitions between modes are of particular importance. When making the transition to a mode where the requirements on the driver for control of the vehicle are changed (either decreased, where the system is taking more responsibility for control of the vehicle; or increased, where the driver has more responsibility for control of the vehicle), the driver must be clear about the status of the system at all times through the transition without this causing undue distraction.

The EC co-funded SARTRE project on vehicle platooning [17] was built on existing experience and results from previous feasibility studies of vehicle platoons. SARTRE examined the operation of platoons on unmodified public motorways. The project developed useful user interface requirements and guidelines for the operation of platoons. These are described in the following sections.

6.1 Aim of the user interface

The aim of the user interface is to manage information to and from the driver such as requests (e.g. leave, join, etc.), acknowledgements (e.g. dissolve, leave, join, etc), cancel (joining, leaving) or discard joining. Furthermore, the HMI manager computes the platoon status and provides information to the driver and to the platoon control. With the help of a graphical user interface, relevant information messages can be sent between vehicles within the platoon. Furthermore, this graphical user interface displays information (position, velocity, distance to vehicle ahead, platoon status, etc.) of the specified (potential) platoon vehicle [18].

Transitions can either be planned (e.g. a driver decides that they want to leave the platoon) or unplanned (e.g. the system suddenly does not function or there is a system failure and the driver needs to take over). In either transition, the system should warn the driver that they will be required to resume control of their vehicle. Allowance must be made for drivers to resume an appropriate driving position with their hands on the steering wheel and feet at the pedals. Furthermore, they may need time to gain awareness of the driving situation. As a consequence, the way that the HMI is developed and the interaction modes that are used to warn driver, must be deeply researched. An appropriate HMI is crucial when innovative technologies are designed and implemented in vehicles [19].

6.2 Requirements for the user interface

Larburu et al. (2010) defined how the HMI has to be designed while minimising negative impact on safety. The HMI must therefore provide information for the driver in a timely and intuitive manner that does not cause undue distraction or require excessive attention in order to function correctly.

In the SARTRE project, driver capabilities and limitations were considered in order to implement platooning successfully. Driver over-reliance on platoon systems was identified as a critical psychological factor. For this reason, human factors were considered during platoon systems development, not only from the perspective of user acceptance of the technology but also from hazards controllability point of view, as well. Addressing these needs, a human behaviour risk analysis was developed. To obtain all risks caused by human factors, the most relevant negative human factors were considered and linked to the following external (relative to the driver) factors:

- Platooning procedure: rules and actuation protocols regarding platoon use cases in SARTRE project
- Other vehicles: i.e. road users who are not part of the platoon,
- Environmental causes: related to weather conditions, road characteristics, etc.
- In-vehicle systems: in this case are related to HMI, communications and platoon autonomous systems, etc.

These causes produce hazardous consequences in three fields that were considered accordingly to the main objectives of SARTRE project: safety loss, user advantage loss (related to comfort) and sustainability loss (related to business). Finally mitigation actions for the hazardous situations were given in six categories:

- Vehicle: including sensors/actuators, HMI, and communications
- Drivers: understood as drivers of potential lead vehicle (PLV) or lead vehicle (LV) and potential following vehicle (PFV) or following vehicle (FV)
- Environment: actions derived from hazards related to weather conditions, road characteristics, etc.
- Back Office: actions derived from hazards in back office normal operation
- Other Vehicle: including vehicle and driver
- Platoon procedure: related to the sequence of manoeuvres needed to complete a SARTRE use case (join, leave, etc.)

Requirements related to Human Factors were extracted from Human Factors Hazard Analysis. Requirements were classified considering the potential and actual lead and following vehicles, the back office infrastructure supporting the platoon(s) and other vehicles.

6.3 CityMobil

The European project CityMobil considered the design of the interface for semi-autonomous and autonomous vehicles [20]. They advocated the guidance of Nielsen (1993) [21] as a basis of the HMI design and this remains appropriate for the design of the HMI for convoying and platooning. The key guidelines are provided below:

- Visibility of system status

  The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.

- Match between system and the real world

  The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms.

- User control and freedom

  Users often choose system functions by mistake and will need a clearly marked "undo" button to leave the undesired state without having to go through an extended menu.

- Consistency and standards

  Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.

- Error prevention

  Even though proper error messages are requires, a good design that prevents a problem from occurring in the first place is to be preferred.

- Recognition rather than recall

  Minimise the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

- Flexibility and efficiency of use

  Special functions may be implemented to improve the interaction for the expert user such that the system can provide services for both inexperienced and experienced users. Allow users to tailor frequent actions.

- Aesthetic and minimalist design

  Dialogues should not contain useless information. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.

- Help users recognise, diagnose, and recover from errors

  Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

- Help and documentation

  Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

In addition to Nielsen's guidelines, the CityMobil project provided further general guidance on interface design. They stated that it is preferable for a visual display to be in the central part of the visual field to minimise time spent with attention away from the road. They provide guidance on contrast, brightness and symbol size to maximise clarity. Also considered are the design of auditory alerts and messages, with guidance provided on duration, frequency range, volume and content. Finally, the use of multimodal interfaces is discussed. Research has indicated the effectiveness of vibro-tactile displays [22] but further studies are necessary to understand how multimodal interfaces may support road train operations.

6.4 Other user interface requirements

6.4.1 Other vehicles

Groups of large, close-following vehicles will present a significant proportion of traffic flow. It may, in certain circumstances, be useful for other vehicles in the vicinity to be aware of the presence of a convoy/platoon. This would enable them to make informed decisions about whether they should overtake or pull in behind the convoy/platoon in order to exit at the next junction.

6.4.2 Fleet management

The task of managing convoys/platoons with many vehicles going to different locations could become complex. Routing/scheduling software is likely to be able optimise decisions about which vehicles should join together as a convoy/platoon in order to maximise efficiency. However, this information will need to be related clearly to the fleet manager so that they can make rational decisions about how to operate the vehicles under their authority.

6.5 Key issues for user Interface requirements

The HMI needs to provide the driver with relevant information in a timely manner so that they can maintain safe control of the vehicle at all times. It must inform the driver of the current status of the vehicle with regard to any driver assistance/automation systems; information about any actions they are currently performing and any upcoming foreseen actions that they are about to perform (e.g. 'driver will resume control in 3 miles'). It is assumed that when convoying, a following vehicle may choose to form a convoy with any other suitable vehicle (i.e. one with similar dynamic characteristics and legal restrictions). Therefore, the HMI requirements are therefore focused on the following vehicles. When platooning, vehicles can only form behind a specific lead vehicle. There are consequently different HMI considerations for the lead and following vehicles.

The user interface requirements for convoying are much simpler than those for platooning as there are fewer responsibilities for the lead driver of a convoy and all drivers are required to retain alertness and attention throughout. There are significantly greater potential benefits to fuel efficiency and driver comfort through platooning. However, these are associated with more sophisticated HMI systems that must take into account the driving context, the driver status and future changes in platooning potential. They must also do more to help vehicles form the platoon and ensure that drivers are suitably alert to resume control when required. There are therefore significantly greater challenges in the development of HMI for platooning than for convoying. Additional interface issues such as the provision of information for other vehicles about the presence of convoys/platoons and for fleet managers about the administration of convoying/platooning vehicles should not be overlooked.

The detailed HMI requirements would be defined in the first phase of a trial project, along with the detailed requirements and specifications for the whole system.

6.6 References

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7 DRIVER TRAINING

The first basic requirement is that drivers participating in a convoy or platoon must hold the correct driving licence for the vehicle they are driving. This section covers the potential additional training requirements for drivers relating to convoying and platooning.

7.1 Convoying

When convoying, the change from normal driving practices is less pronounced than in platoon driving. Consequently, the additional training demands are not extensive.

7.1.1 Lead vehicle driver

When convoying, the driver of a lead vehicle has no direct responsibility or active influence over the behaviour of any vehicles choosing to form a convoy behind their vehicle. Consequently, the additional training requirement for a convoy lead driver would only be that a driver should be aware that following vehicles may form a convoy behind them. This does not represent a significant shift in behaviour or experience; it is common on motorways for large vehicles to form informal convoys due to their similarity in relative speed.

7.1.2 Following vehicle driver

A vehicle in convoy would have its speed and lateral position controlled relative to that of a lead vehicle based on sensors capable of detecting the relative position and speed of the lead vehicle, reading the current road markings and triggering actuators that adjust the behaviour of the vehicle in response. Although the system would have control over the vehicle's lateral and longitudinal position, the driver of a following vehicle would be required to remain alert and attentive in readiness to resume control at all times.

Consequently, there is a potential training requirement for the driver of a vehicle wishing to participate in a convoy in order to understand the purpose, function and implications of convoying. The purpose of convoying is to improve fuel efficiency and driver comfort. A driver should therefore be made aware that it is beneficial for them to form a convoy whenever possible and appropriate based on the traffic and environmental conditions. They therefore need to:

- understand the appropriate traffic and environmental conditions in which it is appropriate to form a convoy;
- be comfortable and familiar with the process of engaging the correct vehicle systems to ensure that their vehicle safely and successfully forms the convoy;
- understand the process for disengaging from a convoy; and
- be aware that they are still fully responsible for control of the vehicle and must remain alert and attentive to the driving situation at all times whilst in convoy.

Following on from the last point, they should also be aware that prolonged convoying may leave them susceptible to fatigue and distractions, each of which may compromise their alertness.

Drivers would also need to be aware that the performance of their vehicle may be different to that of the lead vehicle (e.g. the lead vehicle may be empty, the following vehicle may be fully laden) such that the capability of their own vehicle to remain in convoy with others may be dictated by geographical factors.

7.1.3 Other vehicle drivers

Drivers of other vehicles in the vicinity of convoys have no specific training needs in order to be able to complete their journey safely. Under trial conditions it will be advantageous to not provide any specific training or information to other road users so that the reaction to the convoy can be observed. The reaction of drivers unaware of convoys might then be compared to the reaction of drivers who have been made aware. In the longer term (and outside of a trial), the only training requirement may therefore be giving new drivers information that lorries may form convoys in this manner and that choosing to occupy gaps between participating lorries will disrupt the convoy causing inconvenience for convoy participants.

7.2 Platooning

When platooning, there is a more significant adjustment to the requirements placed on the drivers of participating vehicles. Also the presence of platoons on motorways may have a greater impact on the way these roads operate. Consequently, the training requirements associated with platooning are likely to be more pronounced than those for convoying.

7.2.1 Lead vehicle driver

Presuming that platoons will operate in a similar manner to those tested within the SARTRE project, the lead driver is the focal point for the formation of the platoon. The lead driver is responsible for initiating the formation of a platoon, accepting vehicles wishing to join/leave the platoon and for dissolving the platoon when required. Furthermore, since the controls of following vehicles are linked to those of the lead vehicle over the local area network formed between the platoon vehicles, it is the responsibility of the lead driver to retain smooth control of lateral and longitudinal behaviour of their own vehicle to minimise instability across the platoon.

The driver of the lead vehicle may have to act in a time critical manner to ensure that the platoon dissolves safely and that following drivers are given sufficient opportunity to resume safe control of their vehicle. All the additional responsibilities assigned to the platoon lead vehicle driver must be undertaken without compromising their own ability to drive. Undue distraction of the lead vehicle driver caused by that platoon administration systems may place all the vehicles within the platoon at risk.

Based on these requirements placed upon the platoon lead vehicle driver, there are evident training needs for drivers who are to adopt this role in a vehicle platoon.

7.2.2 Following vehicle driver

The driver of a following vehicle must first understand how they are required to drive their vehicle to meet the platoon on the highway – they must appreciate the position and speed of the platoon relative to their own current speed and position and how they need manage their vehicle in order to arrive in the vicinity of the platoon vehicles such that they may join the road train.

Once in the vicinity of the platoon, the driver must undertake the process of positioning the vehicle such that the automated control systems can connect to the platoon lead and take over control of the vehicle. This would be guided by an in-vehicle interface.

Having successfully joined the platoon, the driver would need to understand:

- what functions the automated control systems were going to perform;
- what functions remain the responsibility of the driver;
- the circumstances under which control might return to the driver;
- how/when they might choose to leave the platoon;
- how any control inputs may affect the behaviour of their vehicle;
- how the behaviour of a leading vehicle (or vehicles) would affect the behaviour of their vehicle;
- how any malfunctions of their vehicle or the automated systems will be reported and what actions the driver is required to take in response;
- the level of situation awareness they are required to retain whilst the automated systems control the vehicle (and whether they are permitted to engage in other activities).

In the SARTRE project, it was also noted that since headway distances in platoons may be shorter than those typically experienced in manual driving, training could help drivers to trust the system to behave reliably at short time headways.

Once the driven vehicle reaches its selected departure point, the driver would need to understand how to manage the process of leaving the platoon and resuming control of their vehicle.

Training may be desirable at every stage in this process to ensure safe management of platooning procedures. The extent to which training is required may depend on the effectiveness of the HMI – a good HMI may reduce the requirement to train drivers in some of the specific processes of platoon formation.

The cost of additional training has been estimated at £2,000 in our Commercial Viability calculations (see chapter 10 and Appendix 4).

7.2.3 Other vehicle drivers

Compared to convoys, the tight formation of vehicles in a platoon may have a greater impact on journeys made by drivers of non-platoon vehicles. In particular, the process by which a driver wishes to join or leave a motorway may be more challenging when a platoon is present. For a trial it is not feasible to train all other drivers, and furthermore, a trial is likely to want to compare the behaviour of drivers aware of platoons with those who are not. In the longer term, there could be benefit in training drivers to identify the presence of heavy vehicle platoons and planning how to negotiate them safely, which could be included, for example, during the theory test.

7.3 Other training requirements

Aside from drivers, the presence of convoys and platoons may have other impacts that could lead to additional minor training requirements. Convoys/platoons of vehicles from the same company may result more vehicles than is typical in arriving at distribution centres/destinations. Training in how to manage these multiple arrivals may be beneficial. The management of vehicle fleets may take on an added level of complexity by the introduction of convoying and/or platooning. It is envisaged that routing and scheduling software will take this functionality into account when planning vehicle itineraries but the software operators will need to understand the benefit and operation of this form of vehicle movement in order to maximise efficiency.

7.4 Discussion

The additional training requirement for convoying operations appears minimal and would not add significantly to the overall training requirement for drivers. The main training issue appears to be ensuring that drivers understand the way in which the technology functions and that they are required to maintain attention and alertness whilst the convoying systems are active.

For platoons, the training issues are more extensive as the way in which vehicles are operated changes more significantly. In particular, the driver of the lead vehicle has considerable additional responsibilities to cover in the safe formation, operation and dissolution of the platoon. Drivers of following vehicles need to know how to meet and join platoons whilst drivers of other vehicles must understand how to identify and manage the presence of heavy vehicle platoons of motorways. The additional training burden that these requirements create must be factored into cost/benefit calculations of platoon operations. Furthermore, there are potentially other groups associated with convoy/platoon operations that may require training to support the overall management of vehicle platoons.

In the longer term drivers wishing to become qualified to participate in convoys/platoons should be required to undertake an extended CPC (Certificate of Professional Competence) training which would include theoretical and practical aspects of convoying/platooning.

7.5 Key issues for driver training

It is important to consider the human factors issues outlined in chapter 5 for the design of convoys/platoons to ensure a safe implementation. Human factors issues can be addressed by effective training methods and also by the design of the human machine interface. The following section describes simple rules to follow to address each of the issues mentioned above and ensure a safe implementation of the convoys/platoons on UK roads.

Drivers need a good knowledge of how automation works to ensure it is used appropriately. This will include:

- Understanding system's reliability: Ideally, the system should be highly reliable to retain drivers' trust. However, as systems do fail, training must provide drivers with a clear understanding of system reliability. Drivers must be aware of the system limits so that their trust in the system does not become affected by any failures of the system. Moreover, drivers must be able to anticipate any unforeseen situations and they must at least be prepared to react in an appropriate way in the case of a system failure.
- Comprehensive driver training: The training required for a trial on UK roads would be more comprehensive and extensive than the training required once more widely implemented. This is because the system being used is a prototype and may not have undergone the same level of testing as a market ready system: additional training may be required to account for this.
- Drivers should be trained in:
  - Platoon formation and dissolution
  - Connect and disconnect procedures (where a vehicle joins or leaves an existing group of vehicles)
  - Emergency situations
- Awareness of risks and benefits: The system is more likely to be accepted by drivers if the advantages are sufficiently balanced with the disadvantages. It is therefore important to make drivers aware of the benefits as well as the risks of automation.
- Skills development: Drivers need to be taught how to have an appropriate reaction in unforeseen circumstances.
- System monitoring: Drivers need to be trained to appropriately monitor the system.
- In the longer term drivers wishing to become qualified to participate in convoys/platoons should be required to pass an extended CPC test which should include theoretical and practical aspects.

8 PUBLIC PERCEPTION

Should convoys/platoons be implemented on unmodified normal motorways, they will be interacting with conventional, non-automated traffic. It is of paramount importance for the implementation of autonomous vehicles that the public has a good attitude toward convoys/platoons and hence accept the presence of semi-autonomous/autonomous vehicles on the public road network. One of the prominent findings from the stakeholder consultation was the attitude of the public and how the perception of the public to the technologies could be influential. Here is a sample of fears that the public could have as a result of the implementation of convoys / platoons on the road:

- Fears linked to the loss of control on the vehicle: What happens to the following drivers if the driver of the first vehicle loses control of their vehicle?
- Fears can be linked to a lack of understanding of how the system works: What happens if the first vehicle brakes suddenly?
- Other road users can fear that convoys / platoons will interfere too much with them and impede them in their driving task: Will I be able to see the traffic signs on the roadside or will they be covered by lengthy platoons? Will I be able to exit the motorway or will the exit be obstructed by lengthy platoons? Why should I trust an automated system?

Individuals generally have fears due to inadequate or incorrect information. Therefore, it is important to make sure that enough information on platoons is delivered to the public, for instance via the media, so that individuals understand the true risks and benefits and lessen their fears. Thus far, positive media coverage of project SARTRE (SAfe Road TRains for the Environment) supported positive opinions on this system.

Public opinion can be influenced in showing the positive aspects of automation such as the reduction of negative externalities [24] (factors which are not directly accounted for by drivers, but are paid for by society e.g. emissions) and the direct benefits for drivers: reduction in fuel consumption, increase in the safety of the driving task, increased traffic flow and reduced workload. Safety, health, environment, and other public concerns can be addressed by government regulation and engineering standards [24]. Also it is important to make sure that the public has a good mental model of how the system works so that they can interact safely with autonomous vehicles in the vicinity.

8.1 Key issues for public perception

It is important to ensure that the public are effectively briefed on the societal benefits of convoys/platoons. Furthermore, any trial should communicate the extent to which the safety measures taken to permit any trail have been tested and to demonstrate that effective controls are in place with respect to the fears of the public.

The stakeholder meeting highlighted managing public perception as one of the important factors for any trial and the longer term implementation of convoying/platooning technologies. Stakeholders suggested that a media consultant should be involved in any trial.

Should a trial be carried out, measures to pass information to other road users that the vehicles are participating in a road train should be considered. However, it will be difficult to gather information on the perception of the public to platoons/convoys if signage is used to communicate the presence of a convoy/platoon to other road users. It would therefore be preferable to solicit information from road users who were previously unaware of the convoy/platoon vehicles. However, there are practical difficulties in targeting the other road users effectively and signage of convoys/platoons might be required in conditions of greater traffic densities.

Public opinion could be collected from other road users by questionnaires to drivers who used particular stretches of the road on which the convoy/platoon travelled or surveys with drivers at service stations along the route. More strategic approaches to public perception involve endorsements of the technologies by road safety groups.

Also, although close following trucks are relatively common, there may be novelty effects of the presence of the road train on UK motorways (e.g. drivers slowing to look at the platoon). Drivers in the platoon should be aware of this possibility.

8.2 References

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9 LOGISTICS AND HAULAGE OPERATORS

9.1 Introduction

Successful delivery of the feasibility study for heavy vehicle platoons on UK roads relies on developing a detailed understanding not just of the technological capabilities of convoy/platoon systems, but also of the likely demand/need for those technologies from the freight transport industry.

This chapter sets out the methodology and the results of the consultation with logistics/haulage operators that took place during the period December 2013 – February 2014.

The consultation set out to explore operators':

- familiarity and attitudes to convoy/platooning technologies
- views on the potential commercial advantages (e.g. driver's hours, changed processes or work practices)
- concerns and risks

At the same time operators appetite for taking part in future trials was assessed along with any special conditions that they might wish to see implemented.

9.2 Methodology

A database of 47 operators was established by the project partners from their existing request to complete the contacts. The database included mainly national UK operators, as well as European or global businesses that have an operating base in the UK. These are the operators considered most likely to have an interest in, and an ability to implement convoying/platooning technologies.

Three rounds of consultation were undertaken to try and establish their views on convoying/platooning. These were:

1) An email request to complete a questionnaire
2) An email request to answer three simple questions
3) A telephone call to elicit their thoughts

The project team developed a questionnaire on convoying/platooning that was circulated to a wide range of organisations that were expected to have a view on convoying/platooning on UK roads. This was sent to all of the 47 operators in the database. Completed questionnaires were returned by 3 operators, a response rate of 6.4%.

Following the deadline for the return of the questionnaires an email was sent to the operators that hadn't responded asking three simple questions regarding convoying/platooning. The three questions were:

1) I am interested in HGV convoying / platooning. (Yes/No)
2) What benefits/disbenefits do you expect to see for convoying / platooning

3) I would like to be kept informed of progress with the project. (Yes/No)

The email was sent out to 44 operators and responses were received from a further 3 operators, a response rate of 6.8%.

Finally, attempts were made to make telephone contact with the remaining 41 operators that hadn't already responded. Contact was established with 12 operators who were asked the above three questions and also requested to complete the full questionnaire. The response rate for this activity was 29.3%.

In addition to the initial request to complete the questionnaire, operators were invited to attend a workshop in January to discuss their responses. Additional operators were also invited to attend the day. Unfortunately, no operators were able to take up this invitation.

9.3 Questionnaire results

Where the question required a 'score' as an answer, the responses were scored on a scale from 1 to 5, with 1 being considered 'not important' and 5 being considered 'very important'.

Respondents were asked to differentiate their response between convoying and platooning. For the vast majority of responses no difference was indicated between the two types of operation. In the rare instances where a difference was indicated, the difference was no more than one point. In those instances either of the point scores is indicated below for scores 2, 3 and 4, and 1 or 5 is indicated if that was one of the responses.

9.3.1 Q1. In your opinion, how important are the following potential benefits of convoys or platoons?

9.3.1.1 Vehicle benefits

From the questionnaire responses it is clear that the potential fuel savings are very important for operators with two operators rating it 5 and the other as a 4.

Reduced vehicle maintenance was considered slightly less important with response ratings of 2 or 3.

Other vehicle-related perceived benefits included:

- Improved Safety
- Reduced accidents
- Less driver's hours infringements
- Better timing

9.3.1.2 Infrastructure benefits

Mixed views were expressed regarding the impact of road infrastructure. Two operators rated the benefits as average or above (3, 4) whilst one operator did not think that there would be any infrastructure benefits (1).

Potential infrastructure benefits highlighted by operators included:

- More consistent road space use
- More understanding from other drivers
- Increased capacity of the road network due to closer running benefits all road users, not just freight

9.3.1.3 Driver and/or other road users

There was a variety of responses to the specific points in this section.

One operator rated ‘reduced accident rate’ and ‘reduced accident severity’ highly (5) whilst the other two rated them between 2 and 4.

‘Reduced driver workload’ and ‘increased comfort’ were rated 1, 2 & 3 by the three operators.

The points ‘possibility of increased driving range due to extending the allowable daily driving time’ and ‘reduced road congestion’ were rated between 2 and 4 by the operators.

An additional point raised regarding other potential benefits related to the drivers or other road users was that:

> ‘*Down-skilling the driver population will make access to the occupation easier. However the risks associated with this are actually of disbenefit’.*

Given the majority of driving skill is related to manoeuvring and operating in more complex traffic, something that would still require manual control, down-skilling the driver population should not be anticipated.

9.3.1.4 Liability and insurance:

There was a difference of opinion regarding the importance of liability and insurance. Two operators rated it as important (4), whilst the third operator rated is as not important (1).

An additional point raised in this section was that:

> *‘It will take many years of evidence before the use of such vehicles will be proven in terms of accident record and therefore the insurance premium benefits being seen by operators. Self-insuring large fleets may be reluctant to take the unknown risks initially as well, although the fact they are self-insuring may mean they are more able to take place in trials are we’re not restricted by premium impact of such activity’.*

9.3.2 Q2. Can you think of any other potential benefits not listed above?

Only one additional point was made by operators in this section. This was regarding

'Emissions benefits associated with the resultant fuel savings'.

9.3.3 Q3. Which fleet operator/logistics/haulage company would be most suited, and least suited, to be involved in a road trial, and what are the important factors to consider?

There was a clear view expressed by all three operators as to the operations most suited to a convoy / platoon road trial. Suggestions were:

- long haul.
- container (i.e. long journeys from ports).
- multiple trunks running to and from the same locations within similar timeframes.
- large volume trunking activity where several vehicles are required to do the same route at the same time.

The point of using road freight transport, rather than for example rail transport, is due to the flexibility required for the local delivery element which takes a vehicle away from the standard corridor where the trial would operate. Therefore national distribution centres, rather than regional distribution centres structures would be better suited, as would anything where high mileage is covered on single journeys.

The suggestions for least suited operations included:

- multi-drop 'groupage'
- small consignment hauliers

It is clear from the above and previous project discussions that care and effort will be required to ensure the best selection of an operating site to support the trials.

9.3.4 Q4. Which parts of the motorway network would be most suitable, and least suitable, for a road trial, and what are the important factors to consider?

A variety of suggestions were made as to the most suitable locations for a road trial. These included;

- M1, M25 (some parts), M3/M4
- Rural Motorways with service areas sufficient to allow for "marshalling" of convoys and platoons
- Night-time obviously being better for any trials and managing risks.
- Night-time running would naturally avoid the worst of this (local traffic moving on / off motorways), and may provide the optimum time for trials.
- Any stretch where a rail link alternative is not available would offer most potential benefit.

Suggestions for the least suitable locations included:

- Urban motorways with multiple junctions and interchanges close together

- Any stretch of motorway with numerous entry/exit slips due to the number of lane changes required by the HGVs as car traffic moves in/out.

9.3.5 Q5. In your opinion, how important is it to mitigate the following potential issues for a UK road trial?

9.3.5.1 Vehicle issues

Vehicle issues were given highest overall importance with two of the three operators scoring 'Technical malfunction (general vehicle components, platooning related hardware components or software)', 'system reliability in adverse weather or lighting conditions' and 'additional system fitted to the vehicle to enable platooning' very important (5), with the remaining operator scoring them a medium rating of 3/4.

'Driver error' was raised as an issue and one operator commented that:

> *'The cost of any extra on-board technology and associated maintenance and repairs of said electronics would have to be off-set against any operational benefits. Repair and maintenance contractors would need training in national coverage for breakdowns of such equipment and the impact on lease and warranty implications would need to be understood'.*

9.3.5.2 Infrastructure issues

Infrastructure issues e.g. 'causing damage to infrastructure (e.g. exceeding bridge loads) was rated as average importance (3) by two operators with the other operator rating it as very important (5).

One operator raised the issue of poor route planning regarding infrastructure constraints as an issue.

9.3.5.3 Driver issues

Driver issues were scored by operators as highly as vehicle issues. The operators were asked to respond to the following driver issues (the scores are given at the end of each point):

- Training required to use a new system (4, 5, 4)
- Additional responsibility of leading a convoy/platoon (5, 5, 3)
- No driver reaction to a system failure (e.g. lack of detection due to previous loss of situation awareness or over-reliance on the system) (4, 5, 5)
- Inappropriate reaction to system failure (e.g. due to previously reduced workload/'underload' or insufficient expertise/training) (4, 5, 5)
- Inappropriate operation of the platooning system (e.g. due to insufficient expertise/training) (4, 5, 5)
- No reaction to the request to regain control (3, 5, 4)

Additional driver issues raised by the operators were:

- *Driver identifying when system needs to be over-ridden for safety, e.g. due to another road users actions.*
- *Training/Briefing to other road users on awareness of convoy and implications.*
- *Down skilling of drivers through the introduction of increased technology will have a negative impact when the same driver is on non-automated work.*
- *Fatigue through lack of interaction is of major concern.*

9.3.5.4 Other road user issues

The operators were asked for their views on a number of points relating to other road users. The points, and the operator's scores, are set out below.

- Distraction of other road users (5, 5, 4)
- Negative influence on driving behaviour of other road users (3, 5, 3)
- Obscuration of information for other road users (signs, markings, etc.) (5, 5, 4)
- Difficult to overtake (4, 3, 2)
- Prevents other road users from exiting the motorway at desired junction (4, 5, 3)
- Motivation of dangerous driving manoeuvres (e.g. pulling ahead of platoon/in the middle of platoon) (4, 5, 4)
- Increased road congestion (3, 3, 4)

The scores show the consideration given to the safety and security of other road users that would be affected by convoying/platooning.

Additional issues relating to other road users highlighted by the operators included:

- *Difficulty joining motorway*

and;

- *It is already difficult enough to educate car drivers on the behaviours of heavy goods vehicles, and the press repeatedly automatically assume the larger vehicle to be at fault in any incident, so the impact of the communications around this trial cannot be underestimated.*

9.3.5.5 Liability and insurance

The questionnaire asked for responses from the operators about various issues relating to liability and insurance. The questions and the operator's scores are set out below.

- Data handling (privacy) (3, 5, 2)
- Data handling (security) (3, 5, 2)
- Unclear definition of precise liability between lead driver, following driver, vehicle manufacturer and platooning/convoying system supplier (4, 5, 3)
- Increased insurance fees (4, 4, 4)
- Difficulty in obtaining insurance for a new technology (4, 3, 3)

The scores, between 2 and 5, indicate that operators have a range of views regarding the importance of liability and insurance issues for an on-road trial in the UK.

An additional comment raised was:

- *Who is liable in the event of a claim*

9.3.6 Q6. Can you think of any other potential issues for a UK road trial not listed above?

Two further potential issues for a UK road trial were raised by the operators. These were:

- *Public awareness*

and;

- *The generally low mileages in the UK, and our motorway infrastructure being used for commuting as well as trunking, means overall benefits may be low as opportunities to actually convoy/platoon for any length of time are limited.*

9.3.7 Q7. How do you think the reaction of other road users to a heavy vehicle convoy/platoon might differ depending on the traffic conditions (heavy/light) or on the type of road (3 lane, 2 lane, tunnel, bridge, etc.)?

Two comments were received from operators regarding this question. These were:

- *I think it will vary significantly and will critically depend on public awareness and education.*
- *As soon as we start making motorway activity more difficult for car users (aka voters) there will be a government resistance to any use of such vehicle groups. Early engagement with road safety groups such as IAM and AA/RAC may help them to understand the safety measures and therefore go on record supporting the trial. To try to run a convoy/platoon in heavy traffic would not be feasible and therefore would not be worth attempting.*

Both these comments relate to communication with the public regarding convoying/platooning. This is a key issue for consideration when developing a methodology for practical on-road trials in the UK.

9.3.8 Q8. Can you think of any other potential longer-term barriers to the implementation of convoying/platooning?

The only point made by operators in response to this question was regarding the '*cost and adoption'* of convoying/platooning.

Q9. What do you think is the single most important question that a road trial should answer?

Safety was the unanimous theme of the response from all three operators to this question.

Other points raised were ‘does the technology work’ and is it ‘practical’.

The operator responses were:

- *Safe use*
- *Does the technology work in practical everyday solutions and under everyday traffic conditions on congested roads rather than under sterile test track conditions and is it safe and will it work practically?*
- *The safety impact of running so close together – there is no fuel saving amount that is worth risking road safety for.*

9.3.9 Q10. Would you like to make any other comments?

Only one further comment was made by the operators. This related to the practicalities and costs of convoying/platooning. The comment was:

> *‘The grouping of e.g. 5 vehicles to run together will cause delays at both the start and end of journeys as drivers and vehicles wait to set off, and all arrive at a DC (distribution centre) at the same time, therefore this increased cost needs to be off set against any fuel savings seen’.*

9.4 Email and telephone follow up results

The original questionnaire distribution to operators was followed up by a simple email and telephone contact to try and elicit operator’s views on the benefits/disbenefits of convoying/platooning.

Three questions were asked. These were:

1) Their interest in HGV convoying/platooning
2) Their views on the benefits/disbenefits of HGV convoying/platooning, and
3) If they wished to be kept informed about project progress.

Responses to the email / telephone follow-up were received from fifteen operators. The results of the follow-up activity are presented below.

9.4.1 Interest in HGV convoying/platooning

The responses to this question indicated that operators do not currently consider HGV convoying/platooning a high priority. Five operators responded saying that they had an interest in convoying/platooning and ten operators indicated that it was not of interest at this particular time.

Reasons given for not currently being interested included:

- This something I not given much thought to, and to be honest I think it is a long way from happening.
- No thoughts on the matter.

- The company works to strict deadlines and therefore does not feel the concept would work for them as couldn't afford to be delayed by other vehicles in the convoy.
- As an operator would not be interested, as a vehicle driver it would help to improve run-times.
- The firm does not run long distances so not so relevant, however the concept is good and would reduce slow lorries overtaking and causing long tailbacks.
- Not interested in the idea.
- It is unrealistic, theoretically it is a great idea, however technically it isn't possible – the UK road network is designed for independent drivers and there would be a lot of technical issues before it would be safe or possible and then beyond that would be issues with legislation and whether this would ever be allowed on the roads.
- The business has very tight time restrictions and therefore does not believe platooning would suit them. Not beneficial to their business at the moment with the current platooning understanding/technologies.
- Can't see any benefits for the firm.
- As a business may not be relevant as they outsource their haulage and have their own vehicles (e.g. road gritters) to which platooning would not be relevant.
- Not interested at the moment.

Two broad themes can be drawn from the above comments.

1) The first is that convoying/platooning is not currently an issue for operators as it is not currently an option for them in the UK, or indeed anywhere else. It is viewed as a futuristic technology. Once the benefits of the technology are demonstrated then it will be given further consideration by operators.
2) The second is that the concept of convoying/platooning wouldn't suit their type of operation or the UK road network. The operator does not perceive any benefits of the technology and considers that it would not be a realistic option for them.

9.4.2 Benefits/disbenefits of convoying/platooning

There were a wide range of responses received from operators regarding the benefits and disbenefits of convoying/platooning.

Identified benefits included fuel savings, safety improvements and environmental benefits. Comments included;

- Fuel saving, reduced accidents.
- Benefits would include savings on fuel and carbon.
- Good for the environment to have set routes and set times. Can't think of any negatives, seems like a good idea.
- From an operational point of view, would be very interesting.

More comments were made expressing concerns and disbenefits. These included;

- Industry is very time sensitive – speeds and time may vary from firm to firm?
- Safety first.
- Safety concerns, would prefer to use active cruise control rather than platooning (prefer to control distance automatically but braking from the driver), not in favour of slip-streaming. This is the view from the engineer perspective, rather than the operational side.
- What would happen if the leading vehicle had an accident/hit a deer? How are the other vehicles affected and would they all have to stop?
- Concerns regarding how you remove vehicles from the middle of the convoy. What happens if the convoy is travelling a further distance and you are in the middle?
- There would be concerns from unions regarding whether this would reduce head counts and health and safety issues.
- Did not feel knowledgeable enough to comment.
- No idea, wouldn't like to comment as lack of knowledge.

These concerns can be grouped under four themes. The first is that the operational convoying/platooning wouldn't suit the businesses operation. The second theme is around safety and the practical operation of convoys/platoons. The third theme is around employee issues, whilst the fourth theme is the lack of knowledge on the topic which precluded a more considered response to the question.

9.4.3 Interest in ongoing progress with the project

The initial question in the email / telephone consultation was about current operator interest in HGV convoying/platooning. The responses indicated that the concept was not of current interest with five operators indicating that they had an interest and ten operators indicating that it was not of interest at this particular time.

The final question in the email / telephone consultation asked if people wished to be kept informed of progress with the project. For this question, the position was reversed, with eleven operators indicating that they would like to be kept informed of progress and only four operators indicating that they had no further interest in the project.

This indicates that operators are keeping an open mind and that their interest in the topic would increase once the technology has been proven in the UK.

9.5 Conclusions

The consultation with operators set out to provide an indication of likely demand/need for convoying/platooning.

From the responses to the consultation it is clear that the most important benefit to be gained is fuel savings. Fuel costs are approximately one-third of operating costs, so savings will appear immediately on the businesses' bottom line. Demonstration of fuel savings in the UK road trial will facilitate acceptance by operators of the technology and will provide a business case for the organisational and supply-chain changes required to maximise the benefits of the technology.

Safety issues were highlighted by many of the responses. There are two aspects to this consideration. Firstly, does the technology work so that convoying/platooning is demonstrated to be safe for all road users? Secondly, will it lead to an improvement in the overall UK road freight safety record?

It is clear that convoying/platooning will commence as a niche activity for the UK logistics industry. To maximise the success of any trial and future uptake of the technology a range of logistics operations should be investigated and the pros and cons of each considered.

Employee issues were not particularly raised by operators, though comments were made regarding deskilling and implementation in a unionised environment. The human factors involved in convoying/platooning will require consideration as part of the trial development.

Many of the responses highlighted the lack of knowledge on the issue, which precluded a more considered response to the questions. It is suggested that one strand of the communications made around any UK road trials should be to operators promoting the technology and its benefits.

The initial response received from operators to the questionnaire and further consultation was limited. This should not be a surprise as convoying/platooning is considered a futuristic technology. The interest shown by operators in being kept informed of trial progress demonstrates that once the technology is proven, and that its application to specific logistics operations is better understood, operators will give the topic greater consideration.

10 COMMERCIAL VIABILITY

For vehicle convoying or platooning to be commercially attractive for fleet operators, the in-use savings need to quickly exceed the upfront investment costs for the technology. Most logistics companies will expect financial payback within less than 2 years.

The factors that influence the commercial viability calculation are discussed below, along with results from high-level analysis of the potential payback period for vehicle convoying and platooning technology conducted by the project team. The chapter concludes with a brief discussion of the various business models that could be applied to provide the financial incentive required to encourage a wider roll-out of vehicle convoying and platooning technology.

It should be noted that this section does not include the benefits that might be possible by increasing driver's hours. This can be considered when the technology has proven that this benefit is attainable. Therefore, the estimates in this section may underestimate the benefits and payback period.

10.1 Factors influencing commercial viability

Many factors influence the business decision for logistics companies considering operating vehicle convoys or platoons.

The upfront investment costs will depend on the technology required to operate the vehicle convoy or platoon, and the installation of this technology into a fleet of vehicles. Additional training on a test track may be required to allow drivers to become familiar with the technology and the process for joining or leaving the convoy or platoon. There will also be annual costs associated with the required support services, such as for vehicle-to-vehicle communication, and any additional maintenance and servicing.

The in-use savings will depend on the fuel savings achieved while operating the vehicle convoy or platoon, the distances travelled by the vehicle convoy or platoon, the number of vehicles in the convoy or platoon, and the price of fuel and AdBlue (a diesel exhaust additive or diesel emissions additive) .

Annual insurance premiums for the fleet operator may be affected. Insurance premiums may increase if the insurance provider considers the technology to be of higher risk because it is new. Or insurance premiums may be lower if the insurer considers the technology to improve safety and reduce the risk of accidents.

The annual mileage of the vehicles will determine how quickly the additional investment is paid back through the in-use savings.

10.2 Estimating the financial payback period

For this feasibility study Ricardo has conducted a high level assessment of the financial payback period for vehicle convoying and vehicle platooning technologies. The analysis has been applied to a fleet of five 44t GVW Euro VI articulated trucks, each consisting of a 3-axle tractor and 3 axle curtain-sided semi-trailer. The assumed annual distance for each truck is 100,000 km, with average fuel consumption.

Three modes of operation were considered:

- For the baseline fleet, the vehicles were assumed to operate independently
- For the vehicle convoy mode, the five vehicles were assumed to travel in a cooperative partial automation convoy for a portion of their annual mileage
- For the vehicle platoon mode, the five vehicles were assumed to travel in a cooperative high automation platoon for a portion of their annual mileage

Assumptions regarding the add-on cost and the in-use savings for the vehicle convoy and platoon technologies were adapted from SARTRE [26]. A full list of the assumed input data for the assumptions, and an explanation of the calculations is provided in Appendix 4.

The portion of time spent in the vehicle convoy or platoon was varied, along with the assumed diesel fuel price, to gain understanding of the impact of these variables on the payback period. Results indicate that the financial payback period is highly dependent on the portion of the annual mileage spent in either vehicle convoy or platoon (see Figure 7), since the fuel saving benefits can only be realised when operating in the convoy or platoon.

This analysis suggests that for a fleet of five 44t vehicles with platooning technology to achieve financial payback within less than 2 years, over 60% of journey time would need to be conducted within the vehicle platoon, assuming the current diesel price of £1.10 per litre for fleet operators.

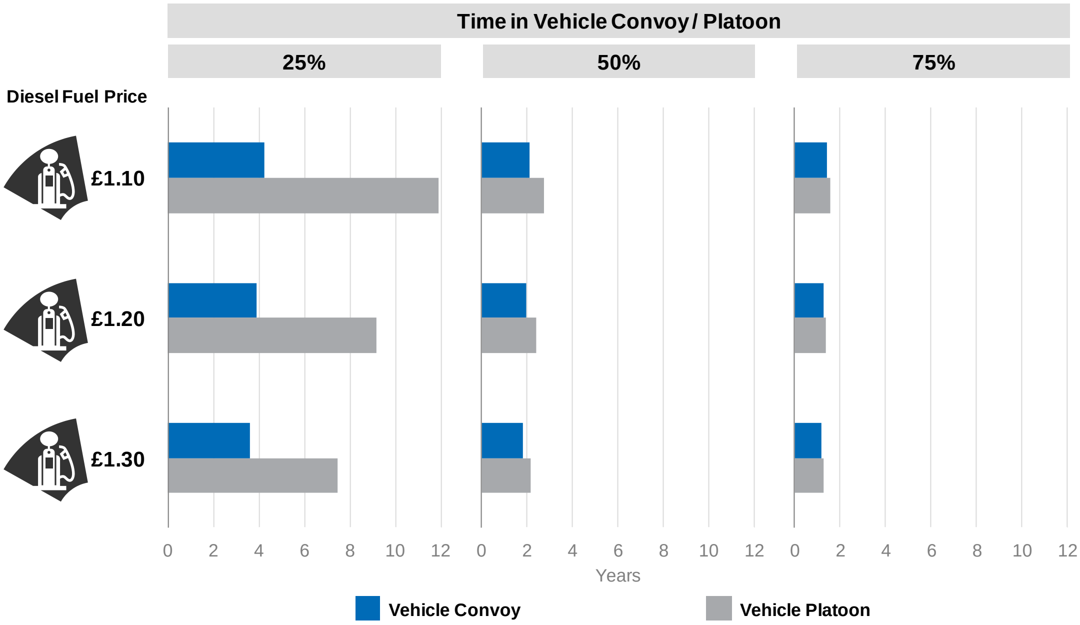

Figure 7: Comparison of financial payback periods for a fleet of five 44t vehicles operating in convoy or platoon

Analysis key assumptions: Euro VI trucks; annual mileage 100,000 km; for convoying 4% fuel saving for lead vehicle and 8% fuel saving for following vehicles; for platooning 8% fuel saving for lead vehicle and 14% fuel saving for following vehicles

10.3 Alternative business models

As technology for vehicle convoying or platooning is rolled out across a wider range of vehicles and fleet operators, alternative business models may be required to encourage commercial vehicle operators to lead convoys or platoons. The following business models could be applied to make vehicle platooning commercially attractive for a range of stakeholders, some of which were also considered in the SARTRE project [26][27]:

- Road trains for commercial vehicles

  A business model for a logistics company with a fleet of long haul trucks that can be operated in a cooperative vehicle convoy or platoon. The additional investment of the technology is paid back via the in-use fuel savings.

- Monthly subscription of road train usage

  A business model for cooperative vehicle convoys or platoons consisting of a mix of heavy-duty trucks and light-duty passenger cars operating along commuter routes. The benefit for the lead vehicle is less than the benefit for the following vehicles. Therefore, the following vehicles pay a subscription to the lead vehicle in the platoon on a prior subscription basis.

- Pay-as-you-go for joining the road train

  A business model for adhoc vehicle convoys or platoons consisting of a mix of heavy-duty trucks and light-duty passenger cars. The following vehicles pay a fee to the lead vehicle based on the distance travelled in the convoy or platoon.

- National road user charging

  A road user charging scheme could offer reduced rates when convoying or platooning.

10.4 References

[25] Eno Center for Transportation, “Preparing a Nation for Autonomous Vehicles”, October 2013

[26] Brännström, M., “Commercial Viability”, SARTRE Report, Deliverable D5.1 (Document Reference SARTRE_5_001_PU), 10 January 2013

[27] Rothoff, M., “SAFE ROAD TRAINS FOR ENVIRONMENT Business Opportunities”, SARTRE Workshop, Borås, Sweden, 12 September 2012

11 IMPACT ASSESSMENT

An impact assessment of the deployment of platoons or convoys on UK motorways requires numerous data inputs, which can be drawn from published research, stakeholder consultations, expert knowledge and, in particular, data recorded during any track or road trial. Should a trial be carried out, this would be required to provide quantitative or, where not possible, qualitative data in terms of costs and benefits relating to:

- Direct economic effects:
  - Fuel economy
  - Wear and tear on vehicles resulting from close running
  - Repair and maintenance costs
  - Effect on logistics schedules
  - Traffic efficiency
- Safety:
  - Interactions with other manually controlled vehicles
  - Safety 'proxy' measures (e.g. harsh braking events, lateral lane deviation, Time to Collision (TTC) monitoring
  - Assessment of HMI systems
  - Assessment of driver behaviour
  - Assessment of information provided to other road users
  - Monitoring and assessment of any risk mitigation measures implemented
- Environmental:
  - CO_2 emissions
- Effects related to trial participants' and other road users' acceptance of convoying/platooning

Other parameters such as air quality and congestion cannot be realistically measured in a trial.

To enable quantification of direct economic effects for the operators of vehicles involved in a platoon, the key aspect will be to record the fuel consumption over time of individual vehicles under variable conditions, particularly varying headway to the preceding vehicle and various numbers of vehicles involved in the platoon. In order to relate the fuel consumption to the driving conditions and to minimise confounding factors, other vehicle data should be recorded, e.g. vehicle speed, gear, pedal positions, brake pressure and environmental conditions. Measurement should be made via the vehicle CAN.

Platooning might potentially also impact on the wear of certain parts of the vehicles involved. The impact will likely be small and therefore difficult to detect. Should the intended duration of the road trial be long enough to facilitate detection, wear of parts like brakes and tyres should be recorded.

The effect on logistic schedules should also be considered, but this will depend on the extent to which the trial is integrated with the operator's activities. For example, if it is schedules which run from point A to point B and convoying can be implemented along the route in accordance with the trial design, then there should not be any negative time effects for the operator. If however, the group of vehicles taking part in the platoon originate from different locations along the route, vehicles which join part way through the journey may need to delay their journey so that they coincide; the impacts of time delays should be recorded if this type of schedule is included in any trial.

In terms of safety effects, it is widely recognised in research literature that platooning is likely to lead to significantly reduced accident rates, at least for equipped drivers, which would provide an immediate societal benefit. However, accurately quantifying these improvements based on a short period road trial is not feasible. As indirect measures, video recordings of the vehicles' surroundings might be useful to draw conclusions on the behaviour of other drivers in relation to the platoon, e.g. their lateral distance when passing, closing speeds when approaching and conflicts when entering or leaving the motorway. These recordings will also be useful to investigate potential safety related incidents occurring during the road trial. The immediate effects on the drivers of the vehicles in the platoon might be assessed by preparing video recordings of their behaviour and questionnaires/interviews into aspects like workload, experienced comfort, etc. This is to enable conclusions regarding safety aspects (capability of platooning drivers to react appropriately to incidents) as well as potential economic effects (Can other work be performed by platooning drivers? Can the platooning time be treated as resting time and allow extending driving periods?).

Vehicle data could also be used to collect data on parameters which can be related to safety; for example: lateral lane deviations, lowest TTC (Time To Collision). This information could be used to assess the frequency of safety relevant conditions, with this being used to compare the safety of the conditions with and without convoying/platooning. This data could be gathered from the convoying/platooning system data, but would also require the 'non-platoon' vehicles in the trial to be equipped with sensors to monitor and record lane positioning and TTC. Depending on the vehicles used for the trial, these sensors might already be fitted, but in any case access to the vehicle CAN carrying the pertinent data would be required.

The behaviour of drivers in the convoy/platoon should also be considered and monitoring their attention or level of disengagement with the driving task is an important factor to measure to ensure that over-reliance on the system does not take place.

CO_2 emissions should be assessed via established relationships with fuel consumption and these compared to emissions from the same journey (and load condition) produced by a vehicle not in a convoy/platoon.

The efficiency of the use of existing infrastructure is an important contributory factor in the cost benefit calculations. The following distance between the platooning vehicles shall therefore be recorded over time. The traffic capacity, i.e. vehicles per hour, of a stretch of road in free traffic is influenced by the following distance of vehicles, which is reduced in platoons. Also, in congested conditions platoons will contribute to a quicker utilisation of road space as the distance while accelerating from a halt is closely controlled, thereby preventing concertina effects. A reduction in congestion provides immediate and quantifiable economic benefits, in terms of fuel savings and work capacity lost waiting in traffic.

Wear of road infrastructure is, according to previous research projects, not influenced by platoons, but only depends on the number of vehicles passing, not their following distance. Recording of corresponding parameters is therefore considered unnecessary.

To assess the impact of platoons, the recorded quantitative data needs baseline data to be compared against. Wherever possible, corresponding baseline data, e.g. on fuel consumption, shall be gathered under comparable conditions but without involvement in a platoon. Furthermore, documentation of the preparation and execution of the trial is, of course, necessary to provide data e.g. on equipment costs and training costs.

In addition, qualitative data from participants in the trial should be recorded to monitor attitudes to the technologies before, during and after the trial. This could be done using questionnaires and/or with debrief sessions. The operator involved would also be in a position to offer valuable feedback on the industry opinion, and attitudes towards convoying/platooning. The views of the public should also be sought to gauge public perception and to provide feedback on acceptance. Targeting this group is difficult, but questionnaires for drivers using the convoy/platoon route at the same time or at nearby motorway services could provide a way to access public feedback.

11.1 Key issues for impact assessment

Significant data is required to inform an impact assessment on convoying/platooning of heavy vehicles on UK roads. Important data that is required can be highlighted as:

- Fuel economy. Access to real time fuel economy data via vehicle data (would require manufacturer participation) and paired comparison data for non-convoy/platoon vehicles. Sufficient repeated samples would be required to obtain robust data.
- Economic information which recorded the benefits and/or disbenefits of vehicle rescheduling to participate in road trains.
- Monitoring of vehicle wear and tear via regular photographic monitoring.
- Multiple video cameras (or observer vehicles) to assess interactions with other road users.
- Safety ‘proxy’ data to examine frequency/level of measures related to safe driving conditions. This would need to be recorded for convoy/platoon vehicles and non-platoon vehicles.
- The behaviour of drivers in the convoy/platoon should also be considered and monitoring their attention or level of disengagement with the driving task is an important factor to measure to ensure that over-reliance on the system does not take place.
- Qualitative data on the effectiveness of HMI systems (survey of convoy/platoon drivers), information and perception of other road users (survey of drivers encountering convoys/platoons on the road).
- Assessment of CO_2 emissions and comparison with identical non-convoy/platoon vehicles.

- Measurement on the differences in road utilisation (headway) between vehicles.
- Qualitative assessment of industry, public and technical expert views on attitudes and perception regarding the implementation of convoying/platooning technologies.
- Once the scale of the trial has been identified, requirements for data storage should be developed along with procedures to retrieve and store any trial data.

12 POLICY AND REGULATION

The main policy and regulation issues for a trial of convoying/platooning vehicles on UK roads relate to ensuring system safety and reliability, and ensuring that the law allows their use for testing. In the longer term, a clear legal framework is required to allow more extensive testing and deployment. The Government announced in their 2013 Autumn Statement that they will conduct a regulatory review of the issues around autonomous vehicles, with conclusions published by the end of 2014.

There is currently no legislation governing autonomous vehicles on UK roads. UK traffic regulations are based on the Geneva and Vienna Conventions on Road Traffic (1949 and 1968). As discussed in chapter 13, these contain several articles which state that the driver must be able to control his vehicle at all times. Several recent European research projects (e.g. APROSYS) recommended the need to update these articles to provide clarity to signatories so that national laws can be updated in line with available technologies.

In the United States, three states (Nevada, California and Florida) have enacted legislation to allow autonomous vehicles to be tested on public roads and the US National Highway Traffic Safety Administration (NHTSA) has published guidance on the rationale for autonomous vehicles and the need for a clear regulatory system to ensure their safe use.

In terms of a UK trial, there is no specific legislation for autonomous vehicles. Regulation 104 of the Road Vehicles (Construction and Use) Regulations 1986 requires that the driver remain in a position from which he is able to control the vehicle and see the road ahead at all times. In order to run a trial, permission should be sought from:

- Network operator – Highways Agency
- Regulator – Department for Transport
- Enforcement – Police, Driver and Vehicle Standards Agency (DVSA)

In all cases a detailed trial plan is likely to be required along with the requirement that a driver remains physically in the driver's seat ready to assume full control of the autonomously controlled vehicle. Test evidence relating to the performance of the system on a test track would likely be required to demonstrate safe operation.

The implications for wider introduction of autonomous convoys/platoons on the road relate to the extent to which "platooning time" can be considered as "working time" or "rest time" rather than "driving time" in the context of driver's hours limits. This change would enable more of the potential benefits of convoying/platooning to be realised, but could only be implemented in the longer term and would also be limited by the upper limit specified by the European Working Time Directive.

13 LIABILITY AND INSURANCE

In order to run a trial on UK roads, a convoy or platoon would require the appropriate insurance cover. The issues of insurance and liability are interlinked because the responsibility for vehicular control is dependent on the complexity and capability of the technologies implemented in any trial vehicles, and the extent to which a driver is in control of the vehicle.

The Vienna Convention on Road Traffic of the 8th November 1968 contains the following points which are relevant to a trial of convoying or platooning:

Article 8, Paragraph 1:

"Every moving vehicle or combination of vehicles shall have a driver."

Article 8, Paragraph 5:

"Every driver shall at all times be able to control his vehicle or to guide his animals."

Article 13 Paragraph 1:

"Every driver of a vehicle shall in all circumstances have his vehicle under control so as to be able to exercise due and proper care and to be at all times in a position to perform all manoeuvres required of him."

The purpose of the Vienna Convention (and the previous Geneva Convention of 1949) was to establish uniform traffic rules among the contracting parties to ensure safety on the road and for road users. However, the Vienna Convention was drawn up before the development of complex active safety systems.

While the wording of the Vienna Convention is read by some authorities to prevent the vehicle taking control of steering or braking, the initial principle of the Convention was to preserve safety; active systems (such as those used in convoying) offer the driver assistance to improve the level of safety and ultimately the driver is still able to take control should he so wish. Thus, systems which preserve or enhance safety could be argued to be in the spirit of the Vienna Convention, despite the functionality of some systems arguably being at odds with the precise wording of the Convention.

Some Advanced Driver Assistance Systems - ADAS (such as those that would be used in platooning) involve the transfer of liability away from the drivers in the following platoon vehicles to the driver of the lead vehicle. Liability is also transferred to the manufacturers of the technologies and components maintaining the platoon because the technology is entirely responsible for the linking of the vehicles. Consequently, the liability and therefore insurance issues are very closely tied to the type of technology used in the any trial and the complexity of the automation technology used (i.e. whether convoying or platooning is used) and to what degree control of the vehicle is surrendered to another driver.

Transfer of liability from a vehicle in the platoon to the lead vehicle is not however a clear cut situation under all circumstances. Take the situation where the lead vehicle has to do an emergency stop and all following vehicles are expected to receive the command to stop and maintain the distance to the vehicle in front. The stopping distance of a vehicle will depend on many factors including the state of the road, the weather conditions, the state of all road tyres and the condition of the braking system. If sensors on the vehicle could accurately predict the stopping distance then this information could be passed to the lead vehicle and use the braking performance of the “weakest link” vehicle in the platoon to bring the platoon to a safe stop. However, providing such information (which in terms of road and weather conditions will be changing dynamically) will be very difficult. Communicating information to each vehicle in the platoon about every other vehicle’s ability to stop could adapt the gap distances to minimise the overall safe stopping distance for the platoon. If the lead vehicle cannot stop as quickly as it is capable due to another vehicle in the platoon with relatively poor brakes then liability for the accident may no longer reside with the former.

It is known that there is no ‘off the shelf’ platooning system available at the present time and so it seems reasonable to assume that any trial would be based on convoying using established systems (e.g. modified LDWS, ACC) to electronically link vehicles. If this is the case, each vehicle would require a driver who was ‘ready to take control’ in each of the vehicles.

Investigations are ongoing, but it is likely that if an insurance company was providing coverage (rather than cover being provided by self-insurance) the insurance company would require a description of the trial in order to make a judgment of any change in risk from normal driving situation. Factors relating to the technology, the engagement of drivers in the platoon to the driving task, driver experience, and the time, location and scale of the trial are likely to be important to ensuring the vehicles can be appropriately insured. The actual vehicles used in the trial should be given a thorough test, especially from the point of view of braking ability, to minimise the risk of collisions within the platoon. It is likely that part of the testing would involve a simulated emergency stop instigated by the lead vehicle. It is considered very likely that any trial would use vehicle systems that are already fitted which allow convoying or a prototype system with similar functionality. Therefore, the drivers in all vehicles would be required to remain engaged with the driving task and could not, for example, read a book or some other secondary task. If the trial implements more advanced technologies, this may make it more difficult to obtain the required insurance cover because the insurer might be reasonably expected to require robust test information on the system performance so that the risk could be accurately assessed.

In the case that insurance companies would not provide insurance cover, another source of insurance would be required to run a road trial, either via the operator or another stakeholder.

13.1 Key issues for liability and insurance

In order to run a trial on UK roads, a convoy or platoon would require the appropriate insurance cover. The issues of insurance and liability are interlinked because the responsibility for vehicular control is dependent on the complexity and capability of the technologies implemented in any trial vehicles, and the extent to which a driver is in control of the vehicle.

It is known that there is no ‘off the shelf’ platooning system available at the present time and so it seems reasonable to assume that any trial would be based on

convoying using established systems (e.g. modified LDWS, ACC) to electronically link vehicles. If this is the case, each vehicle would require a driver who was ‘ready to take control’ in each of the vehicles.

It is likely that any insurance company covering vehicles involved in a trial would require sufficient information to allow the risks to be quantified. There is a possibility that the level of information provided by track testing would fall short of the evidence necessary for an insurance company to provide cover. In this case, self-insurance would be required, either by the vehicle operator or another trial stakeholder.

14 MIXED FLEETS

This project is focused on heavy trucks but some consideration must also be given to mixed fleets with platoons consisting not only of trucks but also of vans or passenger cars.

The market drivers for different types of vehicle are different, which will affect the timing of introduction for different automated vehicle technologies.

For truck fleets, platooning is most attractive for long haul trucks where the main market drivers are improved fuel economy and increased driving range.

For passenger cars and vans, the main market drivers for platooning are convenience and fuel economy. Although fuel economy is still a driver, it will not be as strong a driver as for trucks since fuel costs are a much smaller proportion of the running costs than it is for trucks. For passenger car journeys, platooning would be most useful for the longer distance journeys.

Cars joining mixed platoons will travel at the slower speed limit imposed on trucks. This is likely to limit the attractiveness of mixed platoons to many car drivers although some would still find it an attractive proposition since they would be benefiting from the convenience of being able to carry out other tasks during their journey, or would be able to just relax. Joining a car-only platoon would not have the disadvantage of the lower speed but they will not be as common as mixed platoons.

Many car manufacturers are developing automated driving systems. Although they have not announced their detailed plans for the introduction of such systems, demonstrations to date have been for systems for automated parking, stop/start traffic jam driving or solo motorway driving. There hasn't been a lot of discussion of car platooning. It is therefore likely that these other systems will be introduced commercially before any platooning systems.

14.1 Configuration of a mixed fleet platoon

When configuring a mixed fleet, it will be important to place the heavy trucks at the front of the platoon, and the cars behind. When the platoon is accelerating or braking, the performance of the trucks will generally be lower than that of the cars. This could lead to the platoon stretching out during accelerations, and an increased likelihood of a collision under heavy braking. Within these groups of vehicles, individual vehicles will of course have different performance levels, for example due to the amount of load it is carrying, or the state of the vehicle's tyres and suspension. Ideally, the exact performance of each vehicle would be evaluated and the vehicles would be ordered with the lowest performing vehicles nearer the front of the platoon. In practice, it can be difficult to determine accurately each vehicle's performance characteristics so it may be only possible to order the vehicles based on vehicle type.

In addition to the practical reasons mentioned above, psychologically, it will probably be uncomfortable for a car driver to find themselves with a truck in front and another truck behind at close distance.

When a new vehicle joins an existing platoon, the easiest way for this to happen is for the vehicle to approach the platoon from the rear and join at the back of the platoon. For the reasons listed above, a new vehicle might need to join in the middle of a platoon, so the platoon control system would have to be able to handle this. Joining in the middle of the platoon could also be more disruptive to other road users, although it is a manoeuvre which is likely to take a relatively short amount of time to complete. For trucks, it would be useful to know the weight of the load it was carrying so that the platoon could be configured appropriately.

14.2 Key issues for mixed fleets

Since the market drivers for passenger cars and vans to join platoons are not as compelling as those for trucks, the recommendation is that any trial should only include heavy trucks.

15 STAKEHOLDER INFORMATION

15.1 Background

Issues related to a road trial of convoying/platooning good vehicles on UK roads were investigated via consultation with approximately 100 stakeholders (see Appendix 6). A questionnaire (see Appendix 3) was emailed and follow-up contacts were made by email and phone.

15.2 Questionnaire responses

Of the questionnaires sent out, 17 (18%) were returned. This information was analysed to determine the relative importance of issues identified for a road trial and to allow stakeholders to suggest any appropriate additional issues and mitigation measures.

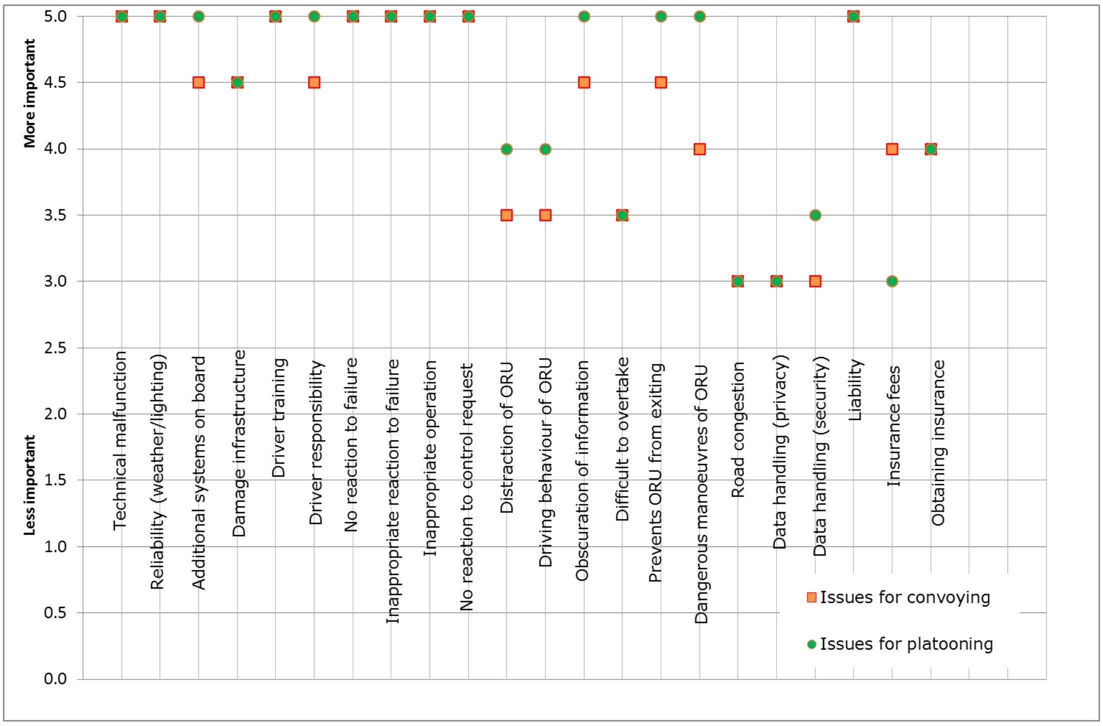

Figure 8: Median stakeholder rating (1-5) for importance of issues for a UK road trial of convoying/platooning heavy vehicles

This highlights that issues for platooning were generally considered more important than convoying. Of those issues with a median rating of 4 or less, these were issues related to the behaviour and distraction of other road users to the road train, the difficulty of overtaking, dangerous manoeuvres of other vehicles, congestion, data security and handing, and insurance.

However, there was significant variation in the qualitative rating given by the stakeholders. Figure 9 shows the variation and provides a general picture of agreement that the issues identified are ones which should be addressed in a road trial specification.

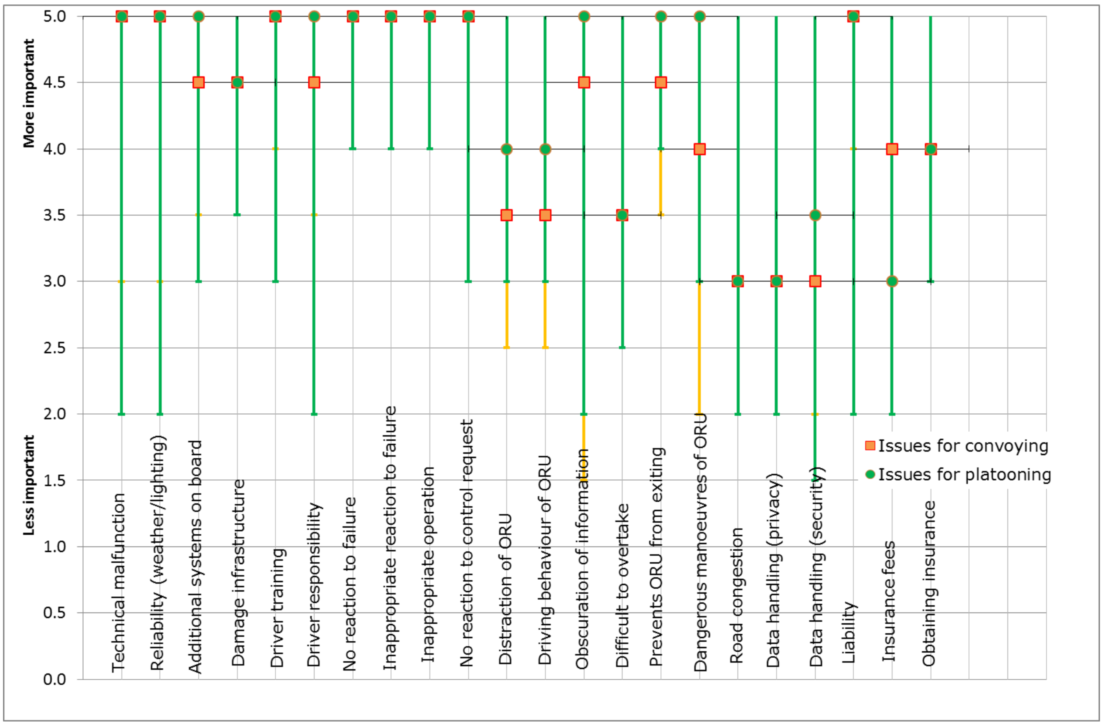

Figure 9: Median (and min/max) stakeholder rating (1-5) for importance of issues for a UK road trial of convoying/platooning heavy vehicles

15.3 Issues/mitigations identified by stakeholders

Consistently important issues for the trial were highlighted as:

- Safety – the risk of accident due to system failure or issue with the lead vehicle
- Communication with the public with respect to heavy goods vehicle convoys/platoons
- Managing interactions at motorway junctions
- The need for specific training for convoy/platoon drivers in general, in emergency situations and when driver re-engaging with driving task after autonomous functionality
- Ensuring appropriate consistency of braking efficiency and latency between one vehicle starting to brake and the next. Similarly, a need to ensure power/weight ratio and acceleration limits when changing speed and when maintaining speed on gradients.
- Ability to over-ride the autonomous control

- Training/briefing for other road users on awareness of convoy/platoon
- Issues for drivers were identified as:
  - Driver 'underload'
  - Making work environment more comfortable and easier; both a benefit and disbenefit since drivers may have an improved experience, yet fear being replaced by autonomous systems
- Possibility of dedicated lane for convoys/platoons
- Down skilling of drivers through the introduction of increased technology could have the potential to have a negative impact when same driver is on non-automated driving
- Motorists preparing to overtake a road train are likely to be unaware that the HGV in front is in a road train. This could be dangerous – particularly approaching an off-slip where a motorist wants to exit. To guard against this, motorist will need to (a) know that road trains exist, and (b) that the vehicle they're about to overtake is part of one. Depending on how road trains are intended to be formed and dissolved, there may be a requirement to dynamically identify/sign the rear vehicle.
- Difficulties obtaining insurance will limit the uptake of the technology and thereby reduce the benefits

Stakeholders commented that some responses would vary depending on other factors.

- Importance of data handling issues and insurance costs vary dependent on load type
- Interactions with other road users dependent on time of day and traffic conditions

Stakeholders also identified issues relating to the longer term implementation of convoying and platooning:

- Repair and maintenance contractors would need training in national coverage for breakdowns of such equipment and the impact on lease and warranty implications need to be understood
- Management of greater noise levels in residential areas
- The ability of a platoon/convoy to navigate road works safely and Emergency Traffic Managements would need to be considered. There may be a need to cross a solid line or follow non-standard methods of delineation e.g. cones barriers, road studs, temporary marking tapes (white) and temporary masking tapes (black).
- There would be similar issues with how systems would cope with active lane control on Smart Motorways (including hard shoulder running) and variable speed limits – e.g. what happens if an active speed limit is changed when a platoon/convoy is passing?
- Several closely following vehicles may affect the motorway's existing traffic control systems – particularly in slower moving traffic. Depending on what else might be happening on the network, higher occupancies on the MIDAS loops may

be misinterpreted resulting in the automatic setting of signals and signs incorrectly.

Additional issues highlighted by the stakeholders for consideration in a UK road trial were as follows:

- Measures or guidance to determine what happens when a convoy/platoon encounters a slower moving vehicle in lane 1. To avoid the road train's overtaking manoeuvre reducing the motorway down to a single carriageway for potentially a significant time / distance, the road train should not be permitted to overtake a vehicle unless it is travelling slower than a particular speed (e.g., 40-50mph). The actual value should be determined by the amount of time the overtaking manoeuvre takes. This will be affected by the size of the road train, the speed of the slower vehicle, and the speed of the road train. At a specific level of congestion this should cease to apply.
- Extensive vehicle data/monitoring will be necessary. In the event of an incident, unless the systems can demonstrate that the road train operated and responded as anticipated, the road train could well be blamed for something it was not responsible for. The politics of this situation will severely restrict further progress.

15.4 Stakeholder meeting

In addition to the questionnaire, each stakeholder was invited to a meeting/workshop that was held on 15th January 2014 at Harwell, Oxfordshire. The workshop was attended by representatives from a useful range of organisations, each able to contribute interesting experiences and knowledge. Notes and the attendees at the meeting are available in [28].

15.4.1 'Six thinking hats' (de Bono, 1985)

The main issues for a convoy/platoon trial were highlighted by stakeholders by using the principles of de Bono's (1985)[1] 'Six thinking hats' – where group members were instructed to adopt specific styles of thinking in timed sessions. This exercise highlighted a range of expectation, issues, benefits and emotions on the topic which were in line with the views of the project team and previous research. A summary of these can be found in [28].

15.4.2 What questions should the demonstrator project answer?

In the second session, participants were given a short time in which to think up the three questions that they would most like to see answered by an on-road trial. The combined output can be categorised and summarised as follows:

- Drivers
  - What do drivers like or dislike about the system?
  - What training and incentives should be given to drivers?

[1] de Bono, E. (1985). *Six Thinking Hats: An Essential Approach to Business Management*. Little, Brown, & Company. ISBN 0-316-17791-1

- Are drivers liable in case of accidents?
- Can the time in a platoon be counted as resting?
- How does the technology really change driver style?
- Will there be a detrimental effect on driver skill?
- How do non-members communicate with 'it'?
- Will drivers in following vehicles within the platoon suffer from motion sickness when the technology is driving their vehicle?
- Does it seem unusual?
- Driver boredom?

- Evaluation
  - What is the real world fuel saving?
  - What is the cost-benefit?
  - How would it affect the supply chain?
  - Will it reduce congestion?
  - Are there issues with noise?
  - What is the effect on air quality?
  - How much safer is a platoon truck than a non-platoon truck?
  - Where does the liability rest in the event of a collision?
  - How big are organisational disruptions in haulage companies?
  - What are benefits for the road operator?
  - What's "in it" for the operator of the leading lorry?
  - How to integrate with fleet management system?

- Safety
  - Can we trust the system?
  - Quantify road safety benefit – are convoys/platoons really safer?
  - What happens if drivers accidentally leave the platoon?
  - How will other drivers behave in the vicinity of platoons?
  - How do other road users react to platoons?
  - How to protect against criminal attacks (e.g. hacking spoofing)?

- Technology
  - Did the technology work?
  - Which next steps in technology development are possible?
  - Convoying to platooning – will drivers/companies accept new technologies?
  - How does the trial fit in the overall technology roadmap for traffic management?

  - How is the process of transfer of control managed, particularly in emergency situations?
  - How can technology be tested during Periodic Technical Inspection?
  - Will jammers (GPS or GSM) of passing vehicles affect the system?
  - Cybersecurity of technology

- Practicalities
  - Are narrower inside lanes possible in the future?
  - Would this result in increased road ‘rutting’?
  - Who will be involved?
  - What are the consequences for bridge structures?
  - Are enough situations being examined?
  - What thought will be given to public perception?

15.4.3 What would a successful trial look like?

In the third and final session, each group discussed the factors that they considered would contribute to a successful trial. All groups identified the importance of the trial fitting in the context of normal truck operations. Identifying an operator that is enthusiastic about the technology and runs truck operations that would benefit from platooning was recognised as key task. Similarly, all groups identified that the trial should increase in complexity, starting with track-based testing/training, followed by limited implementation in a small number of vehicles operating in unchallenging conditions before progressing to more wide-ranging trials.

15.5 Key issues from the stakeholder consultation

15.5.1 Public perception

An issue that concerned all groups participating in the workshop was the threat of negative publicity – firstly, through an unforeseen collision but secondly, through general misconceptions about the technology and plans for its implementations. The likelihood of the former can be mitigated by rigorous planning and testing; however, the latter may require a more pro-active public engagement approach to promote the benefits that research suggests the use of this technology could bring. Associated with this is the behaviour of other road users in the vicinity of road trains. Groups discussed the requirement to ensure that other road users can identify that vehicles are electronically connected as a road train and are aware of the dimensions and likely behaviour of such a platoon.

A related issue is engagement with drivers and haulage companies; co-operation with which (in the prevailing tough economic climate) will be essential to deliver a successful trial. It will be important to ensure that drivers and their employers recognise the potential benefits and can be persuaded to participate in any proposed trial in a manner that does not cause them to experience any negative consequences and potentially enables them to enjoy positive outcomes from participation.

15.5.2 Potential benefits

Workshop participants recognised that there are a number of benefits from pursuing this technology. The SARTRE project provides strong evidence that fuel efficiency will improve whilst support from the vehicle systems in guidance of the vehicle should lead to enhanced safety. Furthermore, increased vehicle density may improve network capacity. However, the group discussions also recognised that these predicted benefits must be validated in real world, operational conditions before the technology will be adopted in the industry more widely. There was also recognition that a successful trial may support UK businesses in making more efficient deliveries and in the use of road train (and associated) technologies.

15.5.3 A successful trial

The groups identified a wide range of topics that could be considered in the context of UK on-road trial of road train technology. However, all groups recognised that a phased approach will be required with road trains being evaluated in increasingly complex situations as the project proceeds. Again, a requirement to engage with the public through the course of the trials programme was noted. In designing the trial phases, it will be important to determine the critical questions that the study is to address and ensure that the proposed study will be able to answer those questions satisfactorily once trialling is complete.

15.6 References

[28] Reed, N., Seidl, M., "Solutions Workshop on Road Trains, Record of Meeting", January 2014

16 CONCLUSIONS

In order to have a robust understanding of the benefits and issues of convoying/platooning for heavy vehicles, a road trial is the only practical way to collect or validate all the required information. This would generate information to enable the evaluation of appropriate policies with respect to semi-autonomous or autonomous platooning. Undertaking such a trial would allow the possibility of assessing convoying/platooning technologies in a scientific manner, informing and encouraging effective systems, rather than relying on technology development to dictate types of system and their operator uptake.

This report examines the feasibility issues for of a road trial and the main conclusions can be summarised as follows:

- Convoying and platooning systems are both technically feasible; convoying with vehicle to vehicle communication has been demonstrated and the fundamental technologies which form the basis of the regulation of following distance and lane keeping exist. Convoying (where drivers remain 'in control' of the vehicle) could be implemented in the short term (1-2 years) and platooning (where drivers could disengage to a greater extent from the immediate driving task) in the medium term (3-5 years).
- However, there is no commercial convoying/platooning system currently available and any system used in a trial would not be a market-ready system. Indeed, it is envisaged that considerable development and testing would be required to produce a system for use in a road trial, even if it is based on an existing prototype platooning system. The likely need to access the CAN bus and manage the interaction of other safety systems means that the involvement of an OEM and their suppliers would be required. Significant modifications to the power steering system would also be required to enable lane-keeping functionality desirable to automate lateral control at small headways. Furthermore, an HMI system might also be necessary to provide information between participating vehicles.
- A trial would provide the opportunity to directly measure the benefits that might be realised in terms of fuel and emissions economy and further investigate commercial viability. A phased trial could also provide information on the interaction between trial vehicles and other road traffic, allow investigation of public perceptions to the technologies, how to provide information to other road users, and allow investigation of how the driving task within the platoon is affected. In the longer term, the benefits for driver's hours might also be assessed.
- In order to collect statistically significant data for an impact assessment, the effect of variations encountered during daily haulage operations should be compensated for. These variations could include load, weather, seasons, driver and routes, and these are known to have significant effects on, for example, fuel economy. Achieving statistically meaningful results in light of these variations will be an important factor in determining the overall size of the trial in terms of the number of vehicles/drivers and the overall duration of the trial.

- The practicalities of collecting data need to be considered when identifying what will be included in an impact assessment. For example, it is unlikely that any trial will be able to collect enough data for a full assessment of the impacts of platooning on road safety. For this reason other parameters, known as proxies, need to be identified which relate to, but are not a direct measure of, road safety. If the amount of data required to reach statistical significance is great, consideration should be given to a road trial to provide information on the issues within the available timescale and budget constraints.
- Road trial feasibility is heavily dependent on a range of parameters which are as yet difficult to define, including:
  - system functionality (the capability and performance of the prototype system);
  - the number of vehicles in the convoy/platoon; and
  - the location and timing of any trial.
- Any trial should:
  - use the same vehicle type so that mismatches in acceleration and braking performance can be minimised (although it is recognised that vehicle load will have a significant effect on this)
  - be limited (initially at least) to a maximum of five vehicles in any one convoy/platoon, in line with previous successful demonstrations so that interactions with infrastructure and the impacts on other traffic could be minimised;
  - exclude cars, vans, tankers and any vehicles with hazardous loads;
  - avoid network pinch-points, tolls, bridges, road works, and areas with lane width restrictions;
  - not take place in extreme weather conditions (e.g. ice, snow), but include commonly occurring conditions (e.g. day/night, rain); and
  - obtain the necessary legal, insurance and highway operations approvals for the use of the technology.
- All drivers involved in any trial must be appropriately trained in the prototype system being used, including normal operation, interaction with other traffic (expected and unexpected) and appropriate emergency procedures.
- Any trial should be run using a phased approach with a comprehensive stepwise review of all risks (using a risk register) and should consist of:
  - System development of the on-vehicle systems as well as the off-vehicle systems as these are not available commercially at the moment
    - Initially carried out on test tracks.
    - Subsequently on public motorways once criteria for reliable and safe operation in expected conditions have been met.
  - Track tests to assess the overall system performance and to train drivers in the technologies and system function, and including:
    - tests involving greater number of vehicles.
    - connect and disconnect procedures “in use” cases (e.g. other vehicles entering the convoy/platoon etc.).

- Road tests on an appropriate stretch of UK motorway in conditions of very low traffic flow, likely to be best achieved by night-time testing.
- As previous step, but using runs which are part of normal haulage operations. First trials in this stage should investigate the best effective way to notify other road users of the vehicles in the trial.
- As previous step, but using runs which are part of normal haulage operations in slightly greater traffic flow conditions and more complex motorway road layouts.

* Using the best information available at the time of writing, a trial of convoying or platooning technologies on an appropriate UK motorway is deemed feasible. However, the safety and key issues should be reviewed at each stage to ensure that the mitigation measures used are appropriate and effective.
* The initial response received from operators to the questionnaire and further consultation was limited and those that provided feedback did not consider convoying/platooning as a high priority. However, it was apparent that the benefits that might be achieved were not widely known. The interest shown by operators in being kept informed of trial progress demonstrates that once the technology is proven, and that its application to specific logistics operations is better understood, operators will give the topic greater consideration.
* The UK has implemented the 1949 Geneva Convention on road traffic in a way that would permit a trial in which control is temporarily ceded to the vehicle, by the driver, as long as he is able to retake control. Changes to the existing law would be unnecessary.
* Insurance cover for any trial – depending on the technology used - is likely to require detailed information on the trial design (scope, size, location, prevailing weather and traffic conditions) and access to information from pre-trial testing before cover can be put in place. If insurance cover is not provided by an insurance company, any trial would need to rely on self-insurance.
* A range of parameters have been identified which should be collected as part of any trial. These will be defined further in the work specification and the types and size of data collected will depend on the specific design aspects of each trial phase and the overall size of the trial.

APPENDIX 1 GLOSSARY

The following terminology and acronyms are used within the document.

ABS	Anti-lock braking system
ACC	Adaptive Cruise Control
AEB	Autonomous Emergency Braking
BASt	Bundesanstalt für Straßenwesen
CACC	Cooperative Adaptive Cruise Control
CAN	Controller Area Network
CPC	Driver Certificate of Professional Competence
EPAS	Electric Power Assisted System
ESC	Electronic Stability Control
HGV	Heavy Goods Vehicle
HMI	Human Machine Interface
LDW	Land Departure Warning
LKA	Lane Keeping Assist
NHTSA	National Highway Traffic Safety Administration
OEM	Original Equipment Manufacturer / Vehicle manufacturer
SAE	Society of Automotive Engineers
TTC	Time To Collision
V2V	Vehicle to Vehicle communication
VOSA	Vehicle and Operator Services Agency

APPENDIX 2 BACKGROUND

Research on the application of advanced vehicle technologies for vehicle platooning has been carried out in Europe, the United States and Japan. This chapter provides an introduction to several current and past projects relevant to this feasibility study on a road trial of vehicle platooning / convoying technology.

Appendix 2A Heavy Duty Vehicle Demonstration Projects in Europe

COMPANION
Cooperative mobility solutions for supervised platooning

Website:	www.companion-project.eu
Period:	2013 – 2016
Budget:	€ 5.4 million / € 3.4 million EC funding EU FP7 research project
Project Partners:	Scania (project coordinator), Volkswagen Group Research, Stockholm's Royal Institute of Technology, (KTH), Oldenburger Institut für Informatik (OFFIS), IDIADA Automotive Technology, Science [&]Corporation (S[&]T) and Transportes Cerezuela

The COMPANION project builds in previous R&D projects on vehicle platooning, including SCANIA's in-house research [29]. This three-year project aims to identify how the platooning concept can be practically applied in daily transport operations. Project activities include:

- Development of a real-time coordination system for creating, maintaining and dissolving platoons
- Development of an integrated information system for presenting relevant information to the vehicle drivers
- Consideration of the European regulations that would permit shorter distances between trucks in the platoon
- Demonstration of the COMPANION system by trialling a vehicle platoon on Spanish roads in the autumn of 2016

SARTRE

Safe Road Trains for the Environment

Website:	www.sartre-project.eu
Period:	2009 - 2012
Budget:	€ 6.4 million total EU FP7 research project
Project Partners:	Ricardo (coordinator), Volvo Cars, Volvo Technology, IDIADA, Tecnalia Robotiker, SP and IKA

This EU FP7 research project delivered a prototype vehicle platoon system using two heavy goods vehicles and three passenger cars [30] (Figure 16.1). The manually driven lead truck was followed by one truck and three Volvo cars (S60, V60 and XC60). All the following vehicles were driven autonomously using real-time information to follow the movements of the lead vehicle while simultaneously coordinating their actions with each other, travelling at speeds up to 90 km/h. The project estimated a potential 10-20% energy saving compared to conventional road transportation.

Figure 16.1: SARTRE Road Train

HAVEit
Highly Automated Vehicles for Intelligent Transport

Website:	www.haveit-eu.org
Period:	February 2008 – June 2011
Budget:	€ 27.5 million / € 17 million EC funding EU FP7 research project
Project Partners:	17 project partners, including Continental (project coordinator), Volkswagen and Volvo Technology

The European HAVEit project [31] developed, validated and demonstrated important intermediate steps towards highly automated driving, including:

- Technologies for situation awareness (driving scene, vehicle state, driver state)
- Suitable HMI concept
- Elaborate safe vehicle architecture

The new capability was demonstrated in seven vehicles ranging from passenger cars to trucks and buses.

KONVOI
Development and examination of the application of electronically coupled truck convoys on highways

Website:	Not currently available
Period:	May 2005 – May 2009
Budget:	Funded by German Federal Ministry of Economics and Technology (BMWi)
Project Partners:	RWTH Aachen University institutes, MAN Nutzfahrzeuge AG and Wabco Development GmbH

The KONVOI project, sponsored by the German government, adapted four heavy-duty commercial vehicles to investigate the effects of truck platoons in real traffic [32]. The first vehicle in the platoon was controlled manually, while the other three vehicles were electronically coupled to the lead vehicle to follow automatically at a distance of 10 metres between vehicles.

The interdisciplinary research team worked closely with freight-forwarding companies, public authorities and a vocational school for professional truck drivers during the development of the vehicle platoon system. Following several phases of functional and verification testing on test tracks, the KONVOI system was trialled on the German motorways A1, A44 and A46 between March and May 2009. The special permit for the automatic operation of the KONVOI vehicles on the public roads required an escort of a BF3 safety car and a motorway police car.

PROMOTE CHAUFFEUR I and PROMOTE CHAUFFEUR II

Website:	n/a
Period:	January 2000 – May 2003
Budget:	EU FP4 and FP5 research projects
Project Partners:	DaimlerChrysler AG, Renault Recherche, Renault Trucks, IVECO, Centro Ricerche Fiat, WABCO, Bosch, ZF Lenksysteme, Central Research Laboratories, TÜV Rheinland, PTV, CSST, Clifford, Chance & Pünder

PROMOTE CHAUFFEUR developed an "electronic tow-bar" applied to DaimlerChrysler and IVECO trucks. The electronic coupling enabled the second truck to follow the first truck while safely maintaining a close (6-12m) distance between the trucks [33] [34]. The technology was a first step towards creating vehicle platoons. In PROMOTE CHAUFFEUR II the technology was extended to include three trucks and to improve the "flexibility" of the electronic tow-bar system. Typical vehicle platooning manoeuvres were demonstrated on a test track.

Appendix 2B Heavy Duty Vehicle Demonstration Projects in USA

EARP BAA 2013 – Topic 1 D: Partial Automation for Truck Platooning

Website:	
Period:	October 2013 – December 2016
Budget:	
Project Partners:	California Department of Transportation (Caltrans) University of California PATH Program Volvo Technology Americas Cambridge Systematics, Inc. Los Angeles Metropolitan Transportation Agency (LA Metro) {cost sharing} Gateway Cities Council of Governments (COG) Peloton Technology {unfunded}

This project is the most recent autonomous technology project funded by the California PATH program [35]. The project team will be applying cooperative adaptive cruise control (CACC) with DSRC technology to three tractor-trailer trucks. The project combines U.S. and European truck platoon experience, and will work closely with local stakeholders on deployment strategies for operating the vehicle platoon on I-710 in Los Angeles. I-710 is 23 miles long, running north from Long Beach to the I-10. Since it is the most direct route from the Port of Long Beach and the railway yards in Vernon and East Los Angeles, the I-710 it has the heaviest volume of truck traffic of any interstate in the USA.

Heavy Truck Cooperative Adaptive Cruise Control: Evaluation, Testing, and Stakeholder Engagement for Near Term Deployment

Website:	
Period:	2013-2016
Budget:	$ 1 million funding + cost share FHWA Exploratory Advanced Research Program Topic 1D: Partial Automation for Truck Platooning
Project Partners:	Auburn University; Peloton; Peterbilt Trucks; Meritor WABCO; American Transportation Research Institute (ATA, TMC); Bishop Consulting

This project is investigating the practical issues associated with implementing CACC technology in a truck fleet [36] [37]. The goal is to increase traffic flow and save fuel. The project is using the Peloton solution – partial automation with integrated vehicle-to-vehicle communication and adaptive cruise control. A two-truck platoon will be tested on Auburn's 1.7 mile test track.

Appendix 2C Heavy Duty Vehicle Demonstration Projects in Japan

Automated Truck Platoon within Energy ITS Project

Website:	n/a
Period:	2008 – 2013
Budget:	¥ 4.4 billion total, ¥ 3.9 billion for automated truck platoon Ministry of Economy, Trade and Industry (METI) and New Energy and Industrial Technology Development Organization (NEDO)
Project Partners:	Japan Automobile Research Institute (JARI), Japanese universities

The Japanese Automated Truck Platoon demonstrated a fully automated truck platoon consisting of three heavy duty trucks and one light duty truck, travelling at speeds up to 80 km/h with a 4 metre gap between vehicles, on the AIST test track [38]. This demonstration project utilised lane marker detection technologies, radar, laser scanning and inter-vehicle communications.

Appendix 2D Light Duty Vehicle Demonstration Projects

Volvo Car Group has announced plans for the world's first large-scale autonomous driving pilot project [39]. The "Drive Me – Self-driving cars for sustainable mobility" project is a joint initiative between Volvo Car Group, the Swedish Transport Administration, the Swedish Transport Agency, Lindholmen Science Park and the City of Gothenburg. The pilot will involve 100 Volvo self-driving cars operating on 50 km of selected roads around Gothenburg. The project will commence in 2014, with the first cars on the road in 2017.

Milton Keynes is planning to introduce fully autonomous pod-type vehicles that will ferry passengers around designated pathways in the city centre, as part of a driverless car trial sponsored by the UK government [40]. An initial batch of 20 driver-operated pods, capable of carrying two passengers, will enter service in 2015, with 100 fully autonomous pods scheduled for 2017.

AdaptIVe (Automated Driving Application & Technologies for Intelligent Vehicles) is the latest European project to progress the integration of technologies for varying levels of automation [41]. This € 25 million project (€ 14.3m EU funding) will run from January 2014 to June 2017. Volkswagen is leading the 26 partner consortium which consists of vehicle manufacturers, Tier 1 suppliers, universities and research centres from 8 member states.

The Support Action for Vehicle and Road Automation (VRA) (www.vra-net.eu) is another EU FP7 project, with the aim of creating a collaboration network of experts and stakeholders working on deployment of automated vehicles and its related infrastructure. The project began in July 2013 and will complete in December 2016. ERTICO – ITS Europe is the project coordinator.

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APPENDIX 3 QUESTIONNAIRE

A Feasibility Study for Heavy Vehicle Platoons
on UK Roads

Background and aims

The UK Department for Transport (DfT) has commissioned a feasibility study on the potential for conducting a heavy goods vehicle convoy or platoon trial on UK roads. This study is assessing the feasibility, operational aspects and measurement metrics associated with conducting a trial, with a focus on goods vehicles as there are recognised economic benefits of allowing these vehicles to travel close together.

The project team is seeking the views of stakeholders and would be grateful if you could answer the following questions as completely as possible.

We would also like to invite you to a workshop to discuss your answers in greater detail, currently planned for 15th or 16th January 2014. Please indicate your intention to participate by emailing roadtrain@trl.co.uk.

Definitions and response instructions

The questions in this survey should be considered based on two different scenarios for technologies for heavy vehicles: ‘convoying’ and ‘platooning’.

Convoying means the formation of groups of heavy vehicles following a manually controlled lead vehicle using technologies to assist the driver. Adaptive Cruise Control (ACC) systems combined with Lane Keeping Assist (LKA) systems provide automated control of the vehicle speed as well as vehicle steering while cruising at motorway speeds. The drivers in the convoy are required to closely supervise the automatic systems and be ready to take over “instantly”, and are still actively in control of their vehicle.

Platooning means the formation of groups of heavy vehicles following a lead vehicle using technologies so that the following vehicles are controlling themselves. A driver in the platoon is not required to actively control the vehicle. The lead vehicle is manually controlled by a professionally trained driver. When a vehicle is platooning, the automated system will control the distance to the preceding vehicle by automatically controlling the engine, gearbox and the brakes. It will also automatically control the steering so that the vehicle follows the preceding vehicle. The driver must, however, be available to take over control at short notice, usually within a few seconds. It should be noted that platooning technologies would only be enabled by the driver at certain specific times and under certain conditions, and that the rest of the time, the vehicle would be driven manually.

In answering the questions, it should be borne in mind that the road trial would take place on the motorway network, would not involve transport of dangerous goods and that the likely size of the convoy/platoon would be around five vehicles of standard dimensions.

Please provide your response to the questions, rate the items where indicated, and email the completed questionnaire to roadtrain@trl.co.uk as soon as possible before the intended stakeholder workshop.

Thank you for your participation

Questions

1. In your opinion, how important are the following potential benefits of convoys or platoons?

Please use the following scale for your response and overwrite the X with your rating:

	Not important	←	→	Very important		Don't know
Convoys	1	2	3	4	5	9
Platoons	1	2	3	4	5	9

If you think a potential benefit listed below will not occur, for example if you think insurance fees will not decrease but stay the same or even increase, please select 1 'Not important'

Vehicle:

- Improved fuel economy[2] Convoy: X
  Platoon: X
- Reduced vehicle maintenance costs Convoy: X
  Platoon: X
- Can you think of other potential benefits related to the vehicle?

Convoy: *Please type response here*	Platoon: *Please type response here*

Infrastructure:

- More efficient use of available infrastructure (space) Convoy: X
  Platoon: X
- Can you think of other potential benefits related to the infrastructure?

Convoy: *Please type response here*	Platoon: *Please type response here*

Driver and/or other road users:

- Reduced accident rate Convoy: X
  Platoon: X
- Reduced accident severity Convoy: X
  Platoon: X
- Reduced driver workload Convoy: X
  Platoon: X

[2] A previous research project, SARTRE, measured reductions in fuel consumption of 8% for the lead truck and 16% on first following truck

- Increased comfort Convoy: X
  Platoon: X

- Possibility of increased driving range due to extending the allowable daily driving time Convoy: X
  Platoon: X

- Reduced road congestion Convoy: X
  Platoon: X

- Can you think of other potential benefits related to the drivers or other road users?

Convoy:	Platoon:
Please type response here	*Please type response here*

Liability and insurance:

- Reduced insurance fees Convoy: X
  Platoon: X

- Can you think of other potential benefits related to liability and insurance?

Convoy:	Platoon:
Please type response here	*Please type response here*

2. Can you think of any other potential benefits not listed above?

Convoy:	Platoon:
Please type response here	*Please type response here*

3. Which fleet operator / logistics / haulage company would be most suited, and least suited, to be involved in a road trial, and what are the important factors to consider?

Please type response here

4. Which parts of the motorway network would be most suitable, and least suitable, for a road trial, and what are the important factors to consider?

Please type response here

5. In your opinion, how important is it to mitigate the following potential issues <u>for a UK road trial</u>?

Please use the following scale for your response and overwrite the X with your rating:

	Not important ← → Very important					Don't know
Convoys	1	2	3	4	5	9
Platoons	1	2	3	4	5	9

Vehicle:

- Technical malfunction (general vehicle components, platooning related hardware components or software) Convoy: X Platoon: X

- System reliability in adverse weather or lighting Convoy: X Platoon: X conditions

- Additional system fitted to the vehicle to enable Convoy: X Platoon: X Platooning

- Can you think of other potential issues related to the vehicle?

Convoy: *Please type response here*	Platoon: *Please type response here*

Infrastructure:

- Causing damage to infrastructure (e.g. exceeding bridge loads) Convoy: X Platoon: X

- Can you think of other potential issues related to the infrastructure?

Convoy: *Please type response here*	Platoon: *Please type response here*

Drivers:

- Training required to use a new system Convoy: X Platoon: X

- Additional responsibility of leading a convoy/platoon Convoy: X Platoon: X

- No driver reaction to a system failure (e.g. lack of detection due to previous loss of situation awareness or over-reliance on the system) Convoy: X Platoon: X

- Inappropriate reaction to system failure (e.g. due to previously reduced workload/underload or insufficient expertise/training) Convoy: X Platoon: X

- Inappropriate operation of the platooning system (e.g. due to insufficient expertise/training) Convoy: X Platoon: X

- No reaction to the request to regain control Convoy: X Platoon: X

- Can you think of other potential issues related to the drivers?

Convoy: Please type response here	Platoon: Please type response here

Other road users:

- Distraction of other road users Convoy: X
  Platoon: X

- Negative influence on driving behaviour of other Convoy: X
  Platoon: X
  road users

- Obscuration of information for other road users Convoy: X
  Platoon: X
  (signs, markings, etc.)

- Difficult to overtake
  Convoy: X Platoon: X

- Prevents other road users from exiting the motorway Convoy: X Platoon: X
  at desired junction

- Motivation of dangerous driving manoeuvres (e.g. pulling Convoy: X
  Platoon: X
  ahead of platoon/in the middle of platoon)

- Increased road congestion
  Convoy: X Platoon: X

- Can you think of other potential issues related to other road users?

Convoy: Please type response here	Platoon: Please type response here

Liability and insurance:

- Data handling (privacy) Convoy: X
  Platoon: X

- Data handling (security) Convoy: X
  Platoon: X

- Unclear definition of precise liability between: Convoy: X
  Platoon: X
  lead driver, following driver, vehicle manufacturer and
  platooning/convoying system supplier

- Increased insurance fees Convoy: X
  Platoon: X

- Difficulty in obtaining insurance for a new technology Convoy: X Platoon: X

- Can you think of other potential issues related to liability and insurance?

Convoy:	Platoon:
Please type response here	*Please type response here*

6. Can you think of any other potential issues <u>for a UK road trial</u> not listed above?

Convoy:	Platoon:
Please type response here	*Please type response here*

7. How do you think the reaction of other road users to a heavy vehicle convoy/platoon might differ depending on the traffic conditions (heavy / light) or on the type of road (3 lane, 2 lane, tunnel, bridge, etc.)?

Please type response here

8. Can you think of any other potential longer-term barriers to the implementation of convoying/platooning?

Convoy:	Platoon:
Please type response here	*Please type response here*

9. What do you think is the single most important question that a road trial should answer?

Please type response here

10. Would you like to make any other comments?

Please type response here

Thank you for your participation – your input is very much appreciated

APPENDIX 4 SUPPORT MATERIAL FOR COMMERCIAL VIABILITY ASSESSMENT

Methodology

The financial payback period, in years, can be calculated by dividing the upfront additional investment by the reduction in annual operating costs.

The additional investment includes:

- The higher retail price for a vehicle equipped for vehicle convoying or platooning, resulting from the additional components required
- Additional driver training on a test track for the fleet drivers to become familiar with forming and driving in a vehicle convoy or platoon

Changes to the annual operating costs will result from:

- Addition of vehicle-to-vehicle communication services required for vehicle platooning
- Additional maintenance, servicing and vehicle testing that may be required
- Changes to the annual insurance premium for the fleet operator due to the introduction of vehicle convoying or platooning technology
- Changes to vehicle excise duty
- Fuel consumption and AdBlue consumption savings

Since the in-use savings for the lead vehicle are different to the in-use savings for the following vehicles, Ricardo applied the commercial viability assessment to a small fleet of five vehicles.

Description of the scenario modes

The analysis considered three modes for fleet operation – **baseline fleet**, **vehicle convoy** and **vehicle platoon**.

	Baseline Fleet	Vehicle Convoy	Vehicle Platoon
BASt Level	**Driver Only**	**Partial Automation**	**High Automation**
Description	Vehicles driven independently - not part of a convoy or platoon	Vehicles follow in convoy. Each driver permanently monitors the system, and is able to take over at any time	Full platooning capability

Input Assumptions

Baseline Vehicle Assumptions			
Vehicle Type	[-]	44t GVW Articulated Vehicle	
Tractor Type	[-]	3 axle tractor	
Trailer Type	[-]	3 axle curtain sided semi trailer	
Euro emissions limit	[-]	Euro VI	
Tractor Price	[£]	90,000	
Trailer Price	[£]	25,000	
Vehicle First Life[3]	[years]	5	
Annual mileage	[km/year]	100,000	
Fuel Consumption	[mpg]	8.0	
Fuel Consumption	[L/100km]	35.3	
AdBlue Consumption	[L/100km]	1.1	
Driver Training[4]	[£]	250	Per driver
Vehicle Excise Duty	[£/year]	1,200	Per vehicle
Annual Insurance	[£/year]	3,000	Per vehicle
Total Annual Maintenance	[£/year]	15,000	Per vehicle – tractor and trailer
Number of vehicles in fleet	[-]	5	

Fuel Assumptions			
Fuel Type	[-]	Diesel	
Fuel Price[5]	[£/L]	1.10	Baseline price
AdBlue Price[6]	[£/L]	0.33	

[3] Although the vehicle may be designed for 10 years, the first owner / operation may only use the vehicle for 3, 5 or 7 years before it is sold for second life
[4] Assume vehicle manufacturer will provide “ride and drive” training to showcase the features of the new truck
[5] Assume purchased at fleet operator rates
[6] Assume purchased as bulk buys

Add-On Cost Assumptions (per vehicle)			
		Vehicle Convoy	**Vehicle Platoon**
Technology add-on cost	[£]	£ 1000	£ 2500
V2V communication services	[£/year]	0	£ 125
Additional maintenance, servicing & vehicle testing	[£/year]	0	£ 750
Additional driver training[7]	[£/driver]	£ 2000	£ 2000
Insurance on-cost[8]	[£/year]	0	0

Fuel consumption saving compared to baseline vehicle[9]			
		Vehicle Convoy	**Vehicle Platoon**
Lead Vehicle	[%]	4%	8%
Following Vehicle	[%]	8%	14%
Gap between vehicles	[m]	12	6

[7] Assume training conducted on a test track. Assume 1-3 day course. Might include travel & subsistence

[8] The annual insurance premium for the fleet operator could change as a consequence of adopting vehicle convoying or platooning technology. However the output from the stakeholder consultation was inconclusive with regard to whether the insurance premium would increase or decrease.

[9] Adapted from SARTRE results

APPENDIX 5 ROAD TRIAL RISK REGISTER

Convoy/platoon Heavy Vehicle UK road trial		**Risk Register Prepared By:** **TRL/Ricardo/TTR**			***Probability***: *<5% Very Low, 5-29% Low30-49% Medium, 50-74% High, >74% Very High* ***Impact***: *VL=Very Low, L=Low, M= Medium, H= High, VH= Very High* **Issue: 1, March 2014**
Risk ID	**Description**	**Probability**	**Impact**	**Effect (description)**	**Reduction Strategy**
1	Prototype technology failing on public roads	VL	VH	Threat to road user safety, road infrastructure and reputation (partners and DfT).	Prototype system developed and tested on test track to ensure safe and reliable operation in expected conditions. Tests on road should not commence until system has been checked in line with feasibility study recommendations. Road trial should start on motorway with low traffic flow and first stages should be attended by observers.
2	Other vehicles entering convoy/platoon unintentionally	L	L	Threat to road user safety.	Prototype system tested on track to ensure that it can cope safely with expected “in use cases” like a non-platoon vehicle entering the platoon. Only proceed to road trials if performance is safe and reliable.
3	Failure of lead vehicle or vehicle in platoon (e.g. tyre blow out or catastrophic failure)	VL	VH	Threat to road user safety	Design system to cope with extreme events (if feasible). If not, then risk equal to normal driving. Use frequent and comprehensive system and equipment checks prior to use.
4	Damage to road infrastructure (road rutting)	VL	L	Threat to road infrastructure	None, risk considered very low and difficult to monitor in any trial.
5	Malicious takeover of platoon (cyber-attack)	VL	VH	Threat to road user safety, road infrastructure and reputation (partners and DfT).	Ensure system is resilient to attack by considering this in development phase. Use only data on vehicle systems/vehicle CAN that cannot be accessed without specialist knowledge and tools.

Convoy/platoon Heavy Vehicle UK road trial		**Risk Register Prepared By:** **TRL/Ricardo/TTR**			***Probability***: *<5% Very Low, 5-29% Low30-49% Medium, 50-74% High, >74% Very High* ***Impact***: *VL=Very Low, L=Low, M= Medium, H= High, VH= Very High* **Issue: 1, March 2014**
Risk ID	**Description**	**Probability**	**Impact**	**Effect (description)**	**Reduction Strategy**
6	Vehicles not available with required sensing systems and access to PAS modification	L/M	VH	Significantly greater cost to develop and test a system to allow trial to take place	Involve OEM/tier one supplier who can provide suitable vehicles, and provide assistance in accessing and modifying the PAS.
7	Lack of access to vehicle CAN	L/M	VH	Lack of data to measure key variables	Involve OEM/tier one supplier who can provide access to CAN data.
8	Conflict between road infrastructure and length of convoy/platoon	L	L	Vehicles cause significant barrier to existing road infrastructure	Form convoy/platoon only on Motorways. Clear criteria developed for dissolution of convoy/platoon. Limit maximum length of convoy/platoon to 5 vehicles (at least initially) in line with previous studies.
9	Adverse environmental conditions affecting sensing capability	H	L	Extreme conditions (fog, snow etc) impair sensing	Exclude extreme conditions from trial. Ensure that 'expected' conditions (e.g. rain) can be dealt with by the system during track tests (see Risk ID 1).
10	Other drivers unaware of convoy/platoon	M	M	Other road users not aware of autonomous vehicles	Consider signage on vehicles or gantry signs in conditions of high traffic flow (only in later stages of trial). Early phases of trial might also benefit from escort/observer vehicles. Note: this may effect ability to collect unbiased data from other road users on the effect of convoys/platoons.
11	Lack of information between vehicles in convoy/platoon	L	H	Vehicles in the platoon are unaware of status of the convoy/platoon or any significant event	Include HMI to inform vehicle drivers of significant convoy/platoon events, including connect and disconnect and emergency warnings.

Convoy/platoon Heavy Vehicle UK road trial		**Risk Register Prepared By:** **TRL/Ricardo/TTR**			***Probability**: <5% Very Low, 5-29% Low30-49% Medium, 50-74% High, >74% Very High* ***Impact**: VL=Very Low, L=Low, M= Medium, H= High, VH= Very High* **Issue: 1, March 2014**
Risk ID	**Description**	**Probability**	**Impact**	**Effect (description)**	**Reduction Strategy**
12	Collisions between vehicles in a convoy/platoon and/or other road users	L	VH	Road user safety	• Develop and test prototype system performance in a phased manner, starting with tests on a suitable test track and progressing to the road situation only when performance has met the required performance level • Use drivers trained in the system and the functionality of the prototype systems • Ensure there is appropriate safety margins built in to the prototype system • Ensure a defined and regular inspection procedure to guarantee the functionality of safety critical systems • Consider additional cab strengthening and/or energy absorbing frontal structures and the use of appropriate secondary safety systems
13	Differences in vehicle size/braking performance/ acceleration performance	L	H	More challenging to develop effective convoy/platoon system	Use vehicles of identical type/size/age etc.
14	Crash involving vehicles carrying dangerous or hazardous loads	VL	VH	Increased safety risk in event of crash	Exclude all dangerous loads from any trial

Convoy/platoon Heavy Vehicle UK road trial		**Risk Register Prepared By:** **TRL/Ricardo/TTR**			***Probability**: <5% Very Low, 5-29% Low30-49% Medium, 50-74% High, >74% Very High* ***Impact**: VL=Very Low, L=Low, M= Medium, H= High, VH= Very High* **Issue: 1, March 2014**
Risk ID	**Description**	**Probability**	**Impact**	**Effect (description)**	**Reduction Strategy**
15	Driver 'underload' or behavioural adaptation to close following	M	H	Longer to assume manual control in emergencies and safety if adapted to close following when under manual control	Design system to provide effective feedback and information to the driver. Include effective HMI system and test on track prior to road trials. Training of drivers to include behavioural adaptation awareness.
16	Lack of driver experience	L	H/VH	Driver's lack experience in convoying/platooning system therefore increasing safety risks	All drivers taking part in the trial must be trained in: • Convoying system and its capabilities/performance limits • Platoon formation and dissolution • Connect procedures • Emergency procedures Drivers must be made aware of the system limits so that their trust in the system does not become affected by any failures of the system. The training required for a trial on UK roads would be more comprehensive and extensive than the training required once more widely implemented.
17	Negative public opinion affecting trial	M/H	H	Lack of public support for trial	Ensure that the public are effectively briefed on the societal benefits of convoys/platoons. Communicate the extent to which the safety measures taken to permit any trail have been tested and to demonstrate effective controls are in place with respect to the fears of the public. Engage with road safety groups to build support for research.

Convoy/platoon Heavy Vehicle UK road trial		**Risk Register Prepared By:** **TRL/Ricardo/TTR**			***Probability**: <5% Very Low, 5-29% Low30-49% Medium, 50-74% High, >74% Very High* ***Impact**: VL=Very Low, L=Low, M= Medium, H= High, VH= Very High* **Issue: 1, March 2014**
Risk ID	**Description**	**Probability**	**Impact**	**Effect (description)**	**Reduction Strategy**
18	Insufficient vehicles/routes to run a trial	M	VH	Not enough vehicles, drivers to run an effective trial	Select appropriate operator(s) based on the requirements of the trial work specification.
19	Insufficient storage space to record required trial data	L	VH	Affect ability of trial to collect and analyse the required information	Ensure that on-board data storage is sufficient and in line with specification of the trial work specification. Develop procedure (linked with trial design and operator(s)) to retrieve and store test data throughout the trial period.
20	Other vehicles not being able to view signs or enter/exit motorway due to convoy/platoon	L/M	M/H	Affect public acceptance and risk to road user safety	Limit convoy/platoon length to 5 vehicles. Use stepwise approach to road testing and monitor effects on surrounding traffic. Provide signage on vehicles and on gantry signs in conditions of high traffic flow. Under specific conditions, convoy/platoon would be dissolved.

APPENDIX 6 STAKEHOLDER LIST

Vehicle manufacturers
DAF Trucks
Ford
Iveco
Isuzu Truck (UK)
Jaguar Land Rover
Scania
Volvo Trucks
Volvo Group Trucks Technology

Technology providers
Bosch
Continental
DENSO
Valeo
VDO

Regulators
Department for Transport (DfT)
Driving Standards Agency (DSA)
VCA

Research organisations/Reviewers
ARUP
Bishop consulting
Thatcham
TNO
VTTI

Network operators
Highways Agency

Emergency services
Association of Chief Police Officers (ACPO)
Fire Service College

Road safety groups
AA
Brake
IAM
RAC Foundation

Insurance companies / legal
Allianz

Security
CPNI

Data handling operators
Imtech

Training providers
AA DriveTech
WTTL
J Coates

Trade associations
Freight Transport Association
Road Haulage Association
Skills for Logistics

Operators / fleet managers / end users	
ADM Milling	Kuehne and Nagel Drinks
Allied Bakeries	Marks and Spencer
Arcadia Group	Martin-Brower UK Ltd.
AS Watson	Morrisons
Asda	Musgrave Retail Partners

B&Q in partnership with DHL
Balfour Beatty
Bedfords Transport
Boots
Canute
Carlsberg
Carntyne Transport
Clipper Logistics
Co-op
Cranleigh Freight Services Ltd.
Dairy Crest
DHL Engineering & Fleet Services
EAT
FiA
Holland and Barratt
House of Fraser
Iceland
John Lewis

NEXT
NFT Distribution Ltd
Parcelforce Worldwide
PC World
Post Office
Royal Mail
Royal Mail Relay
Sainsbury's
Solstor
Symphony Group Plc
Tesco
Tesco Express
Thorntons plc
TK Maxx
TNT
United Biscuits
Yusen Logistics

Note: Multiple contact points were approached for a number of these stakeholders.