

# HelmUK final report

14 July 2022

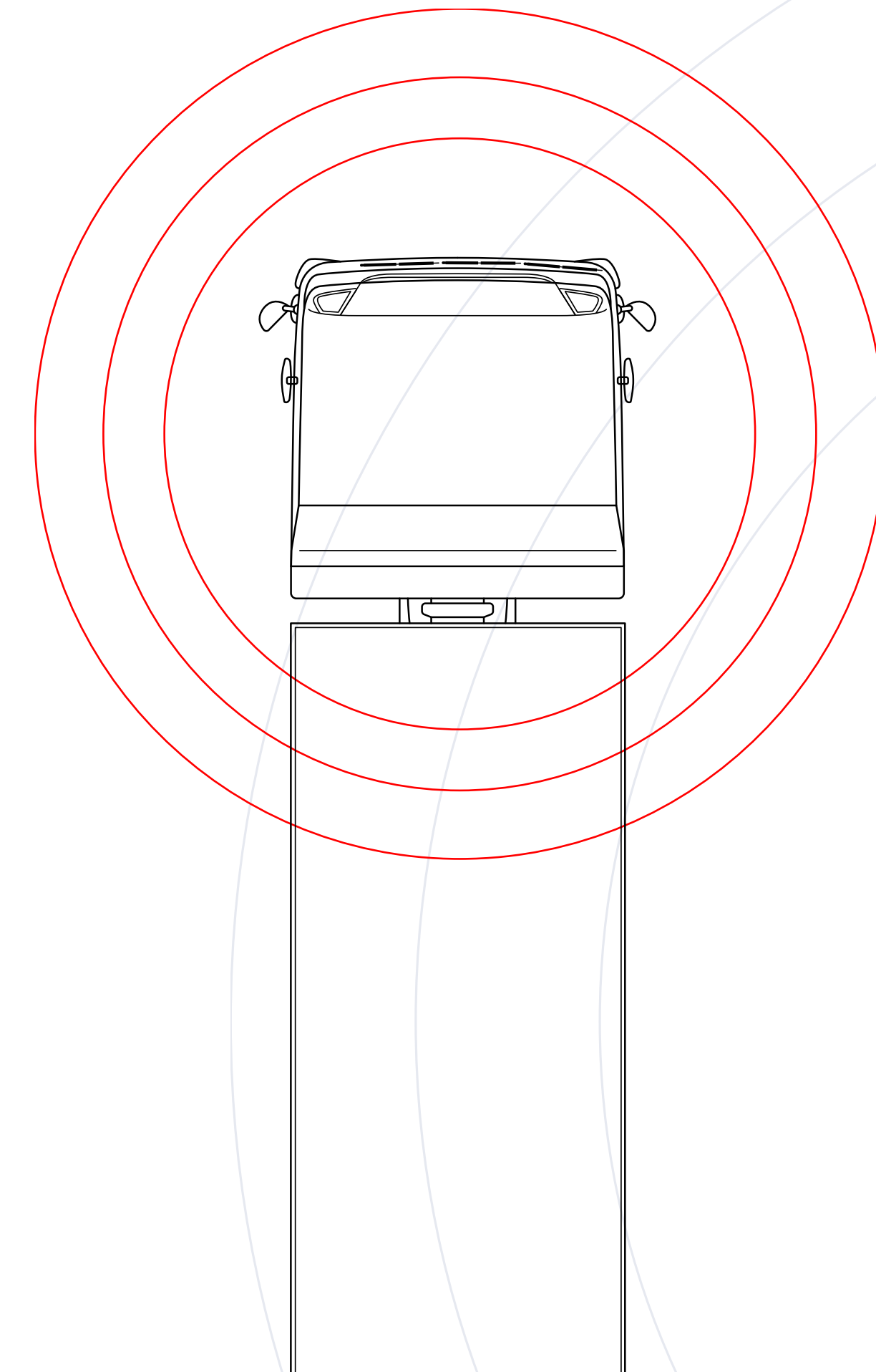
## → Abstract

HelmUK was the UK's first real-world trial of HGV platooning which ran between 2017 and 2022. The concept of platooning is to use advanced driver assistance systems to enable HGVs to safely travel close together to save fuel via a slipstreaming effect. This concept has never been tested in a real-world environment in the UK.

HelmUK ran for 5 years and through exhaustive analysis of real-world trials found that platooning saved small amounts of fuel over Adaptive Cruise Control (ACC) in the real-world. Further analysis found that in a road network optimised for platooning, fuel savings could increase to between 2.5% and 4.1%. HelmUK also found that platooning was as safe as ACC operation, if risks with merging vehicles at junctions are managed.

This report describes the purpose, approach, design, and results of the HelmUK trials covering road safety, fuel savings, effects on the road network, and economic benefits.

The HelmUK final report also discusses the future of platooning for National Highways, the UK government, and the freight industry. Finally, the report makes a series of recommendations for platooning development and deployment. These include consideration of regulation of low headways at junctions and a strong recommendation to deploy the underlying systems enabling platooning at more typical larger headways where they offer safety benefits with no increase in risk.



## → Foreword

HelmUK, the UK's advanced platooning trials, is a fascinating project. The technical and logistical challenges associated with delivering the first on-road trial of heavy goods vehicle (HGV) platooning on the UK's national road network were significant. Unlike platooning demonstrations which have taken place previously using controlled conditions on segregated test tracks, HelmUK's target was to integrate a platoon of vehicles onto the motorway network in a way that ensured there was no erosion of safety performance.

The success of the HelmUK project is a story of partnership between government agencies, research organisations and industrial partners such as technology providers and operators. A project managed by TRL with a robust safety governance structure including an independent reviewer, HelmUK is an excellent example of careful, objective research. The experience captured within this report is of great value to the road transport sector as it endeavours to deliver improvements in sustainability and safety.

The potential benefits of platooning in reducing harmful atmospheric emissions have been debated in the academic literature for some years. Several collaborative studies (such as CHAUFFEUR II, SARTRE, KONVOI) were published in the late 2000s / early 2010s based on the use of platooning systems based on adaptive cruise control, lane control and active braking systems. Early indications were that, assuming the vehicles could be operated safely, the aerodynamic efficiency of a platoon would deliver a tangible improvement in fuel consumption and hence a decrease in emissions.

To test this hypothesis on the UK road network, the HelmUK project was devised. The team acknowledged from the beginning that a real-world trial would carry significant risk which required careful management. A comprehensive and robust safety case was developed using the Safety Risk Assessment process outlined in National Highways guidance document GG104. Potential safety risks covered a broad range of areas including the platooning technology, operating procedures, driver selection and training, infrastructure, operating conditions, the behaviour of other road users, and emergency response. Changes of personnel and consortium partners over the life of the project provided an additional challenge to be managed. Each was documented within a risk register with a clear owner in keeping with best practice. This was a living document that evolved throughout the project as new potential hazards were identified and evaluated.

As independent reviewer, I was impressed by the careful consideration of risks to ensure that each stage of the trial could be delivered to a high level of safety. If a risk was considered unacceptable, the trial was paused, modified, and the risk was mitigated in consultation with the Project Safety Control Review Group (PSCRG) and National Safety Control Review Group (NSCRG). Although this ultimately delayed the project, it ensured that the safety of other road users was never compromised and that a great deal of valuable learning was captured for the future.

The effects of restrictions associated with a global pandemic would have been hard to anticipate at the start of the project. Whilst a broad range of foreseeable risks were identified and evaluated, few could have imagined that the 'real world' would change so dramatically at the point the project was anticipating moving to on-road trials.

While this added further complexity and hence delay to the project, it does not appear to have had a significant negative effect on the quality of the outcome.

More than anything, it is the rich learning that comes from the complexities associated with this project that has been the greatest output. Where new technologies offer exciting opportunities, especially in terms of sustainability and safety, navigating the transition can be difficult. HelmUK has captured many of the potential risks and documented mitigations to ensure an acceptable level of safety for all road users. It has also delivered objective evidence regarding the potential fuel efficiency of platooning trucks. While the actual fuel savings have been less than originally predicted, it is robust evidence to build upon for the future.

The Department for Transport and National Highways are to be applauded for their vision in supporting the HelmUK project. Safety and sustainability are arguably the two most important topics for the road transport sector and where new technologies offer an opportunity, the value of projects such as this to evaluate them is immense.

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## → Executive summary

HelmUK was the first trial of Heavy Goods Vehicle (HGV) platooning on UK roads. The aim of the project was to conduct a comprehensive evaluation of the benefits and risks of the platooning concept using information gathered from real-world trials.

### What is HGV platooning?

HGV platooning is a concept where two or more trucks travel close together in a 'platoon', i.e. a coordinated convoy of vehicles. Platooning is not driverless technology but driver assistance – the drivers must continue to steer and monitor the driving environment and be ready at all times to take over full manual control.

The theory behind platooning is that trucks following the lead vehicle save fuel due to a slip-streaming effect.

Ordinarily, following at distances of 0.5 to 1.0 seconds (around 12 to 24 metres apart at motorway speeds) would be dangerous, so platooning uses vehicle-to-vehicle communication to coordinate acceleration and braking of the vehicles instantaneously. Using these systems, travelling close together can be made as safe as driving 2 seconds apart, as recommended in the Highway Code.

Test-track studies have shown fuel benefits as high as 7% for a lead vehicle and 16% for a following vehicle<sup>1</sup>. However, these were achieved in highly controlled conditions, driving at very low headways, i.e. short distances between vehicles, without any interruptions. HelmUK set out to understand how the benefits of platooning translate to a real-world environment using a prototype platooning system capable of maintaining a 0.8 second time-headway between trucks.

<sup>1</sup> Safe Road Trains for the Environment (SARTRE) (2013) D4.3 – Report on Fuel Consumption

<sup>2</sup> The project was paused from March to October 2020 due to the global COVID-19 pandemic and UK government restrictions.

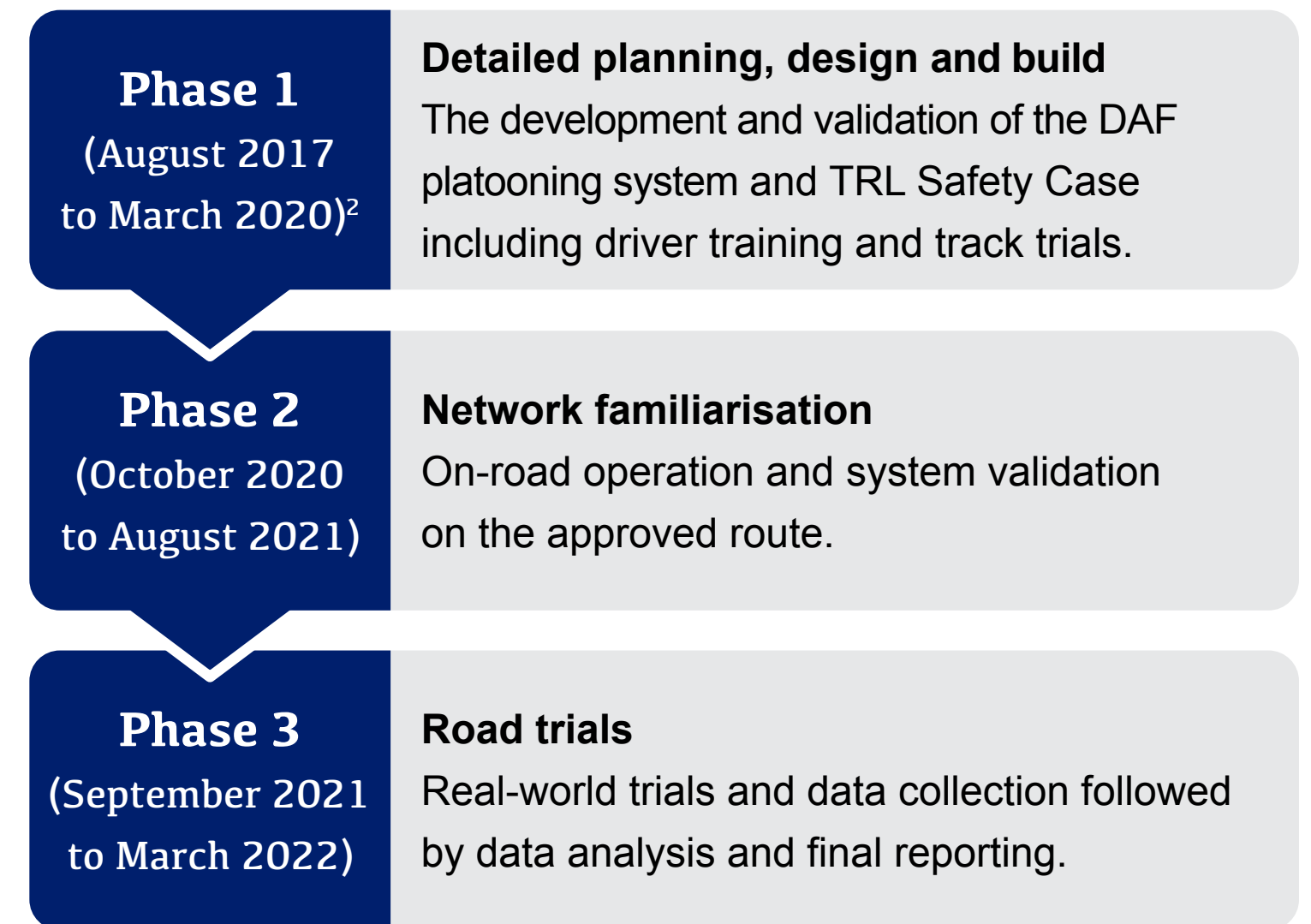
## How close do the trucks travel?

Platooning systems typically travel 0.5 to 1.0 seconds apart (11.9 to 23.7 metres at 53 miles per hour). By comparison, some established adaptive cruise control systems without vehicle-to-vehicle communication allow minimum time-headways of 1.4 seconds (33.6 metres at 53 miles per hour). The Highway Code recommends a time-headway of 2 seconds.

### What were the HelmUK trials?

The HelmUK trials were funded by National Highways and the Department for Transport (DfT) to thoroughly evaluate the real-world benefits and impacts of platooning and what this means for the future of the technology in the UK. The project was carried out by the HelmUK consortium, formed of programme lead, TRL, and the partners: Apollo Vehicle Safety, Connected Places Catapult, Costain, DAF Trucks, DHL, fka, Fusion Processing, Ricardo, UTAC, TNO, TransportPR, VisionTrack and ZF.

The project ran between 2017 and 2022 in three phases:





The road trials were conducted using three articulated HGVs fitted with a prototype DAF platooning system, which was released for a field trial after tests by DAF and TRL. The key features of this platooning system, which allowed safe operation at low following distances, are:

**Cooperative Adaptive Cruise Control**

which keeps the distance between the vehicles constant using short-range vehicle-to-vehicle (V2V) communication.

**Brake Performance Estimator**

which adjusts the distance between the vehicles based on vehicle weight to ensure safety no matter the load or order of the trucks.

**Cooperative Collision Avoidance**

which ensures coordinated automatic emergency braking.

**Lane Keeping Assistance**

which supports the driver's steering to prevent vehicles from veering out of lane.

For such complex trials of new technology, a large part of the preparation for on-road trials was the development of a Safety Case using the principles of National Highways' GG104 risk assessment framework. This safety case ensured that HelmUK met its objectives while pro-actively managing risk to keep the trials safe for all.

The development of the Safety Case for the HelmUK platooning system guided the selection of the trial route, the assessment of junctions which were safe for platooning (about one in every ten junctions), and the operational procedures which supported the trial. The Safety Case took inputs from simulator studies and driver training to ensure a best-in-class approach to risk management.

This included daily safety monitoring and a 'go or no-go' decision at the end of each day on the road. As part of this daily safety monitoring, over 4,000 separate events were reviewed and only four incidents were escalated through the safety management procedure for review with the client.

When on the road, vehicles would engage platooning where it was safe to do so and only on the approved route. Based on the safety case, some junctions were considered suitable for platooning operation while others were not. When platooning, the trucks travelled in lane 1 only, 0.8 seconds apart (cca. 19.0 metres at 53 miles per hour).

The trial route was on the M5 and M6 motorways between Avonmouth and Stafford (and then back again). The total round trip was 218 miles.

The HelmUK trucks were fitted with a range of sensors and data loggers to capture key safety assurance and research data.

Across the project, there were 58 days on-road covering over 12,000 miles and capturing 12 million lines of data and 4,000 hours of video footage.

## How representative is the route?

A key feature of the HelmUK route was the number and density of junctions. For the chosen route on the M5 and M6, the average distance between junctions was 5.59 kilometres.

For motorways in England the average distance between junctions is 5.56 kilometres, so the HelmUK route is very close to the English average.

## What did HelmUK find?

### Platooning is at least as safe as Adaptive Cruise Control (ACC) if risks at junctions are controlled.

HelmUK evaluated a range of road safety impacts from platooning as part of the trial. The key parts of this research looked at:

- The safety of the vehicles themselves using data from the HelmUK trucks to monitor Surrogate Safety Measures
- The impact on other road users (focusing on junctions) using vehicle data, video footage and traffic flow data
- The impact on driver workload from platooning operation.

Overall, HelmUK found that for vehicle safety:



The DAF platooning system was fail-safe in road trials as demonstrated in Phase 1 of the project.



Platooning kept good control over the position of the vehicles relative to one another; no time was spent closer than 0.8 seconds which did occur in non-platooning operation.



Surrogate Safety Measures taken from vehicle data evidenced that, overall, the vehicles were safer in platooning mode.



Cooperative Collision Avoidance functionality reduced collision risk on a few occasions; however, there were some activations which could have posed a risk to following vehicles.



Platooning is not expected to introduce new collision types and is predicted to have a small beneficial effect on common, existing HGV collision types overall.



Driver workload did increase slightly due to platooning, but only by a very small amount – overall, driver workload was not substantially impacted.



For junctions which were platooned through, platooning did not increase risk to other road users or disrupt traffic flow.



The residual risk for platooning systems is conflict with merging vehicles at junctions, which is caused by close following distances.

## What are Surrogate Safety Measures (SSM)?

SSMs are proxies for vehicle safety calculated or measured from vehicle data. A simple example would be 'harsh braking' over a certain threshold.

The frequency and type of these events was monitored throughout the trial.

## Fuel savings from platooning were lower in the real world than previous test track results

The HelmUK trials compared three vehicles in platooning mode (0.8 seconds apart) to Adaptive Cruise Control (typically, but not always, 1.6 seconds apart) to calculate fuel savings that can be realised over existing driving technology. A visual representation of the road trials and vehicle operation is shown in Figure A.

### Real-world fuel savings (0.5%)

HelmUK found that the measured fuel savings across three vehicles were 0.5% in the HelmUK trial. Statistical modelling showed no evidence that fuel consumption was significantly different to trucks using ACC. Analysis confirmed that the number of junctions which could not be safely platooned through was the main reason for the low fuel savings. The vehicles could spend only 53.5% of their driving time in a platoon.

### Optimised fuel savings (2.6%)

To further explore the potential of platooning, two optimised scenarios were created from the HelmUK data to represent possible future scenarios for platooning deployment. The first looked at a route where all junctions were suitable for platooning, and the second looked at areas of the route where a high degree of platooning occurred. The measured fuel savings across three vehicles for these two scenarios rose to 1.7% (at 74.7% of time in platoon) and 1.8% (at 85.7% of time in platoon), respectively. Further statistical modelling performed on these two scenarios, which accounted for other variables on fuel consumption (such as traffic flow, journey direction, platooning states, weather, etc.), showed that the fuel savings of platooning alone were marginally greater than the fuel savings directly measured at 2.5% and 2.6%, respectively.

### Perfect fuel savings (4.1%)

Finally, it was investigated what platooning could achieve in perfect conditions, where there was completely uninterrupted platooning. In this scenario, fuel measurements from HelmUK showed that platooning could produce fuel savings of 4.1% across three vehicles.

## Why do junctions impact fuel savings?

Junctions which cannot be platooned through required the HelmUK vehicles to break the platoon. When the platoon is then reformed, the vehicles accelerate which costs fuel. The more often vehicles do this, the lower the fuel benefits overall.

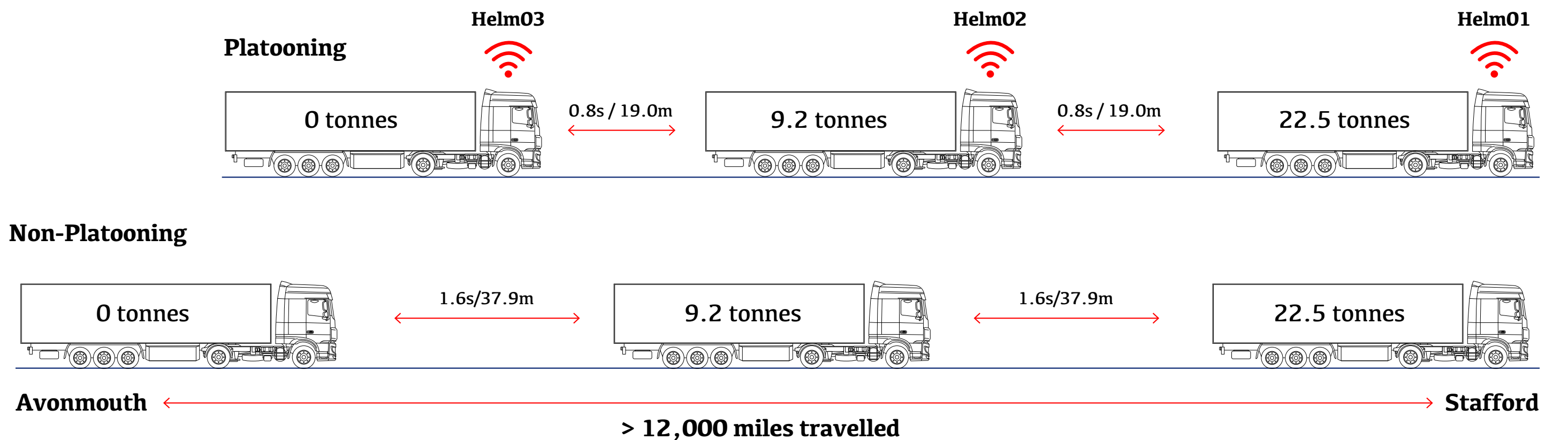


Figure A: HelmUK trial formation, payloads and vehicle spacing for platooning and non-platooning operation.



## **Early adoption of platooning by the freight industry will be limited**

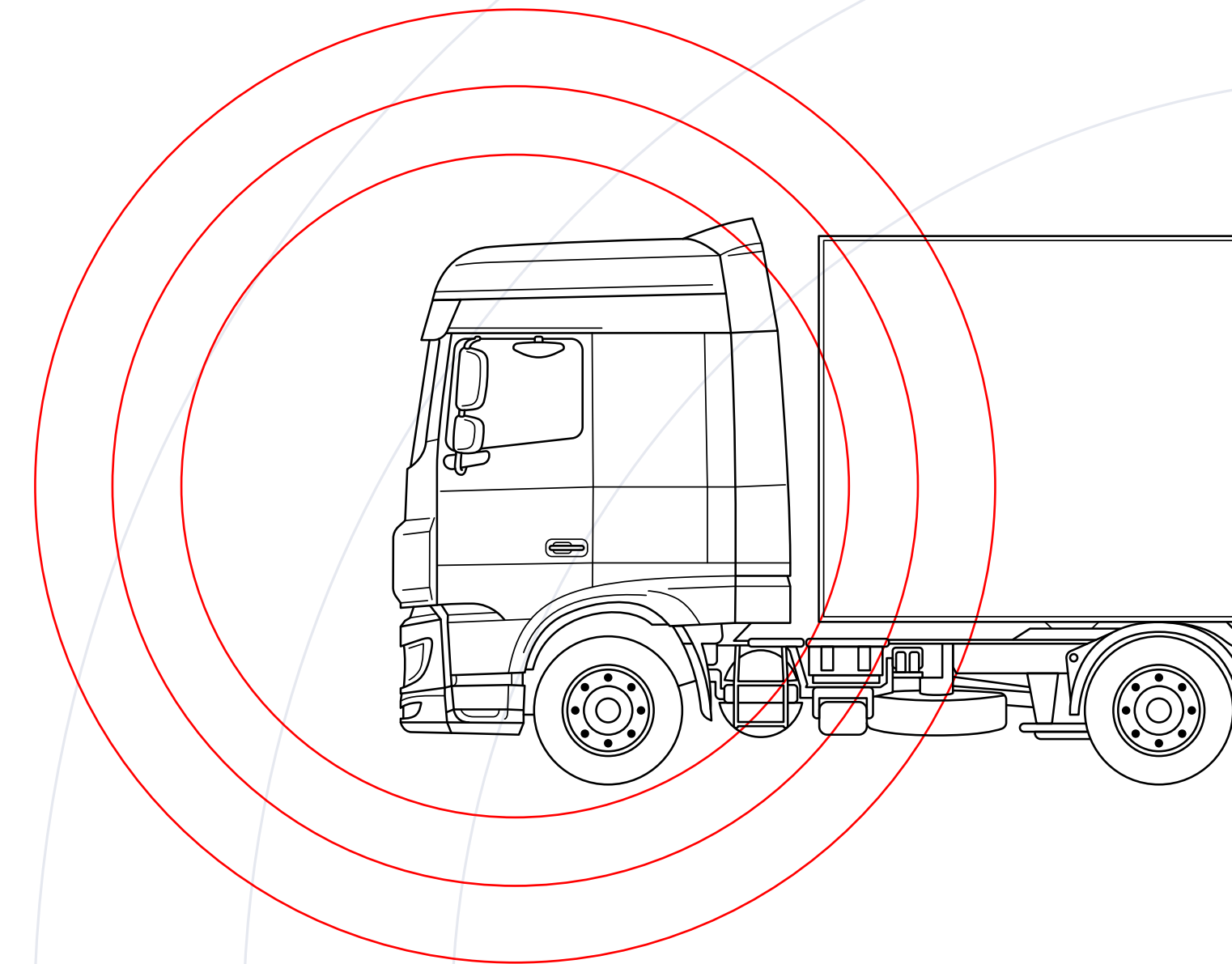
Engagement with the freight industry found that while operators would be willing in principle to consider making operational changes to facilitate platooning, they identified concerns about the operational costs and commercial risks arising from rescheduling trips to enable platooning.

The fuel savings found in HelmUK are below the level which most operators considered worthwhile and are lower than other fuel saving interventions that the industry does invest in (which are operationally less complex and deliver more predictable results).

The very low savings for the lead vehicle could discourage different operators from platooning together. This aspect, and low fleet penetration, is likely to rule out any 'open access' platooning model in the short term. In this model, vehicles platoon opportunistically with nearby vehicles in the course of a trip, rather than pre-planning platooning within a single operator's own fleet, or close partners. Operators should be aware that the order of the vehicles by weight is likely to affect the minimum achievable headway so some coordination may be required to optimise fuel savings – but this is impractical for an ad-hoc platoon.

Platoons of only two vehicles may not be viable, as only one of a pair might actually be saving fuel, so operators would have the greater complexity of needing to find at least three vehicles whose trips can be combined. Consideration has been given to a payment structure to distribute benefits evenly between operators participating in a platoon, but this is believed to be too complex to justify the level of benefits to be redistributed.

Economic analysis showed that a positive business case is likely to be made only for a very small number of operators with quite specific favourable circumstances. It would be necessary for such an operator to undertake regular long-distance trunk haulage trips between fixed locations located close to a motorway, and where vehicles can be relatively easily grouped without significant rescheduling being required.



## How ready is the technology?

Platooning systems are not yet commercially available, but the prototype system HelmUK successfully and safely deployed on real roads demonstrated that the technological building blocks already exist:

- Vehicle-to-vehicle communication for coordinated acceleration and braking, including emergency braking
- Radar detection of cars and larger vehicles cutting into the platoon
- Axle load monitoring for automatic adjustment of headway to weight distribution across the platoon
- Lane keeping assistance to support steering.

For commercial deployment, an ideal platooning system should also:

- Be interoperable with other manufacturers' systems
- Automatically enforce use restrictions, such as maximum length of platoon or road type
- Automatically increase the headway before junctions not suitable for platooning
- Feature a Human Machine Interface (HMI) implementation that does not rely on voice communication between drivers
- Be capable of reliably detecting motorcycles cutting-in.

None of these items are reliant on theoretical technology or require leaps in technological readiness, but rather incremental development over time. Timescales for commercial deployment of platooning systems are not known publicly, but a prerequisite to this is the introduction of a multi-brand communication standard, which can be expected to happen within the next two years. All major European HGV manufacturers have shown an interest in platooning technology, but it is not known which are planning to release systems or when.

## What does this mean for key stakeholders?

<b>For National Highways</b>	<p>Platooning should be restricted to motorways (or roads which conform to the same standards) where it can provide the most benefit for the least risk. In the long term, National Highways could investigate the use of signals, junction layout changes and dedicated lanes to improve fuel savings from platooning while ensuring safety. However, the current business case for doing so is weak for platooning alone; instead, enabling platooning safely should be a use case considered in further adaptation of motorways in England for CAV.</p> <p>National Highways should not act as a platooning service provider coordinating journeys at the moment. Any early adoption of platooning could initially be managed in a similar way to abnormal loads, but this will not be suitable for long-term business as usual operation.</p>
<b>For the Department for Transport</b>	<p>HelmUK did not highlight a strict need to implement type-approval requirements for functionally safe platooning systems if manufacturers follow thorough internal safety procedures.</p> <p>However, type-approval regulation could establish a safe minimum performance threshold across manufacturers and ensure that operational functionalities, such as increasing the headway before junctions and restricting the use to motorway-standard roads, become automated and do not rely on driver adherence.</p>
<b>For UK freight industry</b>	<p>Currently, platooning could provide small fuel benefits and safety benefits to HGV operation. Early adopters are likely to have the following characteristics:</p> <ul style="list-style-type: none"><li>• A large fleet or willingness to partner</li><li>• Operate primarily on motorways</li><li>• Be willing to invest for fuel savings in the region of 2%</li><li>• The ability to coordinate multi-vehicle journeys</li><li>• Common origins for loads</li><li>• The ability to operate at night.</li></ul>

### What does this mean for the future of platooning?

Overall, the business case for platooning is currently weak – the fuel benefits over ACC operation are negligible in a real-world setting at 0.5%. HelmUK’s research has shown that the primary reason for this is the safety requirement to disband the platoon at 9 out of every 10 junctions along the route. With these fuel benefits, meaningful uptake from the freight industry is considered unlikely because HelmUK’s stakeholder engagement found that a minimum fuel saving of 2% would be required for operators with large fleets to invest in platooning technology.

Therefore, unless more junctions on motorways (and other motorway standard roads) are compatible with platooning operation, the fuel benefits from platooning technology will be hard to realise with current generation systems. Most ways of achieving this, such as changes to junction design to accommodate platooning or introducing dedicated lanes for platooning, are likely to require significant investment or changes and could produce fuel savings in the 2.6% to 4.1% region across three vehicles.

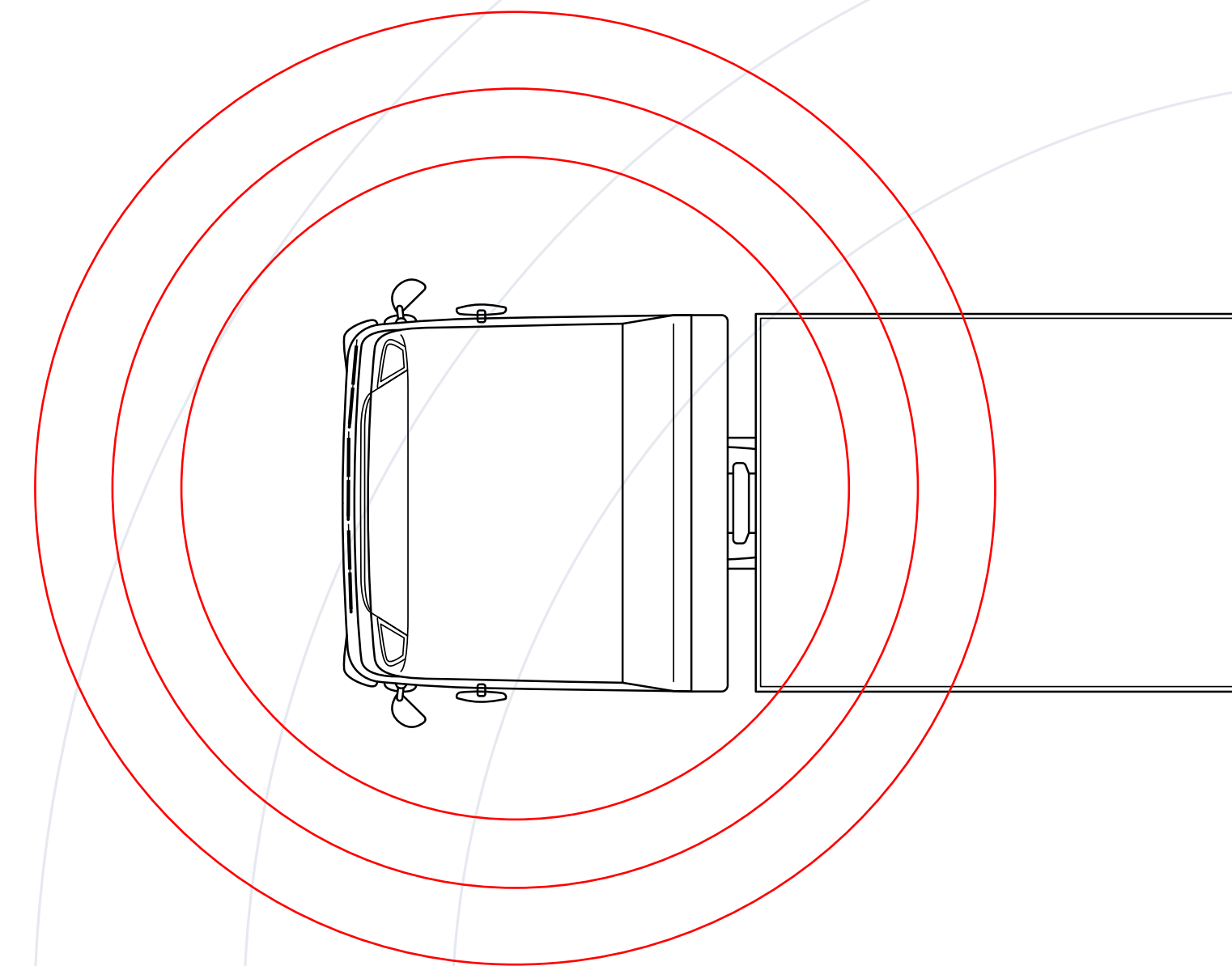
The business case for this level of investment to support platooning is weak in isolation. However, as English Motorways (and the wider Strategic Road Network or SRN) are made more ‘CAV ready,’ merge junctions are likely to be a key pinch point for safe CAV deployment. Platooning should be considered as a use case when assessing potential changes to junctions and road layouts.

Fuel savings could be further improved by:

**Reducing the distance between vehicles** – HelmUK initially targeted a headway of 0.5 seconds, but the variability of brake performance in real-world conditions meant this had to be increased to 0.8 seconds. Future vehicles might be able to reduce this headway, but this will be challenging with a mixed-age fleet.

**Increasing the number of vehicles in a platoon** – HelmUK highlighted risks at junctions from a three HGV platoon, and subsequent research has found that the longest platoon possible for the most suitable junction on the HelmUK route was likely to be no greater than four HGVs.

In contrast to fuel savings, it is plausible that safety benefits of the systems which enable platooning would also be realised at larger headways. These technologies could be introduced without following at close distances regardless of the future success of the platooning concept.





The two main recommendations from HelmUK based on 5 years of research and more than 12,000 miles travelled are:

### **1. Use platooning technology as driver assistance – without low headways**

As well as being the first on-road trial of platooning in the UK, HelmUK is believed to be the first on-road trial of cooperative adaptive cruise control and cooperative collision avoidance, these systems enable safe platooning operation using vehicle-to-vehicle communication.

These systems offer safety benefits over existing systems. HelmUK has proven this functionality using DAF vehicles and the European ENSEMBLE project has proven this functionality across multiple manufacturers.

These systems could be deployed in the near term when sufficiently developed. If implemented without allowing operation closer than the lowest ACC settings (1.6 to 1.4 seconds), they require no additional regulation and do not increase risk at junctions. However, benefits realisation will be dependent on the market penetration of these systems.

These systems are assumed to manage cyber security by application of UN Regulation No.155.

The HelmUK trial found several activations of cooperative braking which could have increased risk for following vehicles, this should be mitigated in production systems.

### **2. Managing platooning deployment in the UK**

A fundamental feature of platooning operation is safely enabling close following distances to save fuel. HelmUK has found that junctions constitute the key risk from platooning, but that disbanding the platoon at most junctions has a major impact on fuel savings.

Based on these findings, there are three possible options for the future of platooning in the UK:

**Maintaining the ‘status quo’** – no regulation or control of platooning. This approach would leave risks at junctions down to either driver judgement or to systems which might be implemented by the freight industry to increase headways at junctions to alleviate the risk to merging traffic. HelmUK’s Safety Case judged that by the time the platooning drivers were able to decide to increase headway at junctions, it was likely to be too late for the vehicles to reach safe headways for most junctions.

**Regulate platooning** – do not permit vehicles traveling at low headways to travel past junctions, low headways being below typical ACC minimum settings of 1.4 seconds. This will mitigate the main risk from platooning technology. Also consider restricting platooning to suitable roads such as motorways.

HelmUK has shown that for current platooning systems there is a limited business case if no junctions can be platooned through as the fuel savings are negligible. This option would allow platooning’s deployment as a driver support system while preserving road safety. It would also keep the door open to operation on routes with lower junction density and for future platooning developments by manufacturers to provide fuel benefits despite this restriction.

**Regulate and support platooning development** – to further support platooning development, more junctions on the network would need to be safe for platooning. This could be done through ITS solutions or signal control (ramp metering) but the business case for such interventions is weak based on HelmUK’s fuel results. Wider changes to English motorways (and the wider SRN) to enable Connected and Automated Vehicles should consider platooning as a use case for these changes.

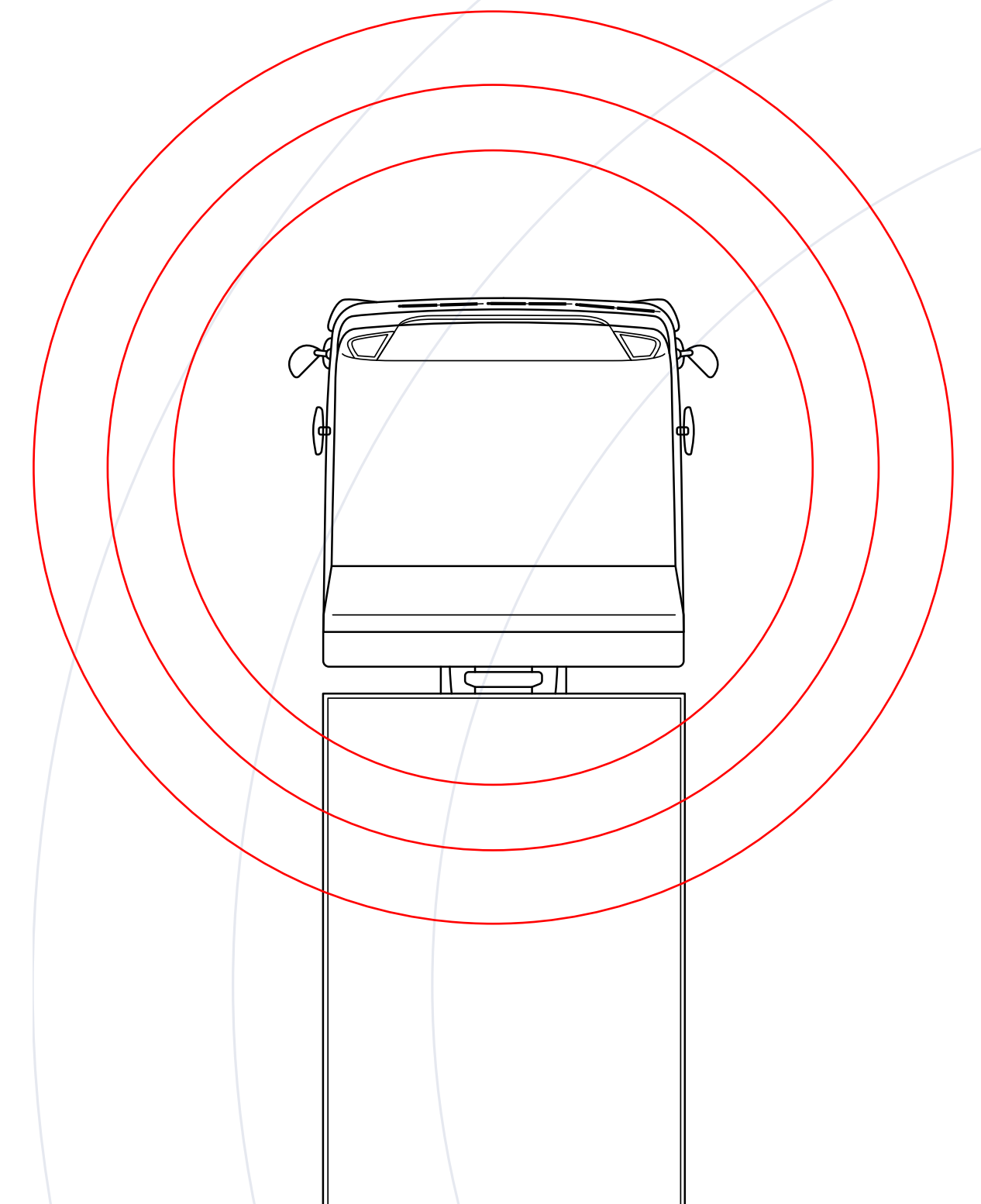
In the short term a more realistic way of supporting platooning may be a framework for identifying and managing risk at junctions, which would allow a case to be made for platooning past certain junction types or in certain conditions.

A practical step would be to apply HelmUK’s junction assessment criteria to English motorways (or roads built to these standards) to determine which junctions are likely to be safe for platooning. HelmUK saw no increase in risk at junctions that were identified to be safe for platooning through the Safety Case development process. This could be developed further to build a case for platooning through junctions under other conditions such as night-time operation, which is a plausible low-risk scenario for platooning deployment.

However, this framework for managing platooning risk would require either UK Government, road operators, the freight industry, or a combination thereof to take ownership of implementing and maintaining this framework.

## Overall recommendations for platooning deployment

- ▶ Based on the findings and project experience of HelmUK, the driver support systems which enable the overall platooning concept would provide safety benefits if they were deployed at headways above current ACC minimums (approximately 1.4 seconds). It is also likely that platooning at larger headways would still save fuel over solo truck operation. This approach will enable a limited form of platooning on the motorways without risks at junctions being uncontrolled. Furthermore, any such deployments would not be affected by regulation of the full platooning concept.
- ▶ HelmUK has shown the main risks from platooning are related to low headways. For closer following distances, as used in HelmUK, consideration should be given to regulating platooning at junctions over an unregulated approach to platooning which aligns with the 'status quo' for driver assist systems. Regulation of platooning through junctions at close following distances will have a negative impact on the economic case for platooning but will mitigate the largest risk from platooning i.e. conflict with merging vehicles.
- ▶ Currently the technological maturity of platooning and the low fuel savings from real-world operation mean that there is not a short-term case for making changes to the road network to support platooning.
- ▶ The longer-term future of platooning would benefit from National Highways, DfT or the freight industry (or a collaboration of these stakeholders) creating a risk management framework which would allow platooning through some junctions on English motorways. Initially, this would be based on the HelmUK junction assessment criteria but could be expanded to cover use cases which are likely to present a low-cost way of reducing the risks of platooning while increasing the fuel savings, such as night-time operation.
- ▶ Beyond this, platooning should be considered as a use case for wider adaptations of English motorways (and the wider SRN) to CAV, especially with regards to 'CAV friendly' junction designs.



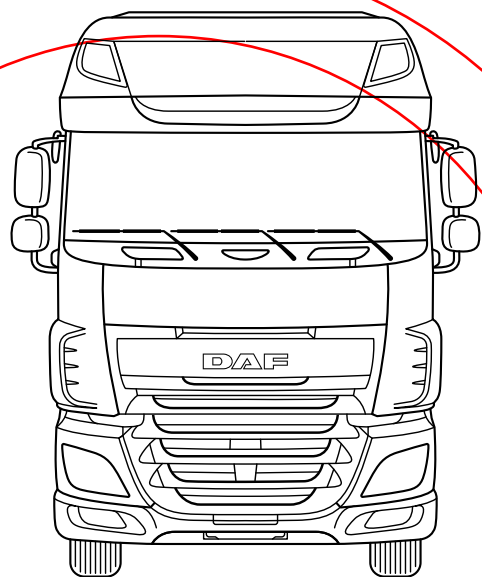
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# Glossary

Item	Definition
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
AEB	Automatic Emergency Braking
ALARP	'As Low As Reasonably Practicable' – reducing risk as far as possible within other constraints. A risk management concept used in National Highways' risk assessment standards such as GG104 – see below
ALKS	Automated Lane Keeping System
AVIS	National Highways' Asset Visualisation and Information System
BPE	Brake Performance Estimator
CACC	Cooperative Adaptive Cruise Control
CAN bus	Controller Area Network bus
CAN signals	Controller Area Network signals,
CAV	Connected and Automated Vehicles
CCA	Cooperative Collision Avoidance
C-ITS	Connected Intelligent Transport System – ITS deployments which make use of connectivity to provide enhanced services and data
'close following'	Travelling at low headway. In platooning, this is to save fuel via slipstreaming.
CO	Carbon Monoxide
CO <sub>2</sub>	Carbon Dioxide
'Cut-in'	A vehicle moving into the gap between platooning vehicles

Item	Definition
DfT	Department for Transport
GG104	National Highways' risk assessment standard
HAPMS	Highways Agency Pavement Management System
HC	Hydro-carbons
Headway	Distance (in metres) between two following vehicles – can also be measured in time (see time-headway)
HGV	Heavy Goods Vehicle
HMI	Human Machine Interface
ITS	Intelligent Transport System
LKA	Lane Keep Assist
MIDAS	Motorway Incident Detection and Automatic Signalling System
'non-platoonable' junction	A junction which isn't suitable for platooning (based on HelmUK's Safety Case)
NO <sub>x</sub>	Nitrogen Oxides
NSCRG	National Safety Control Review Group – National Highways' risk governance body
NTOC	National Traffic Operations Centre
ORU	Other Road User – not part of the platoon
PAEB	Platooning Advanced Emergency Braking
PET	Post Encroachment Time
'platoonable' junction	A junction which is suitable for platooning (based on HelmUK's Safety Case)
'platoonability'	How suitable a road feature is for platooning

Item	Definition
Platooning	Using driver assistance systems to allow vehicles to travel close together to save fuel for following vehicles via a slip-streaming effect
PM	Particulate Matter
PSCRG	Project Safety Control Review Group – National Highways' risk governance body specific to a project
PSP	Platooning Service Provider
Ramp Metering	Using traffic signals to control traffic merging with the motorway
ROC	Regional Operation Centre
Safety Case	A comprehensive document capturing the functional and operational safety elements and risk mitigations for an activity
SRN	England's Strategic Road Network. To avoid confusion with similar road networks in Wales, Scotland, and Northern Ireland this report often styles this as the 'English SRN'
SSM	Surrogate Safety Measure
Time-headway	Time (in seconds) between two following vehicles
TTC	Time to Collision
V2I	Vehicle to Infrastructure communications
V2V	Vehicle to Vehicle communications
V2X	Vehicle to anything communications
VDC	Vehicle Dynamic Control
VMS	Variable Message Sign
VRU	Vulnerable Road User



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# Introduction





# 1. Introduction

## → 1.1 Motivation and aims

The road freight industry is the lifeblood of the UK economy. The Strategic Road Network (SRN) accounts for 2% of all roads in England but carries 66% of all freight. This makes the combination of road freight and network a critical enabler to UK economic growth. However, road freight has a significant impact on road safety, congestion, user experience, fuel efficiency and air quality.

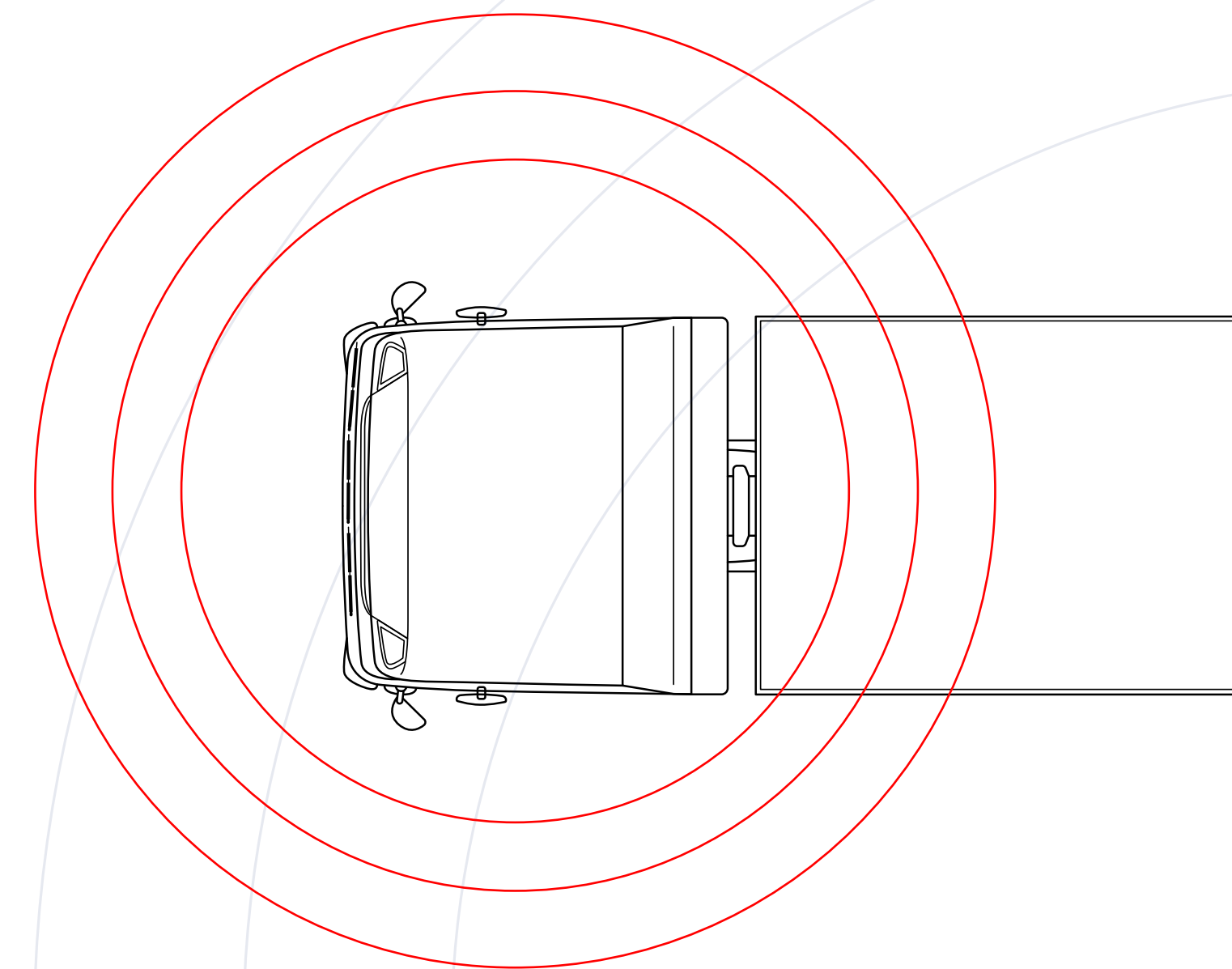
The concept of heavy goods vehicle (HGV) platooning has been researched for over a decade as a way to reduce fuel consumption and emissions and to improve road space usage by allowing short following distances between HGVs, and to reduce driver workload and increase road safety by co-ordinated braking. At the time of writing, the major European HGV manufacturers are working on standardised technical protocols to prepare commercial deployment of the technology.

## What is HGV platooning?

Platooning uses wireless communication technology to allow HGVs to safely travel in close proximity at speed. The aims are to reduce fuel consumption and emissions by making use of the slipstream effect, to improve safety at close following distances thanks to coordinated automatic braking between the lorries, to reduce congestion by improved road space usage, and to reduce driver workload by automated acceleration and braking.

Platooning is not driverless technology. The driver of the lead vehicle controls the speed, acceleration and braking of the whole platoon but all vehicles have a driver ready at all times to leave the platoon and take over manual control if necessary. Drivers are required to steer the vehicles manually at all times.

In contrast to a single tractor pulling more than one trailer, platooning allows vehicles to connect and disconnect at any time during the journey, enabling vehicles to reach their own delivery destinations. HelmUK trialled a platoon consisting of three vehicles, but it is technically possible to connect a larger number of vehicles.



> 1. Introduction > 1.1 Motivation and aims

The benefits of platooning have typically been measured on the test track and the question remained whether these benefits would be realised on the road in mixed traffic. A real-world road trial was required to measure any benefits in real operational use and to investigate whether they can be realised without negative consequences.

HelmUK, the UK's advanced platooning trials, comprehensively evaluated the effects of HGV platooning in a real-world environment with the aim to help inform future decisions of National Highways and the Department for Transport around the potential for platooning technology on the English SRN and to provide the freight industry and the wider public with impartial information on its potential.

Figure 1.1 illustrates the three trial vehicles, Helm01, Helm02 and Helm03, travelling in platoon formation on the motorway and Figure 1.2 shows the platoon on-road as part of the trials. Acceleration and braking of Helm02 and Helm03 were automated to maintain a constant time-headway to the preceding vehicle; steering was manually controlled with support from a lane keeping assistance (LKA) system.

The specific objectives of HelmUK were to develop and document an accurate understanding of:

- Benefits, in particular in terms of potential fuel savings and emissions
- Influence on overall safety risk
- The effect on driver workload
- To what extent signs and other information are obscured by the platoon
- How other drivers perceive and react to platoons
- Impacts on entry/egress to junctions
- The business case for platooning for freight operators and for public investment.



Figure 1.2: The HelmUK platoon (three white HGVs) operating in lane 1 at 0.8 second time-headway on the trial route.

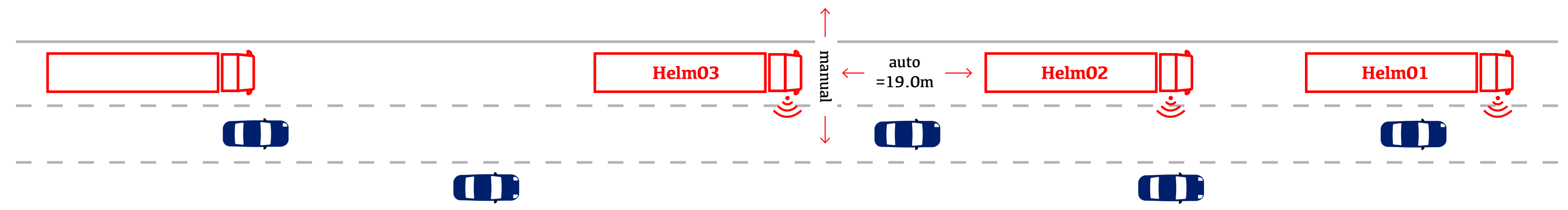


Figure 1.1: Illustration of HelmUK platoon travelling in motorway lane 1 with a headway of 19.0 metres.



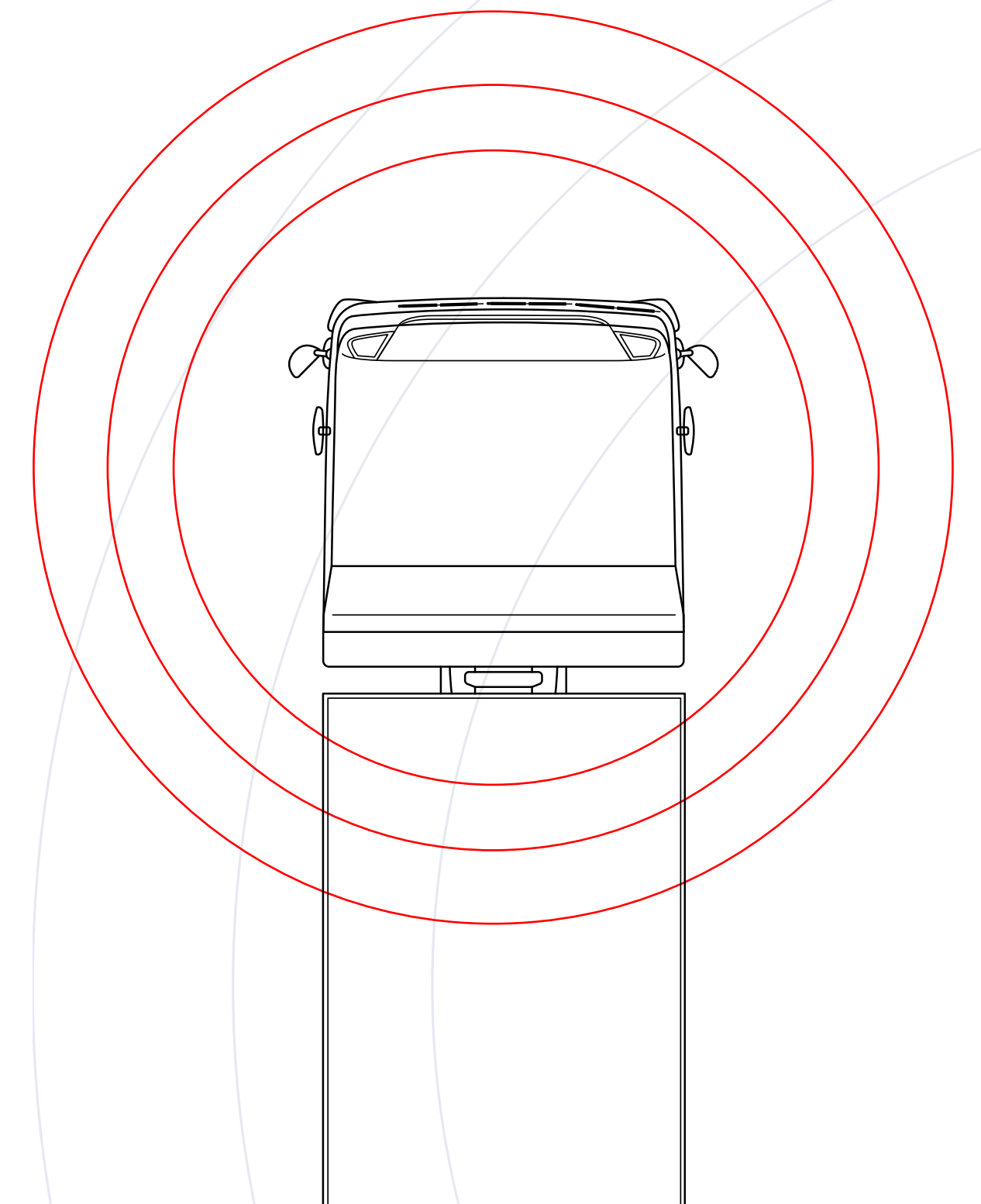
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## → 1.2 Report structure

The purpose of this report is to summarise the findings of the HelmUK programme for government decision makers, road authorities and freight operators, and to provide conclusions and recommendations for the future of HGV platooning on UK roads.

The report is structured into five main sections:

1. **Introduction** – an overview of the HelmUK research programme, summarising aspects of the vehicles and platooning system, the road trials and research questions addressed
2. **HelmUK road trials** – the development of the methodology for the road trials, including the Safety Case, trial design, data collected, and facts about the time spent on road
3. **Key results** – the results from the HelmUK programme, grouped in four categories
4. **The future of platooning** – recommendations for the future of platooning technology on UK roads
5. **Conclusions and recommendations** – overall summary of the results and findings and the key conclusions of the HelmUK project





## → 1.3 Overview of HelmUK

### The research programme

HelmUK<sup>3</sup> trialed the operation of a three-vehicle platoon on the M5 and M6 motorways in England to enable the evaluation of HGV platooning under real-world conditions. Between September 2017 and March 2022, information from over 12,000 miles of road trials, with wide-ranging data from vehicle sensors, driver and safety monitoring, as well as from surveys and driving simulator trials was collected and analysed to assess the effects of HGV platooning on fuel efficiency, emissions and safety, as well as economic impacts and infrastructure aspects. This research was intended to inform future decisions of the project sponsors National Highways and Department for Transport (DfT) around the environmental and economic potential platooning may have for the United Kingdom.

### The project consortium

The HelmUK consortium carrying out this project in collaboration was led by TRL, the UK's Transport Research Laboratory, and involved the partners: Apollo Vehicle Safety, Connected Places Catapult, Costain, DAF Trucks, DHL, fka, Fusion Processing, Ricardo, UTAC, TNO, TransportPR, VisionTrack and ZF.

### The vehicles

Three 5-axle articulated HGVs of 40 tonnes maximum gross weight were used for the trials. All vehicles were of identical specification and model year. The tractor units were DAF XF 480 Super Space Cab from model year 2018, with axle configuration FT 4x2, i.e. one steer axle with 2 wheels and one drive axle with 4 wheels. The trailers were Krone Profi Liner SDP 27 eLB4-CS, i.e. curtain-sided, flatbed, single deck, tri-axle semi-trailers.



Figure 1.3: Trial vehicle Helm03: DAF XF tractor unit with curtain-sided Krone Profi Liner semi-trailer.

<sup>3</sup>HelmUK research project website [click here](#)

## The platooning system

The tractor units were equipped with a prototype platooning system developed by DAF Trucks. The main features of the system included:

**Cooperative Adaptive Cruise Control (CACC)** – the main platooning feature performing automated acceleration and braking. The lead vehicle of the platoon is controlled by the driver, either manually or supported by Adaptive Cruise Control (ACC); the following and trailing vehicles are controlled automatically by CACC to maintain a stable close-following distance. Note that all drivers are responsible for steering the vehicles manually at all times. The CACC system allows minimum vehicle spacings of 0.8 seconds time-headway<sup>4</sup>.

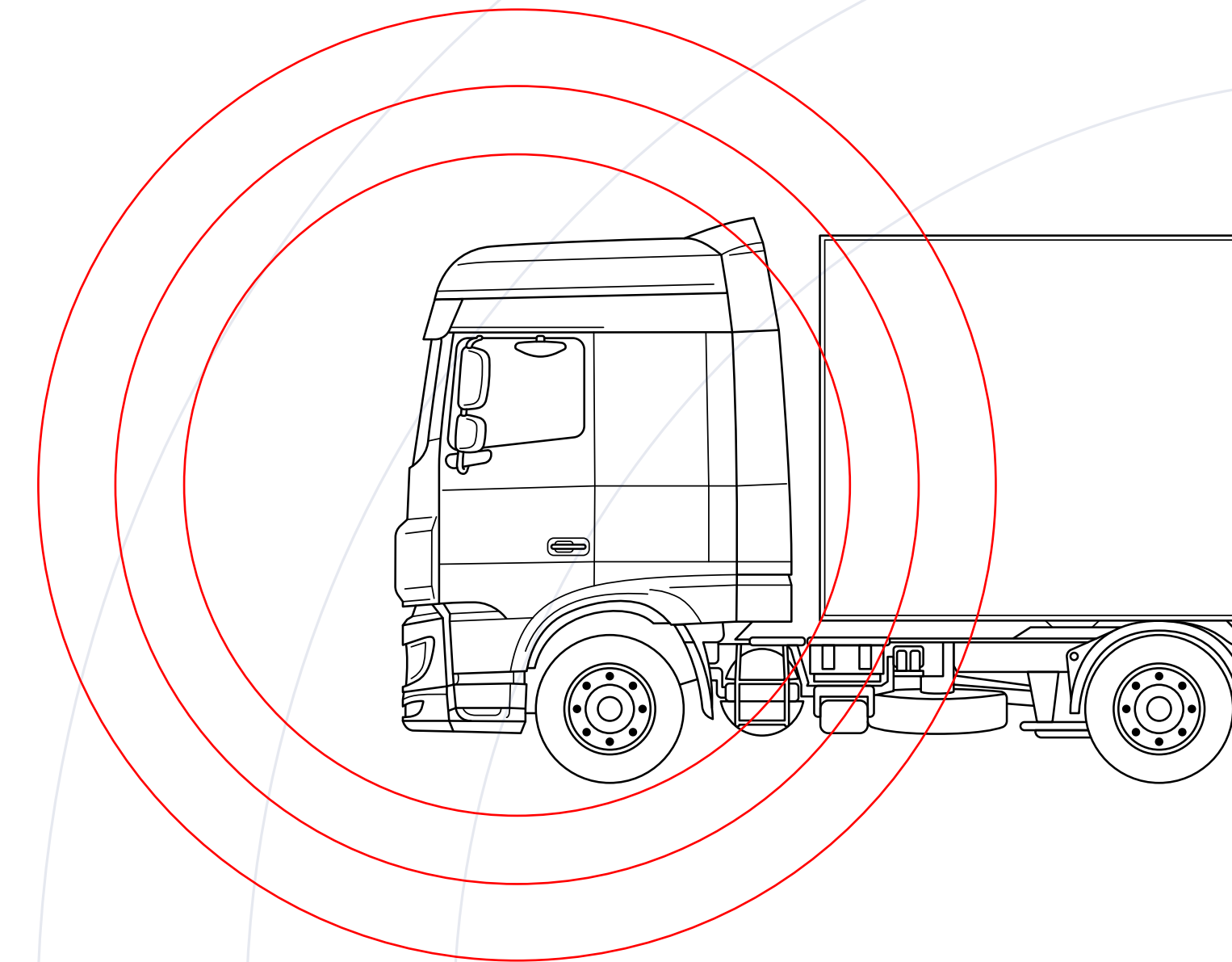
A radar sensor and a short-range vehicle-to-vehicle (V2V) communication link ensure instantaneous reaction to actions of the preceding vehicles with acceleration requests up to  $1\text{m/s}^2$  and deceleration requests up to  $4\text{m/s}^2$ . Passenger cars and larger vehicles cutting-in between platooning vehicles are automatically detected and the gap widened appropriately. CACC in the following and trailing vehicle can be overruled by the driver applying accelerator or brake controls. An audio link allows all three drivers to communicate via headsets for coordination of platoon formation and disbanding.

**Brake Performance Estimator (BPE)** – a feature which uses axle load monitoring systems fitted to the trailers of platooning vehicles to evaluate their relative weight ratios. In case of large weight differences, it automatically enforces larger headways to ensure sufficient space for braking of heavier vehicles. The minimum time-headway of 0.8 seconds can be achieved in all configurations where the following vehicle is half-laden or less, or lighter than the preceding vehicle. If the following vehicle is heavier, the headway is gradually increased. In the most extreme case, fully-laden following unladen, the time-headway is 1.4 seconds.

**Cooperative Collision Avoidance (CCA)** – a feature providing a safety net around CACC. Based on V2V communication and an independent radar sensor, the system rapidly commands emergency braking at deceleration rates up to  $6\text{m/s}^2$  to avoid intra-platoon collisions.

**Platooning Advanced Emergency Braking (PAEB)** – additional emergency braking feature based on a redundant radar sensor. PAEB becomes active in case CCA is not available due to a platooning system error and can command deceleration rates up to  $4\text{m/s}^2$ .

**Lane Keeping Assistance (LKA)** – a driver assistance feature preventing vehicles from veering out of lane. The drivers need to maintain permanent control of the steering, even in platoon formation, but the system actively corrects the steering if lane boundaries are about to be crossed. LKA can be overruled by the driver using the steering control.



<sup>4</sup>Time-headway is the time difference between when the leading vehicle occupies a location and when the following vehicle arrives at this location. A time-headway of 0.8 seconds equates to a spacing of 19.0 metres between the back of the leading vehicle and the front of the following one when travelling at typical motorway speed of 53 miles per hour.



## The road trials and route

The vehicles were driven for over 12,000 miles on a motorway route between Avonmouth (M5, Junction 18) and Stafford (M6, Junction 14) by experienced and operationally-trained drivers. The route measured 109 miles and was travelled in the northbound and southbound direction. It contained a total of 60 junctions (in both directions), of which six were assessed as safe to pass in platoon formation during the trials.<sup>5</sup>

### How representative is the route?

A key feature of the HelmUK route was the number and density of junctions. For the chosen route on the M5 and M6, the average distance between junctions was **5.59 kilometres**.

For motorways in England the average distance between junctions is **5.56 kilometres**, so the HelmUK route is very close to the English average.

For comparison the M1 and M25 are both denser with an average of **5.26 kilometres** between junctions.

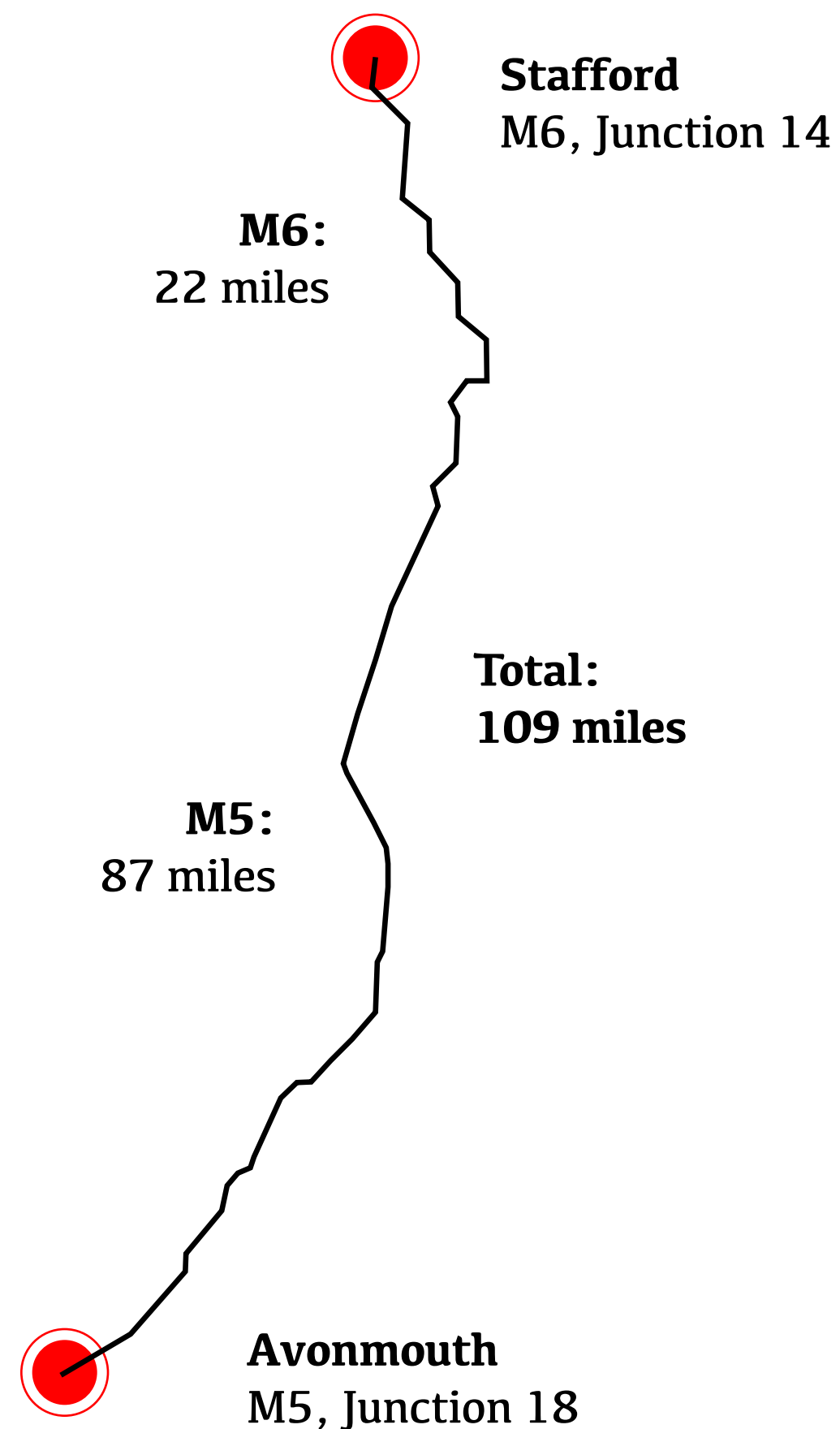
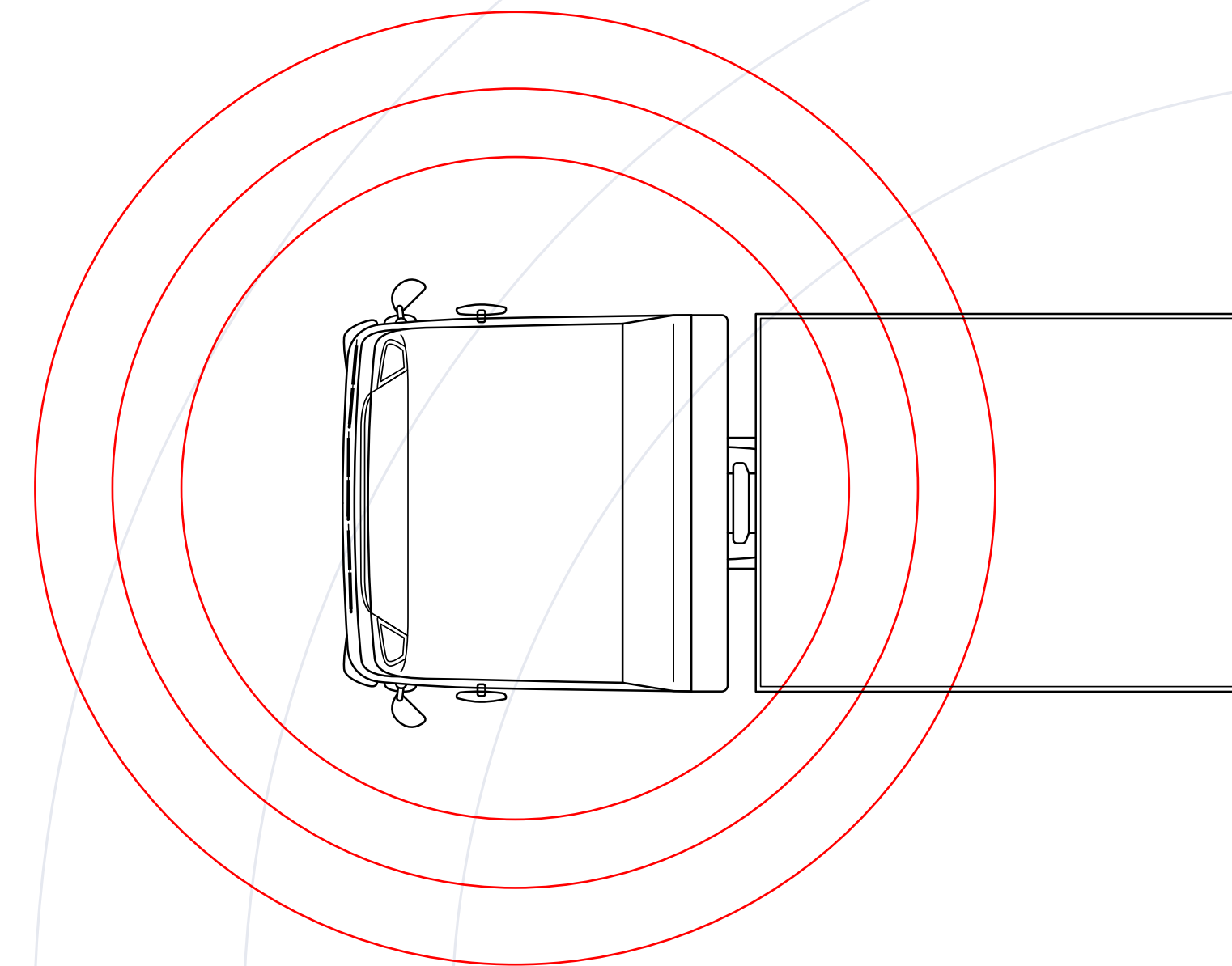


Figure 1.4: Map of the motorway (M5/M6) trial route between Avonmouth and Stafford.



<sup>5</sup>The total junction number counts motorway junctions and connections to services in both directions, i.e. northbound and southbound, and includes the first and last junction at either end. The junction assessment formed part of the Safety Case and considered geometrical factors, such as length of slip roads and curvature, with the aim to mitigate the risk of impeding other road users attempting to merge onto the motorway.

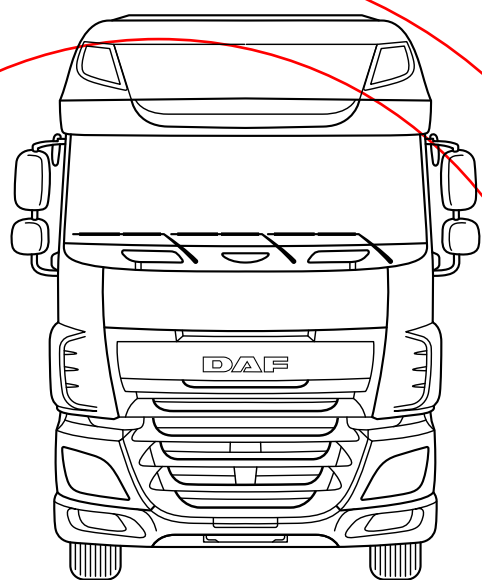




## → 1.4 Research questions

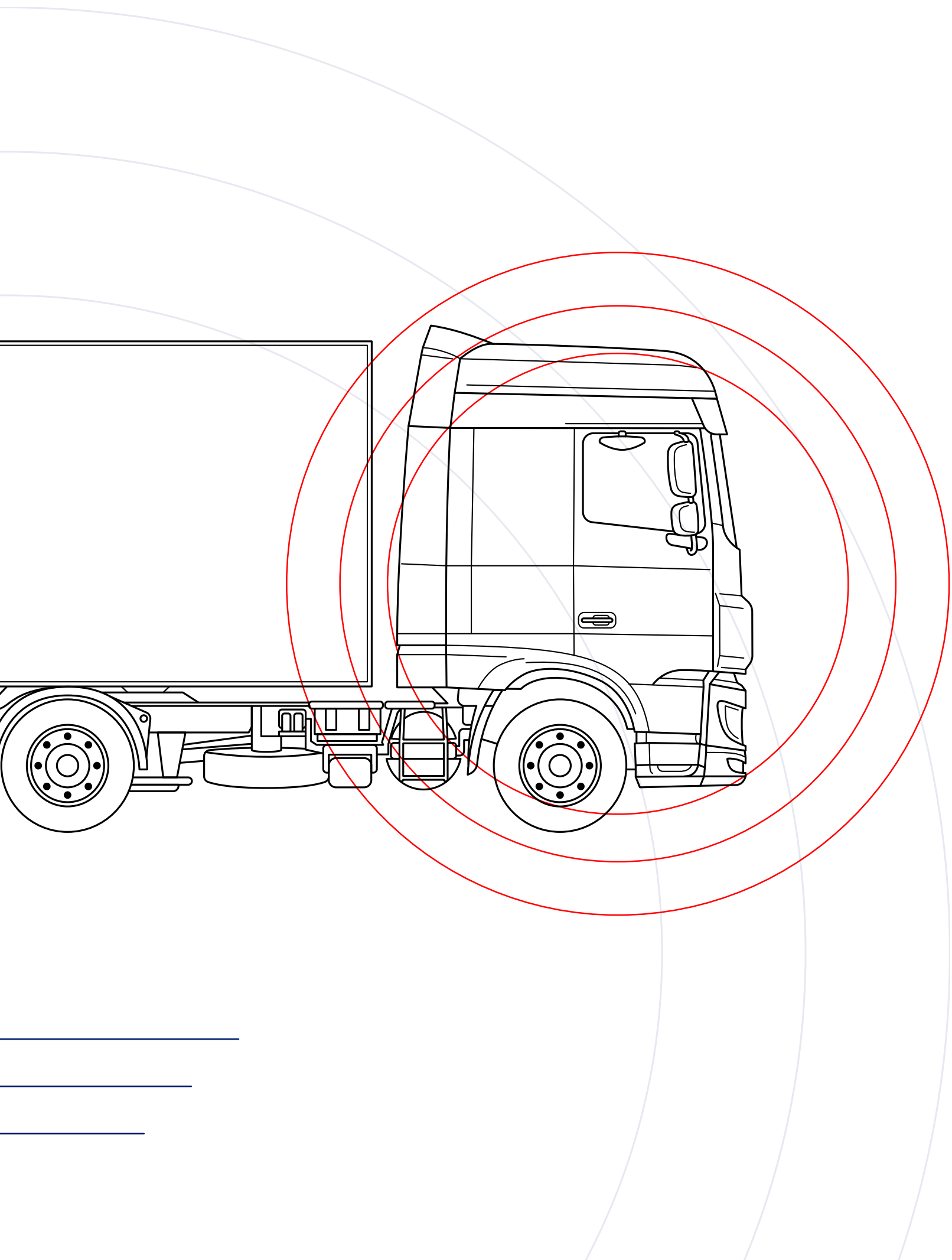
The work covered by the HelmUK programme was subdivided into 19 research questions, as set by the project consortium, and summarised in Table 1.1. They included questions intended to inform later stages of the work, i.e. to allow the road trials to be undertaken, as well as questions covering fundamental aspects such as fuel efficiency and emissions, road and driver safety, impact on the wider SRN, and economic viability.

Key results relating to these fundamental aspects are presented in Section 3. Results from all research questions and wider experience with platooning on UK roads gathered during HelmUK have informed the considerations, conclusions and recommendations put forward in Sections 4 and 5. Note, however, that research questions 3, 4, 8 and 17 were carried out to enable the road trials to be undertaken rather than to create research findings extending beyond the trial.



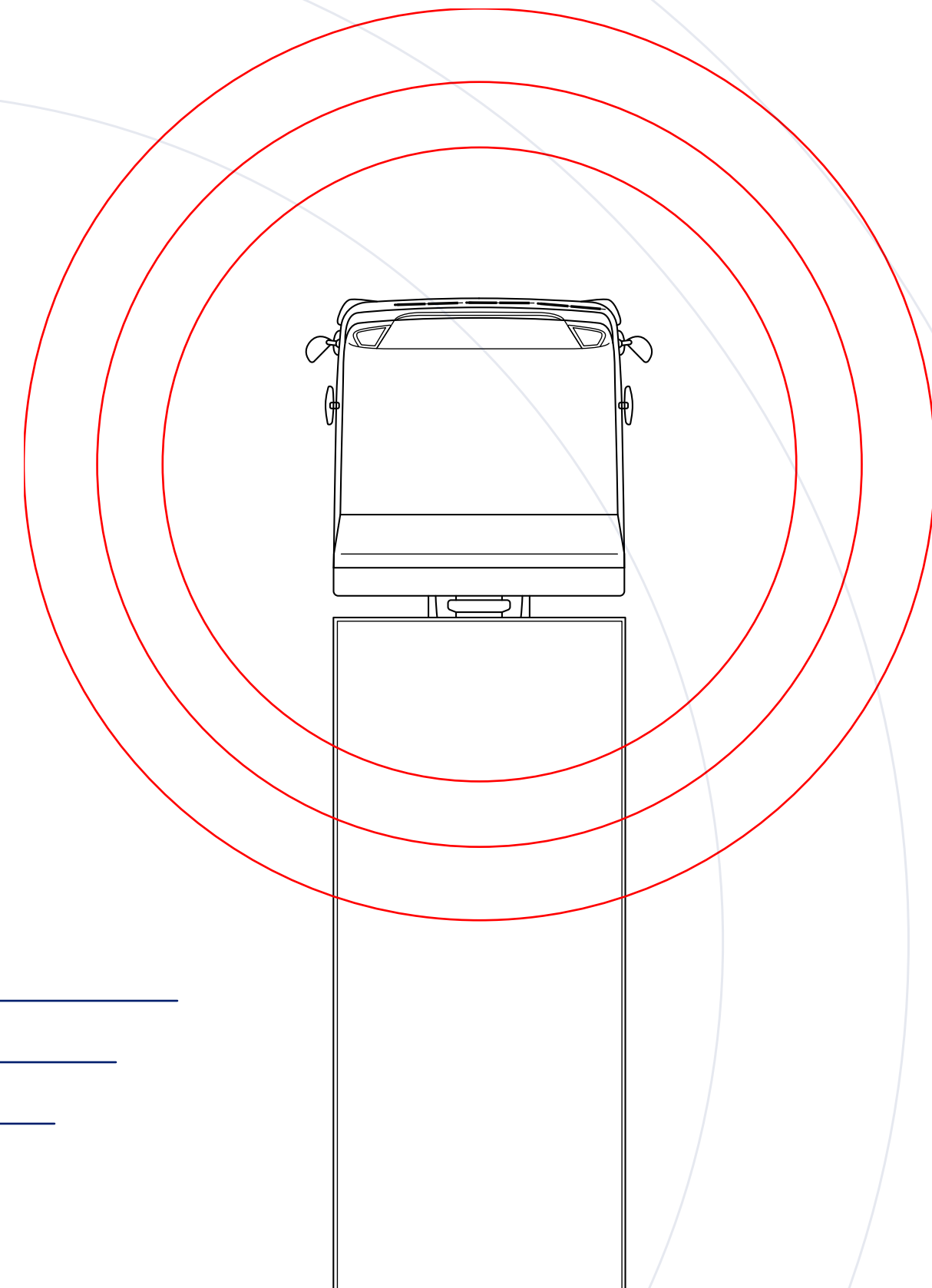
**Table 1.1:** Overview of HelmUK research questions.

No.	Title	Research question objectives	Methods
1	<b>Road safety</b>	Provide an informed opinion on whether operating platoons on motorways and major trunk roads can realise any benefits in terms of casualty reduction on these roads	Analysis of current HGV collisions Analysis of safety proxy data from road trials
2	<b>Effects of the workload on the driver</b>	Understand when workload is highest Understand when particular parts of workload are higher or lower (e.g. effort versus performance) Identify the factors contributing towards workload (e.g. traffic levels, specific joining and leaving options) Interpret how this can affect performance and what can be done to move workload to optimal levels	Statistical analysis of driver workload data from road trials
3	<b>Timing and effects of the transition of control</b>	Understand how HGV drivers interact with the platooning system, specifically regarding the transition of control between driver and system Inform the creation of the trial driver training programme, concentrating on how to effectively and safely use the platooning system	Driving simulator studies using TRL's DigiTruck simulator

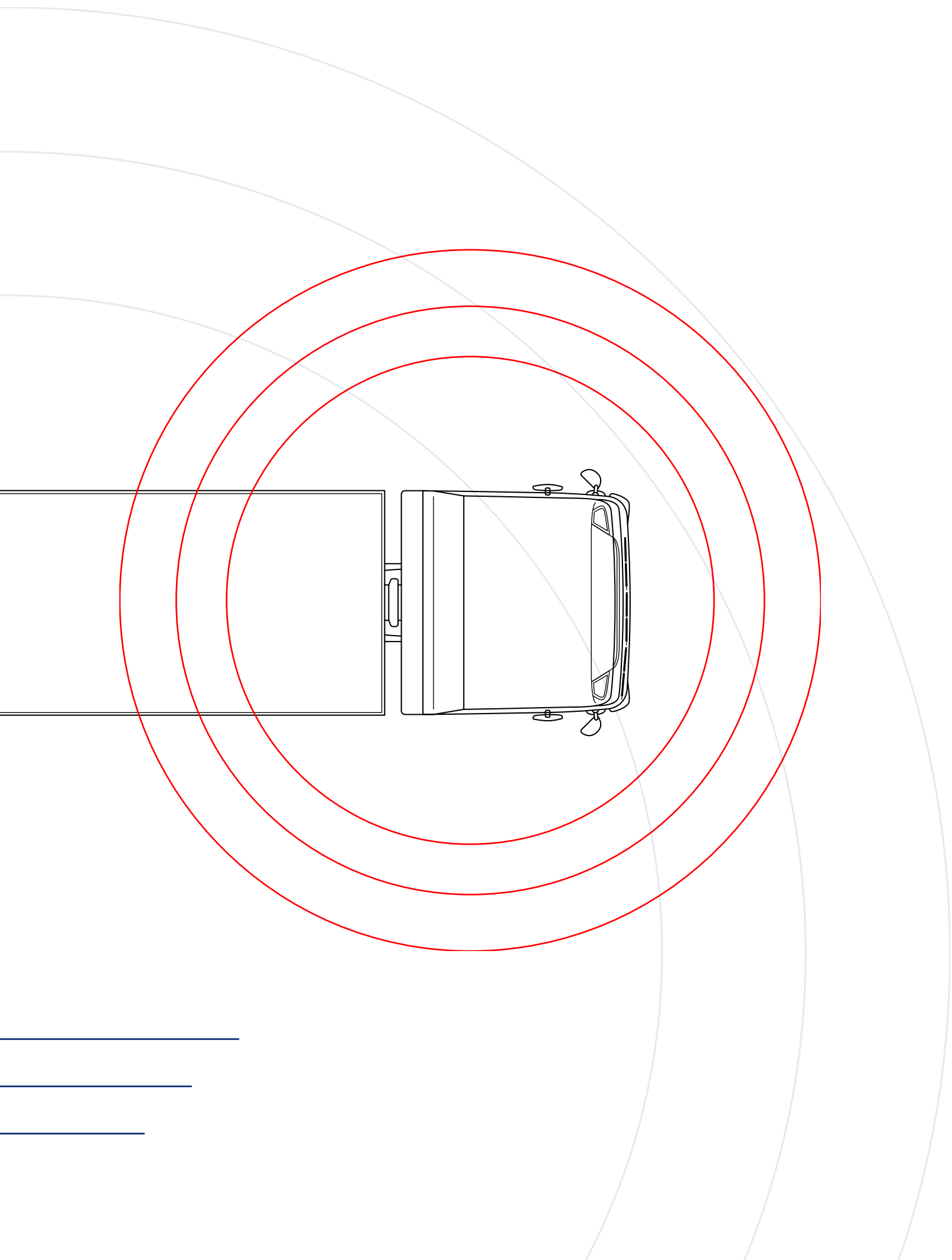


No.	Title	Research question objectives	Methods
4	<b>Effects on attitudes and behaviour of other road users</b>	<p>Understand the behaviour of other road users when they seek to enter a lane occupied by an HGV platoon</p> <p>Inform the development of the HelmUK Safety Case and the safety monitoring plan, in particular regarding junction safety</p>	<p>Driving simulator studies using TRL's DigiCar simulator</p>
5	<b>Ensure that the public are effectively briefed</b>	<p>Evaluate the state of knowledge and opinions that the public have about HGV platooning</p> <p>Ensure that public are effectively briefed in terms of the HelmUK trials and platooning technology</p>	<p>Interviews with HGV drivers and members of the public</p> <p>Social media reviews</p> <p>Creation of project website and frequently asked questions</p>
6	<b>Fuel efficiency, carbon savings and the environment</b>	<p>Quantify the benefits that can be realised in terms of vehicle efficiency and hence fuel consumption reduction for each vehicle in the platoon</p> <p>Calculate the potential carbon savings that can be realised from operating platoons</p> <p>Establish whether data gathered could be used to model the potential reduction in noxious emissions and in specific areas (such as pinch points) whether platoons could improve the air quality, in order to support proposals for future studies</p>	<p>Statistical analysis of fuel consumption data from road trials</p> <p>Vehicle dynamics-based emissions modelling</p>
7	<b>Optimum length of a platoon in the UK</b>	<p>Provide guidance on the optimal number of vehicles in a platoon for UK roads in order to balance benefits and disbenefits of longer platoons</p>	<p>Desk-based cost-benefit analysis drawing on risk assessments and expert opinion</p>



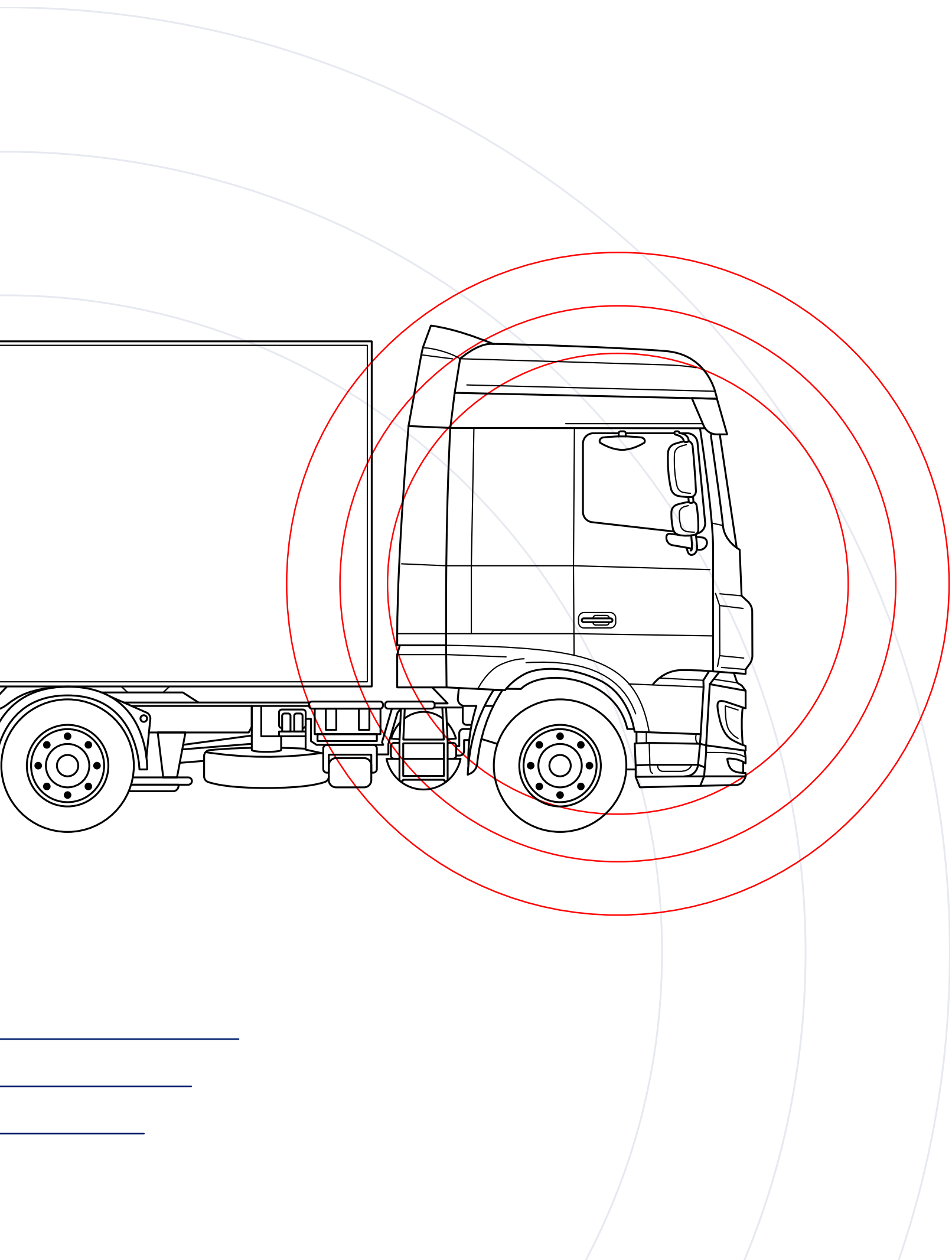


No.	Title	Research question objectives	Methods
8	<b>Procedures for running platoons</b>	<p>Develop platoon operating procedures for the road trials</p> <p>Inform the development of the HelmUK Safety Case</p>	<p>Stakeholder engagement</p> <p>Desk-based analysis</p>
9	<b>Ramp metering upgrades</b>	<p>Evaluate the effects of, and possible changes required for platooning</p> <p>Provide recommendations as to what upgrades would be needed to ramp metering, a traffic management technique, and in what conditions (platoon length, junction layout etc.)</p>	<p>Desk-based analysis and expert opinion</p>
10	<b>Reduced sight lines and visibility of road signs</b>	<p>Research the effects of potentially reduced sight lines and visibility of road signs, particularly for other road users but also for mid-platoon and trailing drivers in the platoon</p> <p>Propose which mitigating actions may need to be taken for operational purposes to inform the HelmUK Safety Case</p>	<p>Simulation using TRL's Motorway Obscuration Assessment Tool</p>
11	<b>Real time management of traffic flow</b>	<p>Determine the effect of platoons on traffic</p> <p>Investigate whether real time management of traffic flow can be used to inform platoon operation or vice versa</p> <p>Provide recommendations for potential interventions and assess their feasibility and benefits</p>	<p>Desk-based analysis and expert opinion based</p>



No.	Title	Research question objectives	Methods
12	<b>Effects on the road network</b>	Investigate the effects of the platoon on the road network, paying particular attention to what procedures need to be followed to negotiate junctions safely, whether certain routes are more suitable than others and whether the time of day makes a significant difference	Analysis of video data captured during the trials Analysis of traffic flows at junctions during the trials Desk-based analysis
13	<b>Impact on how traffic is managed</b>	Investigate what impact platoons have on how Regional Operations Centres (ROCs) and the National Traffic Operations Centre (NTOC) manage traffic on motorways and major A-roads Identify where existing network managing agencies' procedures and information transfer might be improved	Semi-structured interviews with ROC and NTOC staff Desk-based analysis
14	<b>Implications of road operators becoming platooning service providers</b>	Investigate potential positive and negative implications of road operators (such as National Highways) operating as platooning service providers Identify requirements that would be necessary to deliver platooning service provision	Stakeholder engagement Desk-based analysis
15	<b>Impacts on the performance of road infrastructure</b>	Assess the potential impacts of HGV platooning on flexible asphalt pavement performance in the UK Identify knowledge gaps that have not been addressed in the current state of practice	Desk-based analysis using data from National Highways' Pavement Management System (HAPMS) and expert judgement



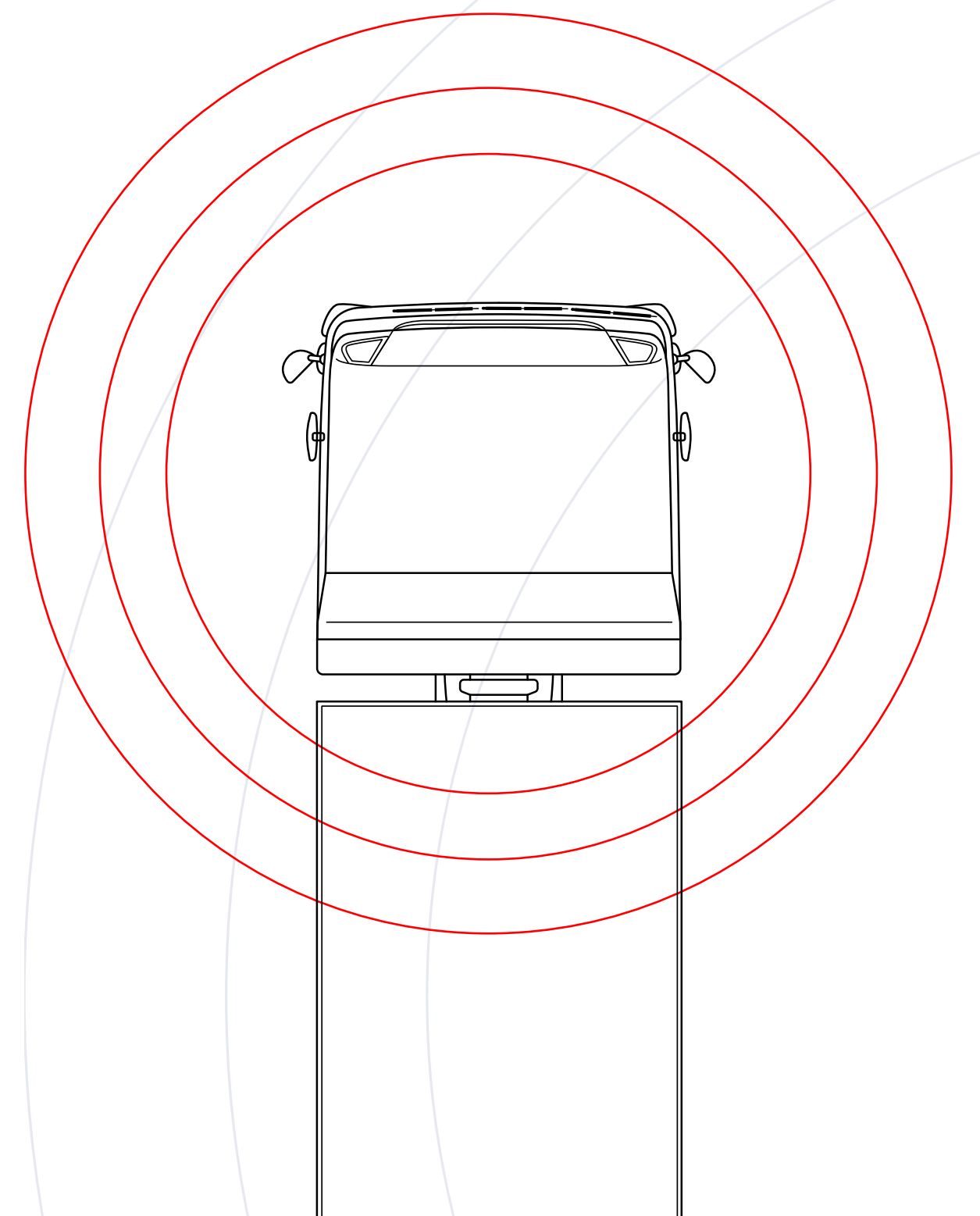
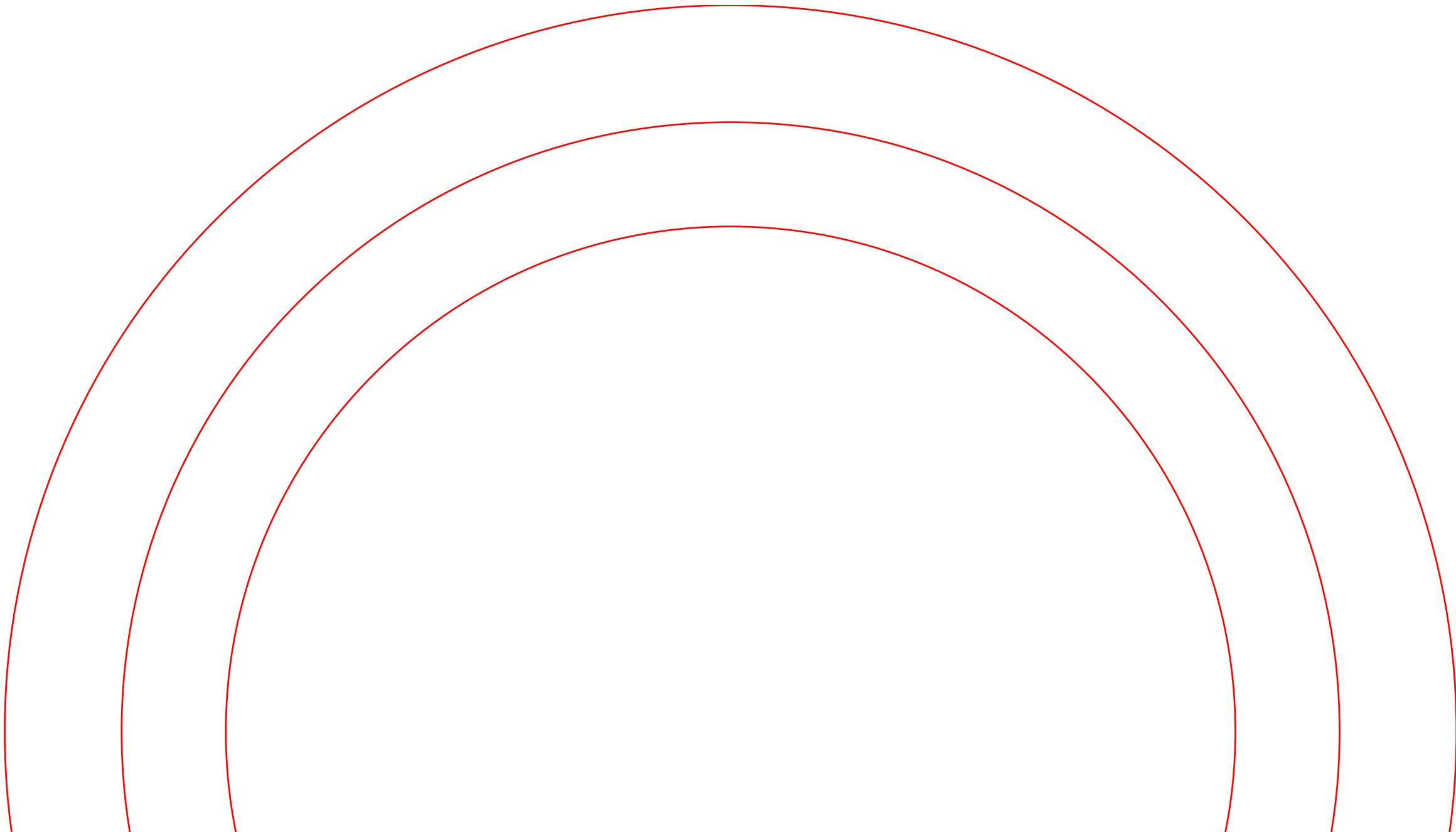


No.	Title	Research question objectives	Methods
16	<b>Economic impact assessment</b>	<p>Determine the potential for platooning across a range of industry sectors</p> <p>Provide an informed view of the operational opportunities and risks associated with platooning</p> <p>Quantify the potential economic costs and benefits of widespread implementation of platooning on the SRN</p>	<p>Semi-structured interviews with freight industry stakeholders and HGV drivers</p> <p>Calculations using a spreadsheet-based cost-benefit model with inputs from road trial results and other data sources</p>
17	<b>Cyber security risk analysis</b>	<p>Ensure that the trial vehicles are adequately secured against the possibility of a cyber-attack, and that suitable mitigations are in place should one be attempted</p> <p>Inform the development of the operational procedures for the trial and the HelmUK Safety Case</p>	<p>Risk analysis of the platooning system</p> <p>Engagement with vehicle manufacturer and suppliers</p> <p>Desk-based analysis</p>
18	<b>Impact on vehicle maintenance</b>	<p>Analyse whether the damage found on platooning vehicles is different to those found on non-platooning journeys</p> <p>Investigate whether maintenance and inspection intervals for platooning vehicles could be more or less frequent than non-platooning vehicles</p>	<p>Analysis of daily walk around forms from road trials and planned and unplanned vehicle maintenance records</p>
19	<b>SRN model</b>	<p>Develop a computer model that allows determining the 'platoonable' proportion of the Strategic Road Network</p>	<p>Model implementation using Python</p>

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## → 1.5 Acknowledgments

TRL would like to acknowledge the numerous stakeholders who contributed their time and effort to support the project consortium in this research. This included the trial drivers, the National Safety Control Review Group, the independent assessor from Cranfield University and the HelmUK Advisory Group, formed of representatives from the AA, ACEA, Brake, British Motorcyclists Federation, Bosch UK, BP, Campaign for Better Transport, Freight Transport Association, Health and Safety Executive, Metropolitan Police, National Cyber Security Centre, National Infrastructure Commission, PACTS, Peloton, Road Haulage Association, SMMT, Thatcham and Transport Focus. Thank you.





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# HelmUK road trials





# 2. HelmUK road trials

## 2.1 Phased approach

The HelmUK project ran between 2017 and 2022 and consisted of three phases:

**Phase 1 (August 2017 to March 2020<sup>8</sup>): Detailed planning, design and build** – the development and validation of the DAF platooning system and TRL Safety Case including driver training and track trials

**Phase 2 (October 2020 to August 2021): Network familiarisation** – on-road operation on the approved route. The initial phase of system validation was carried out by DAF UK drivers under TRL trial management. After successful completion, DAF issued the customer field trial road release for the platooning system

**Phase 3 (September 2021 to March 2022): Road trials** – real-world trials and data collection followed by data analysis and final reporting.

## 2.2 Preparation for on-road operation

In order to run real-world trials of platooning technology on the SRN, there were a number of key inputs required to ensure that this could be conducted safely while meeting the objectives of the project. Each phase of the project built on the previous phase to develop a comprehensive approach to platooning road trials. Figure 2.1 provides an overview of the key requirements for the development of the road trials.

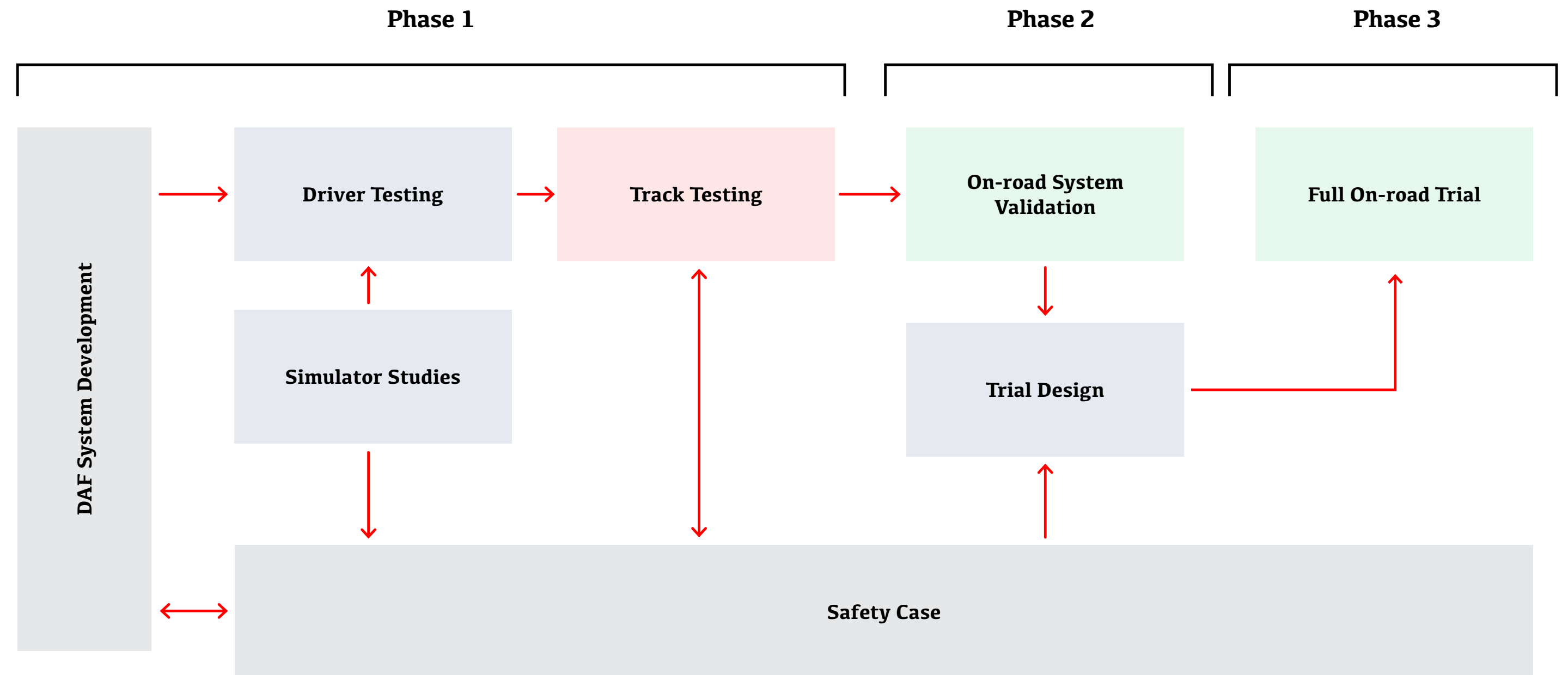


Figure 2.1: Key requirements for road trials.

<sup>8</sup> The project was paused from March to October 2020 due to global COVID-19 pandemic and UK government restrictions. Further information is available in Section 2.8.



## → 2.3 Safety Case

TRL was responsible for ensuring safety throughout the platooning road trials and produced the HelmUK Safety Case based on an operational risk assessment in line with the National Highways GG104 standard: Requirements for safety risk assessment<sup>9</sup>. This overarching risk assessment was supported by cut-in and collision risk analysis, safety assessments of the trial route and junctions, cyber security assessments, simulator trials, and a research ethics assessment. DAF supported this exercise by undertaking design, build, verification and validation of the platooning system.

The overall safety objective was to ensure that all elements of the trials were safe and that all potential risks to affected parties throughout the lifecycle of the trials were identified, managed and minimised so that they were as low as reasonably practicable (ALARP) and were at a level acceptable to National Highways, DfT and other stakeholders. Two safety governance groups, the Project Safety Control Review Group (PSCRG) and the National Safety Control Review Group (NSCRG), were consulted for this project to meet the requirements in the National Highways GG104 standard. Key safety documentation was reviewed and accepted by both groups. The PSCRG also reviewed and accepted the full HelmUK Safety Case.

Cranfield University acted as independent assessors for HelmUK. Their primary role was to review the work done by the project consortium and provide impartial technical advice to DfT on the matters of trial safety and research. Representatives from Cranfield University also participated in PSCRG meetings to discuss aspects of trial safety and in TRL's Research Ethics Committee meetings. At the assessors' recommendation in the ethics assessment, TRL implemented a whistleblower policy to allow those involved in HelmUK to raise potential safety concerns without fear of negative consequences for the individual.

The **key system controls** implemented for the trials were:

**Platooning system design** – the safety critical and nominal functionality of the system was assured by DAF by following the ISO 26262<sup>10</sup> standards and their own internal road release procedure. A number of integrated systems, CACC (with cut-in detection and brake performance estimator), CCA, AEB, and LKA, were designed to achieve safe operation and response in safety critical scenarios.

**Safety verification and validation** – DAF implemented and completed a safety testing regime following their existing in-house procedures for customer field trial vehicles, involving elements of simulation, track tests and on-road trials. This process showed that safe platooning was possible at a minimum time-headway of 0.8 seconds, but, due to variability in brake performance of the articulated combinations, shorter spacings of 0.5 seconds, as initially envisaged, could not be realised safely. Active lifecycle management by DAF was in place, to continuously manage requirements, test cases and software releases for the platooning system. To confirm an adequate approach and testing coverage as well as satisfactory results, TRL reviewed test plans, test records and test reports.

Furthermore, TRL undertook an independent track test programme, which highlighted that the automatic detection of vehicle cut-ins was not sufficiently reliable, in particular in the case of motorcycles. As such, operational responsibility for managing vehicle cut-ins was placed on the driver with the system response acting as a fall-back measure only. With these controls in place, the verification and validation results were found satisfactory to ensure a safe trial at 0.8 seconds minimum time-headway.

<sup>9</sup> GG104 standard: [Click here](#) to visit website.

<sup>10</sup> ISO 26262 Road Vehicles – Functional Safety.



Figure 2.2: Platooning formation at 0.8 seconds time-headway during Safety Case validation on UK test track and on-road.



The **key operational controls** implemented in line with the HelmUK Safety Case were:

**Route selection** – a risk assessment of the motorway route from Avonmouth to Stafford was performed, including a detailed assessment of the hazardous features on the route. This process included: a desk-based review using National Highway’s Asset Visualisation and Information System (AVIS) and Google Maps Street View, consultation with Traffic Officers to understand local hazards and behaviours, and route drives with a car and an HGV to verify consultation findings and receive feedback from the trial drivers on the assessment. The route was found to be adequately safe for the trials and the assessment results have informed operational guidance and training given to drivers.

**Junction selection** – it was considered that road users may have more difficulty merging into lane one from an entry slip lane due to the platooning vehicles. Further assessment has been conducted, in particular of possible merge speeds based on infrastructure characteristics, to identify junctions considered to present a tolerable level of risk to all affected parties when platooned through.

Six suitable junction entry slips along the route were identified; before all other junctions, the platoon had to disband. Junction exits were considered lower risk than entries and did not warrant detailed investigation. However, the risk decision was made to disband before the exit slip road rather than beside it for any ‘non-platoonable’ junctions. Platooning past exit slip roads of ‘platoonable’ junctions was considered tolerable. The junction selection methodology is expanded in Section 2.4 below.

**Operational procedures** – a suite of operational guidance documents was developed for both drivers and trial managers to capture all the operational decisions that have been made on the project to reduce risk, including safety and cyber security aspects, and to ensure full clarity on how the trials should operate.

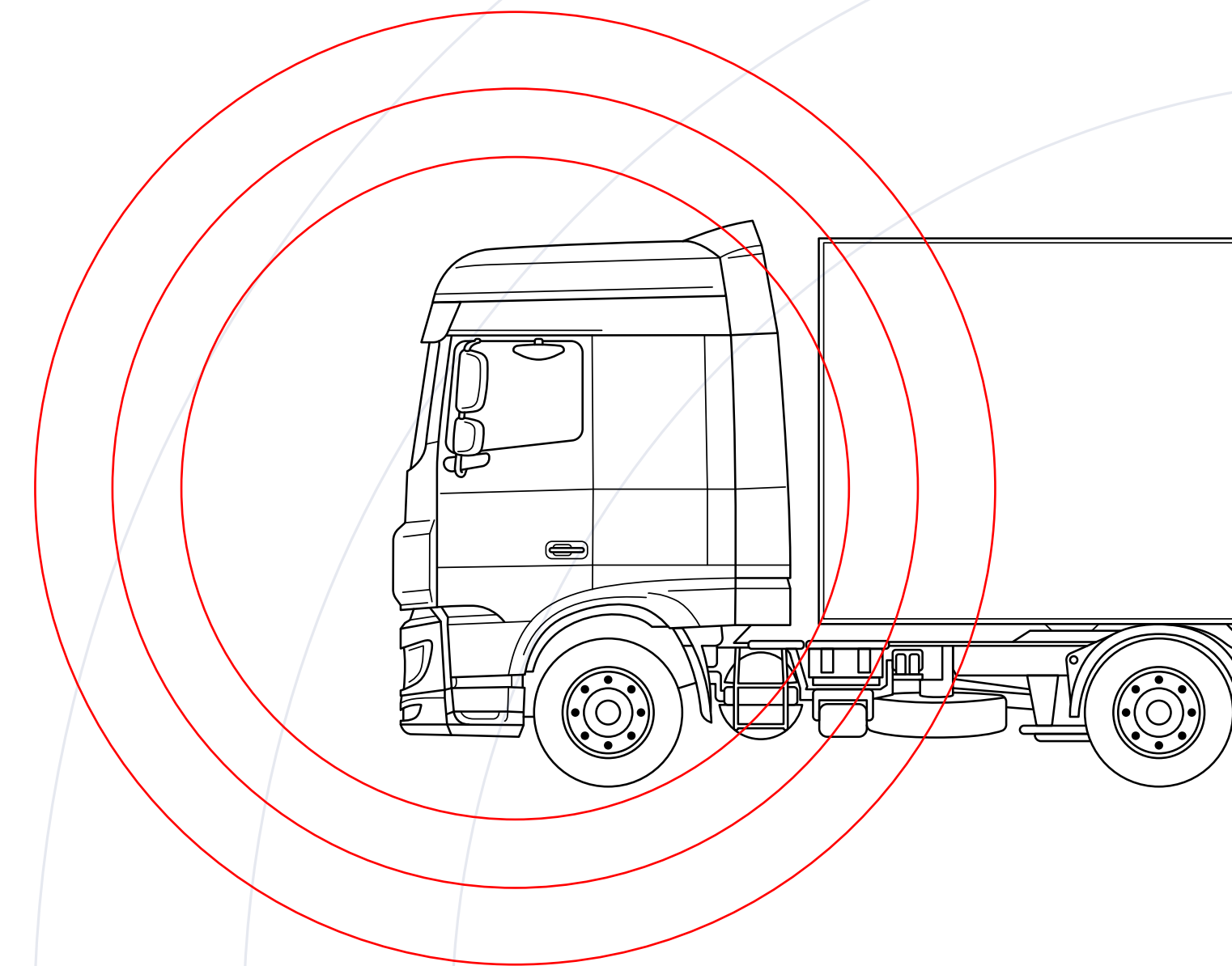
**Driver selection and training** – experienced drivers were selected to participate in the trials. All drivers completed a comprehensive training programme before commencement of platooning on the road.

**Phased approach** – as the platooning technology used in HelmUK was new and previously untested on UK roads, the trials were designed to progressively build up the body of evidence required to inform risk decisions and to increase confidence in the ability of the technology to operate safely.

**Driver fatigue and distraction management** – drivers were monitored throughout the trials for signs of fatigue using a driver facing camera, which can automatically identify actions and expressions that indicate potential driver fatigue. Furthermore, operational guidance was in place to ensure that drivers took sufficient breaks.

**Safety monitoring plan** – daily monitoring was conducted to capture lessons learned from trialling as well as incident data and take an informed go/no-go decision before each trial day based on the latest available information (see Figure 2.8, page 42).

Due to the proper application of the **system** and **operational controls** listed above, and considering the low exposure of the platoon vehicles on-road, the risks posed by the trial were considered to be both ALARP and Globally At Least Equivalent (GALE) to the risk posed currently on the English SRN. This decision was agreed and accepted by PSCRG and NSCRG. Cranfield University’s independent assessors recommended to proceed with the HelmUK road trials.





## → 2.4 Junction selection methodology

The Safety Case for HelmUK is summarised in Section 2.3; this section expands on the approach to junction selection as part of the Safety Case development. This is because junction selection plays a key role in the discussion of HelmUK's results in the conclusions and recommendations (see Section 5).

Four options were considered to manage the risk at junctions:

**Disengaging platooning at all junctions** – this was not chosen as it would not allow research data to be collected on platooning at junctions.

**Temporary increase in headway** – the increase was small and would still present a risk to merging vehicles.

**Allowing the driver to make their own assessment at each junction** – by the time the platooning drivers were able to make a decision to widen the gap to allow safe merging it was judged to be too late for the gap to widen to safe headways for most junctions.

**Platooning through only selected junctions** – this option was chosen for the HelmUK trials as it presented the lowest risk which can reasonably be achieved.

The chosen option required an assessment of each junction on the approved route. Each junction type was assessed for its platooning suitability. Broadly speaking, parallel and taper merge junction types are suitable for platooning; see Appendix B: Junction type classification for a full breakdown of junction types.

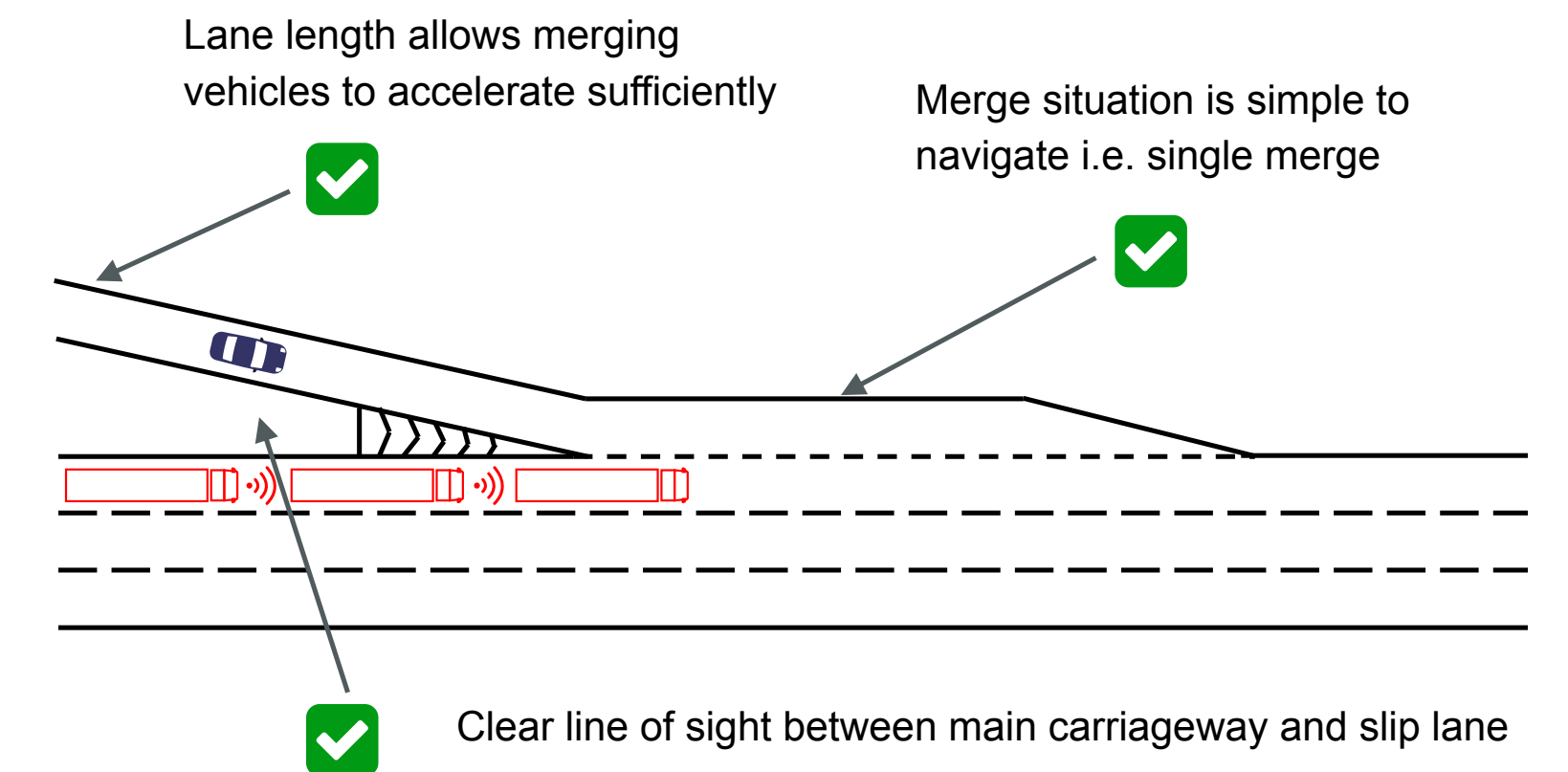
A calculation was carried out to estimate the worst-case merge speed at each junction on the route. Junctions where a merging vehicle would have to slow more than the worst-case merge speed without platooning were ruled out; this was equivalent to a 255 metres available distance for merging. Based on this calculation alone, 15 junctions out of 60 were deemed to be 'platoonable'.

Qualitative factors were also reviewed, including:

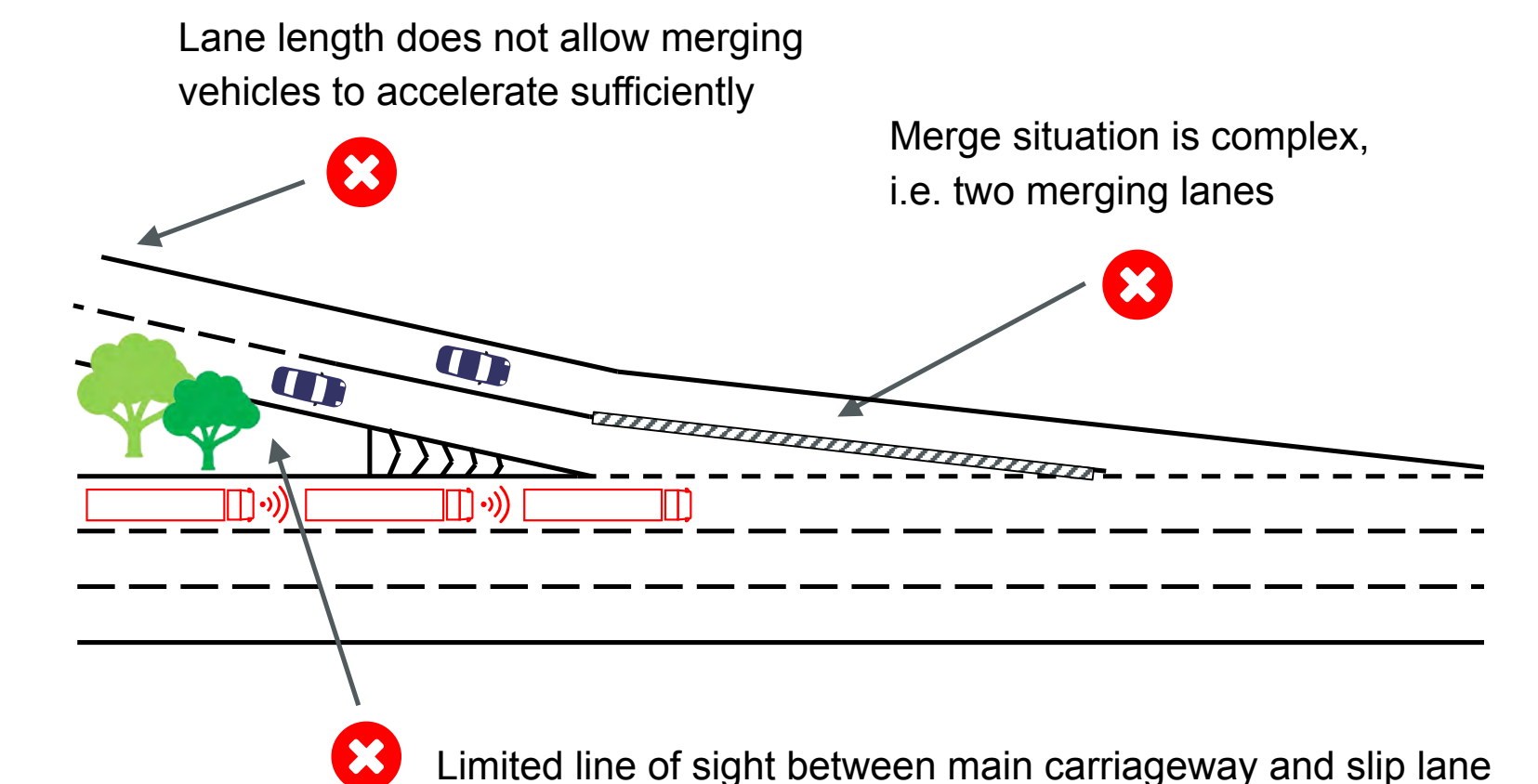
- Whether merging vehicles will have a reasonable opportunity to accelerate before reaching the slip road
- Whether sight lines are adequate
- Whether there are unusually complex features e.g. a merge followed immediately by a diverge
- Whether a suitable hard shoulder or other overrun area exists in case vehicles cannot complete the merge
- Traffic Officer feedback was also sought and taken into account.

Once qualitative factors are considered, the final number of 'platoonable' junctions reduced to 6 junctions out of 60.

Junctions most suited to current generation platooning technology will have the following features:



Junctions **less** suited to current generation platooning technology will have the following features:



## → 2.5 Road trials design

The design for the Phase 3 road trials was built on the project objectives as shown in Figure 2.3.



Safely conduct an on-road trial of platooning



Gain insights into the real-world effects of platooning



Gather a comprehensive dataset for research

Figure 2.3: Key objectives of road trials.

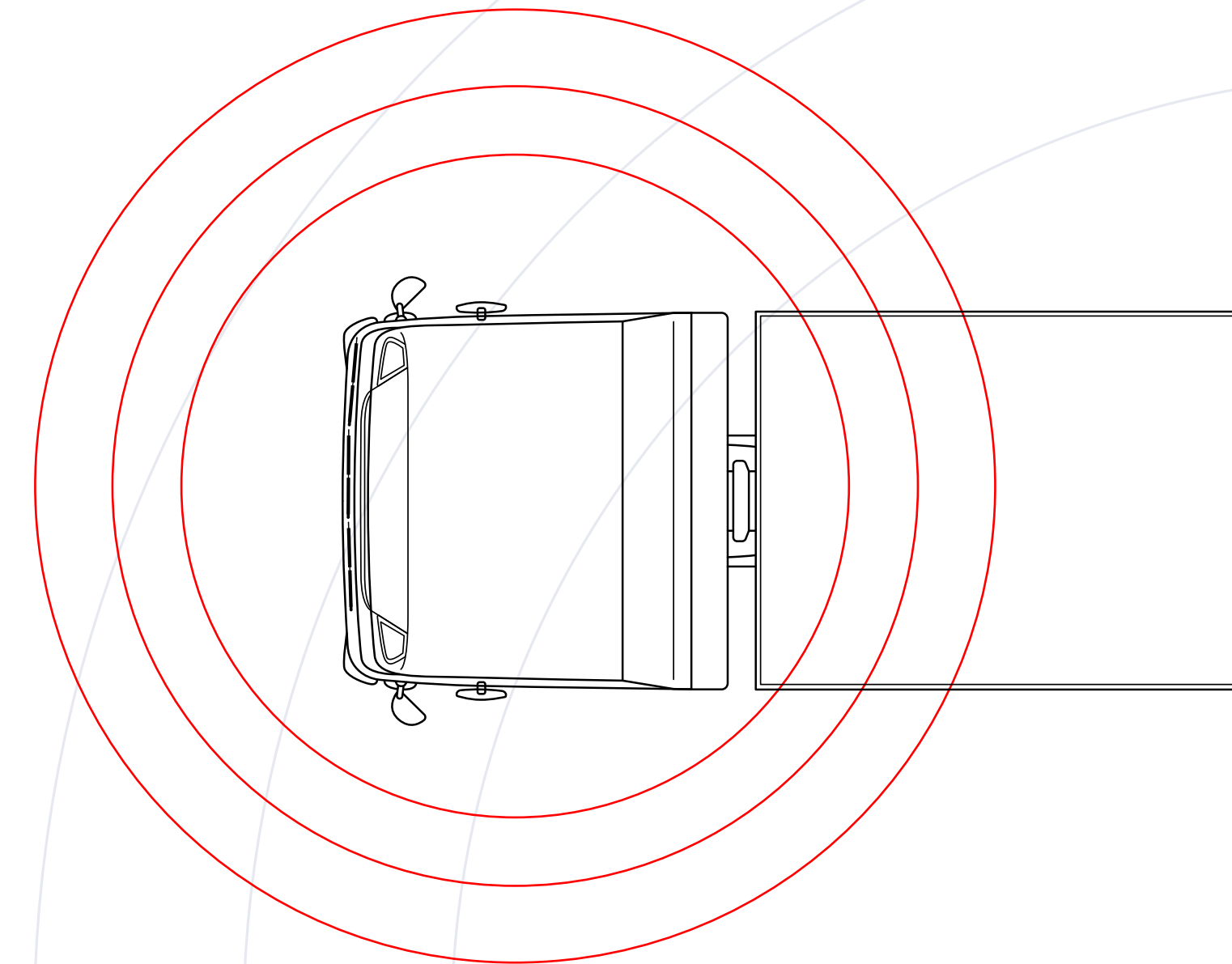
The design of the road trials needed to balance the requirements of a wide range of research questions and data sources to achieve those objectives. The key considerations when designing the trials were:

- Enabling a comparison between platooning and non-platooning operation
- Maximising data consistency in real world conditions
- Ensuring the trials remained safe.

### Comparison between platooning and non-platooning

The main element which was deliberately changed during trials was whether platooning functionality was used for a journey. This was varied per day, so a trial day was either 'platooning' or 'non-platooning'. On a 'platooning' day, platooning operation was permitted where the drivers deemed it safe, and where it was permitted by the Safety Case, i.e. the vehicles did not spend all the time on a platooning day in platooning operation.

This was compared with non-platooning operation. On these days the drivers were encouraged to drive as they normally would. The vehicles travelled together and made use of all the driver assistance systems on the vehicle such as Adaptive Cruise Control (ACC). It was considered in the trial design if use of ACC should be discouraged. It was decided that this would provide an unrealistic comparison between platooning and non-platooning and limit the insights for the future of platooning in the UK. Therefore, the non-platooning baseline was set using new HGVs equipped with ACC and drivers were encouraged to drive as they normally would.





### Fixed parameters

A number of variables were controlled during the trials in order to give consistency to the data. The variables kept constant were:

**Number of trial vehicles** – there were three tractor units outfitted with platooning equipment and there were always three vehicles in the platoon

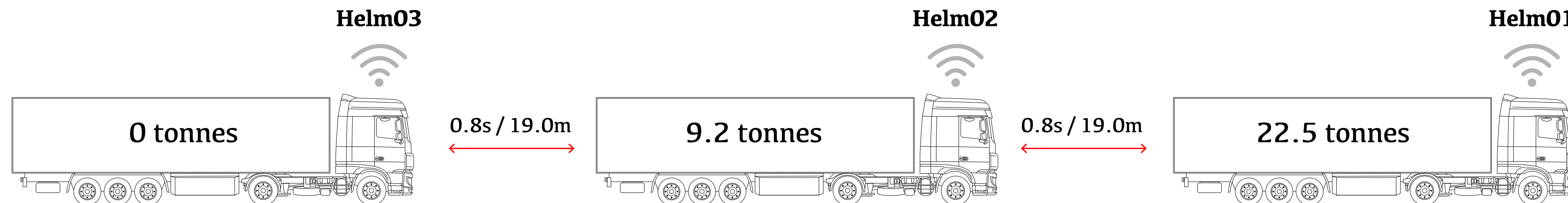
**Position of the vehicles in the platoon** – Helm01 always led followed by Helm02 and Helm03

**Vehicle load** – each vehicle was loaded so that the combined gross combination weight of the entire platoon represented the average UK load carried by comparable vehicles on domestic freight journeys.

The loads were kept constant throughout Phase 3:

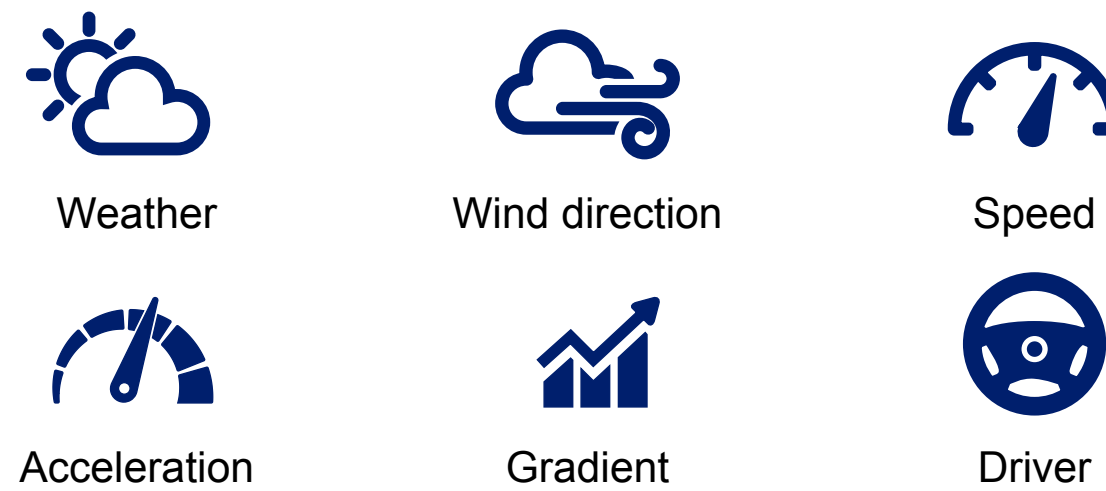
- Helm01: 22.5 tonnes / 37.2 tonnes (payload / gross combination weight)
- Helm02: 9.2 tonnes / 23.9 tonnes
- Helm03: 0 tonnes (unladen) / 14.7 tonnes

### Demonstration of the fixed parameters



### Variable parameters

HelmUK's core aim was to conduct trials in a real-world setting. Therefore, there were a number of variables which could not be controlled for during the trials, but which can be controlled when analysing the data. These included:



The route was largely oriented in north-south direction. The prevailing wind direction during the road trials was from the south-southwest at Staverton weather station (nearer the south of the route), and from the west at Birmingham weather station (nearer the north of the route). The average wind speed was between 3 and 4 metres per second (approximately 8 miles per hour).

### Duration and statistical significance

Phase 3 aimed to collect around 30 days of on-road data; the number of days planned on-road was greater than 30 to provide contingency. To compare the modes of operation the trials targeted an equal number of platooning and non-platooning days. A break point was agreed approximately halfway into the trials where the statistical significance of the fuel benefit data was examined to determine if any change to the duration of the trials was needed.

The interim statistical test on the fuel consumption data showed small differences between platooning and non-platooning days at the overall journey level (this is discussed further in Section 3.1 – Fuel Consumption). This small difference meant that to achieve 95% confidence in the difference between platooning and non-platooning would have required thousands of journeys which was beyond the scope of the HelmUK project. The original target of 30 days remained the focus for data collection and a larger emphasis on statistical modelling was required for data analysis.

## 2.6 Data sources

HelmUK's research relied on data captured by several systems during the trials. This section describes the key sources of data for the project which were scoped and procured as part of Phase 1 of the project.

### 2.6.1 VisionTrack video telematics system

VisionTrack is an integrated camera and vehicle telematics platform. This platform is accessed via a desktop application and shows the position of the vehicles and the camera feeds in real time. The HelmUK team used the platform for day-to-day trial management. Recorded footage can also be reviewed using this platform, which was critical for safety assurance and research. The key features of the VisionTrack video telematics system are shown in Figure 2.4 below.

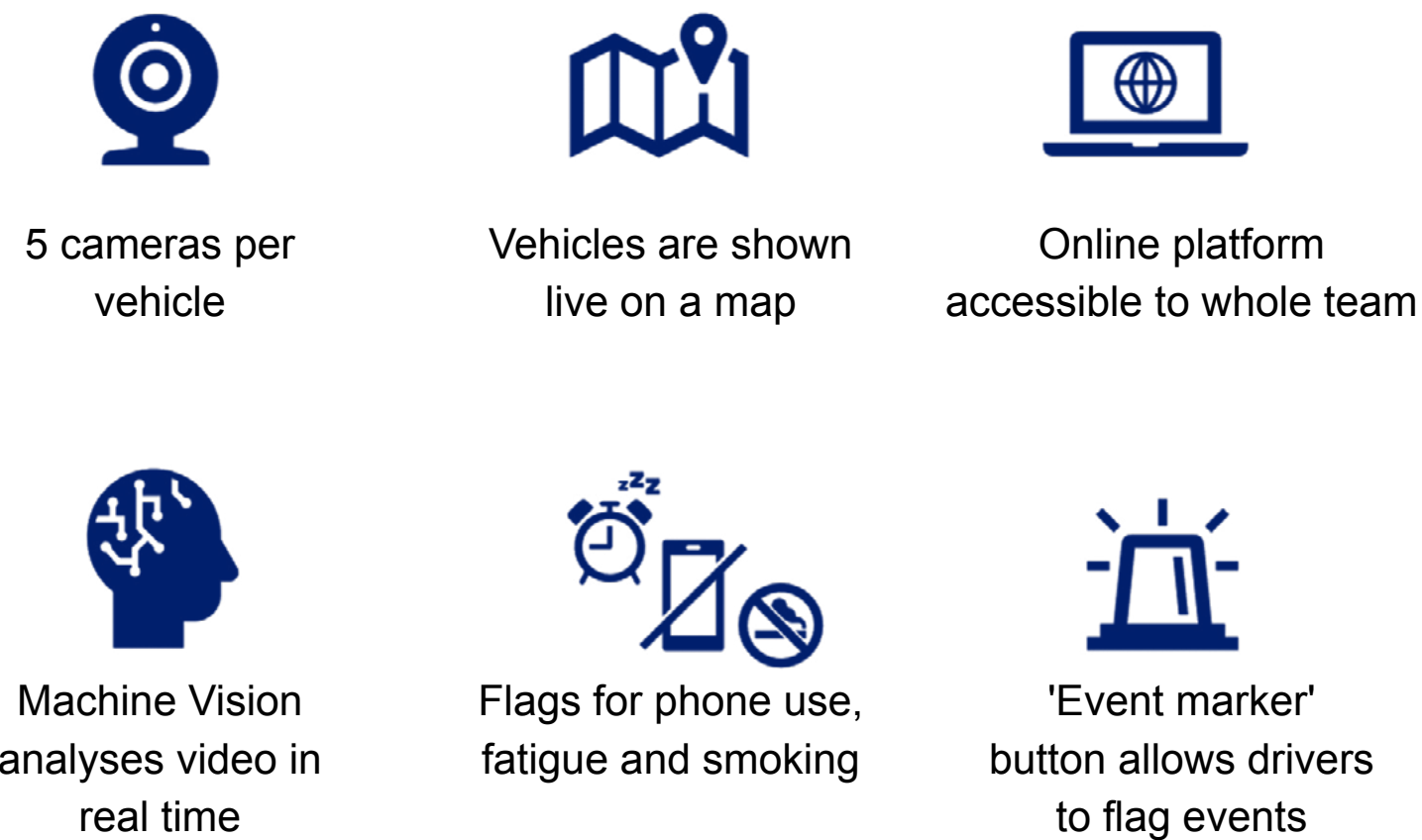


Figure 2.4: Key features of the VisionTrack platform.

VisionTrack captured all of the video data for HelmUK and its principal use was in daily safety monitoring activities, where any flagged incidents could be reviewed using this video footage. An example of the VisionTrack interface is shown in Figure 2.5. The key data from VisionTrack was:

**Video data for all three vehicles** – from five cameras per vehicle with forward facing, rear facing, left side, right side and driver facing views. This data was used for incident review and safety monitoring as well as research data.

**Event marker button presses** – these allowed the drivers to mark events, while driving, by pressing a button on the dashboard. These events were then reviewed daily by the safety team.

**Driver behaviour flags** – these are generated by VisionTrack using the driver facing camera. The flags which were reviewed each day for this project were smoking, phone use and lane departure warning.

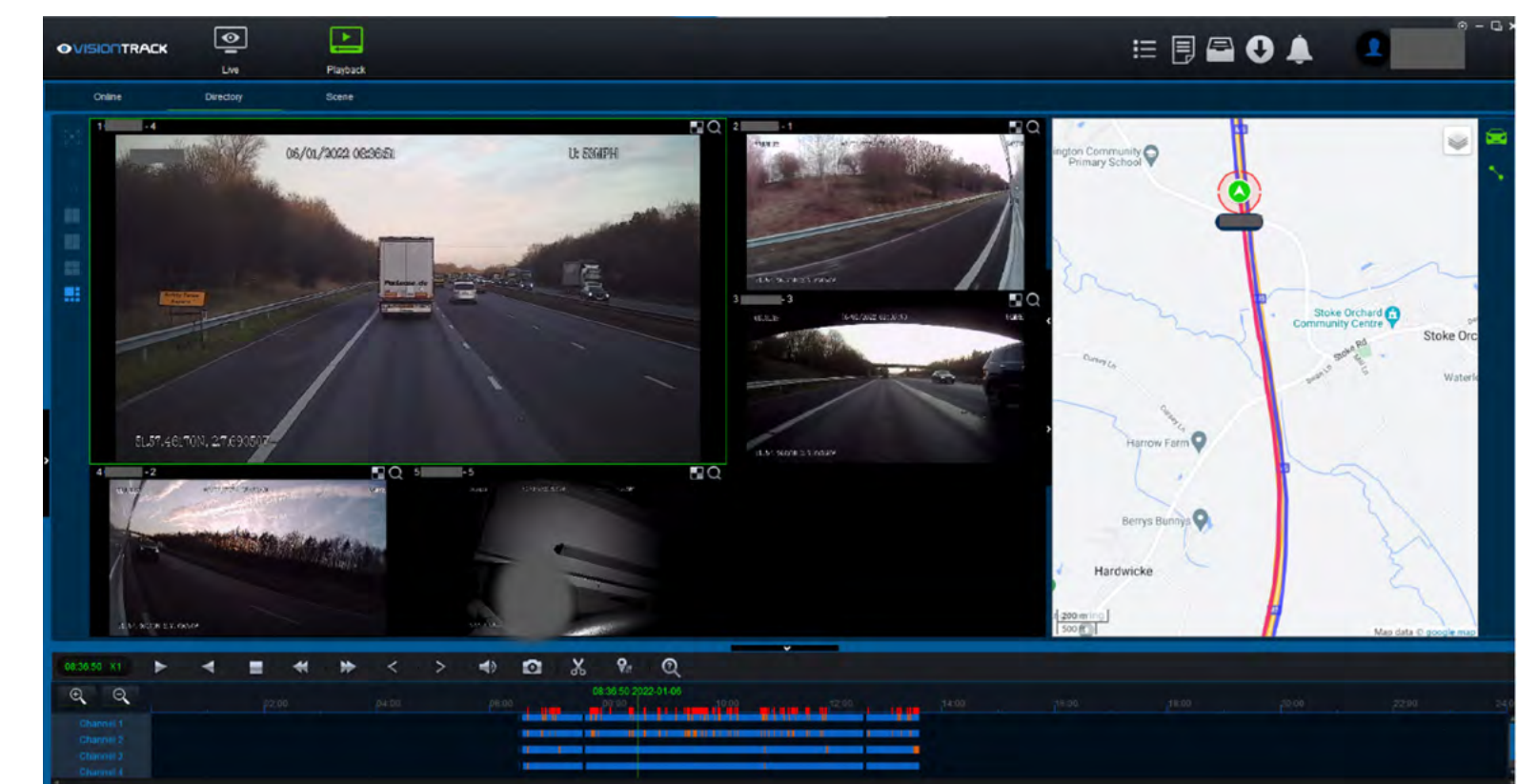


Figure 2.5: Example of the VisionTrack platform (driver's face and number plates obscured).



## 2.6.2 Fusion Processing data loggers

To provide the vehicle data needed for HelmUK's research, TRL worked with DAF to identify the key Controller Area Network (CAN bus) signals that would be needed; these range from platooning status to vehicle speed. These CAN signals needed to be collected and stored to enable both research and safety assurance activities.

Three data loggers were provided by Fusion Processing. These loggers were fitted to the vehicles and interfaced with the CAN bus. The key features of the data loggers are shown in Figure 2.6.

A number of upgrades were made to the data loggers in Phase 2 to improve transmission and reliability. The key data from the data loggers were:

**CAN signals** – all relevant CAN signals were captured from the trucks at 10Hz, this hugely rich data source enabled both research and daily safety monitoring (this process is further described in 2.7.1)

**Fuel data** – the data loggers also captured the data from the fuel meter fitted to the vehicles as part of the trials (see Section 2.6.3 below)

**Calculated fields** – a series of more complex data fields were calculated by the data logger based on the raw CAN signals or fuel input. These fields captured elements such as cumulative fuel consumption and braking magnitude

**Safety critical signals** – within the data above (primarily the CAN signals) there was a subset of data which was critical for our safety review process; these flags were reviewed daily along with associated video footage to capture any near misses or other events.

## 2.6.3 Fuel meter

To provide accurate fuel consumption measurements, each of the three trial vehicles was equipped with a mechanical precision diesel consumption flow meter, type AIC-4008 Veritas. To measure the true diesel consumption, the fuel return flow from the injectors was switched from the tank directly to the fuel supply line. This measuring system provided 800 pulses per litre to determine instantaneous and cumulative fuel consumption values, which were captured by the Fusion Processing data loggers.

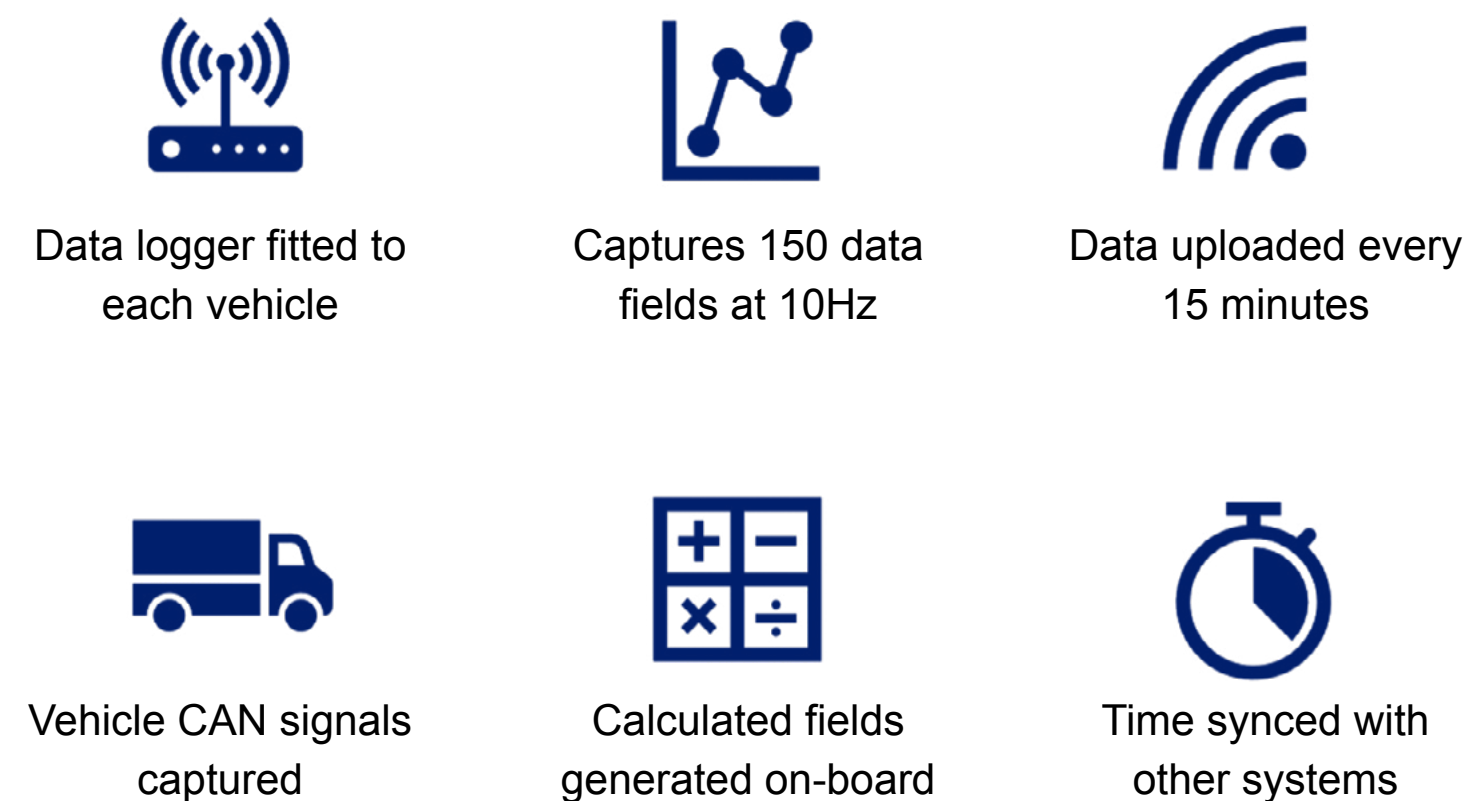


Figure 2.6: Key features of the Fusion Processing data loggers.

## → 2.7 Time on-road

In the HelmUK project there were two distinct on-road activities, Phase 2 and Phase 3 (see Section 2.1). The on-road aspects of the HelmUK project were the focus of the programme and this section captures the key achievements and challenges of the project during the on-road activities. An overview is provided in Figure 2.7.

Phase 2 consisted of the 'Long Run' system verification which ran from December 2020 to February 2021. There was then a pause until COVID-19 restrictions eased to allow drivers to share cabs safely before additional data collection in June and July of 2021. The total number of days on-road in Phase 2 was 30.

Phase 3 ran from September 2021 to January 2022. Of the 37 days on-road as part of Phase 3, 28 days were used for the analysis in this report; the remaining 9 had issues which affected operation or data quality and were excluded.



**58 full days spent on-road**



**Over 12,000 miles travelled**



**Over 12 million lines of data captured**

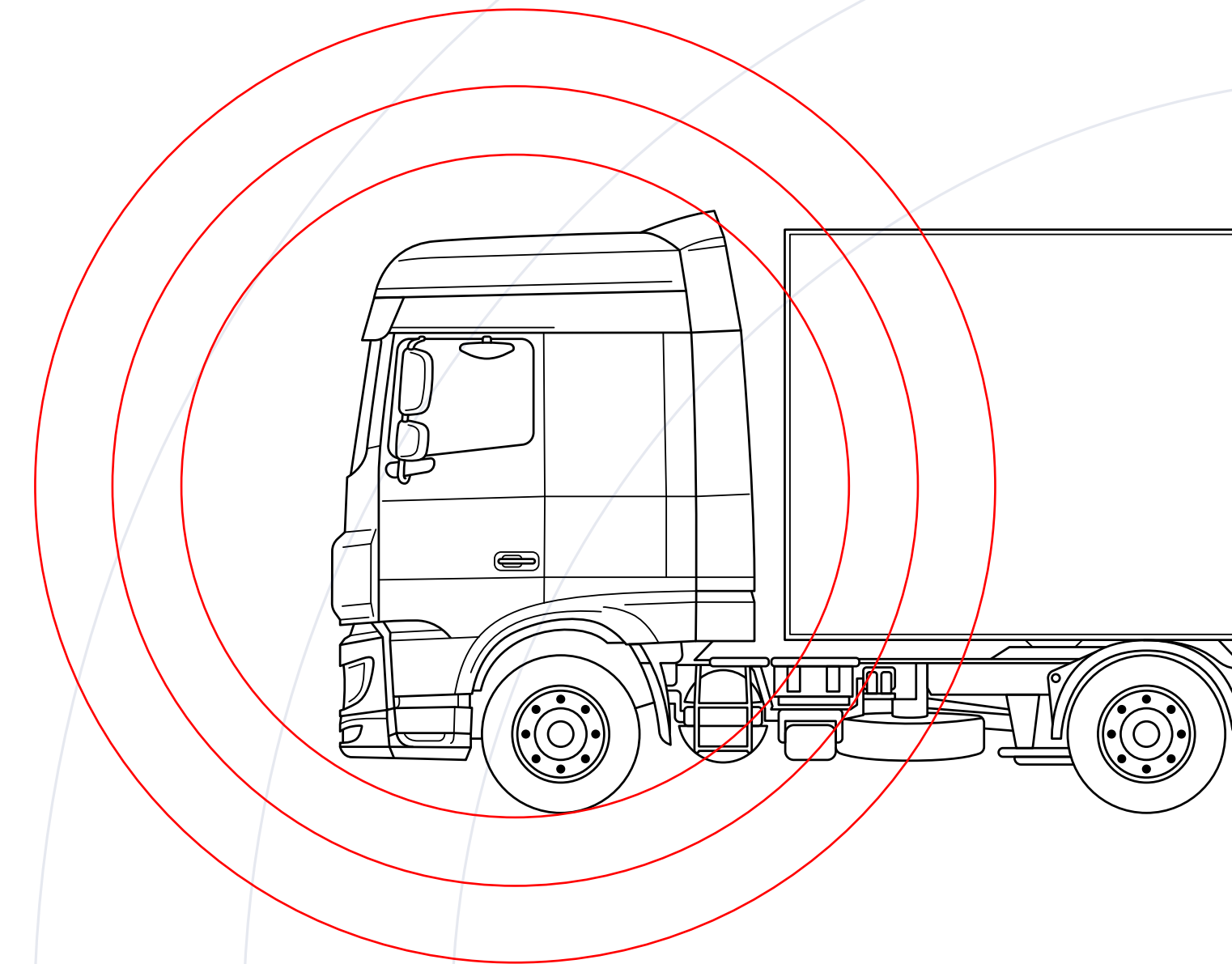


**Safety review of 4,000 data flags**



**4 events escalated for higher review**

Figure 2.7: Summary of HelmUK's time on-road in Phase 2 and 2a.





## 2.7.1 Safety outcomes

Safety was monitored daily throughout the trials to ensure that all events impacting safety were identified and any lessons learnt implemented before the following day of operation.

Table 2.1 shows the events flagged in the Fusion and VisionTrack data that were reviewed after each journey as part of the safety monitoring.

**Table 2.1:** Fusion Processing and VisionTrack events reviewed during daily safety monitoring.

Event	Data source	Description
<b>Event marker press</b>	VisionTrack	Events identified by the drivers that they deemed unsafe compared to standard HGV driving
<b>Close proximity to another road user</b>	Fusion Processing	Events where the HelmUK vehicles experienced a short time headway to another road user or were a short time period from a collision at current trajectory and speed; often relating to cut-ins or harsh braking
<b>Emergency braking</b>	Fusion	Activation of AEB or the equivalent platooning-based systems (CCA or PAEB)
<b>Lane Departure</b>	VisionTrack	The vehicles leaving their lane without indication or unintentionally
<b>Interaction with other road users at the 'platoonable' junctions</b>	Fusion	Particularly cut-ins or harsh braking at the off and on-slips of the 'platoonable' junctions
<b>Phone use and smoking</b>	VisionTrack	Events flagged that indicated the drivers were using their mobile phone or smoking

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> 2. HelmUK road trials > 2.7 Time on-road > 2.7.1 Safety outcomes

Any further events highlighted by feedback from the drivers or incident report forms were also reviewed, although there were very few events reported in this way that were not already flagged in the Fusion or VisionTrack data.

VisionTrack hard drives recorded the footage during each journey. Upon receipt of this data, the video footage for each of the events was analysed by TRL's data team to determine whether escalation to the risk team was required. Any safety critical events (such as near-misses with other road users) or events with potential safety implications for platooning were reviewed and categorised at a go/no-go meeting with the TRL risk team at the end of each day.

At this meeting it was decided whether the trials should proceed or whether a suspension was required for further review by PSCRG and NSCRG. Lessons learned were communicated to the drivers and trial manager as necessary before on-road operation resumed. Figure 2.8 shows the continuous feedback loop related to the daily safety monitoring.

On average, between one and two events per day were raised for discussion with TRL's risk team in go/no-go meetings during Phase 3 and there were many days where nothing required further discussion. Of the events that were escalated, most related to poor driving from other road users, cut-ins or braking events at junctions, or the platooning cooperative collision avoidance system (CCA) activating.

Early during Phase 2 there was uncertainty around the impacts of CCA braking on other road users (ORUs). As a precautionary measure the trials were paused to review the CCA events. After a review with DAF and National Highways, the decision was taken that it was safe to proceed as the events did not cause immediate hazards to following traffic and reduced risk to the platooning vehicles. As part of this decision TRL continued to monitor CCA impacts on ORUs throughout the trials. No safety related events resulted in the suspension of the trials during Phase 3.



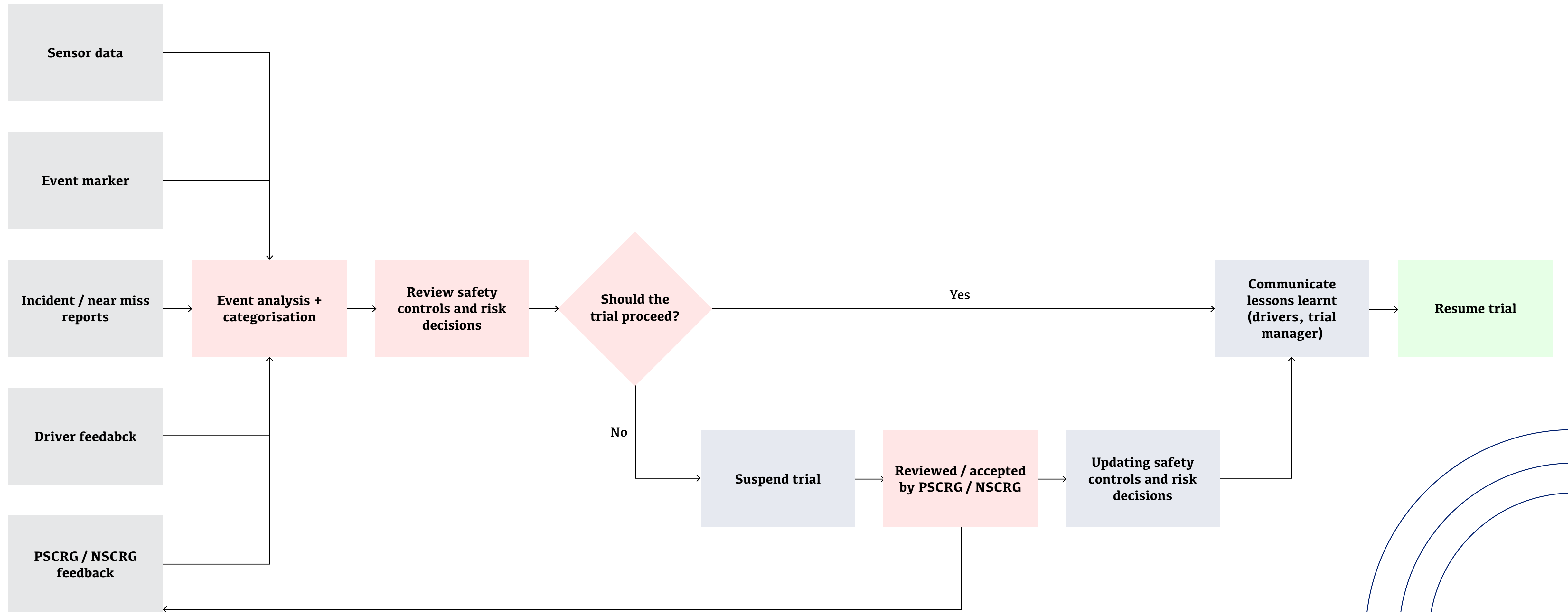
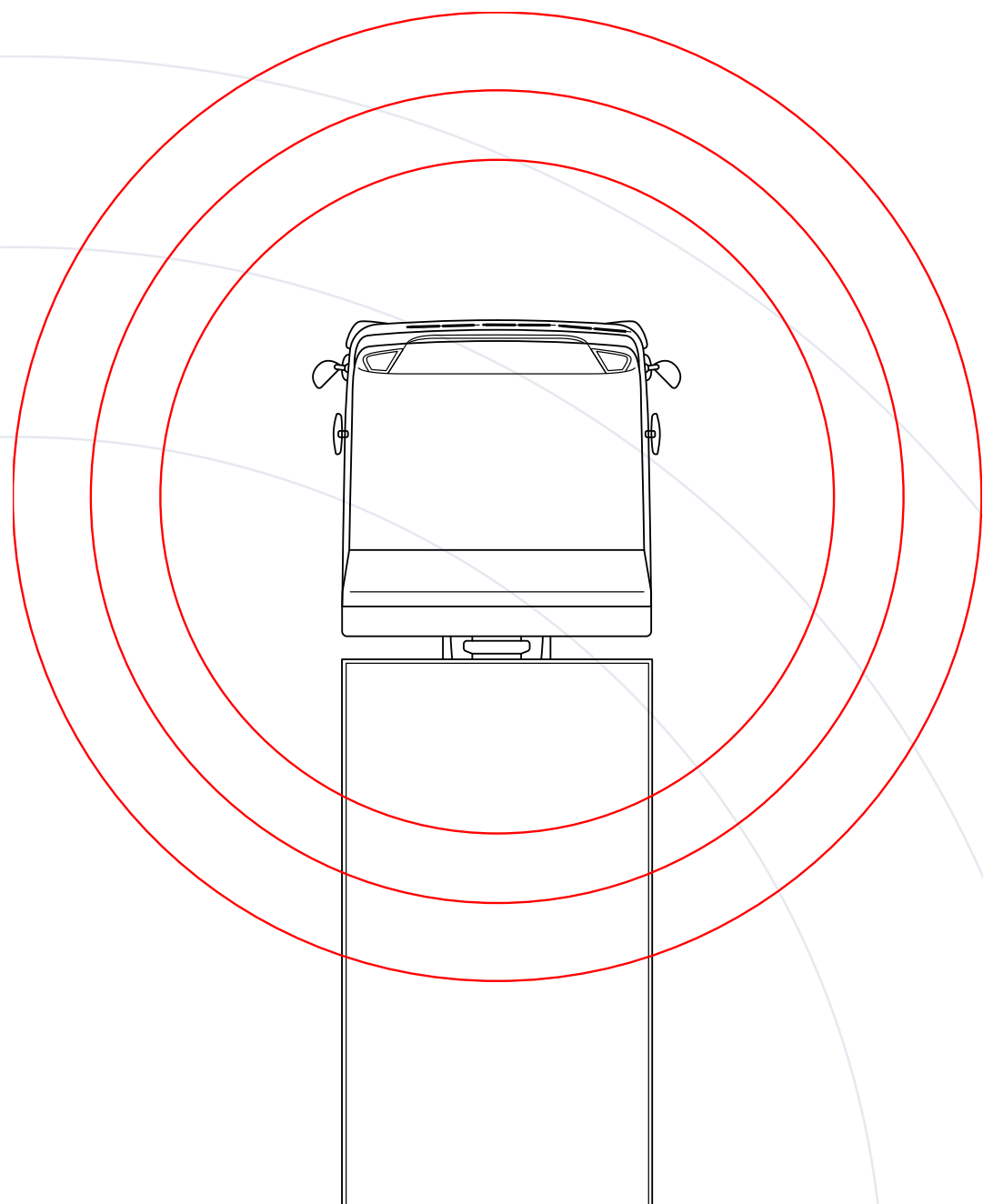


Figure 2.8: Safety monitoring feedback loop.

## → 2.8 Lessons learnt

HelmUK was a complex project which set out to test a novel technology in real-world conditions and in doing so had to achieve a wide range of different objectives and research questions while keeping the public, trial team and drivers safe throughout the trials.

This section discusses some of the key lessons learnt as part of the HelmUK programme and how they might relate to future trials.



### Track testing

UK test track trials of the platooning system began at Millbrook in October 2019. Initial assessment of the Millbrook Test Track rated it as suitable for testing of the HGVs in the required platooning formation. This was key to validate the system suitability for delivering Phase 2.

However, the platooning system would not engage at the Millbrook test track. Further investigation revealed that because the 'High Speed Circuit' at Millbrook is a near perfect circle this caused the vehicle radar to generate an error due to the consistent lateral movement.

These issues caused a delay in the schedule for the validation of the system and for this reason the platooning system components are not approved for use under circular track conditions. The mitigation was to conduct further trials at a track with different geometry – MIRA was selected.

### Track testing in future trials

Consider the often 'inorganic' conditions of track testing and how conditions on a track may differ from real-world testing – and how this will affect the performance of a technology or system. It also highlights the need to understand the range of test tracks suitable in the relevant region in case testing schedules have to be adapted rapidly.

### Motorcycle cut-ins

Tests at MIRA in November 2019 involving motorcycle cut-ins, where a motorcycle moved between platooning vehicles, did not produce the results expected by TRL. Namely, the headway between vehicles did not increase, nor did platooning disengage automatically. Results of subsequent tests in the UK and Netherlands were varied, but overall, motorcycle cut-ins were not reliably detected.

TRL conducted additional quantitative and qualitative risk analysis and updated operational guidance to ensure this risk was mitigated through driver intervention during on-road trials. Instances of motorcycle cut-ins were a high priority for daily safety monitoring for each day of the trial; no hazardous events were identified.

### Consideration for future trials

This emphasises the importance of the safety drivers, a key mitigation when trialling prototype systems. If this risk could not be managed by the drivers, the project would have experienced significant additional delay in order to deal with this through technological methods.



## COVID-19 pandemic impacts

The largest overall impact on the HelmUK project was from the COVID-19 pandemic. UK government restrictions began in March 2020 as HelmUK was due to enter Phase 2. This resulted in a delay to the start of Phase 2 until autumn 2020 during which time the project was placed on 'pause'.

A key risk to manage over a long pause on a highly complex project was knowledge retention. The risk being that progress and readiness for the first on-road phase of the trial would be lost or forgotten. To mitigate this risk each research question and several other key elements of TRL's work captured progress to date and next steps in a series of 'restart guidance' documents which were invaluable when the project was officially restarted and allowed the teams to restart work with minimal risk of knowledge loss. In some cases, these documents also supported staffing changes without disrupting the programme.

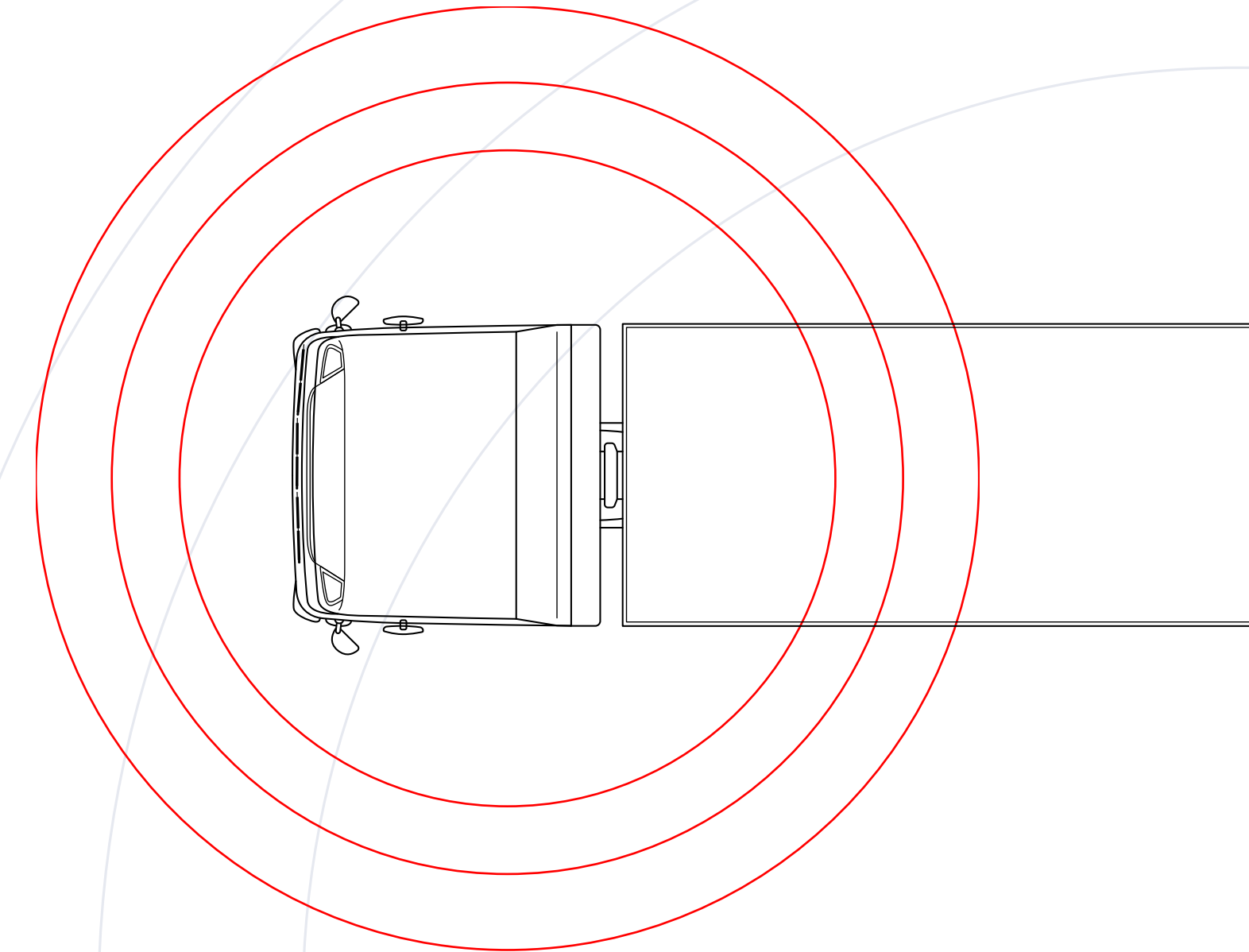
Even after the first 'wave' of the pandemic passed, government restrictions and organisational policies continued to impact on the project. Phase 2's system verification task was carried out entirely during a period of national 'lockdowns' in the UK. This required a health and safety led approach from the project team to ensure that trial activities could be conducted in a 'COVID-secure' manner.

An example of the challenges around COVID-19 which continued to impact on HelmUK is that even though system verification was completed on-road successfully by February 2021, further driver training ahead of Phase 3 was delayed until summer 2021 due to COVID-19 related risks around having two drivers in a vehicle cab. By this time, vaccines were more widely available, and the overall infection rate was lower.

Overall, despite the challenges from COVID-19, HelmUK conducted a highly successful and safe trial, both from a road safety perspective, but also in terms of safeguarding project members and partners from COVID-19 related risks.

## Programme management in future trials

While global pandemics are nearly impossible to predict, a key lesson which came out of the HelmUK programme was the value of having clear documentation of progress and next steps when such a complex programme is put on 'pause' for any significant period.



### **HGV driver training and UK wide shortage**

A challenge with any new technology deployment such as HelmUK is additional training required for drivers and operators. This training is necessitated by both the novel nature of a prototype system and the emphasis on managing risk which is a priority for any real-world trial.

As part of the HelmUK, five specialist DAF drivers were trained in the use of the system. These drivers were familiar with DAF trucks and work with prototype technology in their day job. In turn, these highly experienced drivers were due to train DHL drivers in the use of the platooning system.

### **Phase 3 and driver availability**

In the initial project plan, Phase 3 used DHL drivers to drive the HelmUK vehicles along the approved route.

DHL driver training began in June 2021, but several issues meant that this was not completed. The following challenges were identified:

- Driver expectation that the system would be more 'automated' which highlighted the need for briefing materials to be more straightforward
- Classroom style training and subsequent tests created a higher-pressure environment that anticipated
- Voice communication protocols using headsets were taxing to learn on a test track
- The UK wide HGV driver shortage was impacting the availability of additional drivers to undergo training in the required time period.

Several options were put to the HelmUK project board to mitigate the risks to the programme and still deliver the projects key objectives of an on-road platooning trial. As a result, Phase 3 used the experienced DAF drivers rather than DHL drivers.

### **Driver training in future trials**

Driver training is a key part of safety and risk management or any on-road trial of new technology. Different professional drivers are used to being trained in different ways and a training programme should take account of these expectations and address them in how the training is designed and delivered. Consideration should be given to the time required to adequately train drivers bearing in mind different learning styles.

To support training, briefing materials need to be as simple as possible so that it is easily understood what is and what is not expected of a safety driver in a complex trial. Visual aids and diagrams can help contextualise what is expected of drivers in the role day to day.



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# Key results



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# 3. Key results

## → 3.1 Road and driver safety

Road safety was a focus of the HelmUK project and improvements in road safety are a proposed benefit of platooning technology. Four research questions wholly or partially focussed on road and driver safety.

### **Safety benefits of platooning technology**

Using surrogate safety measures (SSMs) to determine whether operating platoons on motorways and major trunk roads can realise any benefits in terms of casualty reduction on these roads.

### **Driver workload**

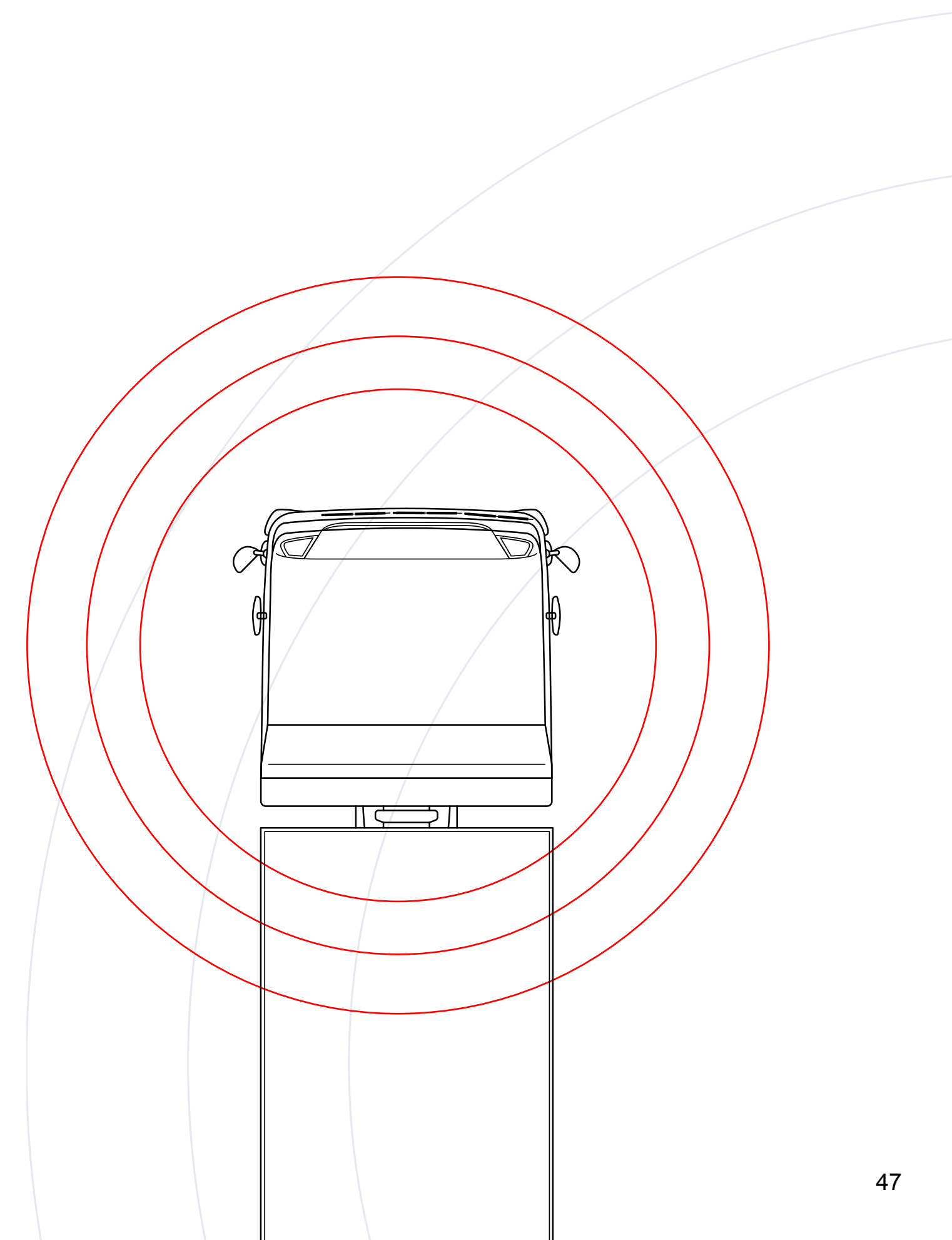
Looking at changes and impacts on driver workloads based on platooning state, platooning versus non-platooning driving, and truck position within the platoon.

### **Sight lines and visibility of road signs**

Assessing the impact HGV platoons may have on sign obscuration for the platooning drivers and other road users.

### **Effects on the road network**

Interaction between the platoon and road features; this research focused on interactions at junctions which are a key safety feature and concern.





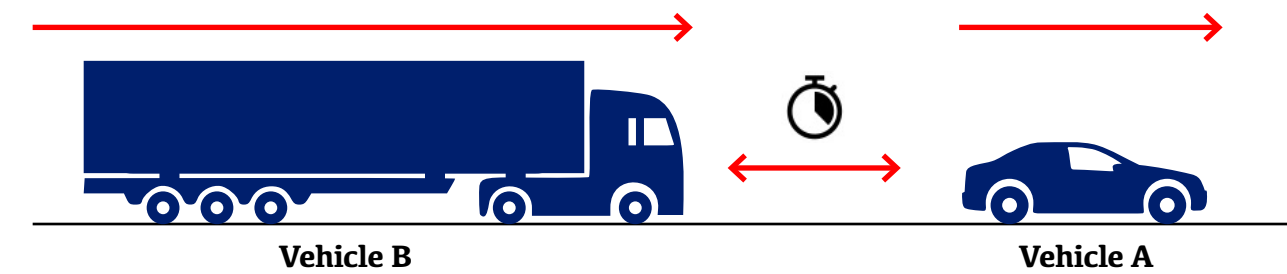
### 3.1.1 Safety benefits of platooning technology

The method used to answer this question consisted of five steps as follows:

1. Collision analysis to determine typical truck collision types, the related number of casualties and contributory factors
2. Identify, collect and analyse Surrogate Safety Measure (SSM) data from HelmUK trials. This data is generated by the on-board data logger using CAN Bus data
3. Estimate the likely change to the number of casualties by collision type, for the introduction of platooning based on contributory factor information, trial data, and expert judgement
4. Consider whether additional collision types are likely to be introduced by platooning
5. Make an informed judgement of the effect of platooning on collision types.

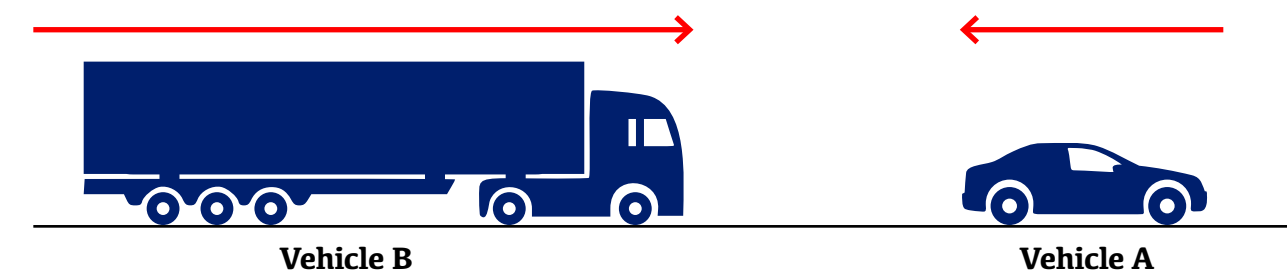
#### Surrogate Safety Measures – captured by the on-board data logger.

##### Post encroachment time (PET)



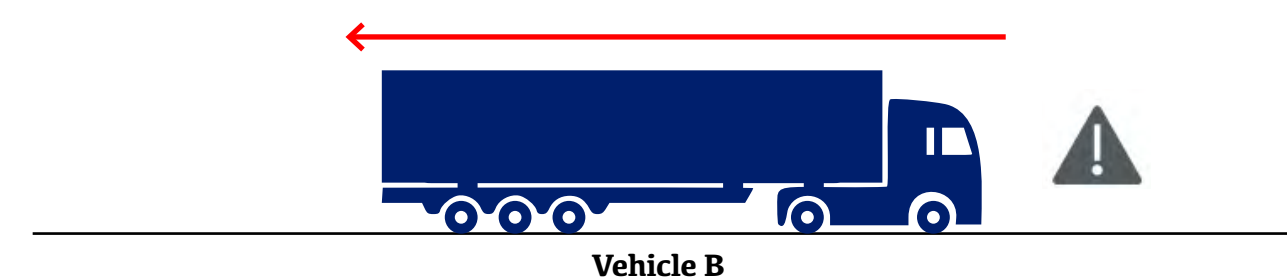
Time between vehicles or time-headway. More formally, time taken for the front of Vehicle B to reach the previous position of Vehicle A.

##### Time-to-collision (TTC)



Time taken for Vehicle B to collide with Vehicle A if they remain on the same path at the same speed.

##### Harsh braking



Defined as braking events with higher decelerations than typical of normal driving, so indicative of unsafe events.

A STATS19<sup>11</sup> collision analysis identified the main collision types for HGVs on motorways and dual carriageways to be as follows (percentages in brackets are the proportion of ‘fatal and serious’ collisions accounted for by each accident type):

#### HGV collisions by vehicle type

##### HGV into rear of another vehicle (29.8%)



##### Lane change-related (27.9%)



##### Other vehicle into rear of HGV (22.2%)



##### Single HGV (5.4%)



##### Vulnerable Road Users (VRU) (5.4%)



<sup>11</sup> The STATS19 database is a collection of all road traffic accidents that resulted in a personal injury and were reported to the police within 30 days of the accident [click here](#).

Analysis of the data collected in the Phase 3 on-road trial, in particular the Surrogate Safety Measure (SSM) data, revealed the following key findings:

- The longitudinal control of the vehicles was excellent when in platooning mode. Both PET and TTC showed safer and more consistent results when in platooning mode vs non-platooning, despite the lower headway. When platooning at 0.8 second time-headway the platooning system never got closer than this time-headway, however when non-platooning this did occur
- A number of cases of the Cooperative Collision Avoidance (CCA) functionality activating (which is active in platooning mode) were observed. Around half the time these events were the system responding as expected i.e. to avoid any potential for collisions. However, a number of cases were identified where the CCA functionality activated in circumstances which were less clear. Most of these activations were due to lane changes and didn't pose any risk. In two cases, this was associated with harsh braking events which could increase the risk of a front-to-rear collision for following vehicles. This functionality is prototype and further refinement of the performance is expected.

Building on the analysis of SSM, further analysis of the effect of platooning on common collision types referenced above showed:

- No new collision types are likely to be introduced by platooning technology as deployed in HelmUK
- Of the five main collision types for HGVs overall, platooning had mostly small benefits or was neutral. The results are summarised in Table 3.1

**Table 3.1:** Summary of likely safety effect of platooning on different collision types (percentages are for current collisions).

Collision type	Safety benefits summary
<b>Single HGV</b> 5.4% of fatal and serious collisions	Small disbenefit to platooning because severity of swerve-related collisions may be increased due to closer headways in platooning mode reducing visibility and awareness.  However, larger benefit from LKA fitment as an integral part of platooning system would likely out-weigh this disbenefit because run-off road sub-type forms majority of collisions of this type. This will also provide benefit for non-platooning operation.
<b>HGV into rear of other vehicle (HGV, car, or van)</b> 29.8% of fatal and serious collisions	Benefit to platooning operation for in-lane collisions because platooning system maintains better control of the vehicles relative positions despite the lower headway. Vehicles in platooning mode never get closer than 0.8s time headway but this does occur in non-platooning.  LKA fitment to platooning vehicles provides further benefits for both platooning and non-platooning operation for collisions into vehicles on the hard shoulder.
<b>Other vehicle (HGV, car, or van) into rear of HGV</b> 22.2% of fatal and serious collisions	Benefit for platooning for Lead and Following vehicles (Helm01 and 02), because they are shielded against rear collisions by HGVs platooning behind them.



## Conclusions

- As deployed in the HelmUK trials, platooning is as least as safe as ACC despite travelling at half the headway and is unlikely to introduce new collision types.
- Overall, platooning has a positive effect on two of the five main HGV collision types; it has negligible effect on two and only provides a small disbenefit to lane change-related collisions.
- Platooning helps eliminate undesirable close following and low TTC. Previous TRL research on the M1 motorway has shown that ~27% of HGVs follow closer than 2 seconds and ~7% closer than 1 second<sup>12</sup>
- The systems which are required for platooning operation, such as LKA, offer additional safety improvements regardless of whether platooning is operational or not
- CCA has high potential to reduce collision likelihood and severity when platooning
- Further refinement of CCA should be investigated to reduce any undesired activations
- Risks remain around lane changes and junctions, but this isn't clearly reflected in the SSM analysis and associated data.

Collision type	Safety benefits summary
<b>Lane change-related</b> 27.9% of fatal and serious collisions	Some disbenefit for platooning because of shorter headways which increase risk during Other Road User (ORU) lane changes and non-ideal behaviour of CCA braking during lane change events. Improvements to this functionality are possible which will offset the risk from CCA activation.  However, this disbenefit can be expected to be offset somewhat because platooning is also likely to discourage and reduce the number of lane change manoeuvres compared to normal driving because of the effort required to perform them, e.g. for slow moving traffic, disengage platoon, change lane, overtake, change lane, re-engage platoon.
<b>Vulnerable Road Users (VRU) including pedestrians, pedal cycles and motorcycles</b> 5.4% of fatal and serious collisions	No benefit / disbenefit for platooning.  LKA fitment as integral part of platooning system offers benefit for both operational modes because it will help to reduce collisions with VRUs on hard shoulder.

### Motorcycle cut-in detection

Track testing as part of the validation of the platooning system in Phase 1 highlighted that detection of motorcycle cut-ins (where a vehicle inserts itself between two platooning vehicles) was unreliable. Further detail can be found in Section 2.8.

This is not an issue specific to the platooning system but a wider detection reliability issue related to radar on vehicles which are required to detect cars but not specifically motorcycles. In the 4,000 data points reviewed via video as part of the daily safety monitoring, HelmUK saw no incidents involving motorcycle cut-ins. Future platooning systems would need to have radar capable of reliably detecting motorcycles to trigger the appropriate response, such as disbanding the platoon or increasing the headway between vehicles.

<sup>12</sup> See Appendix C: Previous research on close following for further details.

## 3.1.2 Driver workload

HelmUK investigated how platooning impacts the workload experienced by HGV drivers. The term 'workload' is generally defined as "a hypothetical construct that represents the cost incurred by a human operator to achieve a particular level of performance"<sup>13</sup>. It is important to understand the impact of tasks on workload because humans have a finite capacity for processing information and performing tasks.

Overload can result in human performance issues, such as errors and slow reactions, which could result in dangerous driving or collisions. Underload can also lead to poor performance, due to boredom, distraction, and loss of situation awareness. Therefore, strong changes in workload when platooning compared to manual driving might have implications for road safety and safety of the individual drivers using the technology.

The workload measure used was the NASA Task Load Index (TLX), which uses six subscales (mental demand, physical demand, temporal demand, performance, effort, and frustration). On each of these, drivers selected points that matched their experience of completing a task such as joining, driving within, or leaving a platoon, or driving the route manually. A baseline workload measure was taken, before commencing a journey, to understand general differences between drivers.

This research allowed the following conclusions:

- It is important to note that these conclusions are based on a platooning system which performed full longitudinal control (acceleration and braking) but required the drivers to steer the vehicles with support from LKA
- Driver workload when platooning was higher compared to non-platooning. The difference was statistically significant, albeit very small in scale<sup>14</sup> and therefore not warranting safety concerns related to overloading drivers when platooning. Note that the trial's safety precautions required drivers to disengage and re-engage platooning frequently around junctions. Future systems could automate this step which may reduce workload
- Across the three phases of platooning (joining a platoon, driving within a platoon and leaving a platoon), workload did not significantly differ. This suggests that there was also no individual phase of platooning operation which impacted on the driver's workload to an extent that should raise safety concerns
- There were small, yet statistically significant, differences in workload across the three positions within a platoon (leading, following, trailing). Workload was highest in the trailing vehicle and lowest in the leading. However, from the data it cannot be confidently concluded that this is a real effect of platoon position rather than an artefact caused by between-driver differences<sup>15</sup>
- Overall, the HelmUK trials did not identify an effect of platooning on driver workload which is large enough in scale to warrant safety concerns related to potential overloading or underloading of drivers.

### Does platooning create safety risks by changing the driver workload?

- ▶ There was concern whether operating HGVs in a platoon might overload drivers, thus leading to errors or slow reactions, or substantially underload drivers, potentially resulting in poor performance, due to boredom, distraction, and loss of situational awareness. The HelmUK trials did not identify an effect of platooning on driver workload which is large enough in scale to warrant such safety concerns.

<sup>13</sup> Hart, S. G. & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock and N. Meshkati (Eds.) Human Mental Workload. Amsterdam: North Holland Press.

<sup>14</sup> The difference in mean is approximately 0.6, on a scale that ranged from 1 to 100, with a large confidence interval, indicating a very small real impact on driver workload.

<sup>15</sup> Driver positions, and therefore roles in the platoon, were altered between trial runs, but practical trial management restrictions did not allow drivers to undertake the same number of runs in each position.



### 3.1.3 Sight lines and visibility of road signs

In preparation for the road trials, HelmUK performed an assessment of the effect HGV platooning may have on sight lines and sign visibility through an existing software model and line-of-sight analysis.

Sign obscuration occurs when the line of sight of a driver to the sign being viewed is interrupted by another vehicle. The consequences depend on the nature of the sign in question, and the needs of the driver, and may vary from insignificant to severe. As may be expected, one of the key variables affecting the level of obscuration is the percentage of large vehicles or HGVs present. Due to their relative size and prevalence in nearside lanes, most obscuration experienced by car drivers is caused by HGVs. It is natural, therefore, to postulate that increasing the number of HGVs travelling in platoons may have an impact on sign visibility, both for other drivers and for those within the platoon.

The following research questions were investigated:

1. How do the 'overall obscuration' levels of signs in the presence of platoons compare with those where no platoons are present?
2. Do following drivers in a platoon have difficulty seeing road signs?
3. How does the shorter headway between HGVs in a platoon affect the ability of other road users to see signs through the gaps?

The sign types considered (Figure 3.1) were large, verge-mounted variable message signs (MS4), usually used to display speed limit or lane closure information, advance direction signs (ADS), which provide notice of an upcoming motorway junction, and gantry-mounted advance motorway indicators (AMI), which are used to indicate lane-specific restrictions.



Figure 3.1: Sign types considered for analysis: MS4 (left), ADS (middle), AMI (right); Reproduced from Highways England (2008)<sup>16</sup>.

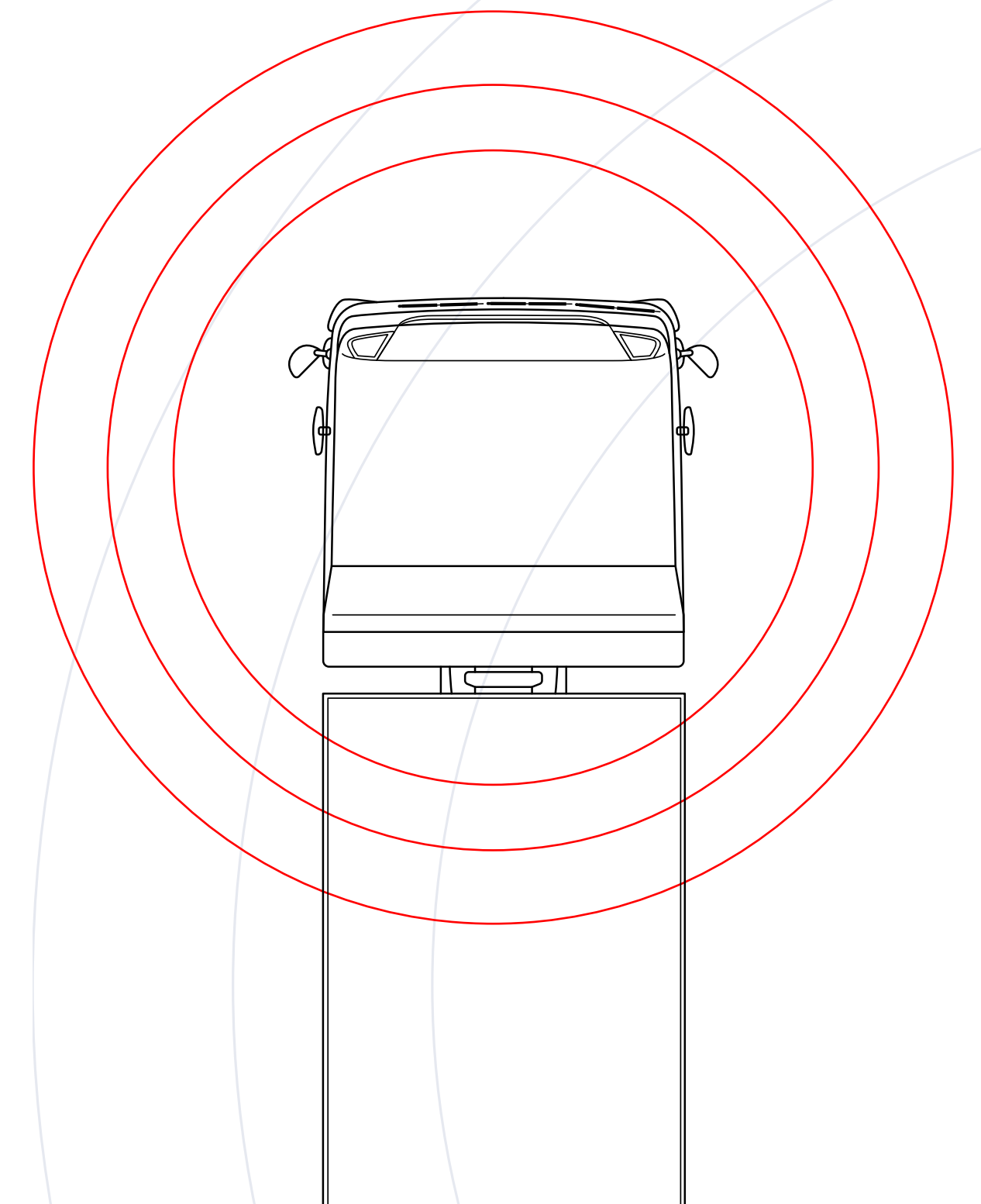
<sup>16</sup> Highways England, 2008. Interim Advice Note 109/08. [Click here](#) to view pdf.

The findings suggest that when considering the impact of HGV platoons on sign visibility, an area of concern is the view of following drivers in the platoon. According to the modelling, most drivers of HGVs within platoons will not be able to see either MS4s or ADS. This did not cause issues during trial operation; however, for commercial deployment the following drivers within a platoon would need to rely on the lead driver to obey any dynamic restrictions displayed and would require other means for navigation rather than relying on ADS.

For other road users, there are two specific situations where this study suggests that HGV platooning may have a negative impact on their sign visibility:

- For drivers viewing ADS in congested conditions
- For drivers viewing MS4 with a hard shoulder present.

The impact in the former situation is larger than in the latter, and, compared with the estimated obscuration of following platoon drivers, both are relatively small; however, they might represent a noticeable negative impact on the ability of other drivers to see the signs. During the HelmUK trial operation, no occurrences were reported in driver de-briefings where this caused an apparent issue to other road users around the platoon, but it should be noted that this aspect could not be objectively monitored during on-road operation.





### 3.1.4 Effects on the road network from platooning

This research question investigated the impact of platooning on the road network – specifically the effect on other road users and traffic flow at junctions – where vehicles are leaving or joining the motorway. Data from 10 junctions along the approved route were analysed:

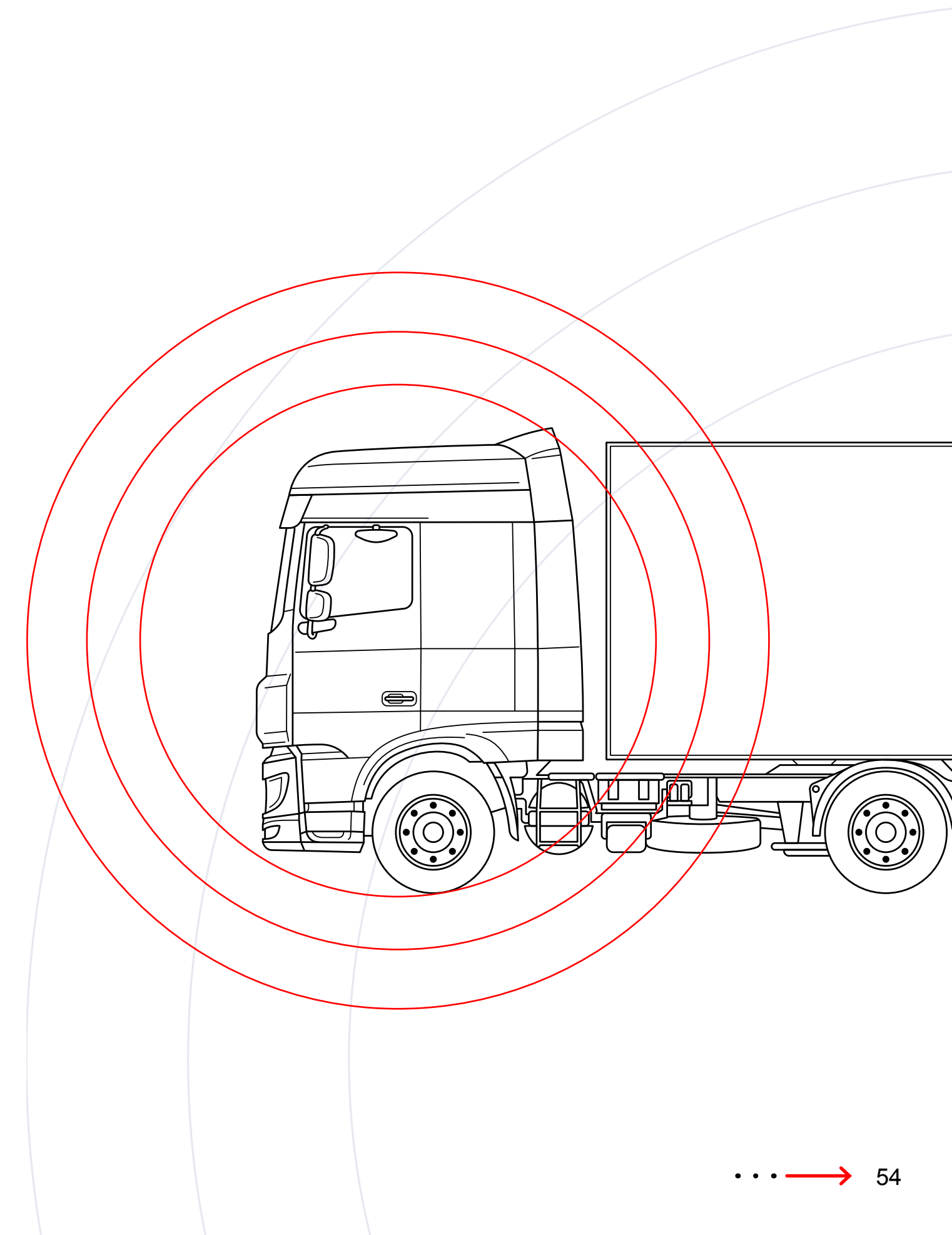
- The six junctions which were ‘platoonable’
- Three ‘non-platoonable’ junctions representing the worst-case scenario in terms of risks
- One ‘non-platoonable’ junction representing a mid-level risk.

The ‘non-platoonable’ junctions were selected based on their geometry and the presence of MIDAS<sup>17</sup> loops.

Three analytical approaches were used for data within 1 kilometre of the junctions:

1. Video analysis of footage from the cameras fitted on the HelmUK vehicles (VisionTrack system – see Section 2.6.1)
2. Analysing Surrogate Safety Measures (SSMs)
3. Analysing the data relating to traffic speed and flow, as captured by the MIDAS loops installed on the approve route.

<sup>17</sup> MIDAS, or Motorway Incident Detection and Automatic Signalling, is a network of traffic sensors, mostly inductive loops, distributed on UK motorways.



### Key findings from the research

- At a junction level, the proportion of platooning varied. The vehicles formed at least a 2-vehicle platoon for around half the time spent travelling through the 'platoonable' junctions on platooning days
- The type of junction geometry clearly affected the number of cut-ins, which were more common at taper than parallel merge junctions. Further analysis showed no clear correlation between the length of slip road and the number of cut-ins
- Video footage analysis showed no clear trend relating to the impact of platooning on other road users or traffic flow when comparing 'platooning' and 'non-platoonable' junctions or platooning and non-platooning journeys
- A single on-road situation caused a harsh braking and CCA event at the off-slip of a 'platoonable' junction on a platooning day; caused mostly by poor driving from another road user and an HGV moving off the hard shoulder
- With the exception of the above event, there were no harsh braking, CCA, AEB, PAEB or VDC events recorded within 1 kilometre of either the 'platoonable' or 'non-platoonable' junctions during the trials (platooning and non-platooning days)

- Two events where other road users were forced to brake harshly or accelerate to join or leave the motorway were recorded. After review, these events were not linked to the platooning status or a particular junction type, and were as likely to occur if the trial had not been in operation (i.e. occur in normal driving conditions).
- Regarding the recorded PET and TTC SSMs, there were no clear differences between platooning and non-platooning days and no clear differences between the 'platoonable' and 'non-platoonable' junctions that can be reported
- There were higher levels of acceleration and braking (considering values  $>0.5 \text{ m/s}^2$  in magnitude) through the 'platoonable' junctions on non-platooning days than on platooning days, except for the single harsh braking event, indicating good longitudinal control applied by the platooning system
- Analysis of flow-weighted average speed and average flow per minute at 'platoonable' junctions showed no indication that the HelmUK vehicles had a discernible effect on either traffic speeds or flows whilst travelling through 'platoonable' junctions on platooning days
- Flow-weighted average speed was much more variable across 'non-platoonable' junctions than at 'platoonable' junctions. The same is true for average flow per minute. This was probably because 'non-platoonable' junctions appeared to have higher volumes of traffic joining the motorway than 'platoonable' junctions.

## Collision avoidance systems

AEB – Advanced Emergency Braking: A standard system on modern HGVs to prevent or mitigate front-to-rear collisions by automated braking based on radar detection. When following in a platoon AEB is deactivated and replaced by CCA.

CCA – Cooperative Collision Avoidance: Prevents or mitigates intra-platoon collisions by commanding emergency braking at high deceleration rates based on V2V communication and an independent radar sensor.

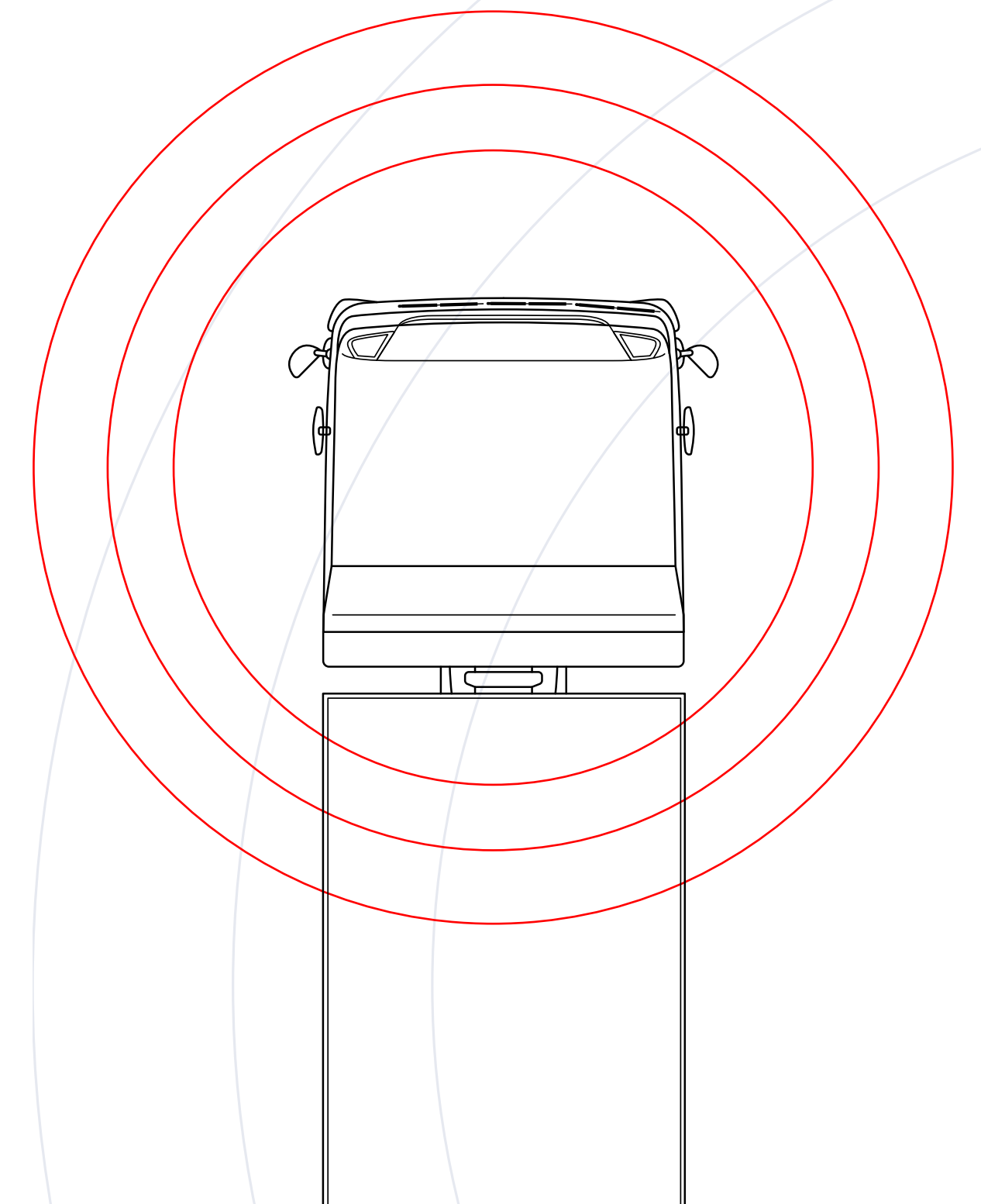
PAEB – Platooning Advanced Emergency Braking: Emergency braking system based on a redundant radar sensor which becomes active in case CCA is not available due to a platooning system error.

VDC – Vehicle Dynamics Controls: Improves the dynamic stability of the vehicle by detecting situations close to losing directional control (e.g. understeer, oversteer, jack-knifing) and/or rollover control and braking selected individual wheels to stabilise the vehicle.



## General conclusions

- ▶ Based on the video footage, SSM and MIDAS analysis, no clear trends relating to the impact of platooning through junctions could be identified when comparing the 'platoonable' and 'non-platoonable' junctions or platooning and non-platooning journeys.
- ▶ There were very few significant events recorded at the 10 analysed junctions. One was related to the HGVs' harsh braking, caused by the bad driving of ORUs, and two involved ORUs having to brake harshly or accelerate to merge with the traffic. None of these events could be linked to platooning or any particular junction.
- ▶ Junctions were identified with similar flows and geometry, similar levels of cut-ins and generally similar profiles, which still present very different platooning percentages, indicating that there must be other reasons for this variation. Some of these reasons have been identified under this research question, such as the proximity to 'non-platoonable' junctions, including service stops, but further research would be required to identify them all. To further develop a methodology for determining whether a junction is suitable for platooning, flow levels on exit and entry slip roads at all junctions could be analysed and compared with data from 'platoonable' junctions.



## → 3.2 Fuel efficiency and emissions

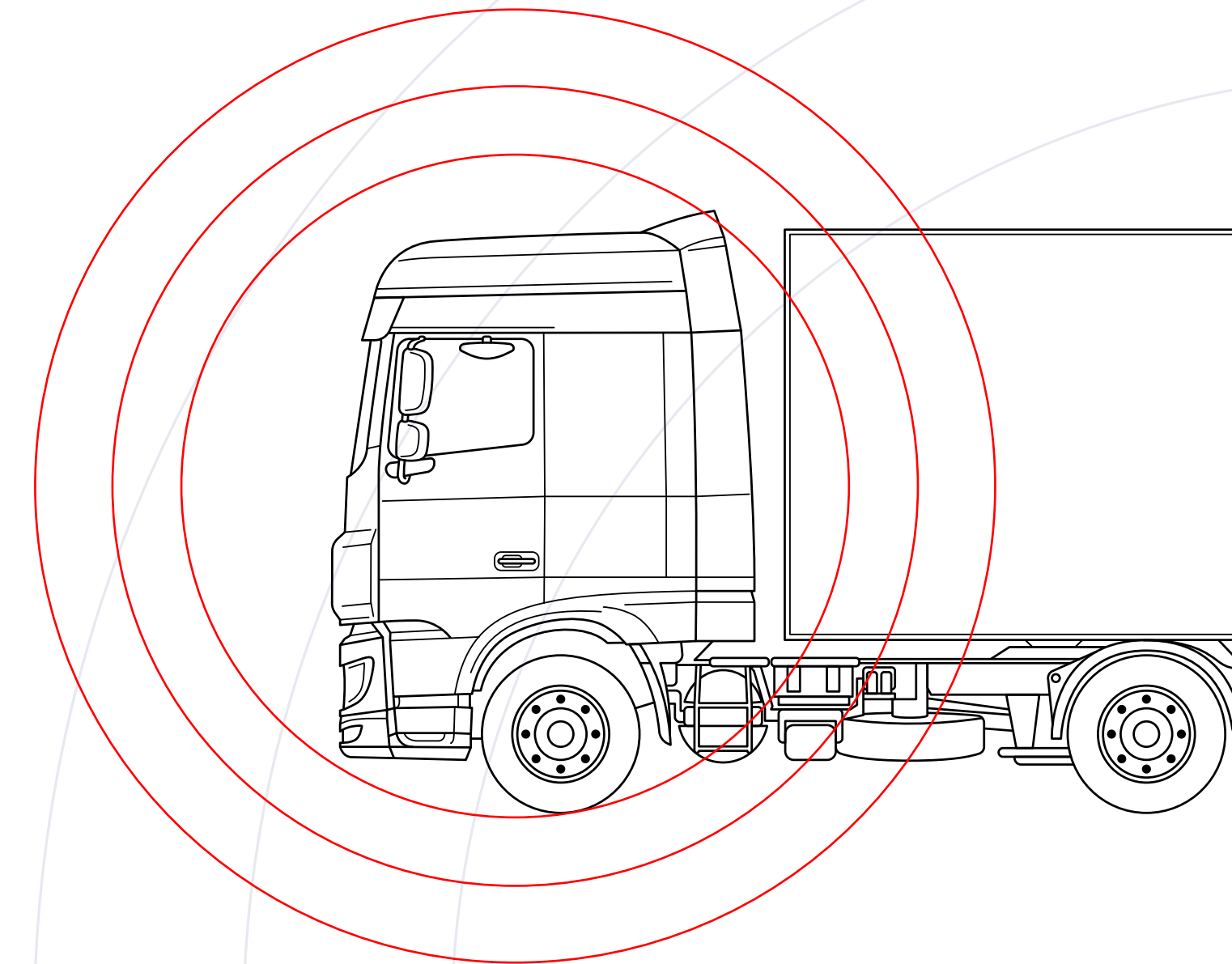
### 3.2.1 Fuel and carbon savings

#### Savings on current road network

One of HelmUK's main objectives was to quantify the potential improvements in fuel efficiency and associated carbon savings for HGVs that can be achieved with platooning technology. The focus of the research was to provide a comparison in a live-traffic, real-world environment to reflect the infrastructure characteristics and traffic conditions of English motorways. The road trials served as a comparison between three HGVs equipped with platooning systems capable of driving with a spacing of 0.8 seconds time-headway and the same vehicles equipped with standard Adaptive Cruise Control (ACC) capable of 1.6 seconds time-headway at the lowest-distance setting, with the same cruise speed set in both conditions<sup>18</sup> (see Section 2 for more detail).

### Fuel savings and carbon emissions

The carbon emissions from a combustion engine consist mainly of CO<sub>2</sub> (carbon dioxide) plus small amounts of CO (carbon monoxide), HC (hydrocarbons) and PM (particulate matter). As this carbon comes from the fuel used, the engine's carbon emissions are directly proportional to fuel used. In addition, the carbon emissions associated with the well-to-tank processes are also proportional to the amount of fuel used. Therefore, each percentage reduction in fuel consumption will give the same overall percentage reduction in carbon emissions.



<sup>18</sup> HelmUK looked at this topic from the perspective of a haulage operator faced with the decision whether to adopt platooning for their business. One option is to invest in platooning systems for their vehicles and make operational adjustments to ensure journeys coincide often enough (this can be within a single business or across various companies); the alternative option that provides the fairest comparison is to make the same operational adjustments and ensure the drivers use ACC. Note that this is different to some previous projects which compared the platoon to a solo-driving HGV, i.e. to a baseline with higher fuel consumption than an ACC convoy, thus implicitly measuring greater platooning benefits. The ACC cruise speed was set to 53 miles per hours, which is lower than the speed limit on motorways, but it reflective of a common maximum speed limiter setting chosen by freight operators for their vehicles to reduce fuel usage across their fleet.



> 3. Key results > 3.2 Fuel efficiency and emissions > 3.2.1 Fuel and carbon savings

The HelmUK road trials found that fuel savings of 0.5%<sup>19</sup> could be realised by a three-vehicle platoon compared to operation mostly in ACC convoy on the current road network, which involved disbanding the platoon before the large majority of junctions. When performing an initial analysis of the full 109-mile motorway route along the M5 and M6 between Avonmouth and Stafford, the measured difference in fuel consumption was higher at 1.6%. However, it was found that the dataset is skewed in favour of platooning and additional statistical modelling performed on the full dataset failed to identify platooning as a factor which impacted fuel consumption in a statistically significant way<sup>20</sup>.

A more detailed look at the characteristics and results for motorways M5 and M6 separately can provide a clearer picture. The vehicles could not drive in platoon-formation for the entire journey due to a variety of real-world factors including safety precautions (specifically disengagement before the majority of junctions), congested traffic conditions, and prevailing environmental conditions:

- Measured over the full trial route, platooning<sup>21</sup> could be achieved for 36.8% of the driving time on platooning runs; 5.7% of time was spent gap closing
- The section of route on the M6, measuring 22 miles, allowed only a small amount of platooning due to short distances between junctions and high traffic density: 13.6% platooning, 2.5% gap closing
- The section of the route on the M5, measuring 87 miles, allowed a higher proportion of platooning: 46.7% platooning, 6.8% gap closing

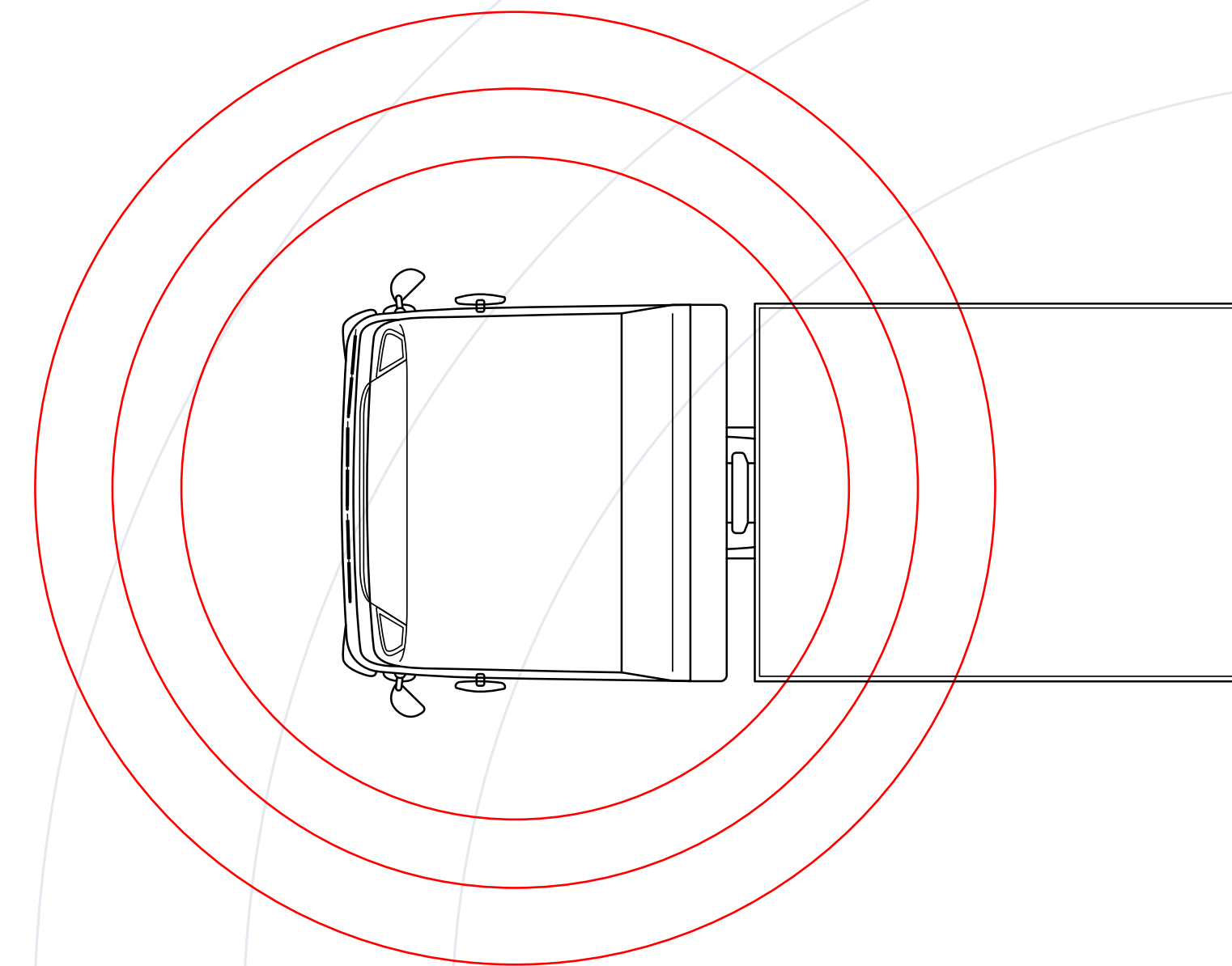
The fuel savings calculated for platooning, however, are substantially different between the two motorways:

- The section of the route on the M6 showed average fuel savings of 4.2% for the three-vehicle platoon
- The section of the route on the M5 showed lower fuel savings of 0.5%.

<sup>19</sup> All fuel savings are reported relative to the baseline fuel consumption of non-platooning trial runs. Absolute fuel consumption values measured are not being reported for confidentiality reasons.

<sup>20</sup> Note this does not mean that no effect of platooning on fuel consumption exists, but rather that an arguably existing effect was too small in comparison to other factors to quantify with 95% confidence in the overall dataset, which contained a relatively low proportion of platooning. A significant effect might be identified in a larger dataset.

<sup>21</sup> The platooning status was analysed separately per vehicle; 'platooning', in the context of this study, describes the condition when the CAN bus signal of a vehicle's platooning system indicated the status 'platoon lead' (for leading vehicle), 'platoon follow' (for following vehicle) or 'platoon trail' (for trailing vehicle); this condition is preceded by 'gap closing' phases for the following and trailing vehicles while they transition from ACC headway to the shorter platooning headway; the leading vehicle therefore spends a greater amount of time in platooning than following and trailing vehicles; the percentage value presented is the average across all three vehicles.



> 3. Key results > 3.2 Fuel efficiency and emissions > 3.2.1 Fuel and carbon savings

This tendency is contrary to what would be expected if platooning was the main influencing factor on fuel consumption in both parts of the datasets. Furthermore, the fuel savings measured were very similar across the three vehicles, whereas platooning should benefit the following and trailing vehicle more than the lead vehicle.

Average driving speed was identified as a confounding factor, where particularly runs on the M6 in the southbound direction showed a large speed difference between platooning and non-platooning days (Figure 3.2), arguably due to traffic conditions having been worse on non-platooning days, which skews the dataset in favour of platooning. Taking these considerations into account, the results for the M5, despite also not being statistically significant, are considered a more reliable estimate of the effect of platooning on fuel consumption than the overall value reported above.

In conclusion, the best estimate found in HelmUK for fuel savings that could be realised on the current motorway network by platooning compared to ACC is 0.5% for a three-vehicle platoon, with no evidence that this constitutes a significant difference from the non-platooning baseline.

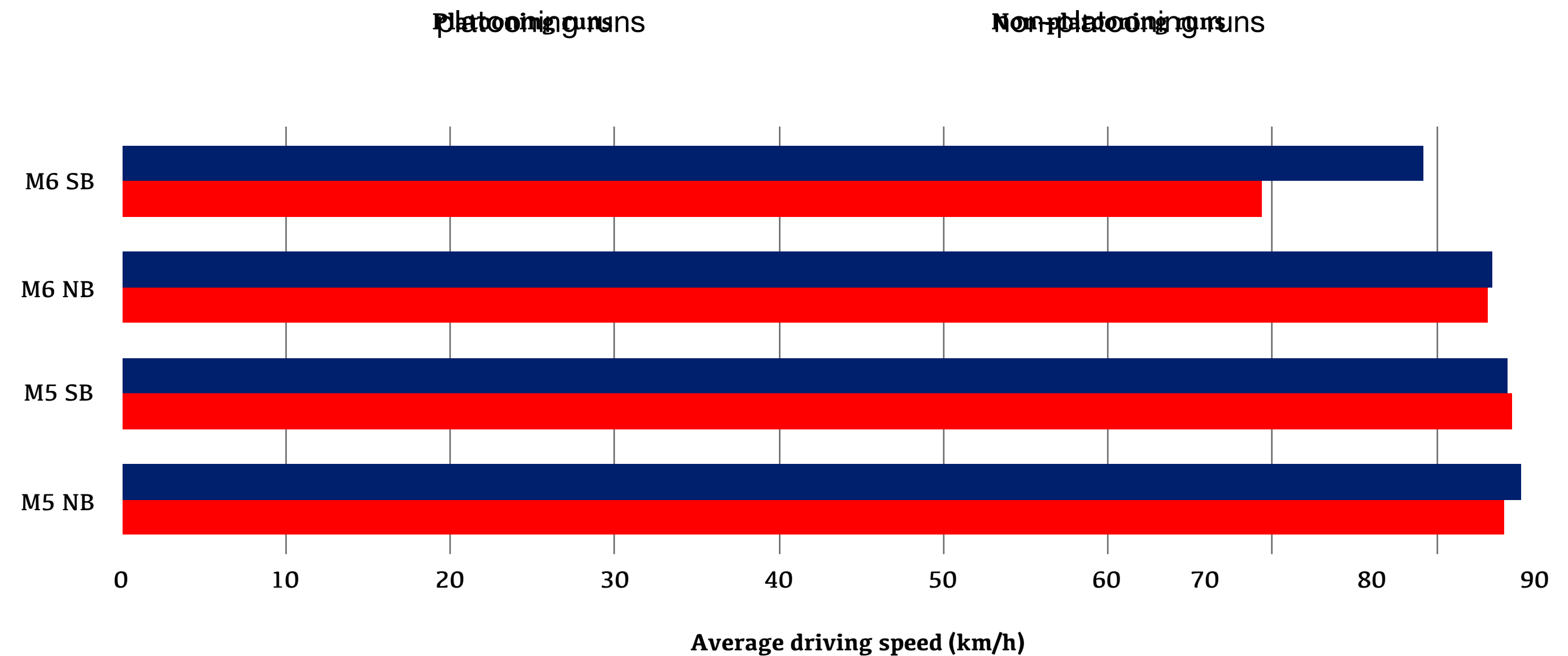


Figure 3.2: Average driving speeds observed in the dataset on platooning and non-platooning trial runs split by motorway and direction (SB: southbound, NB: northbound); speed difference on motorway M6 southbound is substantially greater than on other route sections.



### Impact of interruptions to platooning

The platoon had to be disbanded frequently on the trial route: A typical period of platooning only lasted between 2 and 3 minutes<sup>22</sup>, with the majority of periods lasting less than 2 minutes. The maximum durations observed were about 11 minutes for the leading vehicle and about 8 minutes for following and trailing vehicle (note remarks on platooning status definition in Footnote 21). Arguably, disbanding and reforming the platoon is detrimental for realising fuel savings because additional energy is expended during gap closing to accelerate the following and trailing vehicle.

‘Non-platooning’ junctions were a major factor leading to frequent disengagements during the road trials – a step that is not required in ACC operation because the same, much larger, time-headway can be maintained while passing junction entry slips. Figure 3.3 shows example speed traces when disbanding for a non-platooning junction compared to ACC (non-platooning) operation across the same junction.

### How long does platoon formation need to be maintained to overcome the fuel penalty from re-forming?

- ▶ Disbanding and then re-forming a platoon uses more fuel than cruising in ACC convoy. While some fuel is saved during the gap opening phase when the following vehicle falls back, more fuel is then required to accelerate the vehicle up and close the gap.
- ▶ Detailed analysis of the fuel rates measured in HelmUK during these phases shows that a platoon typically needs to be maintained for about 100 to 120 seconds, or 1.5 to 1.8 miles, to overcome the fuel penalty compared to carrying on in ACC convoy.

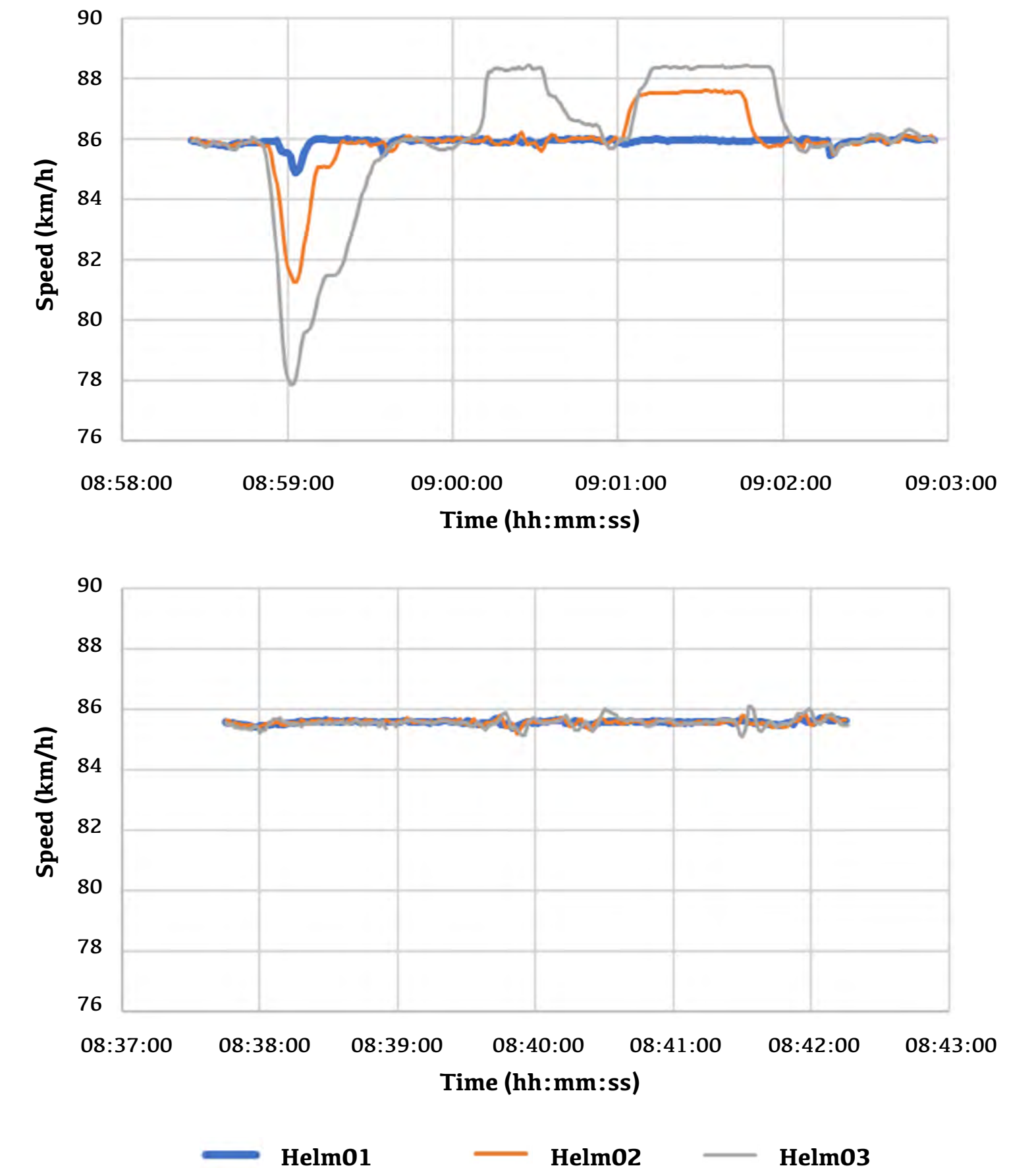


Figure 3.3: Speed traces when passing a non-platooning junction on a platooning trial run (top) and non-platooning run (bottom); Helm01: lead vehicle, Helm02: following vehicle; Helm03: trailing vehicle; following and trailing vehicle reduce their speed for the gap opening phase by 5 km/h and 8 km/h respectively, then accelerate up to 2 km/h above cruise speed for the gap closing phase.

<sup>22</sup> Four typical platooning days were analysed in detail, which showed the following average durations of a period of platooning: Lead vehicle: 148 to 199 seconds; following vehicle: 133 to 173 seconds; trailing vehicle: 116 to 177 seconds.

> 3. Key results > 3.2 Fuel efficiency and emissions > 3.2.1 Fuel and carbon savings

The detrimental effect of junctions on fuel benefits could be observed in the dataset when the effect of gradually removing route segments around 'non-platoonable' junctions from the dataset was analysed<sup>23</sup>. It can be seen in Figure 3.4 that the fuel savings measured show an increasing trend with a greater proportion of junctions being disregarded. This was used, below, to estimate potential fuel savings on a hypothetical road network optimised for platooning.

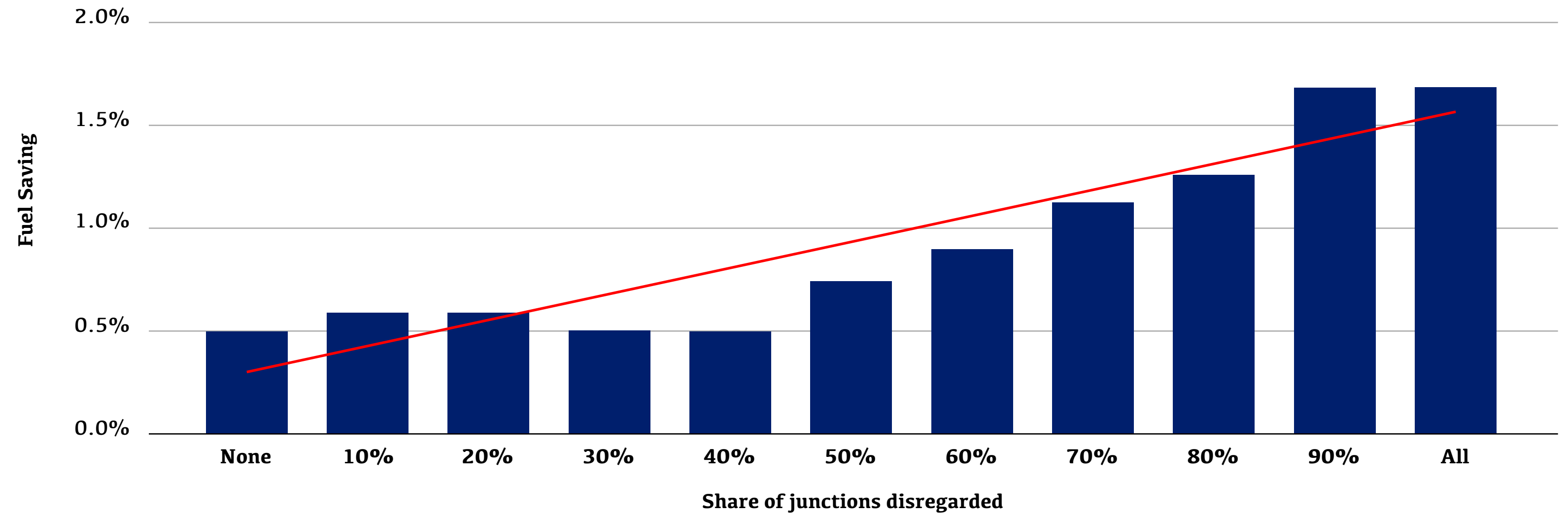
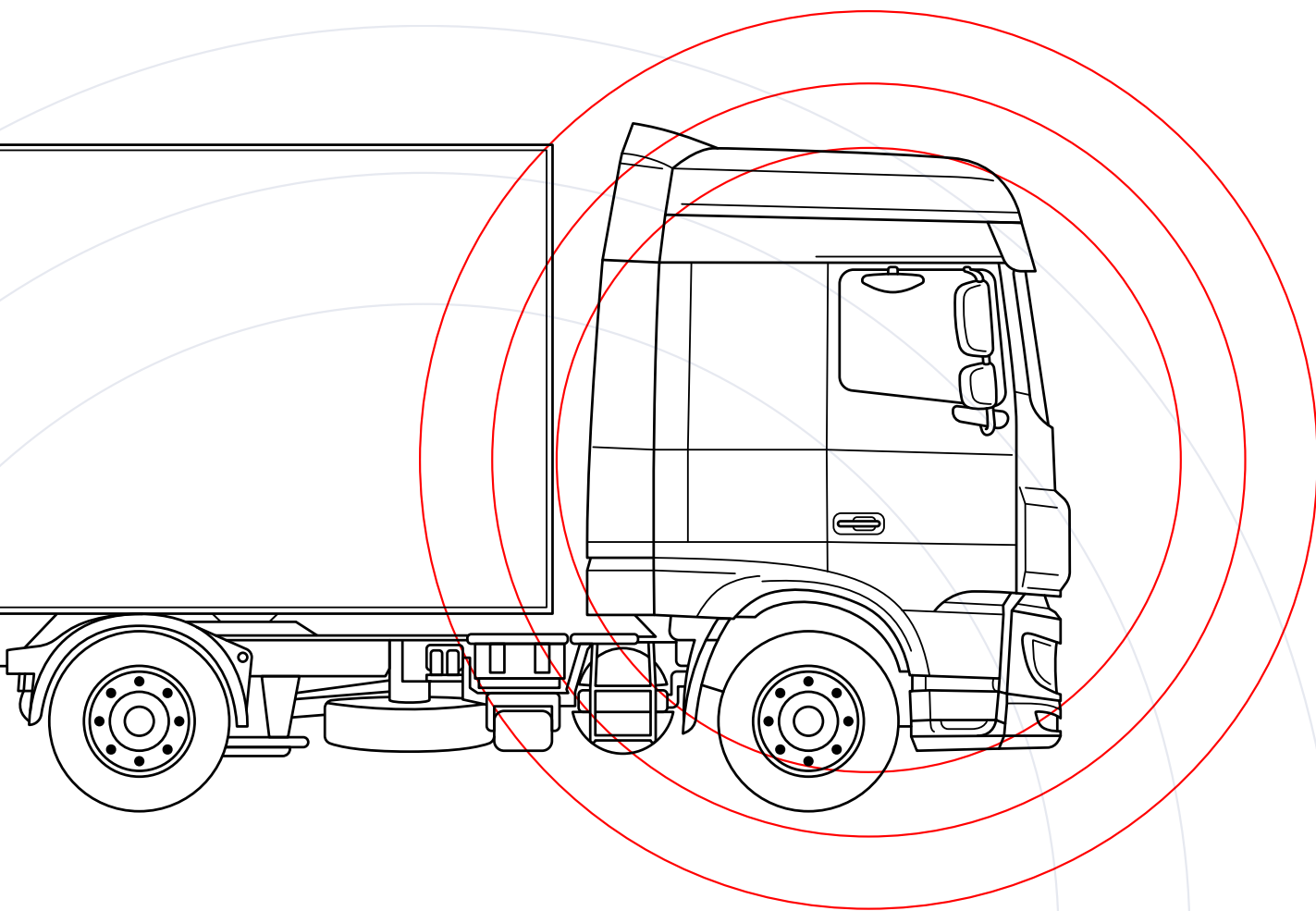


Figure 3.4: Average fuel savings when comparing platooning to non-platooning trial runs on motorway M5; 'non-platoonable' junctions gradually removed from dataset going from left to right, i.e. left bar represents full trial route on M5, right bar represents same route but with all 'non-platoonable' junctions removed; red line represents linear trendline.



<sup>23</sup>To maintain a robust comparison, the same route segments were removed from the datasets of platooning and non-platooning trial runs based on the GPS location recorded. The disregarded section around each junction reached from the beginning of the exit slip road to a point typically between 200 and 750 metres after the end of the entry slip road in order to eliminate the non-platooning phase and the majority of gap closing time.



### Expected savings on optimised road network

Based on the considerations above, fuel savings could be further improved by reducing the number of disengagements and increasing the amount of platooning that can be realised on motorways to levels beyond those observed during the HelmUK trials, by optimising the road network in order to eliminate restricting factors (see Section 4.3.3 for further considerations).

Operation with fewer disengagements could not be realised during the road trials because platooning was not permitted for the majority of junctions based on safety considerations. To estimate the effect of an optimised road network, the trial data was instead segmented and selectively analysed in two different ways to approximate such future scenarios:

**Removing ‘non-platoonable’ junctions** – the trial route was ‘optimised’ by focusing on the M5 motorway only (to eliminate speed as a confounding factor, as outlined above) and removing segments with ‘non-platoonable’ junctions as described above. The average fuel savings measured for the entire platoon were 1.7% when all junctions were removed (71.3% platooning; 3.4% gap closing). In this dataset, platooning was identified as a statistically significant factor (p-value < 0.00001). The statistical modelling, which took into account other variables impacting on fuel consumption (such as traffic flow, journey direction, platooning states, weather, etc.), showed that the fuel savings attributable to platooning were marginally greater than those directly measured at 2.5%. This value is the best estimate found in HelmUK for a route without ‘non-platoonable’ junctions

**Selecting areas with high platooning proportion** – when focusing the analysis only on route segments where a high share of platooning was actually observed during the trial, i.e. eliminating other segments from both datasets, the average fuel savings for the entire platoon rose to 1.8% (82.1% platooning; 3.6% gap closing). Again, platooning was a significant factor in this dataset (p-value < 0.00000001). Statistical modelling indicated a fuel saving of 2.6% attributable to platooning, which is the best estimate found for a route where a high share of platooning can be achieved consistently.

It can be seen that both of these ‘virtual’ scenarios showed increased fuel savings compared to the previous results. The values presented can be considered to represent a range of savings that could be expected with an optimised road network or updated junction procedures.

### How much fuel can ACC save compared to solo driving?

- ▶ For the road trials we compared platooning to an ACC convoy equipped with current technology, which typically travelled at 1.6 seconds time-headway.
- ▶ This ACC convoy formation already offers aerodynamic benefits compared to solo driving: In preparation for the road trials, a fuel baselining exercise was conducted under controlled on-road conditions which showed potential fuel savings of 2.9% in uninterrupted ACC convoy (lead vehicle: 0.4%, following vehicle: 3.5%, trailing vehicle: 5.1%).
- ▶ The reported savings for uninterrupted platooning were measured on top of this benefit.

### Expected savings for uninterrupted platooning

To further approximate the upper boundary of fuel savings that could be achieved if the vehicles could drive constantly in steady-state platooning<sup>24</sup> formation, the data from platooning and non-platooning trial days was compared by platooning state, i.e. comparing non-platooning on non-platooning runs with steady-state platooning on platooning runs. This analysis<sup>25</sup> showed savings of up to 4.1%<sup>26</sup> could be achieved in this hypothetical case, which approximates a situation where platoons could, for instance, operate in dedicated lanes with low traffic occupancy.

### Impact of vehicle position in platoon

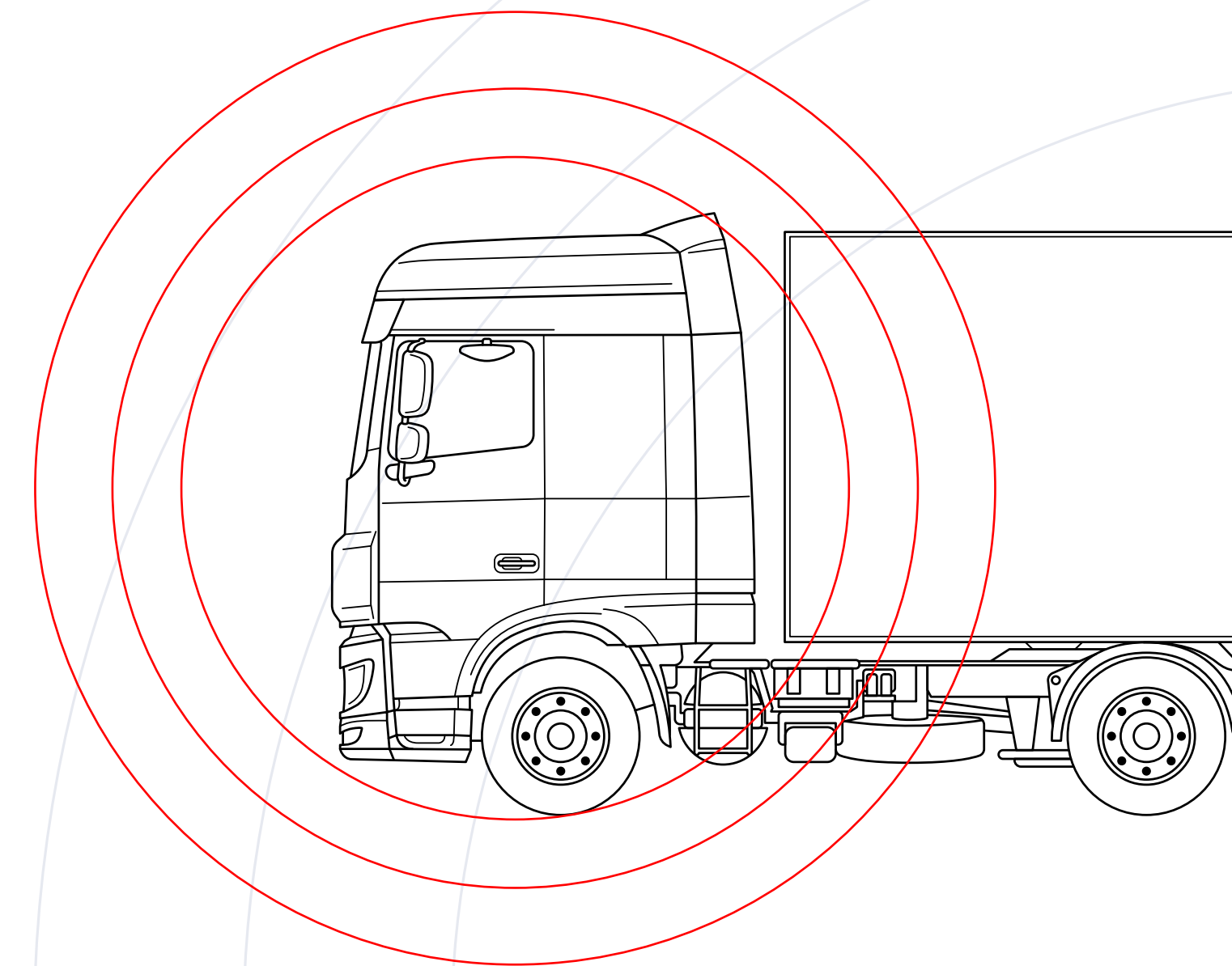
The results discussed up to this point considered the three-vehicle platoon in its entirety, but the fuel savings observed vary by vehicle position. As could be expected from mechanical considerations, the lead vehicle benefitted less from the slipstream effect than the following and trailing vehicle.

When considering the more robust current network results from the M5 motorway and the optimised network results, the fuel savings for the leading vehicle ranged from a slight disbenefit (–0.1%) to a saving of 0.4%, whereas the following vehicle experienced savings between 0.8% and 2.3%, and the trailing vehicle achieved savings between 1.1% and 3.6%. In the hypothetical scenario of uninterrupted platooning, the savings calculated were 1.6%, 5.9% and 6.2% for leading, following and trailing vehicle, respectively. The figures from all the above scenarios suggest that expanding platoons to sizes going beyond three vehicles could increase the average fuel savings that can be realised.

<sup>24</sup> Steady-state platooning describes the condition when all three vehicles drive in platoon formation, i.e. have completed gap closing and maintain a constant platooning headway. CAN bus signals: platoon lead, platoon follow, platoon trail (concurrently).

<sup>25</sup> This analysis method no longer ensures that identical route segments are compared on platooning and non-platooning runs and therefore has a higher level of uncertainty attached than the previous results. To minimise the influence of areas of heavy traffic, which would only be included in the non-platooning data because platooning is not possible in such conditions, and of periods of acceleration or deceleration, the data was filtered for times of driving with close to typical cruise speed (85 km/h ... 90 km/h) and little to no longitudinal deceleration/acceleration (–0.1 m/s<sup>2</sup> ... +0.1 m/s<sup>2</sup>).

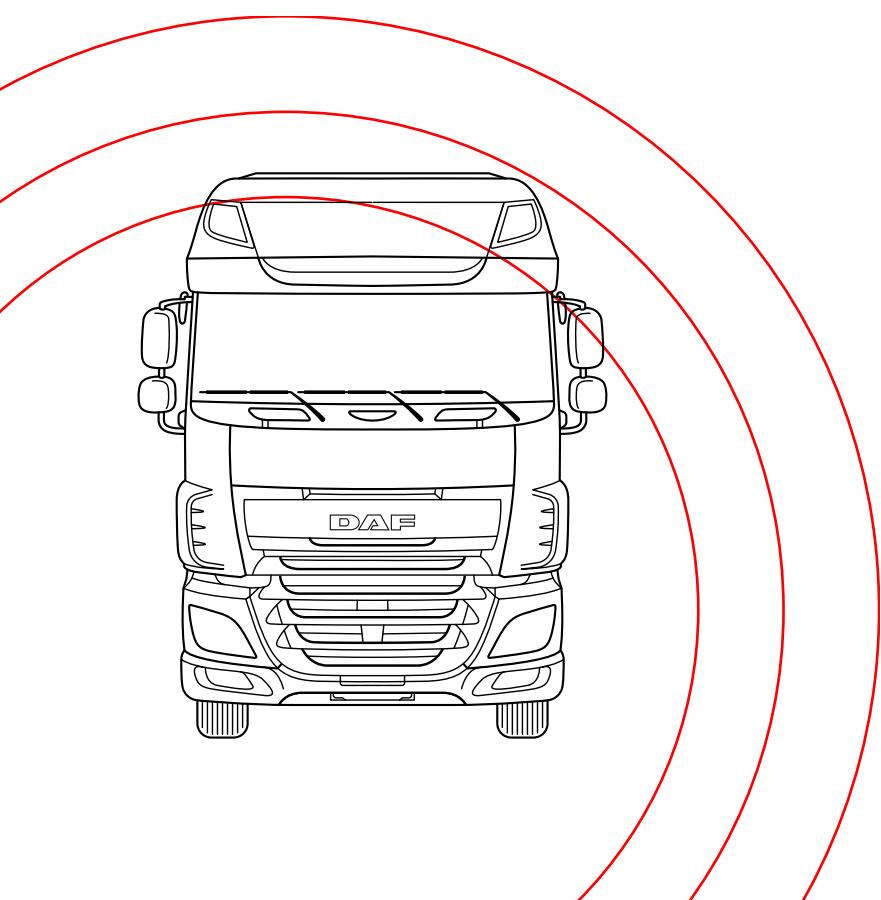
<sup>26</sup> Initial fuel baselining tests undertaken in Phase 1 of HelmUK under controlled, open-road conditions indicated possible fuel savings of platooning over ACC between 3.7% and 7.2%.





### Summary of results

The results described above for current road network, optimised road network and uninterrupted platooning are summarised in the tables and figures below.



**Table 3.2:** Overview of share of platooning achieved on platooning trial runs for full trial route and various sub-segments; P: platooning, GC: gap closing, NP/GO: non-platooning or gap opening.

Route segment	Length	Share of time on platooning runs spent ...		
		P	GC	NP/GO
<b>Full route</b>	109 miles	<b>36.8%</b>	5.7%	57.5%
<b>Full route without 'non-platoonable' junctions</b>	57 miles	<b>59.5%</b>	3.3%	37.2%
<b>M5 segment</b>	87 miles	<b>46.7%</b>	6.8%	46.5%
<b>M5 segment without 'non-platoonable' junctions</b>	44 miles	<b>71.3%</b>	3.4%	25.3%
<b>M6 segment</b>	22 miles	<b>13.6%</b>	2.5%	83.9%
<b>M6 segment without 'non-platoonable' junctions</b>	13 miles	<b>20.3%</b>	2.9%	76.8%

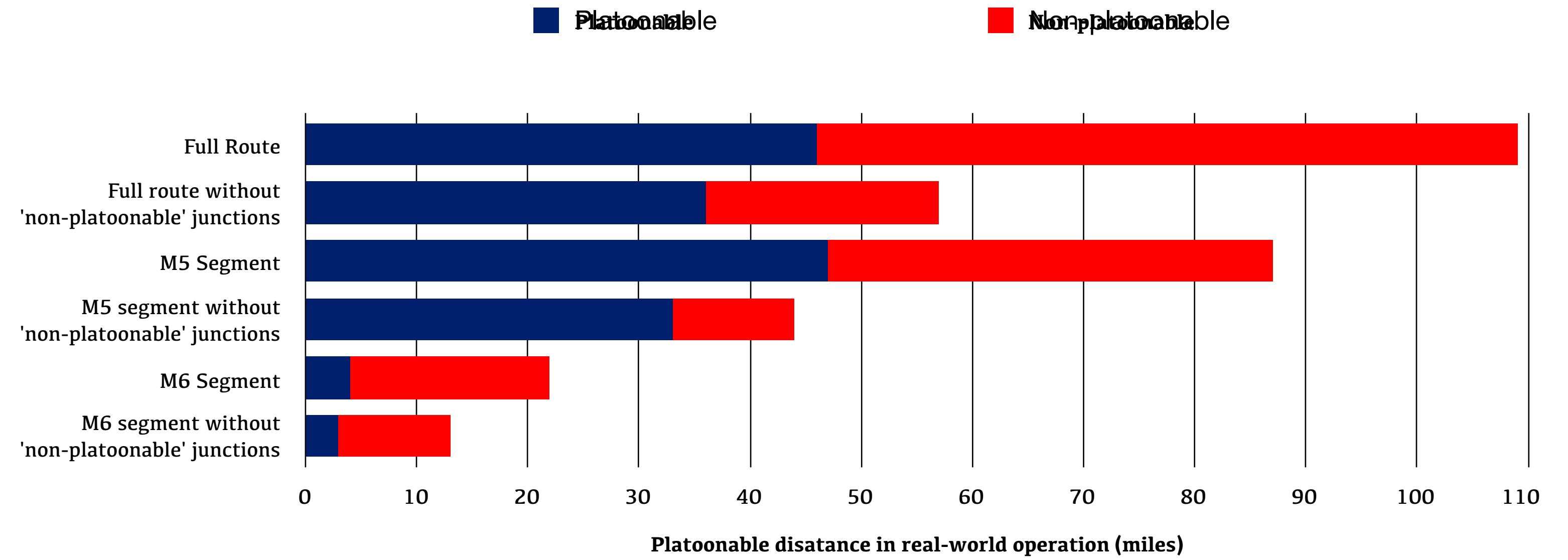
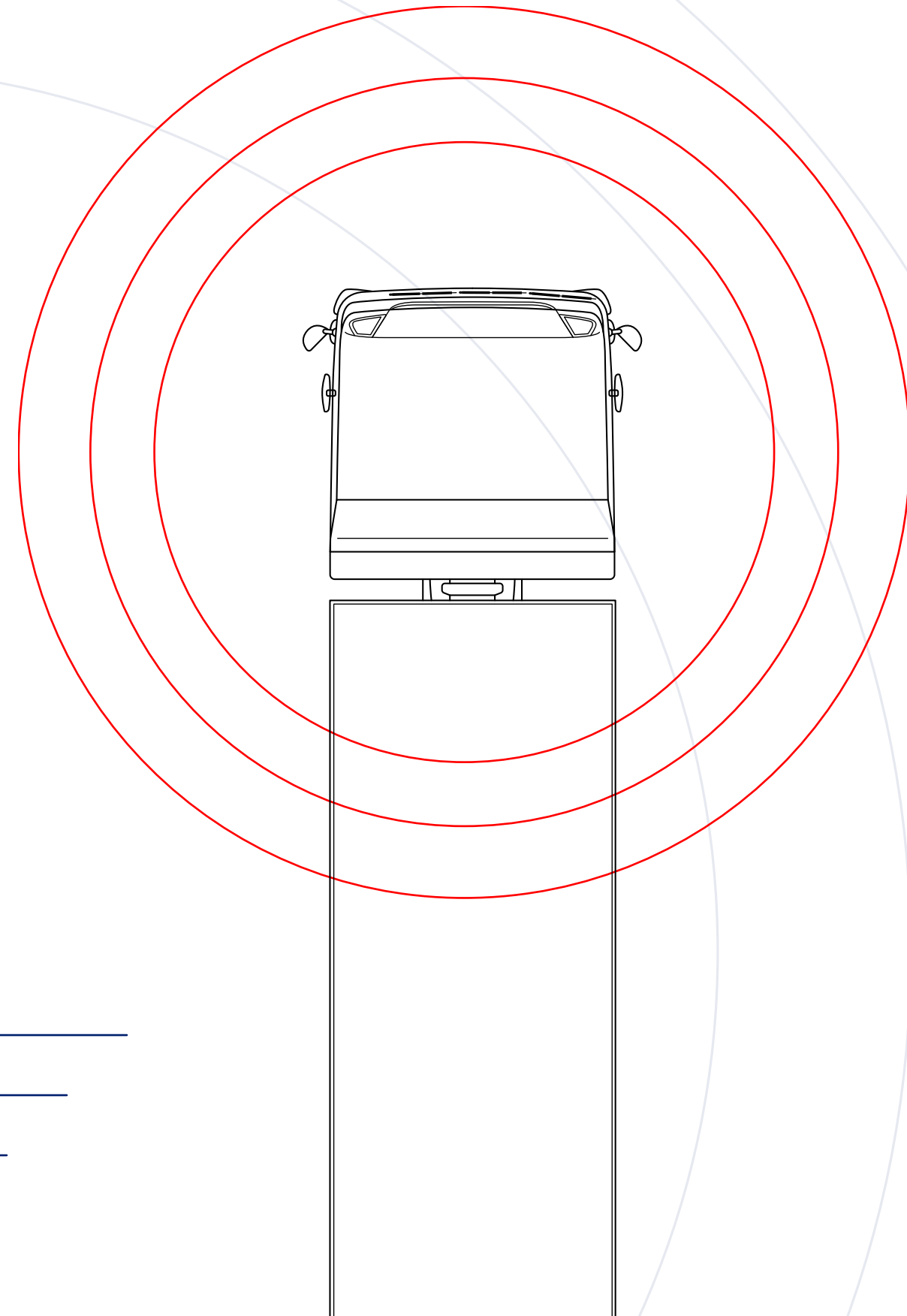


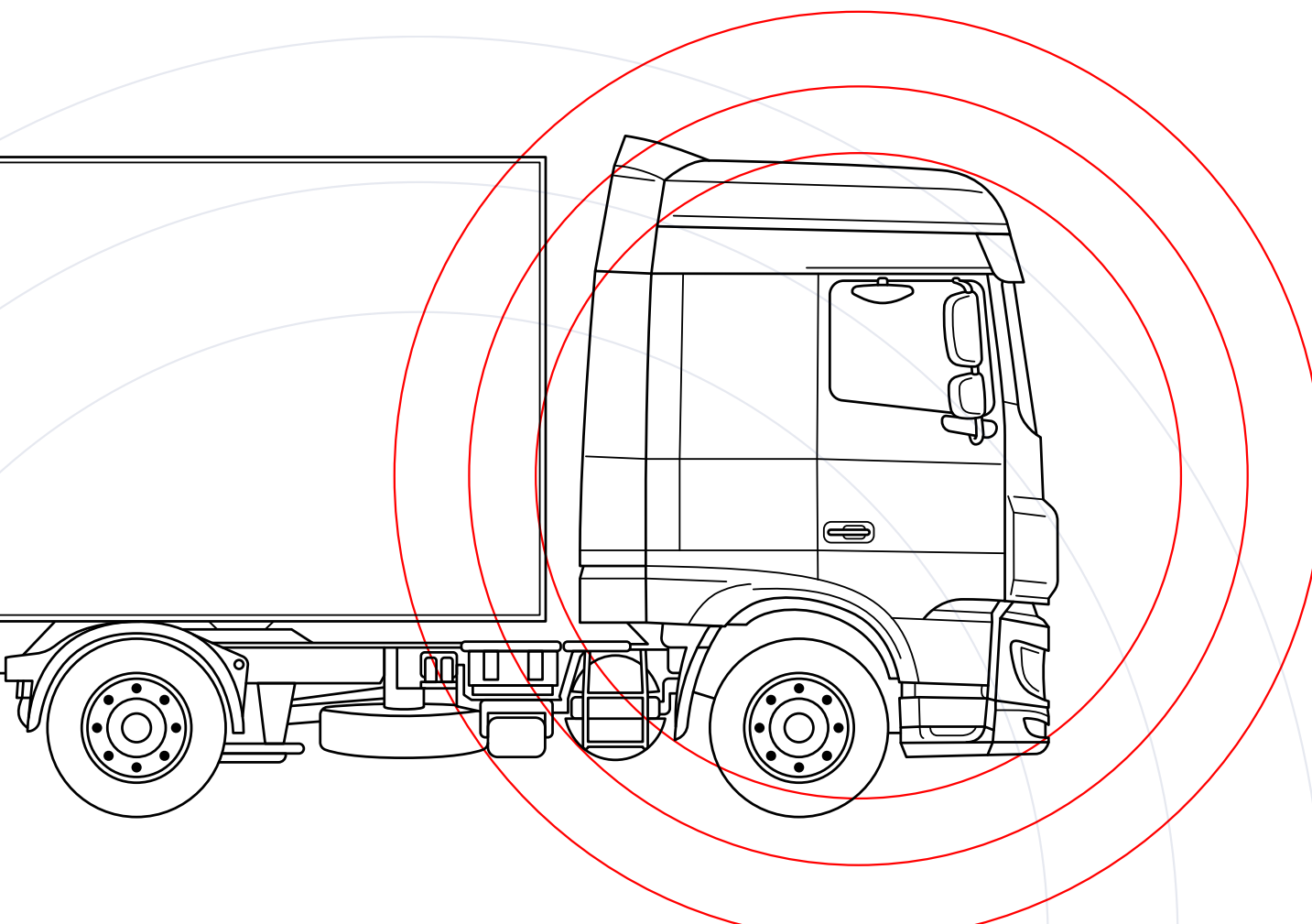
Figure 3.5: Average distance found 'platoonable' in real-world operation during the platooning trial runs; results shown for full trial route and various sub-segments; note that results are calculated from share of time travelled in each state multiplied by length of segment, i.e. the distance figures are an approximation not accounting for speed variations between trial runs; potential causes for non-platooning include: 'non-platoonable' junctions, lane changing (e.g. at lane gain/drop or for overtaking), congested traffic conditions, adverse weather, other road user cut-ins, roadworks or failure to engage platooning because distance to next junction considered too short..



**Table 3.3:** Overview of fuel efficiency results per scenario; positive numbers denote saved fuel when comparing platooning to non-platooning (ACC) trial runs; numbers set in bold represent best estimate found in HelmUK for a three-vehicle platoon in each scenario; platooning share based on percentage of time spent platooning or gap closing during platooning trial runs; LV/FV/TV/P: leading vehicle/following vehicle/trailing vehicle/platoon; CI: confidence interval.

Route segment	Platooning share	Fuel/carbon savings measured based on:					
		Direct measurement				Statistical modelling	
		LV	FV	TV	P	P	95% CI
<b>Current road network</b> M5 segment	53.5%	-0.1%	0.8%	1.1%	<b>0.5%</b>	n/a	n/a
<b>Optimised road network</b> M5 segment without 'non-platooning' junctions	74.7%	0.4%	1.9%	3.1%	1.7%	<b>2.5%</b>	1.6% - 3.4%
<b>Optimised road network</b> Route segments with high platooning proportion	85.7%	0.0%	2.3%	3.6%	1.8%	<b>2.6%</b>	1.8% - 3.4%
<b>Uninterrupted platooning</b> Constant steady-state platooning	100.0%	1.6%	5.9%	6.2%	<b>4.1%</b>	n/a	n/a

Note that the figures for the entire platoon cannot be calculated by simply averaging the percentage savings of individual vehicles because the vehicles carried different payloads and therefore had different baseline fuel consumption and because the three vehicles spent a different amount of time in platooning condition.



## How do the fuel savings found in HelmUK compare to previous research?

The SARTRE study (2013) reported large potential fuel savings for platooning compared to solo driving: In a two-HGV platoon, the lead vehicle could save up to 7%, the following vehicle up to 16%. However, these figures were found for a very short following distance of 5 metres with experiments carried out in the safe environment of a test track. The closest following distance HelmUK could safely realise in live traffic was approximately 20 metres, which can be expected to be associated with considerably smaller fuel savings.

The real-world trial EDDI (2019), conducted on a German motorway, used following distances more similar to HelmUK: A two-HGV platoon was operated at night-time at distances of 15 metres and 21 metres. The trial reported fuel savings of 1.3% for the lead vehicle and 3% to 4% for the following vehicle (results not reported separately per following distance). The platoon had to disband before motorway intersections, but not before the majority of junctions, which arguably allowed platooning with fewer interruptions compared to HelmUK.

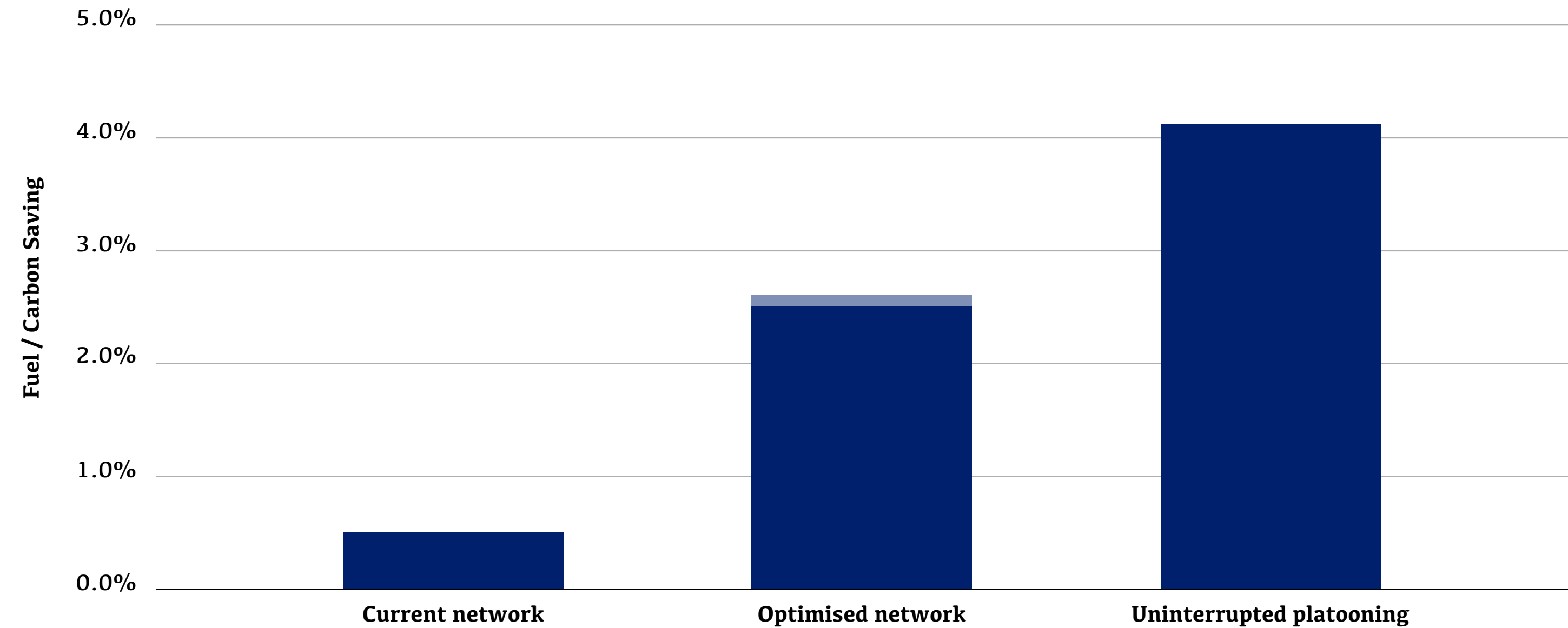


Figure 3.6: Average fuel/carbon savings of three-vehicle platoon when comparing platooning to non-platooning trial runs for: Motorway M5 (current network), motorway M5 without 'non-platoonable' junctions (optimised network, lower value); segments with high platooning proportion (optimised network, upper value), constant steady-state platooning (uninterrupted platooning).



## How much fuel can platooning save over adaptive cruise control?

- ▶ The HelmUK road trials identified fuel savings from platooning that exceed what can be achieved by using ACC. Based on these results, the following average savings can be expected for a three-vehicle platoon compared to ACC operation:
  - Current road network: 0.5%
  - Optimised road network: 2.6%
  - Uninterrupted platooning: 4.1%
- ▶ Adding more than three vehicles to a platoon could increase the average saving beyond these levels.
- ▶ The ‘current road network’ result reflects what was measured on the M5 motorway when comparing platooning to non-platooning trial runs.
- ▶ The ‘optimised road network’ figure reflects the higher value out of two scenarios where only selected route segments were analysed to approximate a situation where platooning across all junctions is possible and/or generally high proportions of platooning can be achieved on the network.
- ▶ The ‘uninterrupted platooning’ figure reflects a hypothetical upper boundary of what could be achieved if uninterrupted steady-state platooning could be realised. This approximates a situation where platoons could, for instance, operate in dedicated lanes with low traffic occupancy.

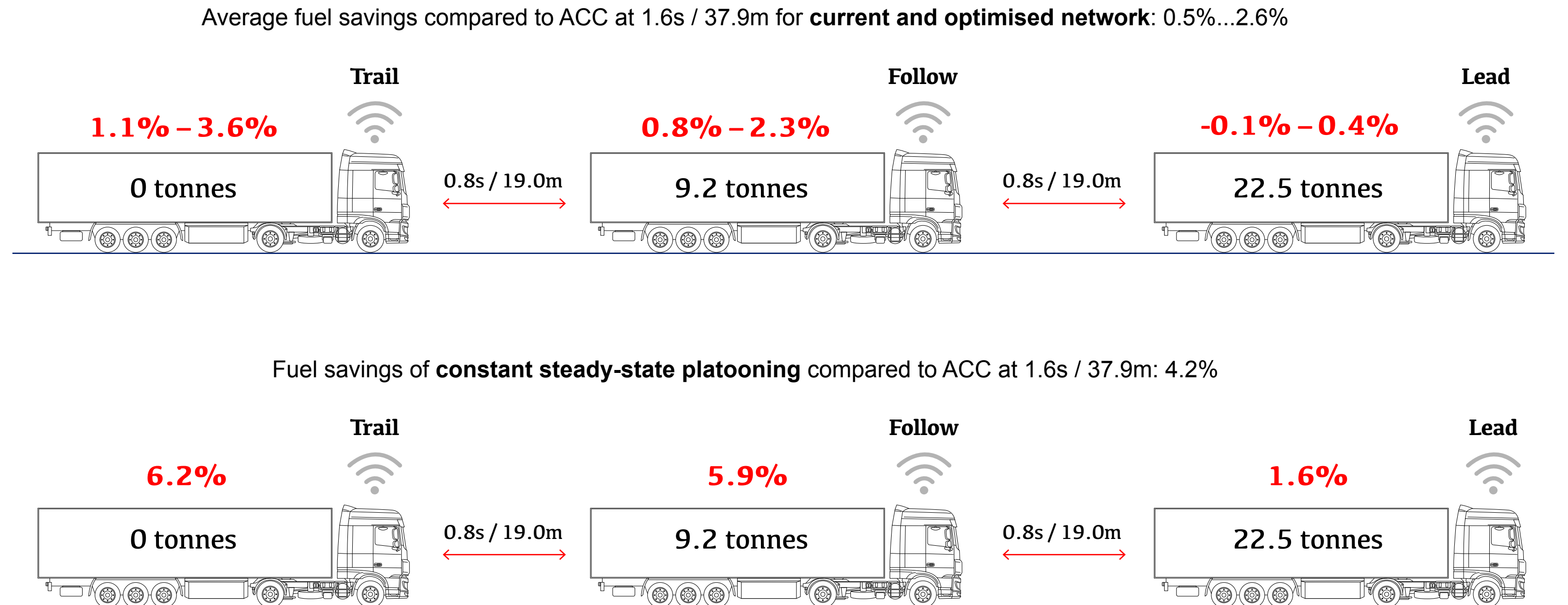


Figure 3.7: Fuel/carbon savings identified on current and optimised road network (upper image) and hypothetical uninterrupted platooning (lower image) for the entire three-vehicle platoon and individual vehicles; positive numbers denote saved fuel when comparing platooning to non-platooning (ACC) trial runs.

### 3.2.2 Regulated emissions

To approximate the potential impact of platooning on NO<sub>x</sub> (nitrogen oxides) and PM (particulate matter) emissions, typical relationships between fuel consumption and emissions for Euro VI articulated HGVs were derived from Defra's Emission Factor Toolkit<sup>27</sup>, see Figure 3.8. Typical fuel consumption values of articulated HGVs depending on weight and speed are shown in Figure 3.9.

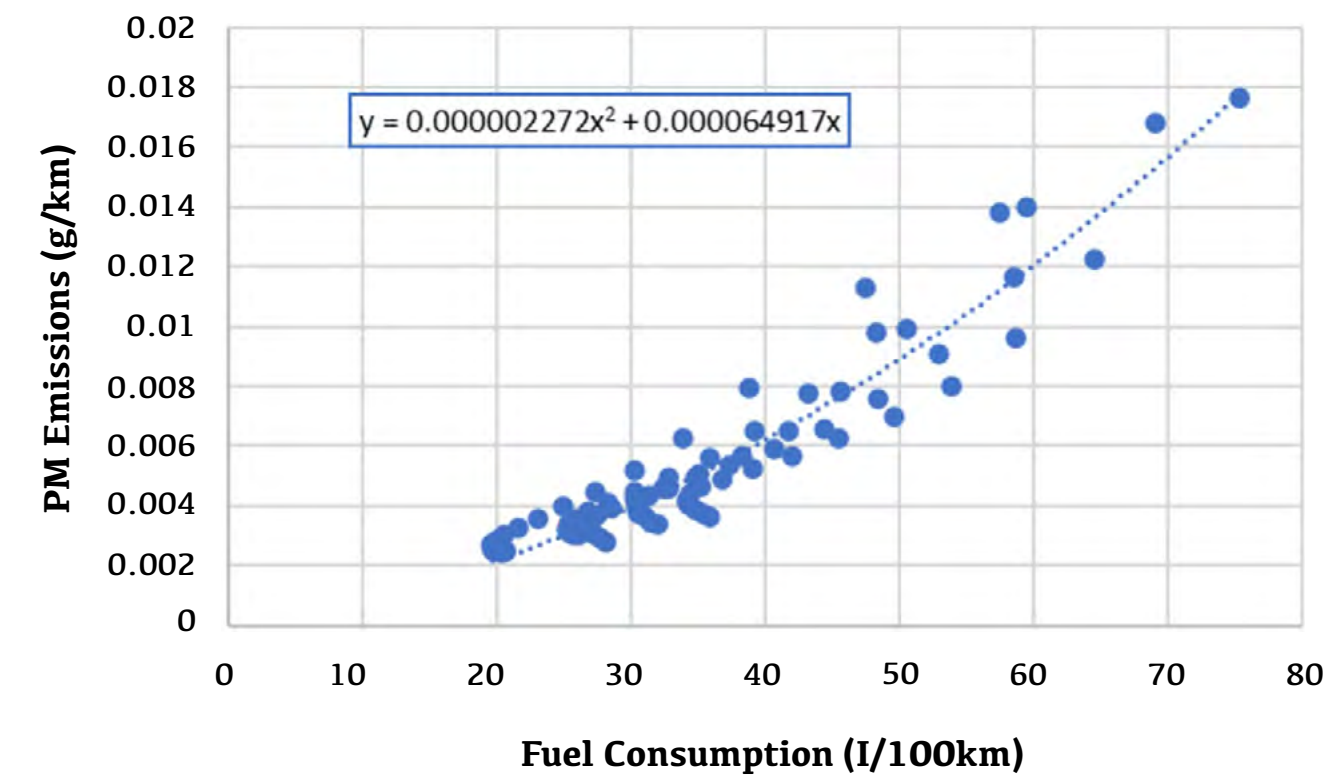
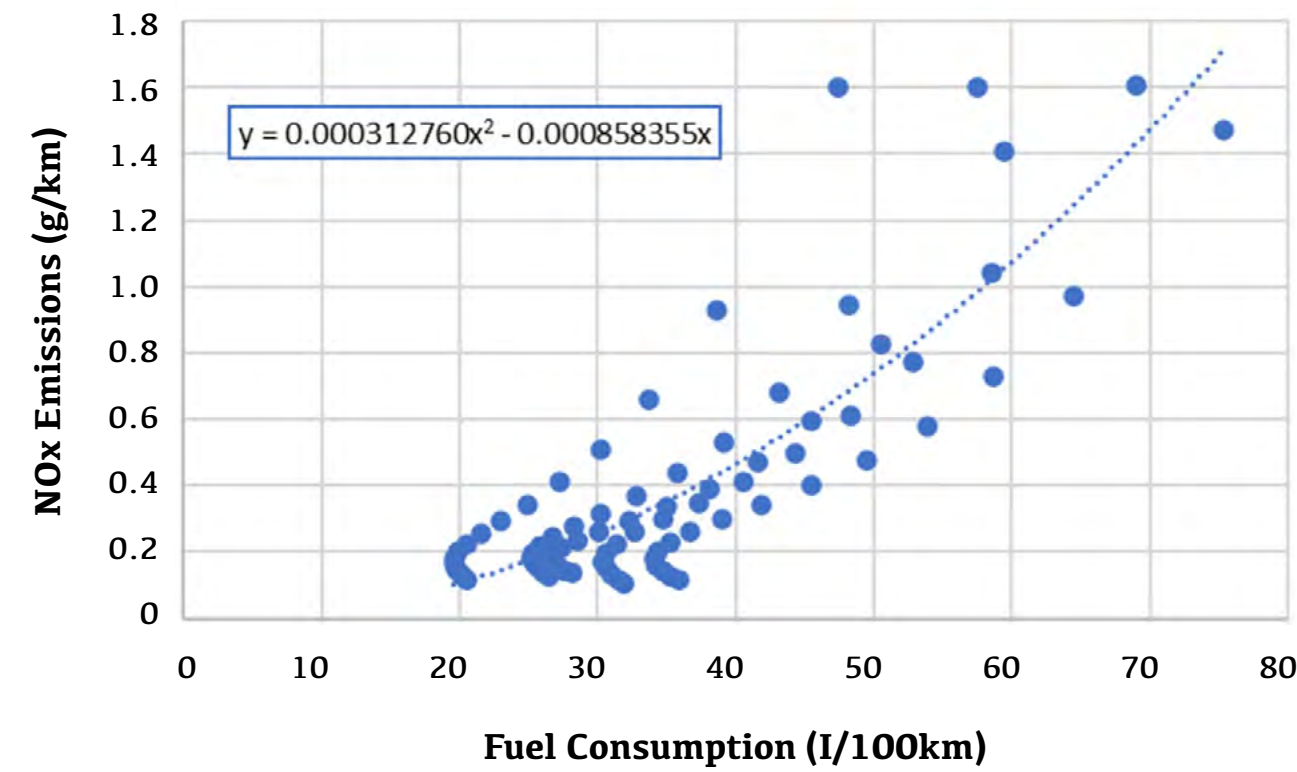


Figure 3.8: Relationship between fuel consumption and NO<sub>x</sub> emissions (top) and PM emissions (bottom); 2nd order polynomial trend line forced through origin and its formula shown on graphs.

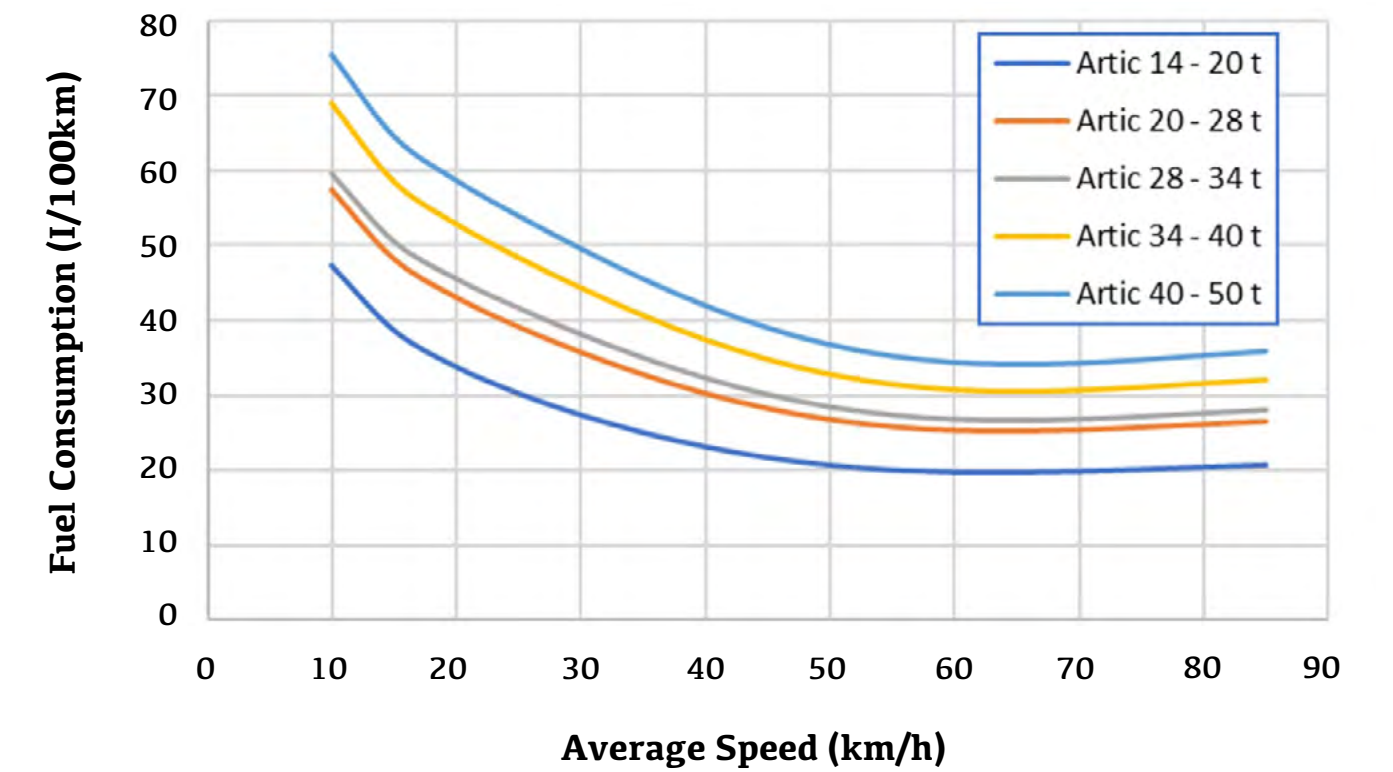


Figure 3.9: Typical fuel consumption of articulated HGVs depending on gross combination weight and driving speed; note that the fuel rate is lowest at relatively high average speeds of around 60 km/h to 80 km/h because of more steady-state driving (fewer decelerations and accelerations) and use of higher gears.

<sup>27</sup> Emissions Factors Toolkit v11.0, released November 2021.



> 3. Key results > 3.2 Fuel efficiency and emissions > 3.2.2 Regulated emissions

The fuel savings expected from platooning over ACC are 0.5% for the current network and could increase to 2.6% or 4.1% depending on the hypothetical future scenario analysed (see Section 3.2.1). The potential NO<sub>x</sub> and PM emissions savings associated with these, calculated based on the relationships described above, are presented in Table 3.4, Table 3.5 and Table 3.6.

**Table 3.4:** NO<sub>x</sub> and PM emissions savings based on current road network results (0.5% fuel saving) for typical fuel consumption values; baseline fuel consumption represents use of ACC at typical operating speeds with gross combination weights in the range of 20 tonnes to 40 tonnes.

Fuel consumption (l/100 km)			NO <sub>x</sub> emissions (mg/km)			PM emissions (mg/km)		
ACC	Platoon	Saving	ACC	Platoon	Saving	ACC	Platoon	Saving
20.00	19.90	0.5%	107.9	106.8	1.1%	2.207	2.192	0.7%
25.00	24.88	0.5%	174.0	172.2	1.1%	3.043	3.021	0.7%
30.00	29.85	0.5%	255.7	253.1	1.0%	3.992	3.962	0.8%
35.00	34.83	0.5%	353.1	349.4	1.0%	5.055	5.016	0.8%

**Table 3.5:** NO<sub>x</sub> and PM emissions savings based on optimised road network results (2.6% fuel saving) for typical fuel consumption values; baseline fuel consumption represents use of ACC at typical operating speeds with gross combination weights in the range of 20 tonnes to 40 tonnes.

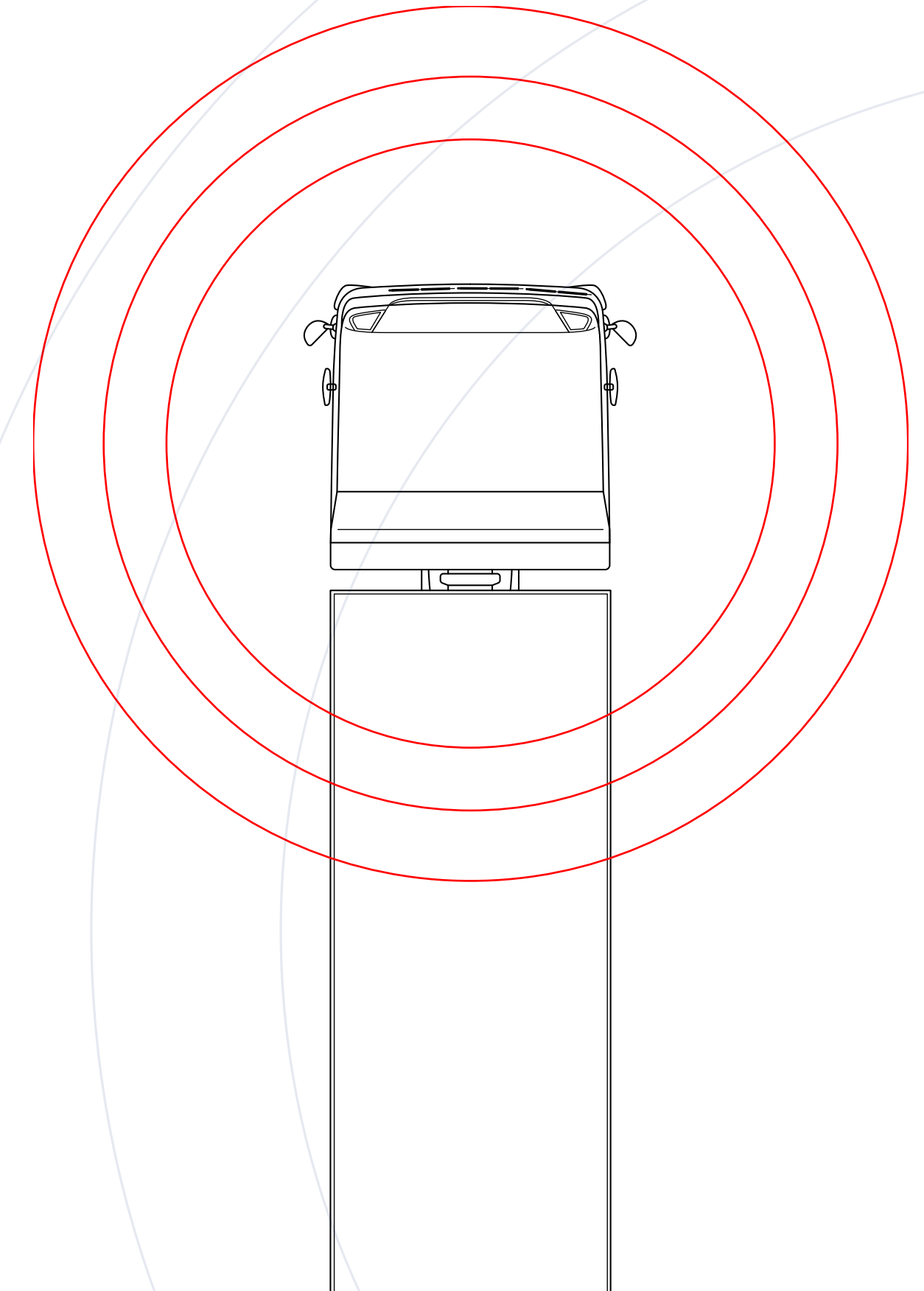
Fuel consumption (l/100 km)			NO <sub>x</sub> emissions (mg/km)			PM emissions (mg/km)		
ACC	Platoon	Saving	ACC	Platoon	Saving	ACC	Platoon	Saving
20.00	19.48	2.6%	107.9	102.0	5.5%	2.207	2.127	3.6%
25.00	24.35	2.6%	174.0	164.5	5.4%	3.043	2.928	3.8%
30.00	29.22	2.6%	255.7	242.0	5.4%	3.992	3.837	3.9%
35.00	34.09	2.6%	353.1	334.2	5.3%	5.055	4.853	4.0%

**Table 3.6:** NO<sub>x</sub> and PM emissions savings based on uninterrupted platooning results (4.1% fuel saving) for typical fuel consumption values; baseline fuel consumption represents use of ACC at typical operating speeds with gross combination weights in the range of 20 tonnes to 40 tonnes.

Fuel consumption (l/100 km)			NO <sub>x</sub> emissions (mg/km)			PM emissions (mg/km)		
ACC	Platoon	Saving	ACC	Platoon	Saving	ACC	Platoon	Saving
20.00	19.12	4.1%	107.9	98.6	8.7%	2.207	2.081	5.7%
25.00	23.90	4.1%	174.0	159.2	8.5%	3.043	2.862	5.9%
30.00	28.68	4.1%	255.7	234.2	8.4%	3.992	3.748	6.1%
35.00	33.46	4.1%	353.1	323.5	8.4%	5.055	4.739	6.3%

## What impact could platooning have on NO<sub>x</sub> and PM emissions?

- ▶ Based on the fuel savings identified in HelmUK, the following reductions of nitrogen oxide and particulate matter emissions can be expected for a three-vehicle platoon compared to ACC operation, depending on vehicle load, driving speed and associated base fuel consumption:
  - Current road network: NO<sub>x</sub>: 1.0% – 1.1%; PM: 0.7% – 0.8%
  - Optimised road network: NO<sub>x</sub>: 5.3% – 5.5%; PM: 3.6% – 4.0%
  - Uninterrupted platooning: NO<sub>x</sub>: 8.4% – 8.7%; PM: 5.7% – 6.8%
- ▶ Adding more than three vehicles to a platoon could increase the average reductions beyond these levels.
- ▶ The 'current road network' result is based on fuel savings measured on the M5 motorway.
- ▶ The 'optimised road network' value reflects a situation where high proportions of platooning could be achieved on the network.
- ▶ The 'uninterrupted platooning' figure reflects a hypothetical upper boundary of what could be achieved if uninterrupted steady-state platooning could be realised.





## → 3.3 Impact on the wider English SRN

A number of research questions looked at the impacts of HGV platooning on the wider English SRN including on traffic management, traffic control and infrastructure.

### 3.3.1 Platooning and real-time management of traffic flow

In the majority of instances, HGV platooning operation is unlikely to affect National Highways' ability to manage traffic on the English SRN in real time. In a limited number of instances, however, platooning operation may have the following impacts on real-time traffic management:

1. At high market penetration rates, there may be undesirable activation of congestion management systems because platooning HGVs occupy a smaller road space which may exceed current thresholds
2. The obscuration of adjacent lane or carriageway vehicle detection for locations with only a single side-firing radar sensor, this is an existing impact from HGVs which may be exacerbated by platooning
3. The obscuration of nearside verge mounted Variable Message Signs (VMS) for road users following closely behind a platoon, again this is this is an existing impact from HGVs which may be exacerbated by platooning.

These impacts are only likely to be significant at high market penetration rates when platooning is common. Overall, no immediate changes to real-time traffic management are needed in order to introduce platooning technology.

For congestion management systems, if platooning operation becomes common, there may be a need to amend the lane occupancy thresholds which trigger a system response to account for the fact that widespread platooning will effectively increase the capacity of lanes in which platooning occurs because vehicles are travelling closer together.

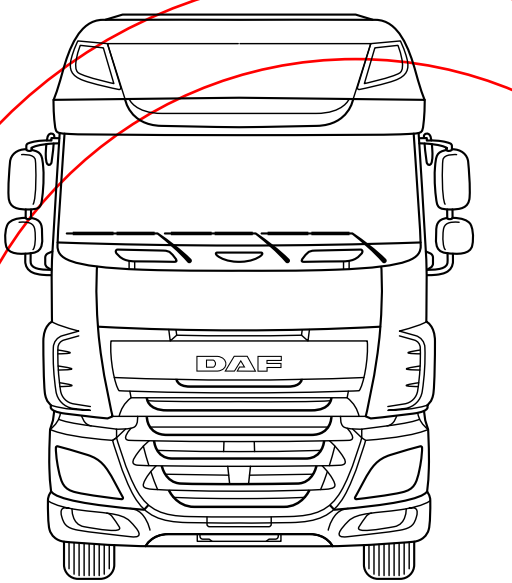
#### Sharing of information between platoons and National Highways

In an ideal 'business as usual' state of HGV platooning, little information will need to be shared between HGV platoons and National Highways for both to operate effectively. This reflects the existing situation for many other current driver assistance systems in operation on-road and reduces the burden on National Highways' infrastructure and staff. How National Highways staff interact with platooning on the English SRN is further discussed in Section 3.3.3.

However, information sharing can play a role in addressing potential challenges with platooning identified through the HelmUK project and allow platooning to be deployed on English motorway-standard roads more safely and quickly.

A key challenge for platooning is maintaining road safety at junctions, as discussed in Section 3.1.4. The risk at junctions is dependent on several factors, including dynamic factors such as traffic flow. If information was shared between infrastructure and the platoon detailing the numbers and types of vehicles on the approach to entry slips, this could facilitate a dynamic response to junctions, such a widening the gap between platooning vehicles to allow traffic to merge. This information could also be used to enhance traffic management techniques at junctions, as covered in the next Section 3.3.2 on ramp metering.

The real-time, dynamic identification of which junctions are safe for platooning would provide a critical risk mitigation for platooning operations. It could greatly increase the time spent platooning and result in realisation of greater fuel, carbon, and emissions benefits.



### 3.3.2 Ramp metering

The key risk for HGV platooning is conflict between vehicles joining the carriageway at junctions and the platoon. This conflict could increase the chances of a collision or mean that vehicles have to join the main carriageway at a dangerously low speed.

One potential solution to this issue is the use of ramp metering to manage the traffic joining the mainline carriageway.

#### Ramp metering

Ramp metering is a traffic management technique which uses traffic signals to regulate the number of vehicles joining the motorway via an entry slip. The goal is to prevent or delay flow breakdown on the main carriageway. The traffic signals hold merging traffic until it is suitable for them to join the main carriageway, as shown in Figure 3.10.

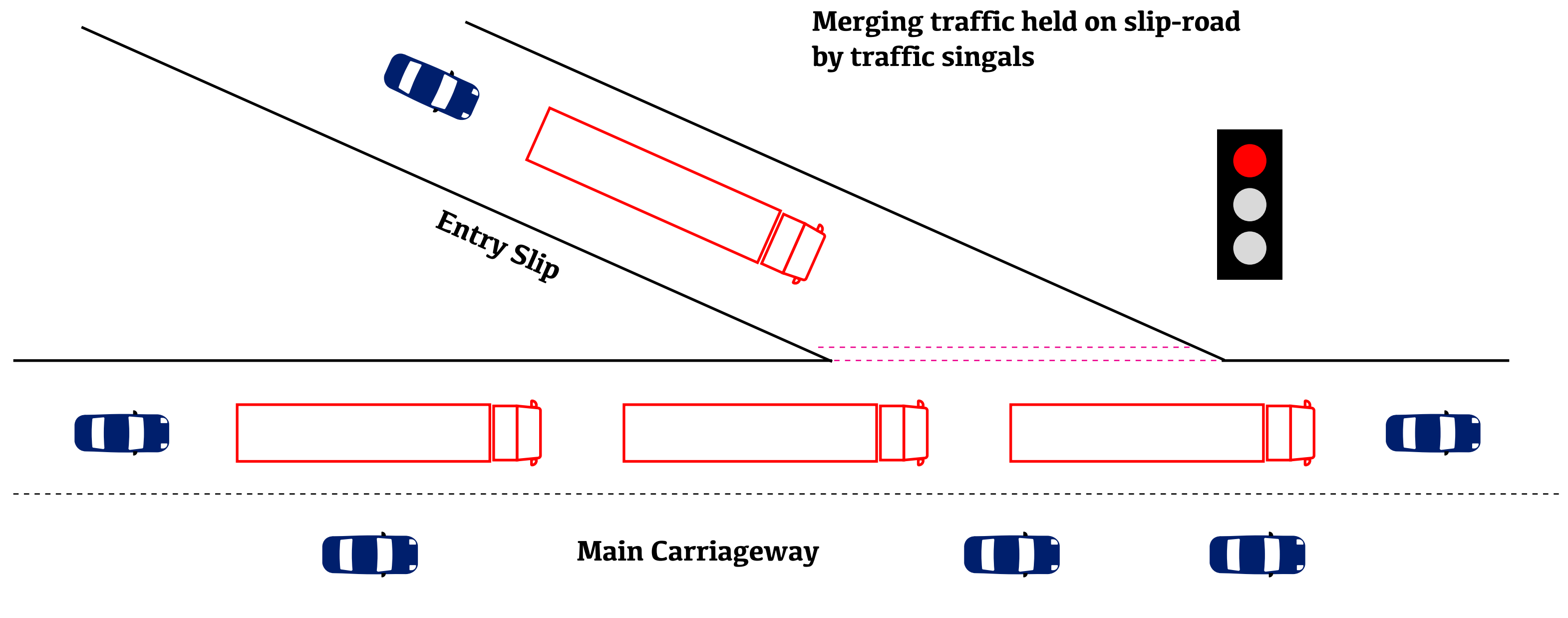


Figure 3.10: Ramp metering operation.



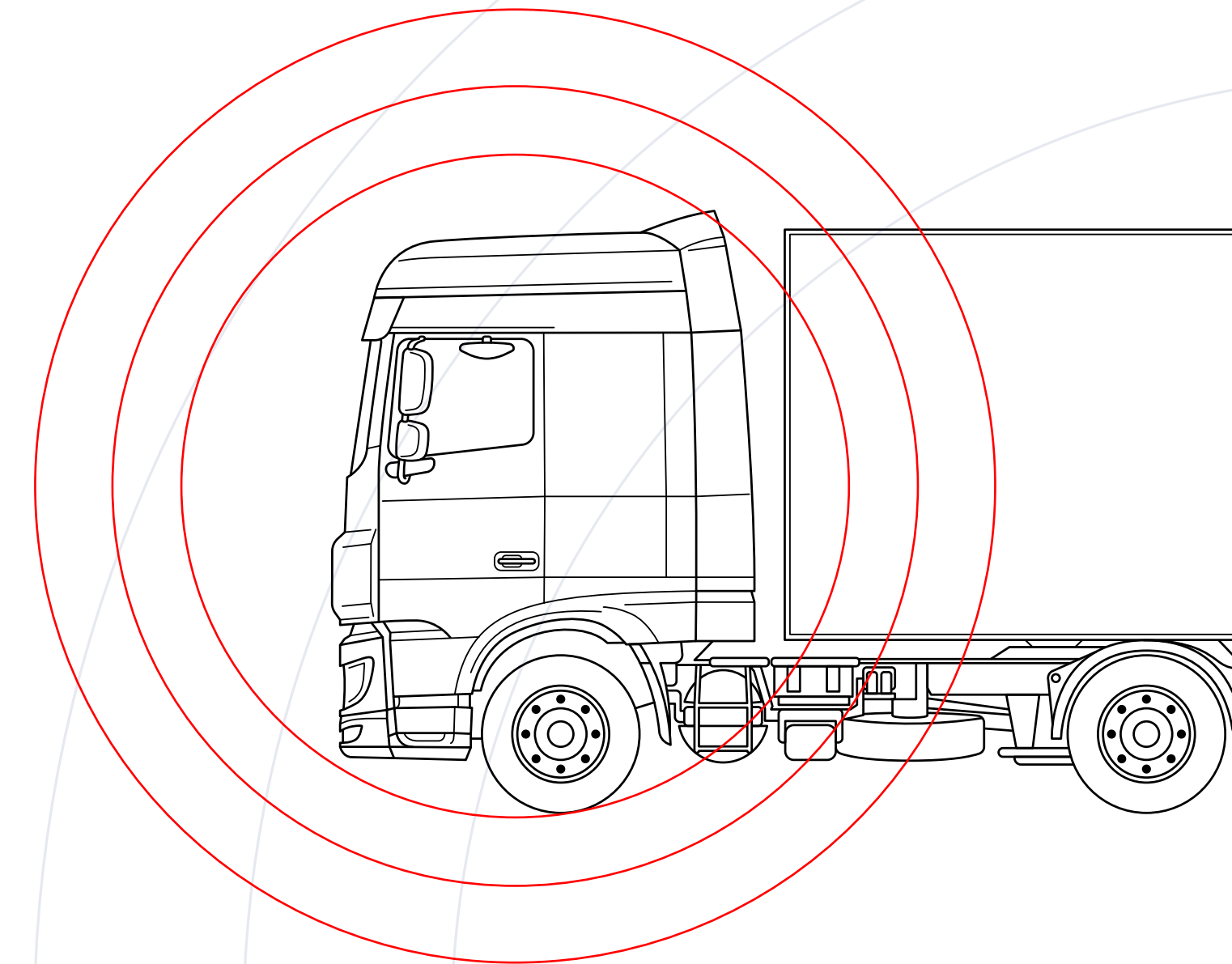
### **Impact of using ramp metering to support platooning operation**

- Ramp metering could be used to hold back vehicles on an entry slip while a platoon passes on the main carriageway. The main benefit is improved road safety, but it also enables the fuel benefits of HGV platooning to be maintained because the platoon does not need to disband and reform to pass the junction (as was required at most junctions in the HelmUK trials)
- There are disbenefits to this approach and it would increase travel time and queue length while decreasing journey time reliability for vehicles joining the main carriageway at ramp metering sites. The balance between saving fuel for platooning HGVs versus the additional fuel consumption for traffic held on the slip road should be considered
- The impact on local roads which feed the SRN must be accounted for, slip roads and motorway junctions have limited capacity so care must be taken that queues and associated emissions are not 'shifted' onto the local roads that are off National Highways' network
- To maximise benefit and minimise disbenefits, the decision to hold vehicles at an on-ramp while a platoon passes on the main carriageway has to be taken for different traffic conditions and platoon characteristics, because multiple factors govern vehicle and HGV platoon interactions
- For high traffic volumes and a high number of platoons, the safety benefits for merging vehicles from ramp metering are likely to outweigh the impact on journey time

- However, for lower traffic volumes and lower numbers of platoons, the safety benefits of holding vehicles on the entry slip may be outweighed by the possible disbenefits to the performance of the ramp metering site for merging traffic.

### **Changes to ramp metering required to realise these benefits**

- Ramp metering sites would need to have Vehicle-to-Infrastructure (V2I) communication so that the traffic control is aware of a platoon's approach to a junction
- Ramp metering sites would have to be assessed for 'platoonability' based on geometric design (spatial) and flow variability (temporal)
- The use of HGV platooning at ramp metering sites could initially be limited to off-peak, low flow and overnight periods until the impacts are understood. However, ramp metering is typically only used in high-flow conditions, so consideration needs to be given to any new risks associated with low-flow use of ramp metering
- The maximum platoon lengths safely permissible for a given ramp metering site can be determined and communicated to platooning vehicles
- Ramp metering roll out could support a wider integrated traffic management system between local roads and the English SRN.



### 3.3.3 Managing platooning traffic on the English SRN

HelmUK coordinated closely with the relevant Regional Operations Centres (ROCs) as part of the road trials. However, this approach isn't suitable for a 'business as usual' deployment of HGV platooning in the future. Rather than treating platooning vehicles in a similar manner to abnormal loads, in the future, platooning should be able to operate safely on motorway-standard roads (and eventually the wider SRN) without relying on National Highways staff.

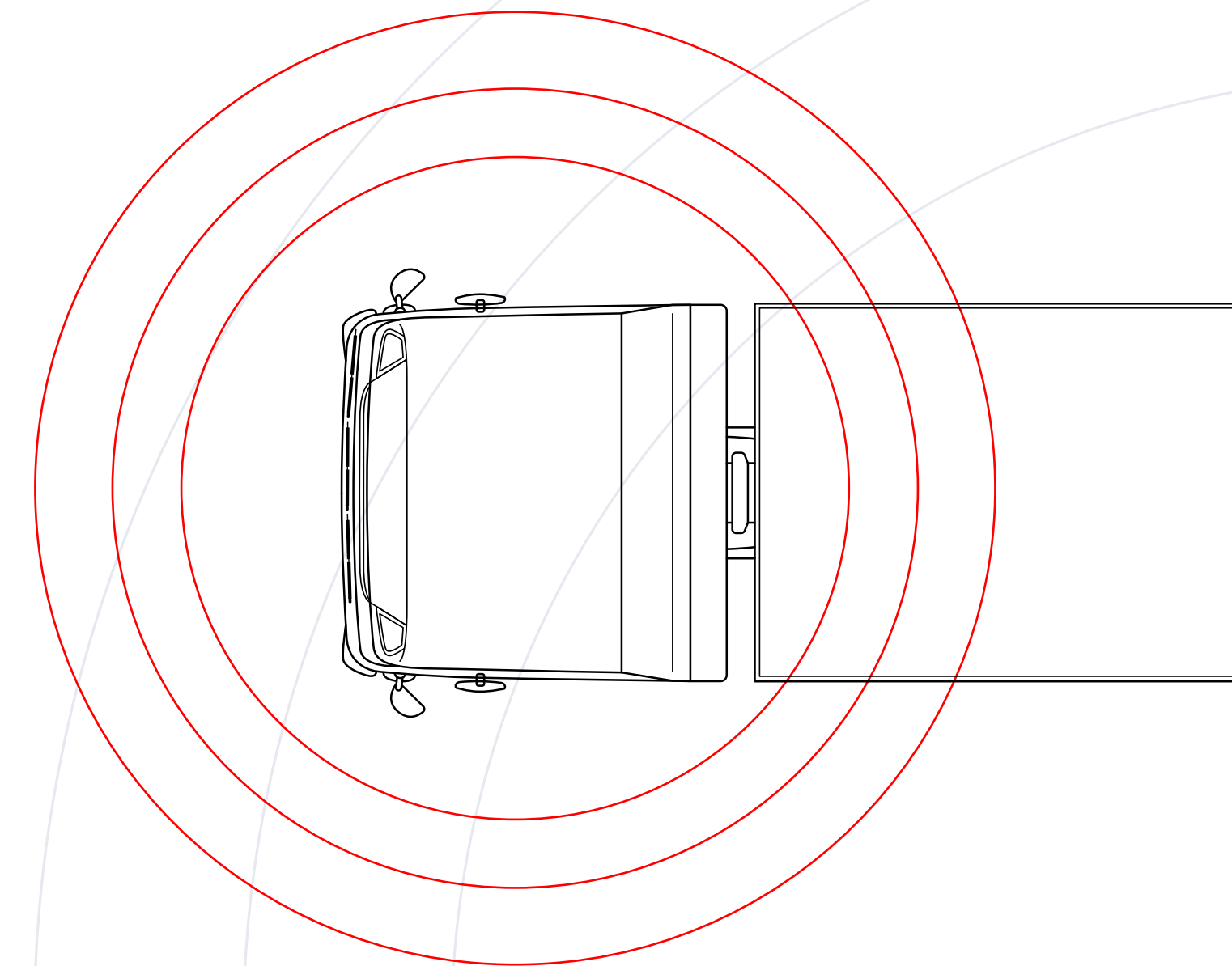
To understand how platooning could affect traffic management on the English SRN, HelmUK consulted staff from National Highways' Operations Centres, including eight ROCs and the National Traffic Operations Centre (NTOC).

The consultation identified areas where National Highways' staff believed additional development of procedures and processes may be required should HGV platooning become more widespread. The findings from this consultation are as follows:

- If platooning were to be further deployed on the English SRN, guidance around when platooning can and cannot take place would be required. Based on discussions with National Highways staff, the guidance may cover weather, roadworks, and other local conditions
- National Highways staff want to populate ROC network monitoring logs to capture platooning journeys on the network. For the HelmUK trials, this was done via a phone call, but telephone communication is not suitable to have awareness of widespread platooning operations on the network.

Possible solutions to this challenge are:

- An automated system to monitor platooning journeys in which platooning vehicles are required to provide information to National Highways and 'declare' their presence on the network
- Clear guidance to National Highways staff that network monitoring logs are not required to track platooning journeys based on safety assurance from manufacturers
- ROCs have a planned response and escalation process for incidents on the English SRN; feedback from National Highways staff is that it is essential that any future platooning operation has effective risk assessment of any non-standard aspects that might affect incident response actions
  - This need can be eliminated if the manufacturer proves the platooning system to be safe and that it requires no additional response from emergency services beyond any normal incident response involving HGVs. As part of the HelmUK project no elements of the system required specialist intervention from incident responders
- Should platooning become widespread, there may be benefits from providing suitable, targeted, information and briefings for staff potentially affected by wider introduction of platooning. These briefings should be developed with the involvement of the target audiences.



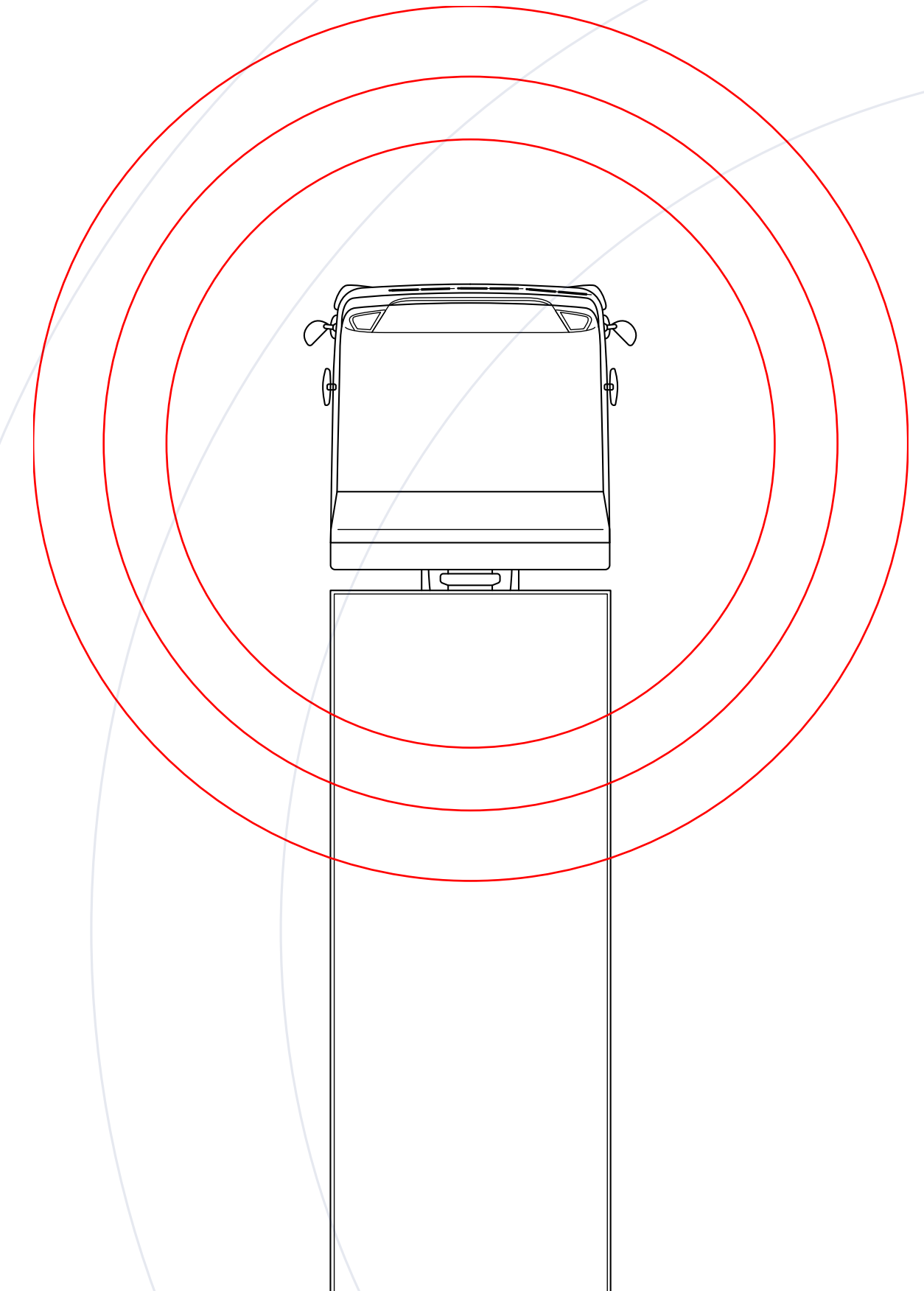


The consultation showed that National Highways operations staff feel they need information on platooning to manage the risks to the network. There are two risks with this approach:

1. This creates a large additional workload for ROCs. While some of this information processing could be automated, this would still require investment and management from National Highways.
2. The Safety Case for platooning technology becomes reliant on interactions with the ROCs. This is not a viable approach to manage platooning safety.

This engagement has allowed a clearer understanding of both the possible operational pressures and the perception of platooning technology within the ROCs. Based on the findings of HelmUK, 'business as usual' platooning deployments must not become reliant on National Highways managing risks. Instead, the safe 'business as usual' deployment of platooning should be achieved by working closely with ROC staff and taking their legitimate concerns into account.

Platooning operation should therefore be implemented in such a way as to minimise the required monitoring by National Highways staff and remove the need for any active involvement in platooning operations. Platooning technology will need to demonstrate that there is no requirement for risk assessments or for platooning journeys to be logged by ROCs. Type-approval regulation could be a way to ensure that traffic safety related functionalities, such as increasing the headway before junctions, become automated and don't rely on driver adherence (see Section 4.4.1).



### 3.3.4 Impact of road operators becoming platooning service providers

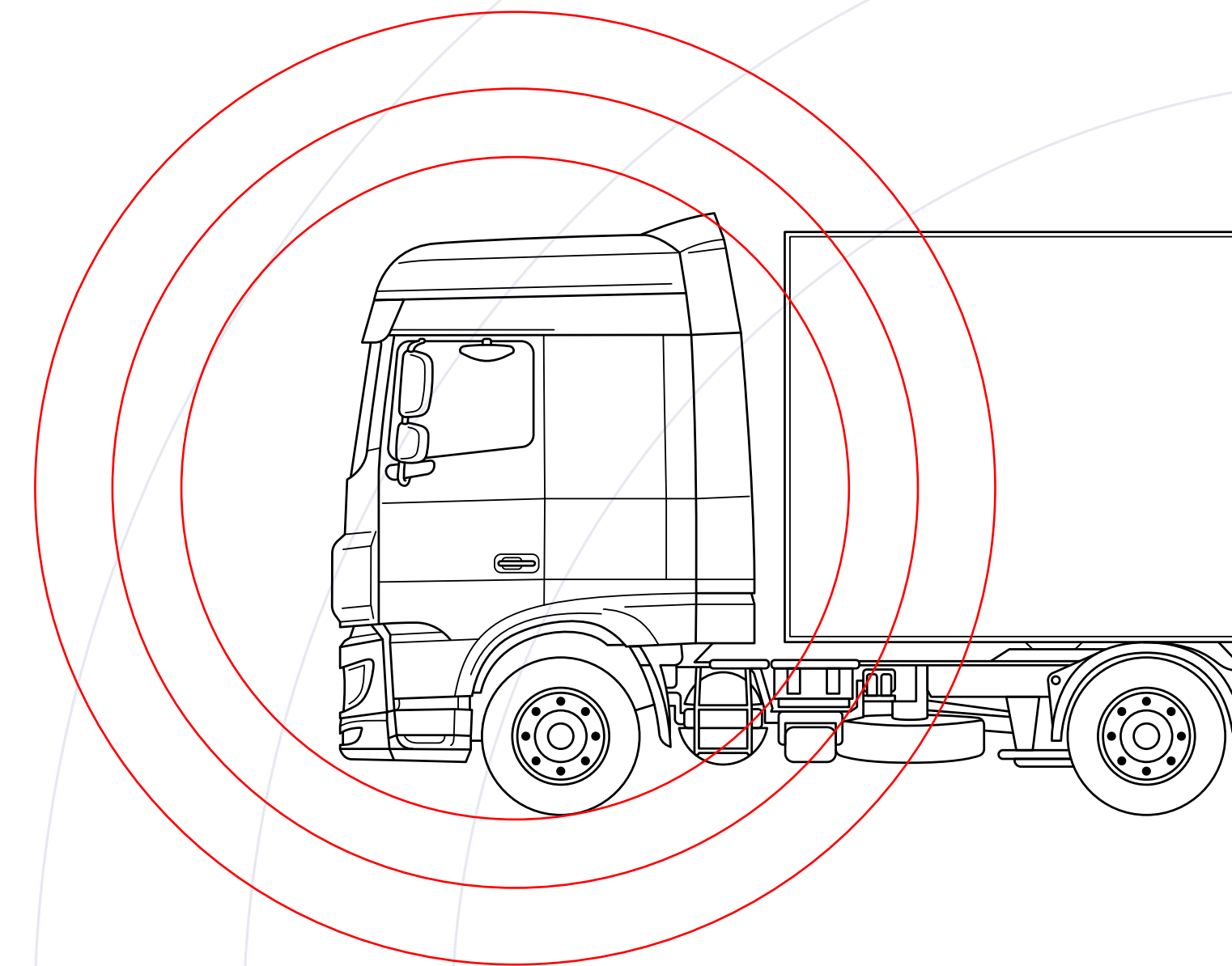
Forming platoons with multiple operators may require one or more Platooning Service Providers (PSPs), which have knowledge and understanding of proposed journeys from multiple operators so that potential platoon participants can be coordinated. As part of this research, TRL has evaluated the implications of road operators (such as National Highways) acting as Platooning Service Providers.

- A single PSP for a given geographical region offers the most chance of maximising platooning operation and therefore benefits
- The PSP should cover a contiguous geographical area, such as Great Britain
- Platooning is most likely to occur on motorways (or roads which conform to the same standards). It is important that all road operators who manage motorways or other similar roads the UK are closely aligned to the PSP

- It is important that any PSP is a trusted third party and not a freight operator because commercially sensitive information may be involved in platoon coordination. A third party would also be better suited to handle any financial transactions
- Acting as a PSP will provide a road operator with additional real-time data which can be used to improve traffic management and incident response effectiveness
- Road operators may not currently have the resources or skills to act as PSP. The most likely route to becoming a PSP is to sub-contract significant parts of the service
- If a road operator acts as a provider of enabling information for a contracted PSP it will play to its strengths; but will also lose much of the ability that a full PSP has to actively manage platoons and hence optimise traffic flows.

#### What is a Platooning Service Provider?

A PSP is a central authority which coordinates vehicles to enable platooning journeys.





### 3.3.5 Perception of the motoring public

HelmUK evaluated the state of knowledge and opinions about HGV platooning amongst the public in order to understand what information needed to be published, so that members of the public have an accurate knowledge of platooning technology, the potential benefits, and understand the purpose of the HelmUK trials. The research activities conducted were: social media reviews; interviews with members of the public, i.e. other road users, after a simulator trial; and interviews with professional HGV drivers before, during and after their HelmUK training. The overall approach to this research is shown in Figure 3.11.

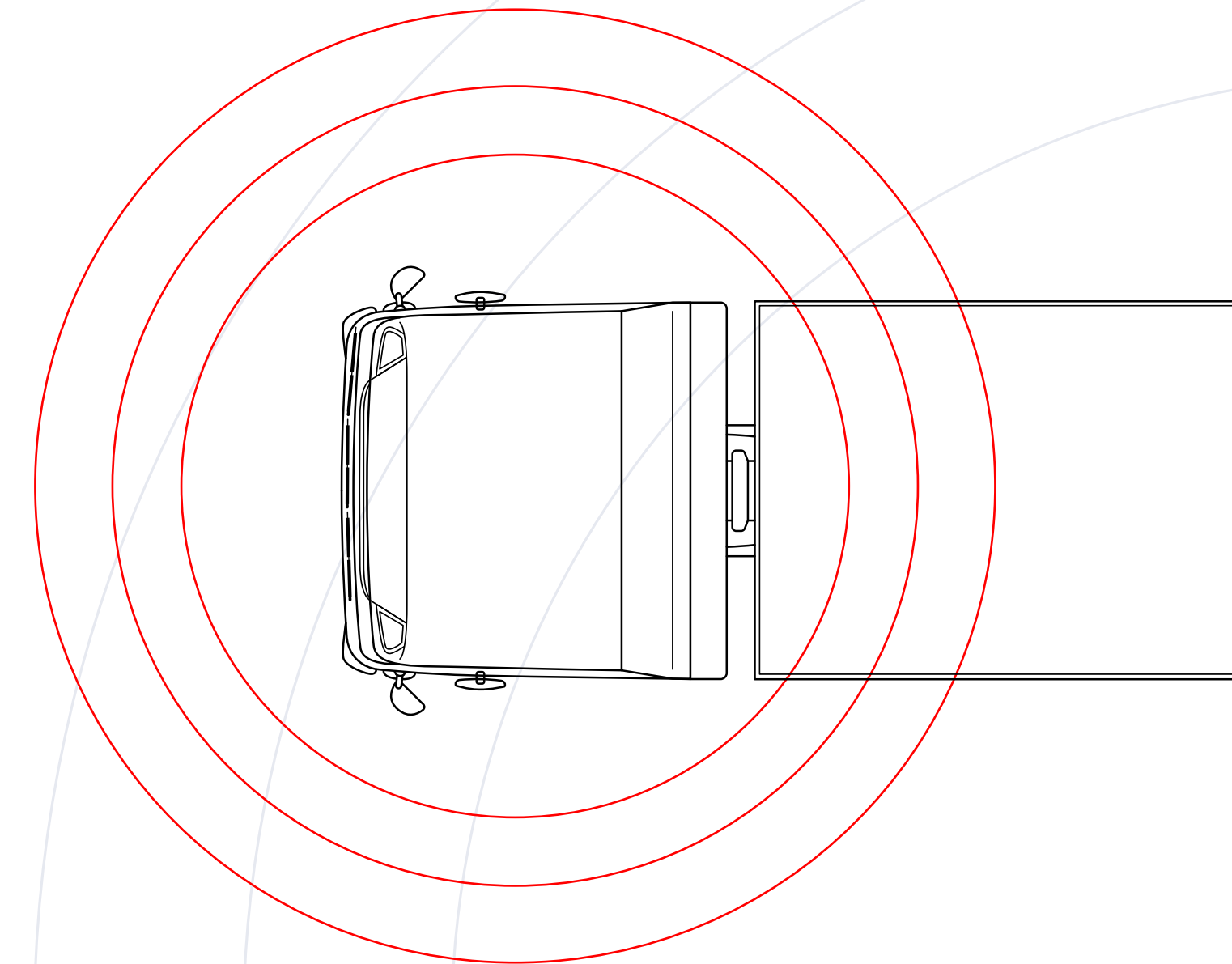
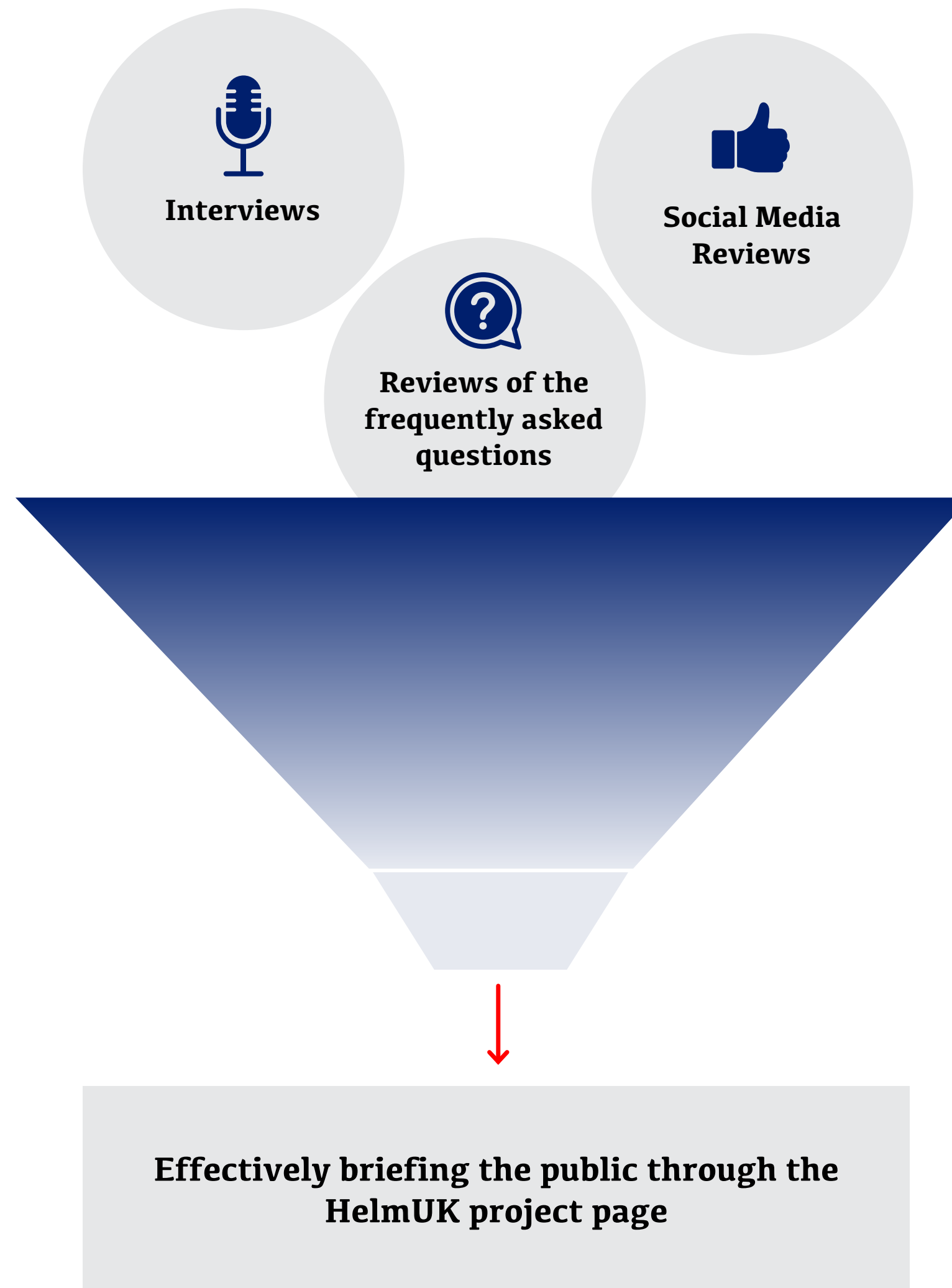


Figure 3.11: Summary of research approach and activities.

The most important potential risks and benefits of platooning in the public's perception (Table 3.7) were very similar across the groups interviewed: the main benefits were focused on the environmental benefits of the fuel saving and the benefits of having fewer HGVs in the middle lane. These were closely followed by the safety of all road users and less congestion. As regards safety risks, concerns were shared about reduced forward visibility as well as the risk of cars cutting in, regardless of their levels of experience with platooning.

Difficulty using the entry slip lane was considered to be important to the general public; however, those with experience driving in a platoon were aware that the platoon would disengage around junctions and therefore considered that this would be less of an issue.

**Table 3.7:** The most important potential risks and benefits of platooning in the public's perception.

Group consulted	Highest rated factors	
	Benefits of platooning	Safety risks of platooning
<b>HelmUK's HGV drivers</b>	<ul style="list-style-type: none"> <li>• Environmental benefits</li> <li>• Fewer HGVs in the middle lane                             <ul style="list-style-type: none"> <li>• Less congestion</li> </ul> </li> <li>• Safety of all road users</li> </ul>	<ul style="list-style-type: none"> <li>• Difficulty using the entry slip lane</li> <li>• Risk of cars cutting into the platoon                             <ul style="list-style-type: none"> <li>• Reduced visibility of signs</li> <li>• Risk of driver error</li> </ul> </li> </ul>
<b>Other road users</b>	<ul style="list-style-type: none"> <li>• Fewer HGVs in the middle lane</li> <li>• Environmental benefits</li> <li>• Safety of all road users</li> </ul>	<ul style="list-style-type: none"> <li>• Risk of cars cutting into the platoon                             <ul style="list-style-type: none"> <li>• Reduced visibility of signs</li> </ul> </li> <li>• Difficulty using the entry slip lane</li> </ul>

The HelmUK trial HGV drivers' views on the platooning system were generally very positive or neutral after having experienced it on the roads. Drivers had either been reassured that platooning was safer than they first thought or had seen the system working on-road. Many stated that they could see the benefits of platooning in terms of saving fuel and space on the roads, however some did have concerns about forward vision and whether companies would invest in the technology. Drivers thought that the public would support platooning if they thought it would improve their lives. It was argued that "information is key":

The public needed the facts and would support it if the technology was explained to them, and benefits and safety aspects were clearly communicated. It was also suggested that increased awareness of how other road users need to act around HGVs and platoons would be beneficial.

The findings from this research fed into an online Frequently Asked Questions (FAQs) resource, maintained on the HelmUK website<sup>28</sup>. The final version of the FAQs is reproduced in Appendix A: Frequently asked questions about platooning.

<sup>28</sup> HelmUK online FAQs [click here](#).



### 3.3.6 Benefits and impact of platooning on infrastructure

The principal impact of platooning on infrastructure is on the road pavement structure. HelmUK looked at the likely impacts on pavements; the main findings from the study were:

- HGV platooning is likely to present a different pattern of traffic loading to conventional HGV traffic which could modify pavement deterioration modes and rates
  - The extent of any pavement deterioration will depend on factors such as vehicle spacing, the number of vehicles in platoons, traffic flow, driving conditions, and where HGV platoons operate, i.e. in dedicated lanes or in mixed traffic
  - The effect of platooning will also depend on the strength of the pavement. If dedicated lanes (the most demanding application from a pavement perspective) were used, then ensuring that these are designed and built to be resilient would be key to overcoming these issues
  - HGV platoons travelling along the same wheel path are likely to increase surface deterioration, accelerate rutting rates, and increase fatigue failures
  - Within the HelmUK programme, the platooning system provides longitudinal control but only lane-keeping assistance to avoid line crossing, not permanent lane-centring. Therefore, there is no reason to expect any greater alignment of wheel paths than with normal HGVs. However, these findings are potentially relevant for platooning systems of the future, which may offer both lateral and longitudinal control
- The potential impacts on performance are most likely to be associated with the application of HGV platooning in dedicated lanes. In contrast, the impact on pavement performance of platooning operating in mixed traffic is likely to be minimal
  - The potential maintenance costs associated with deterioration from platooning were estimated by analysing the effects of reduced service life over a 60-year period. This relatively simple analysis indicated that reductions in service life of 10 or 20%, suggested by other researchers, could result in an increase in maintenance cost Net Present Value per lane kilometre of between 12% and 27%
  - One possible way to mitigate some of the above risks could be to use automated vehicle technology to manipulate the driving lines of the vehicles in the platoons (or of whole platoons) to distribute the loading more evenly across the lane width and/or optimise the spacing between vehicles. However, this is dependent on the width of the lanes, the capability of the automation technology, and may reduce fuel savings as vehicle alignment is important for reducing air resistance
  - For initial platooning systems, as used in the HelmUK trials, the risks are mitigated to some extent through the absence of lateral control beyond lane-keeping assistance.

To understand more about these risks and to mitigate them, the following recommendations are made:

- Carry out a thorough assessment of parts of the UK road network where platooning is likely to be implemented to determine the structural adequacy and robustness of these pavements. The assessment should include all pavement types and not just the flexible pavements considered in this research
- Investigate the effects of shorter rest periods between loads and reduced vehicle wander on the current design and maintenance criteria for flexible pavements through practical trials
- Where HGV platooning is deployed on the UK road network, the condition of the pavement surface and structure should be closely monitored.

## → 3.4 Economic viability

### 3.4.1 Freight industry perspective on platooning

HelmUK sought views from freight industry experts, HGV operators and drivers on the potential for platooning across a range of industry sectors and the operational opportunities and risks associated with platooning. The key aims were to explore the factors that would influence an operator's decision to adopt platooning, to gain feedback on some hypothetical business models for platooning, and to understand the opportunities and constraints they would present to different types of freight operation.

Three hypothetical business models discussed within the research were:

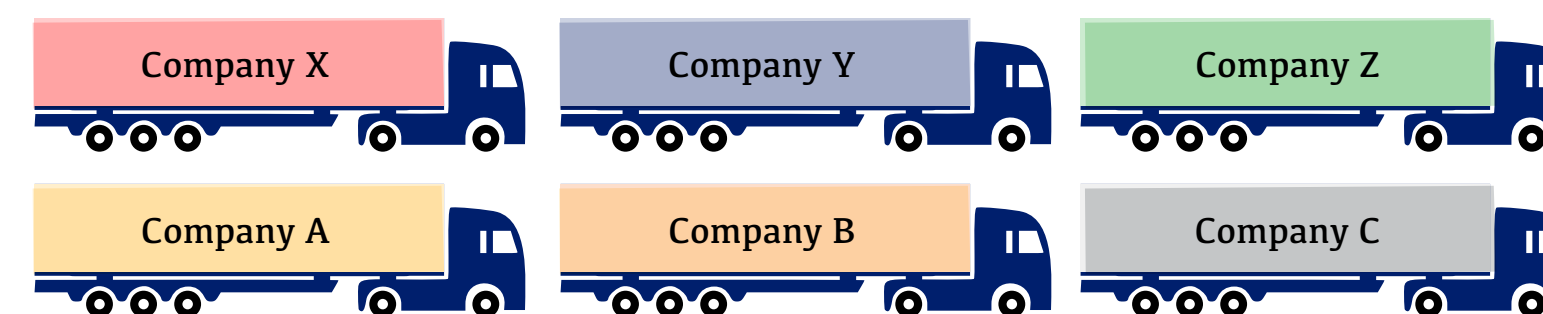
**Model 1** – Platooning exclusively inside a company, e.g. Company X would have the technology installed in its vehicles and would platoon along the network only in groups of vehicles within the same company fleet.



**Model 2** – Platooning alliances, e.g. Company X and Y would both have platooning technology installed and would platoon along the network with a combination of vehicles from either company.



**Model 3** – Connected platooning, e.g. Company X, Y, Z, A, B, and C would all have platooning technology installed and could participate in platoons with vehicles from multiple operators across the network.



It was suggested by the freight industry that Models 2 and 3 could be managed via third-party Platooning Service Providers (PSPs) who would take on a number of roles to help oversee and coordinate platooning activities, including identifying matching trips and management of payments between parties, to achieve the fair sharing of financial benefits.

Some of the key findings from the research were:

- Platooning would need to deliver at least 5% fuel savings to be perceived to be a viable investment for operators. The only exception was for some of the larger fleet operators (above 200 vehicles) who indicated they would consider investing for fuel savings between 2-5%
- Unlike other potential investments in fuel efficiency, platooning is operationally complex and using platooning to its full potential is dependent upon other operators also deciding to make that investment
- On average, 72% of operators' vehicle operations are conducted on roads suitable for future platooning (i.e. the SRN). Again, there was variance according to enterprise size, with larger operators reporting the highest proportion of SRN usage and smaller operators mainly operating in city centres or on last-mile deliveries
- From the findings above, it is envisaged that the pioneers and early adopters of platooning will be the large operators who have the resources (not just financial) to dedicate to trialling new initiatives and also to undertake a high proportion of their vehicle operations on the SRN and specifically motorways
- Connected platooning (Model 3) was believed to offer the greatest number of opportunities to platoon with least operational impact.



> 3. Key results > 3.4 Economic viability > 3.4.1 Freight industry perspective on platooning

However, there are a number of concerns to be addressed in relation to safety (ensuring that the drivers' behaviours are considerate, potential driver distraction due to ad-hoc alerts, load security of other vehicles), organisational culture (being linked to other operators who might not be as compliant with legislation, challenges in leaving the decision on accepting an ad-hoc connection to the drivers) and the technical compatibility of platooning systems (interoperability with different vehicle manufacturers' systems)

- Also, for connected platooning to be a viable model there needs to be a significant number of platooning equipped vehicles operating and on the market. In the first instance this will require large operators to invest in the technology for platooning Model 1 or 2, so that equipped vehicles pass to the second-hand market to then also be used by smaller operators. Therefore, the platooning technology has to deliver a return on investment to large operators in only two or three years, or no-one will invest for any of the platooning models
- HGV operators were not keen on the idea of using PSPs to facilitate platooning interactions and were instead in favour of using in-cab

systems to identify platooning opportunities and to establish and interact with other companies on an ad-hoc basis. However, this might still require some sort of service, e.g. an app provider, to facilitate the communication with other vehicles and their companies

- The most viable application of platooning was considered for night-time trunk haulage trips, because the roads are relatively quiet, and any safety concerns related to other road users would be minimal. There were also other operations that were referenced as being well suited to platooning including parcel companies and pallet networks
- HGV drivers perceived platooning to be safer than driving in conventional mode as a result of the enhanced safety features of the technology and heightened driver awareness. This is a significant finding because the HGV drivers interviewed actually had first-hand experience of platooning, in contrast to operators and industry experts who were not involved in the trials
- All stakeholders identified a number of operational hurdles that would have to be overcome and could be a barrier to the mainstream adoption of platooning. Operational challenges included: incompatibility of processes and vehicles between different companies; platooning being limited to non-peak times and specific road networks; limited opportunities to match vehicles travelling on the same routes at the same times; space constraints in service stations and depots; and time wasting and working time implications

- The future success of platooning relies on the freight industry getting support from third parties including their clients, the insurance sector, vehicle manufacturers and the Government. Government support mentioned included funding, guidance, and co-ordination

Finally, discussions with the HGV drivers that were involved in the trials identified some key areas that require further research including:

- The potential to allow drivers to platoon through more junctions to achieve uninterrupted journeys and maximise the fuel savings from platooning
- The requirement for headset communications for platooning and how to ensure their effective use.

The research concluded that whilst there are some potential benefits that could be achieved through driving in platoons (e.g. fuel savings and safety), the decision to invest in the technology would be a commercial risk because of the uncertainties around market uptake and the fuel savings that could be achieved in practice.

Furthermore, to take advantage of platooning, operators would need to make significant changes to their fleet operation and scheduling, and the cost and commercial risk of making these changes may outweigh the fuel savings that could be achieved. Therefore, the economic benefits for logistics/haulage companies to operate platoons are conditional upon fuel savings being at least comparable to savings available from investment in other efficiency measures, significant uptake by other operators, and the ability to reschedule deliveries without adverse commercial impacts.

## 3.4.2 Driver workload

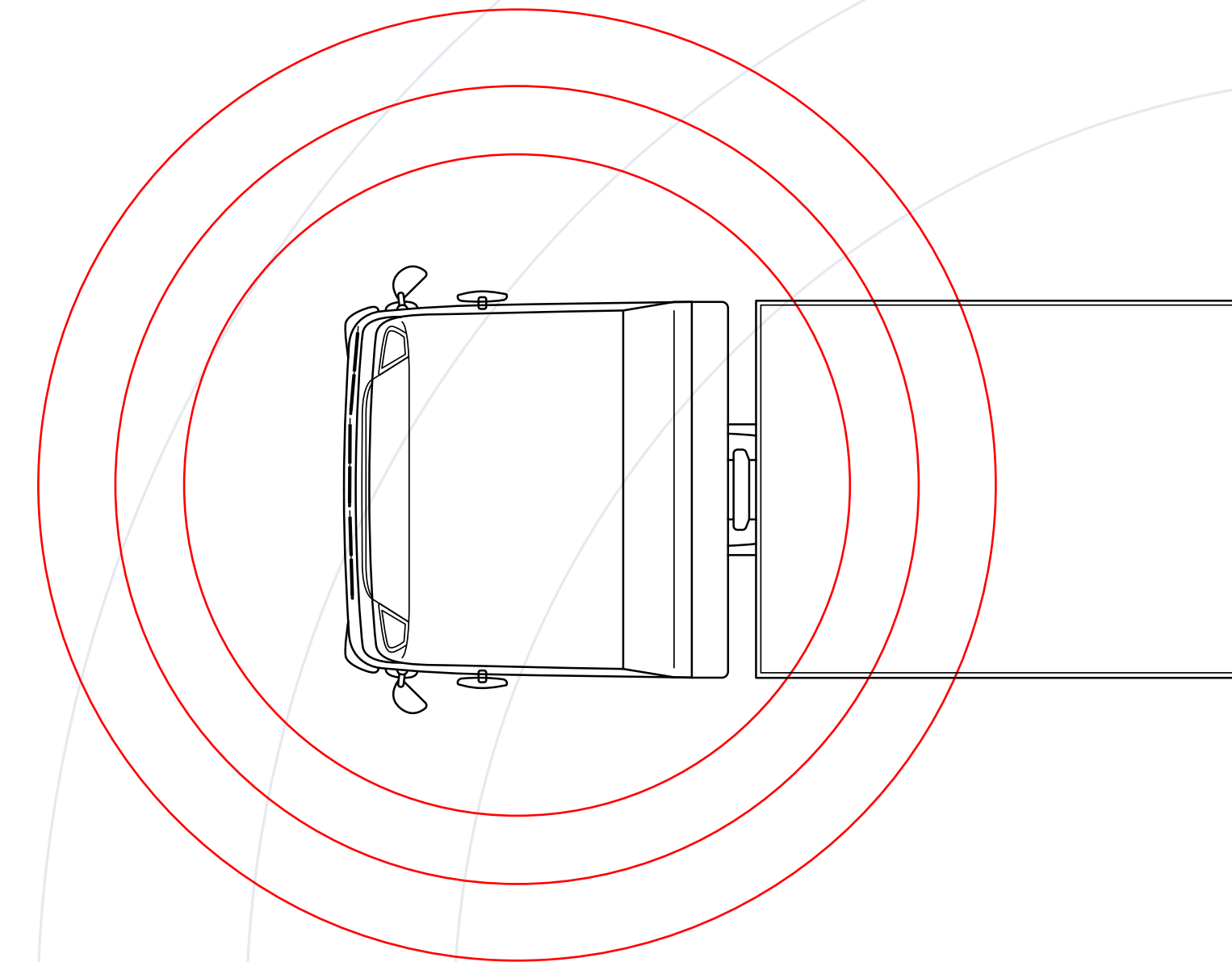
The UK sets maximum limits on daily and weekly driving hours for HGV drivers and prescribes minimum break and rest times. The objective of these rules is to ensure attentive drivers and thus avoid road safety risks. In general discussion, stakeholders asked whether time spent as a following driver in a platoon could be counted only partially towards driving hours because the driver would experience reduced workload. The findings of the driver workload research question (see Section 3.1.2) do not support this idea: Driver workload when platooning was found to be slightly higher compared to normal driving<sup>29</sup>

## 3.4.3 Vehicle maintenance

The project investigated whether the maintenance and inspection intervals for platooning vehicles would need to be more or less frequent than currently applied for conventional HGVs. Primary data was collected through general and trial-specific 'walk around forms' which drivers used to record damage to the vehicles and to trial-specific equipment. With regard to wear and tear of the standard HGV equipment, subject matter experts from DAF Trucks provided an opinion on whether the wear on the internal components of the vehicles was different to what would be expected of normal operation. Specific attention was paid to the condition of the vehicle radiators, engine bays and tyres, because a previous platooning trial had, anecdotally, reported abnormal wear and tear on these components.

During the HelmUK trials, no evidence was found to indicate increased wear and tear or specific issues relating to damage to body panels due to grit, engine contamination or uneven tyre wear. DAF Trucks identified no meaningful differences whilst conducting routine servicing and maintenance of the vehicles. The platooning system components themselves do not require regular maintenance. Therefore, based on the information available, there is no indication that the maintenance and inspection intervals for platooning vehicles needed to differ from those of non-platooning vehicles.

It should be noted that the trial duration and mileage only covered a fraction of the working lifespan of the vehicles used. It cannot be ruled out that platooning over longer durations could reveal increased wear and tear on components with longer design lives and service intervals. Evidence of this nature could likely only be gathered during monitoring of commercial platooning operations.



<sup>29</sup> The difference was very small in scale. Note that the trial's safety precautions required drivers to disengage and re-engage platooning frequently around junctions. Future systems could automate this step which may reduce workload.



### 3.4.4 Optimum length of a platoon

The HelmUK road trials were carried out with a 3-HGV platoon and did not actively investigate the impact of different platoon lengths on safety and fuel efficiency. In general terms, the optimum length of the platoon is dependent on a range of fixed factors (e.g., the specification and condition of the involved vehicles and road/junction geometry) and temporal factors (e.g., prevailing traffic flow and environmental conditions) and therefore the optimum length will vary accordingly. In theory, as the platoon length increases, potential fuel benefits increase because more vehicles are positioned in the middle of the platoon where they benefit from both headwind resistance and aerodynamic drag being reduced. However, longer platoons also pose potential safety issues to other road users, particularly related to joining and exiting at junctions.

A key finding of HelmUK is that there is a requirement to increase the headway between platooning vehicles at junctions to reduce the risk of conflict with vehicles trying to merge onto the main carriageway. This increase in headway to safely navigate junctions was needed for 90% of junctions on the HelmUK trial route; afterwards the platoon had to reform. Fuel consumption research showed that this had a considerable impact on fuel savings from platooning technology. Therefore, across English motorways the optimum length is heavily influenced by how many vehicles can navigate a junction without requiring the platoon to disband and reform. Based on the overall findings of the HelmUK trial this is likely to be the most significant factor affecting the optimum length of a platoon.

This means broadly that the optimum platoon length is one which strikes a balance between how often there is a need to disband and how many vehicles are in the platoon. This research first determined how the number of junctions which were 'platoonable' changed with a varying number of vehicles in the platoon and how this impacted on maximum platoon lengths and fuel consumption.

The original safety case analysis of junctions for 3-HGV platoons was expanded to consider 2-, 3-, 4-, and 5-HGV platoons. This research found:

- For 5 out of 6 junctions which were platoonable in HelmUK the maximum platoon length was 3 HGVs, with one junction which could accommodate a 4-HGV platoon.
- Expanding this analysis to all junctions on the HelmUK route has shown that junction 'platoonability' is very sensitive to the number of vehicles in the platoon, with each additional vehicle approximately halving the number of junctions which are platoonable.

The question of optimal platoon length was further examined by extrapolating average fuel savings for 2-, 3-, 4- and 5-HGV platoons from HelmUK trial data which gradually cut out non-platooning junctions. Including the percentage of the route which was platoonable for different platoon lengths this analysis found that:

- 4- and 5-HGV platoons saved less fuel than 3-HGV platoons
- 3- and 2-HGV platoons were comparable, with 2-HGV platoons saving marginally more fuel

The conclusion of this analysis is that for the HelmUK route the optimal length of the platoon is 2 to 3 HGVs. It is likely that this is true in broader English motorway context as the HelmUK route is representative of England in terms of junction frequency (although details on junction geometry are unknown which has an impact on 'platoonability'). Platoon lengths longer than 3 HGVs are unlikely to be optimal for the wider UK road network until challenges for platooning operation at junctions can be resolved. A potential way of doing this could be ramp metering controlling the flow of traffic entering the carriageway (see Section 3.3.2 for more information) or more complete measures such as the use of dedicated lanes for platooning.

### 3.4.5 Economic benefits for operators and government

During Phase 1, HelmUK developed an economic model to determine the potential costs and benefits of widespread implementation of platooning on the English SRN using methods compatible with the DfT's Transport Appraisal Guidance (TAG). Two economic cases were considered:

**The business case for freight operators** – this considers the costs (e.g. in-vehicle equipment and driver training) and the benefits (e.g. fuel savings) that would be incurred by an operator if they were to introduce platooning

**The case for public investment** – this considers the much broader range of costs and benefits that are taken into account in transport appraisal, in particular environmental benefits such as greenhouse gas reduction, and the impacts on public accounts, as well as the economic impacts on operators.

The model was piloted using input data from a review of previous research, in particular the Energy ITS<sup>30</sup> and SARTRE<sup>31</sup> projects, with the intention of updating the analysis with scenarios developed from data gathered during the HelmUK trials, most importantly in relation to the expected fuel savings.

<sup>30</sup> Tsugawa et al. (2016) A Review of Truck Platooning Projects for Energy Savings.

<sup>31</sup> Safe Road Trains for the Environment (SARTRE) (2013) D5.1 – Commercial Viability.

#### Interpretation of key findings from HelmUK

The observed fuel savings of platooning in real-world operation (see Section 3.2.1) were lower than might have been expected from previous research, which was either based on track tests at very short time-headways, not achievable safely in real-world traffic with current technology, or reported as comparisons to a solo-driving HGV rather than to an ACC convoy. The fuel savings found in HelmUK are summarised below:

- ▶ **Current road network – 0.5% savings.** This reflects the average savings achieved over the full trial trip, with platooning not possible through the majority of junctions, and including sections where platooning could not be undertaken because of congestion
- ▶ **Optimised network – 2.6% savings.** This reflects the average savings that could be achieved if platooning were permitted through junctions and is not otherwise prevented by congestion
- ▶ **Dedicated network – 4.1% savings.** This is a hypothetical upper ceiling predicted for operation in platoon over long distances without interruptions; for example, if dedicated lanes were provided for the purpose. A dedicated network would require significant infrastructural changes and reallocation of road space.

The fuel savings reported above are the average for the three vehicles in the platoon. The savings for the lead vehicle were found to be very low.

The trial results show that under real-world driving conditions, additional fuel is required to bring vehicles into position to form a platoon.

If the vehicles are not already in closely following positions when they join the motorway or become separated by other vehicles at junctions or congestion, then the acceleration required to bring them together increases fuel consumption. Unless the vehicles are able to continue in an uninterrupted platoon for a reasonable distance after the platoon is formed, then the fuel savings may not justify the additional fuel usage to bring the platoon together.

The implications of the observed impacts on fuel consumption need to be interpreted in the light of the findings from the qualitative research conducted with freight operators, which are summarised in Section 3.4.1. While operators were interested in fuel saving measures, the majority would not consider investing in fuel savings lower than 5%. Only 14% of respondents (mostly larger operators) would consider investing in savings worth 2% to 5%. Although business cases would not normally be based on arbitrary savings thresholds, in practice there will always be management and administrative costs in evaluating and implementing any cost-saving measure, so the responses provide an indication of a reasonable minimum saving that operators would be willing to spend time considering.

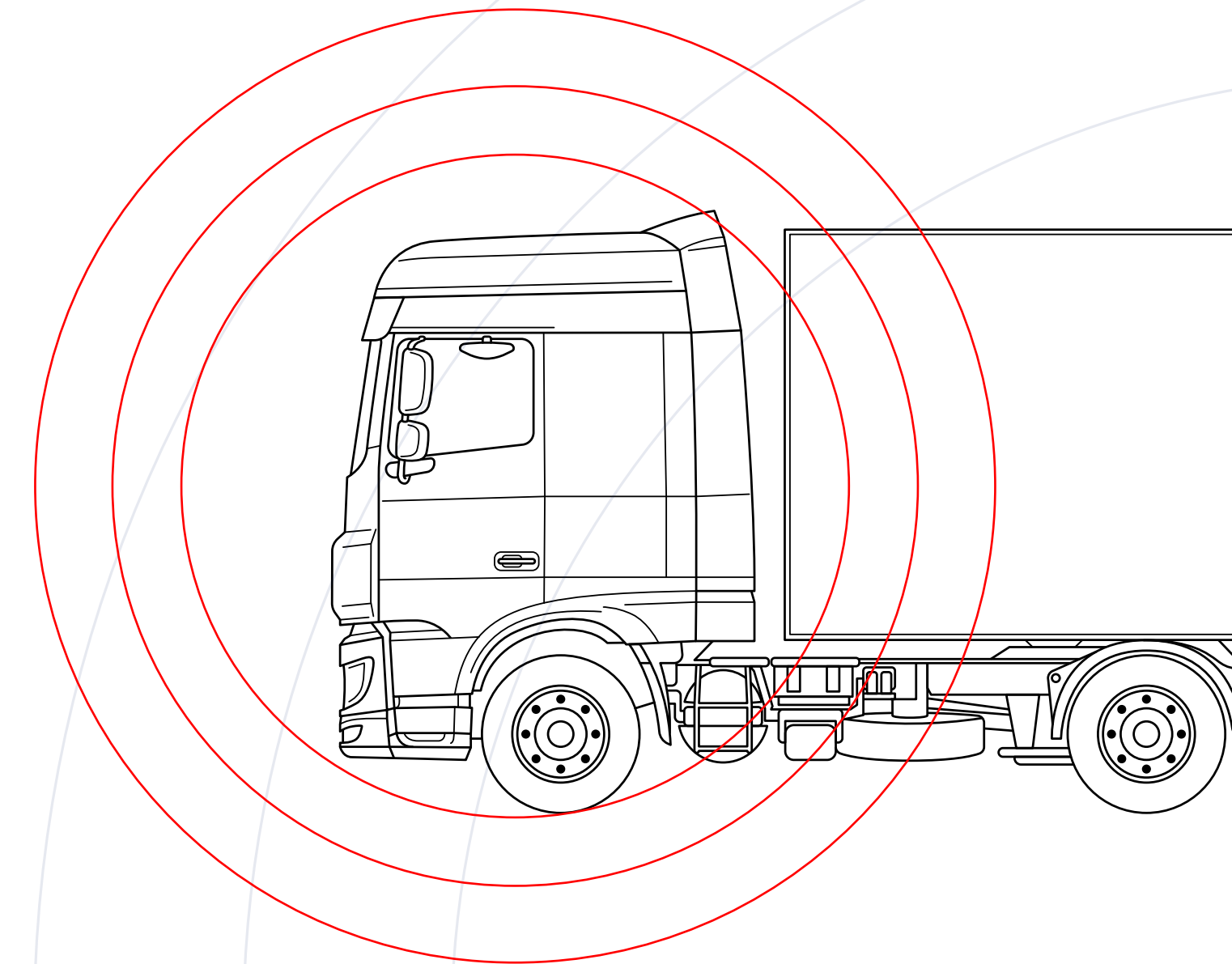


While operators would be willing in principle to consider making operational changes to facilitate platooning, they identified concerns about the operational costs and commercial risks arising from rescheduling trips to enable platooning. For example, there could be adverse effects on journey time reliability, lower vehicle utilisation, and impacts on distribution centres, including the requirement for more space. These costs would be very specific to an individual operator's circumstances and are not possible to estimate for a more general analysis.

Considering both the fuel savings and operator feedback, the following conclusions can be drawn:

- The fuel savings found in HelmUK are below the level at which most operators said they would consider it to be worthwhile; and are lower than other fuel saving interventions that the industry does invest in (and that are operationally less complex and deliver more predictable results)
- The comparatively low savings achieved while in a platoon require that vehicles would have to be used in a platoon for a very high proportion of their motorway mileage in order to deliver worthwhile savings, which would require significant rescheduling of deliveries into 'platoonable' trips, with associated operational costs
- The very low savings for the lead vehicle could discourage different operators from platooning together, as a mechanism for sharing benefits would increase complexity

- Platoons of only two vehicles may not be viable, as only one of a pair might actually be saving fuel, so operators would have the greater complexity of needing to find at least three vehicles whose trips can be combined
- The observed fuel penalty for gap-closing in order to form a platoon means that platooning for short distances may need to be discouraged, so a system for advising drivers on whether to platoon would be required, using data on the route and traffic ahead; this would add complexity and hence cost
- Low fuel savings will reduce take-up of the technology, limiting participation. This is likely to rule out any 'open access' platooning models in which vehicles platoon opportunistically with nearby vehicles in the course of a trip, rather than pre-planning it within the operator's own fleet, or close partners
- Low take up of the technology would reduce the likelihood of costs reducing through economies of scale and would also mean that equipped vehicles would have little additional value in the second-hand market. The benefits would therefore need to be achieved within the first year or two, rather than the equipment costs being discounted over a vehicle's lifetime.



### The business case for freight operators

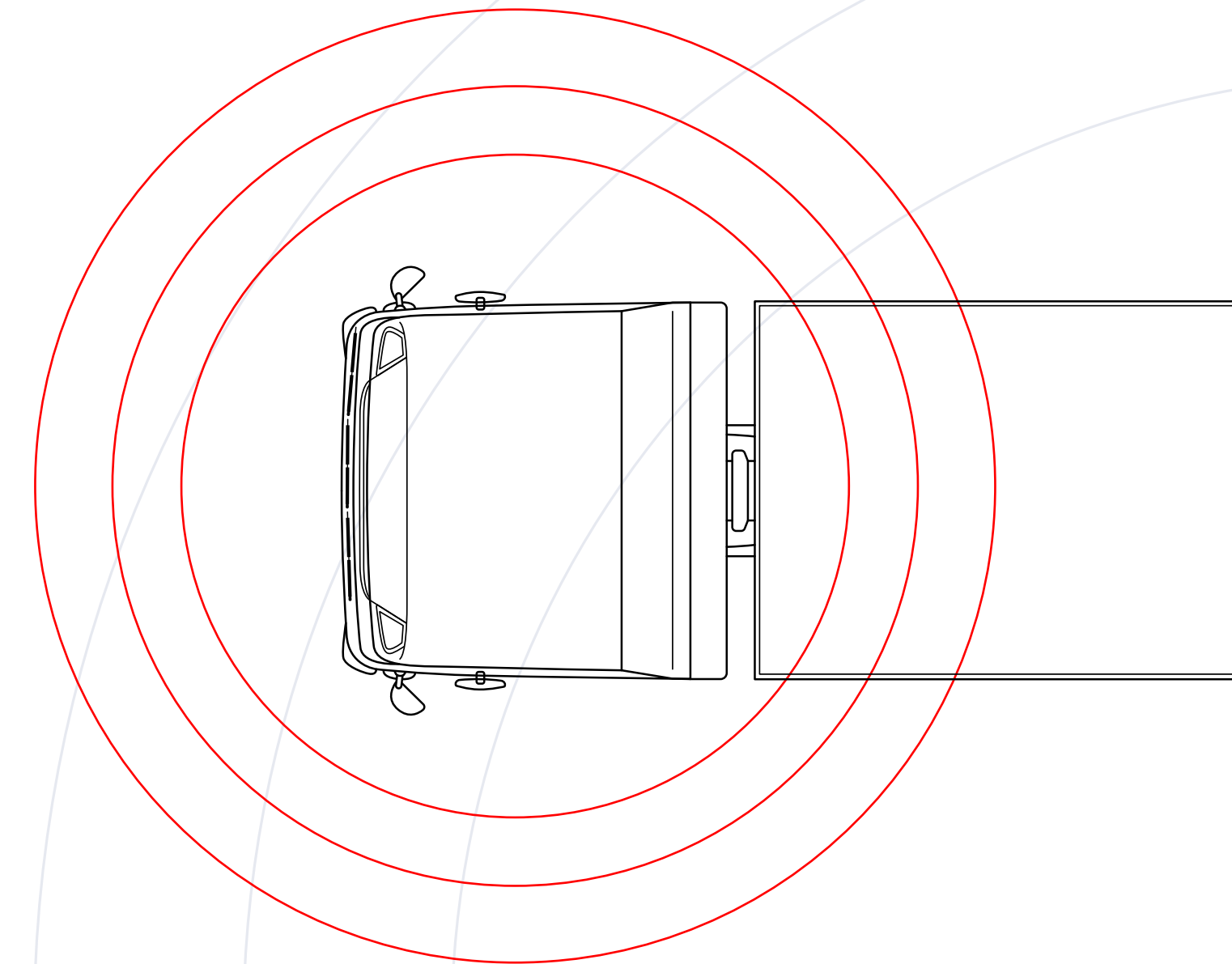
Clearly the operational costs of rescheduling deliveries into platooning would be an important commercial consideration. In the absence of quantitative data on such costs, it is helpful to consider the value of fuel savings that could be achieved under different scenarios, and make a judgement as to whether the value of any savings is sufficient to cover additional operational costs while still giving the operator a return on investment. For this purpose, an estimate was made of the initial technology, training costs and subscription to a service provider of approximately £3,000 per vehicle (i.e. £9,000 per three-vehicle platoon).

For an operator using its vehicles for approximately 117,500 kilometres per year, of which 72% is on the SRN (the average reported by respondents to the operator surveys), fuel savings at 2.6% would be worth around £8,550 (per three vehicle platoon) over 10 years if 50% of trips can be platooned, but £855 if only 5% can be platooned. In neither case would the technology and training costs for a three-vehicle platoon be recovered. Even if 90% of the annual kilometres travelled were on the motorway, and 90.5% of the trips were platoonable, the fuel savings would take five years to offset the investment.

For the hypothetical 'dedicated network', where 4.1% fuel savings would be possible, if 90% of the kilometres were driven on the motorway, of which 90.5% in platoon, then the operator would save approximately £37,200 over ten years. However, it would still take more than two years to cover the estimated training and equipment costs.

Note that the absence of any payback under most scenarios means that, even if the technology and training costs could be reduced significantly, there would be very little savings income to cover administrative and operational costs associated with ensuring that a very high proportion of trips can be scheduled as platoons. It is also important to note that even under a very optimistic scenario, with a very high proportion of platooning undertaken, benefits are still unlikely to be met within the early years of a new vehicle.

The above analysis does not mean that no operator could benefit commercially from platooning; however, this is only likely to be the case for a very small number of operators with quite specific favourable circumstances. It would be necessary for such an operator to undertake regular long-distance trunk haulage trips between fixed locations very closely located to the SRN (and particularly motorways), and where vehicles can be relatively easily grouped without significant rescheduling being required.



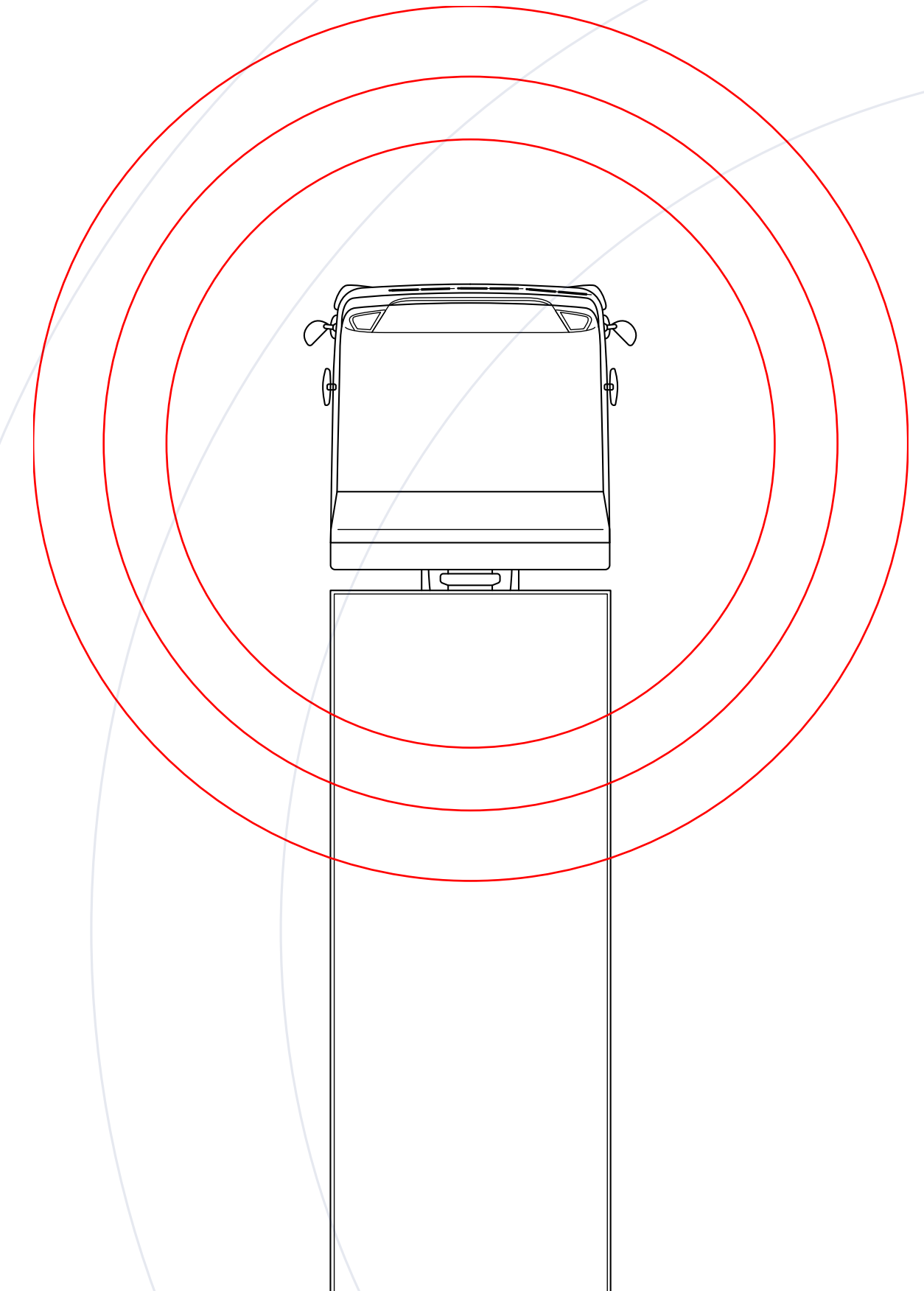


### The case for public investment

It was originally envisaged that the case for public sector investment could be investigated by modelling a range of scenarios for the adoption and use of platooning technology. However, given the low level of fuel savings compared with the likely technology and operational costs of platooning, it was concluded that scenarios involving widespread adoption would not be plausible. It would not, therefore, be appropriate to pursue a method based on this approach. However, a number of broader implications can be identified when considering the case for public sector investment:

- When the potential operational costs of rescheduling vehicles to take advantage of platooning are considered, it is likely that platooning would increase the costs of the freight industry and potentially reduce its efficiency (in terms of reliability, vehicle utilisation, etc.)
- The fuel savings and consequent greenhouse gas savings found in the HelmUK trials are lower than those delivered by a number of different fuel saving interventions that are already in use without public subsidy, such as improved aerodynamics. By way of comparison, the UK Government provides an incentive for Low Emission Buses of 6p/km; however, to qualify for this, greenhouse gas savings of at least 15% must be demonstrated under controlled trials. It is also important to note that, following the Government's target to end sales of diesel goods vehicles by 2040, the potential greenhouse gas benefits of platooning will decline over time

- The potential for night-time platooning may justify further consideration; however, the advantages of freely flowing traffic at night would mean that there would be minimal congestion benefits to justify public support
- A higher proportion of operators would be likely to achieve commercial benefit if the 'dedicated network' savings of 4.1% could be achieved; however, this would require significant investment in infrastructure and traffic management, the costs of which would require extensive additional analysis to quantify, and overall uptake would likely remain small because only a minority of operators would be able to utilise the dedicated network sufficiently to create a commercial return.





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# The future of platooning



# 4. The future of platooning

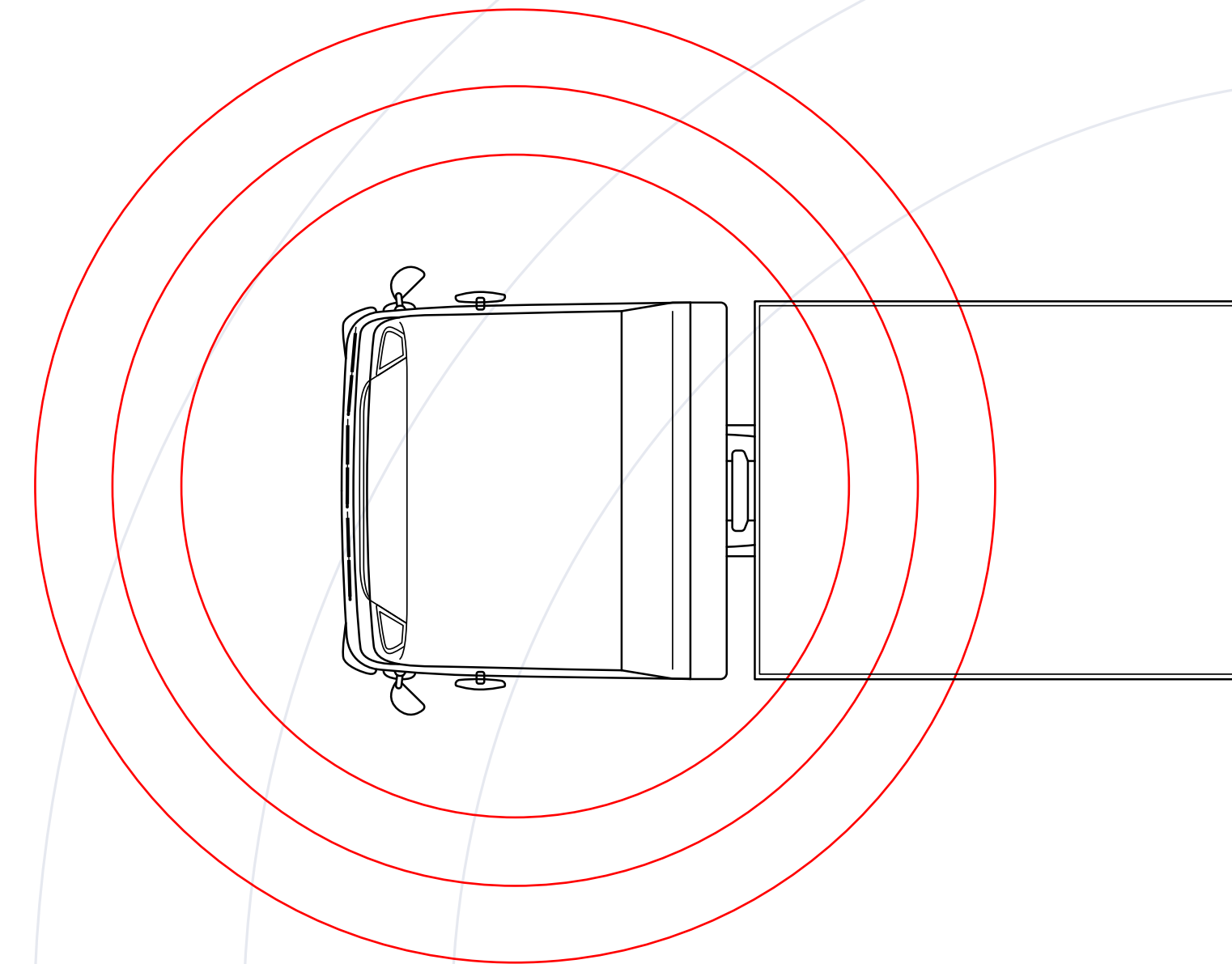
The purpose of this section is to explore what the key findings of the HelmUK project mean for the future of platooning in the UK. These insights are broken down into five sections which are relevant for different audiences and will cover similar topics from different perspectives. An interested reader can, of course, read all five sections. The five sections are:

- 4.1 – What functionality would be required for a real-world deployment of platooning technology ‘here and now’.
- 4.2 – Analysis of how future platooning operation could change to realise greater benefits.
- 4.3 – The future of platooning from the perspective of road authorities/operators.
- 4.4 – The future of platooning from the perspective of the UK government, especially DfT.
- 4.5 – The future of platooning from the perspective of the freight industry.

For Road Authorities, Sections 4.1, 4.2 and 4.3 are the most relevant.

For UK Government, Sections 4.1 and 4.4 are the most relevant.

For the freight industry, Sections 4.1, 4.4 and 4.5 are of the most interest.



## 4.1 Current deployment

Before exploring how future platooning operation may improve, it is important to consider what a ‘here-and-now’ deployment of platooning would look like today if it followed a similar model to HelmUK.

The key operational features of the HelmUK project are summarised below in Figure 4.1.

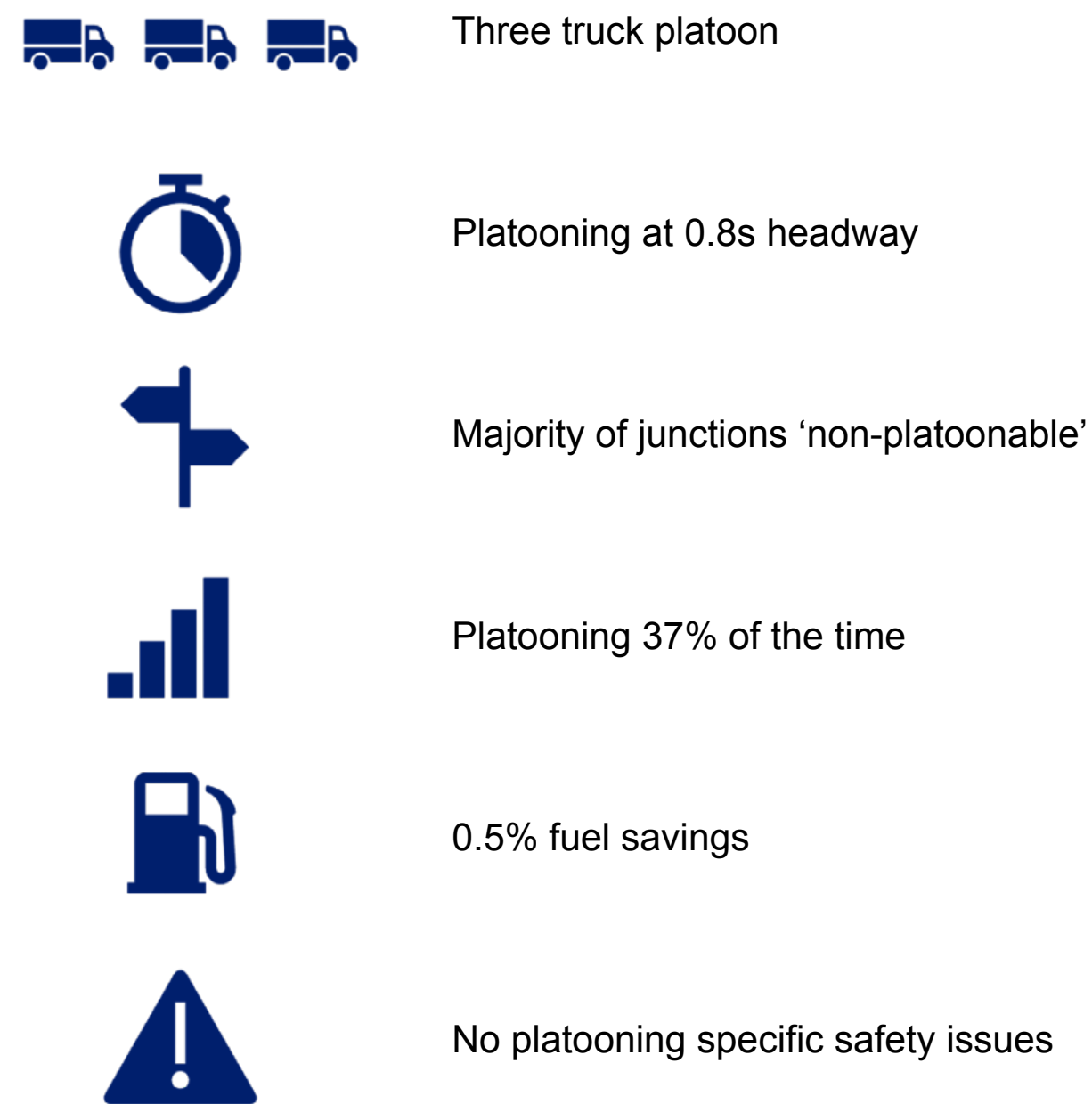


Figure 4.1: Summary of key operational features of HelmUK's on road trials.

Overall, the fuel benefits (see Section 3.2.1) to this type of operation are small and the business case is weak overall. However, there is no evidence for an increased risk due to platooning operation – which is a key consideration for the introduction of platooning technology. This means that despite the modest fuel benefit, a platooning model similar to HelmUK could be safely deployed on the UK roads.

However, in order to scale up from controlled trials to a commercial operation with similar features to HelmUK, a number of features would be required which are summarised below.

### 4.1.1 Automatic disbanding or headway increase at junctions

During the trials the drivers manually disbanded the platoon at ‘non-platoonable’ junctions. This was suitable because the trials operated on the same route each day with specially trained drivers and inter-vehicle voice communication. This was a key part of ensuring safety as part of the HelmUK trials, but none of these elements can be guaranteed in future deployments.

**Future applications of platooning should automate disengagement at junctions that are not suitable for platooning.**

To deploy platooning in a commercial setting, automated headway increase functionality would be needed to allow safe navigation of ‘non-platooning’ junctions. Based on research and experience in the trials, this could be achieved in three ways or via a combination of methods.

**On-board systems** – vehicles could include sensors and systems which recognise road features or signage to trigger an increase in headway as the vehicles pass junctions. This approach would be very unlikely to be able to distinguish between platooning and non-platooning junctions, so would likely disengage at all junctions on the network. However, this simplistic system would not be reliant on outside data sources.

**Junction database** – platooning operation at a junction would be based on assessment of static risk factors such as junction geometry and layout. HelmUK conducted an assessment of the junctions on the approved trial route taking into account junction type and slip-lane length to determine risk. A similar approach could be taken here, which would require:

- An assessment would need to be conducted for the English SRN and made into a database of ‘platoonable’ and/or ‘non-platoonable’ junctions.
- The database would need to be available to manufacturers and operators.
- The database would need maintenance and updating.



**Vehicle to Infrastructure (V2I) communication** – this would allow decisions about platooning operation based on dynamic risk factors such as traffic flow as well as static factors such as junction geometry and layout. While the potential benefits to this approach are high, the considerations are as follows:

- This would require road authorities to install V2I comms equipment at junctions and use existing sensors or install new sensors
- Standardisation across industry of platooning communication with infrastructure
- It may not be possible to sense individual vehicles on the slip road and communicate this to a platoon in time
- This approach could be strengthened by combining it with the junction database above, some junctions could be ‘always platoon’ others ‘never platoon’ and some ‘variable’ based on V2I communication.

## 4.1.2 Platooning system functional and operational safety

A large part of the HelmUK project was assuring the functional and operational safety of the DAF platooning system in preparation for an on-road deployment in real world conditions. As part of the trials, the safety performance of the vehicles showed no significant differences between platooning and non-platooning operation despite the significantly reduced minimum headway in the former. Key elements of the DAF system should be common to future platooning vehicles to ensure similar performance; this is discussed in detail in Section 4.4.

## 4.1.3 Driver training and acceptance

The HelmUK trials required several elements, such as voice communication between the vehicles and extensive driver training, which are unlikely to be components of a successful platooning deployment as ‘business as usual’.

**Voice communication** was used on the trial to coordinate platooning engagement and, as an enhanced safety measure, enable the drivers to alert one another to hazards. However, for a future deployment of platooning there are several issues with this:

- HGV drivers operating in the UK come from a range of countries in Europe and beyond and language barriers would reduce the effectiveness of voice communication.
- The headsets could represent a potential driver distraction hazard.
- HelmUK found during driver training that it was hard to teach a consistent approach to headset communication. Using the style of a radio communication ‘discipline’ to ensure clear messages can be confusing with headsets.

Future platooning systems shouldn’t rely on voice communication to operate safely on-road and as such the Human Machine Interface (HMI) of the vehicles should support platoon formation and disbanding without the need for voice communication. Section 4.4.1 covers the HMI elements of a future platooning system in more depth.

**Driver training** – a successful platooning system should require minimal formal training for use and should be in line with similar ADAS such as adaptive cruise control. HelmUK carried out an extensive driver training program which would have a major impact on the already limited business case for platooning if it was required for each platooning driver. The key is for future platooning systems to be safe and intuitive to use. Section 4.5.2 discusses driver training requirements for the freight industry.

## → 4.2 Key improvements for platooning operation

For a more robust business case for platooning technology, real-world fuel savings need to be improved without impacting road safety. HelmUK's research allowed the identification of several approaches to increasing fuel savings which are discussed in detail in this section.

### 4.2.1 Increasing the number of 'platoonable' junctions

Section 3.2.1 discusses the impact of disbanding and reforming the platoon on fuel consumption; the more frequently disbanding and reforming of the platoon happens, the lower the fuel benefits for platooning.

A key cause for disbanding the platoon during the trials was junctions which were not assessed to be safe for platooning. Section 2.4 expands on the junction selection criteria as part of HelmUK's Safety Case.

HelmUK's research confirms that if more junctions were 'platoonable' then platooning operation would provide greater fuel savings up to a theoretical maximum which is more dependent on headway between the vehicles (see below). Figure 3.4, page 61, specifically shows the benefits to fuel consumption from removing junctions from the data set.

The main risk at junctions is another road user having to join the carriageway at low speed due to conflict with a platoon of HGVs. Increasing the number of 'platoonable' junctions can be done by reducing this risk through the following methods:

#### Cooperative Intelligent Transport System solution

Use sensor technology to monitor traffic flow on slip roads in real time and use V2I communication to provide a 'go' or 'no go' signal to the platoon in advance of the junction.

- ✓ Platoon is only disbanded when there is a risk of conflict – maximises how often a platoon can travel through a junction and avoids a blanket classification of 'non-platoonable'
- ✓ Enables longer platoons
- ✓ Can be fail safe – revert to non-platooning if no signal is received
- ✓ Would allow automated gap-widening at junctions (see Section 4.1)
- ✗ In the HelmUK trials, the platoon had to begin disbanding 500 metres from the junction; it is unlikely that an ITS system could measure or predict vehicles on the slip road with sufficient accuracy to provide a signal to the platoon that far in advance
- ✗ Requires sensor technology (exists at some junctions) and communication capability between infrastructure and platooning vehicles
- ✗ Would need widespread rollout to maximise benefits from platooning

#### Ramp metering upgrade

Adapted ramp metering sites could hold merging traffic on slip roads until a platoon has passed the junction.

- ✓ Ramp metering would actively limit conflict between platoons and other road users at junctions and could guarantee longer periods of uninterrupted operations rather than responding passively to traffic flow
- ✓ Enables longer platoons
- ✗ This would require communication between infrastructure and platooning vehicles which is an upgrade to current ramp metering functionality
- ✗ Maximising benefits would require a further rollout of ramp metering alongside V2I communications
- ✗ Holding traffic on the slip road would consume more fuel for those vehicles so ramp metering would need to be balanced between the fuel benefits for platooning vehicles versus the disbenefit to traffic held on the slip road
- ✗ Traffic held on the slip road would find their journey time increased and reliability decreased



### Enhanced junction assessment

HelmUK's Safety Case identified risk around junctions based on likely conflict scenarios. The key elements of this risk assessment were junction type and slip lane length. HelmUK identified 6 junctions (out of 60) which were likely to be safe for platooning, this is expanded on in Section 2.4.

As this was the first on-road deployment of platooning technology on the UK's roads, this risk assessment had no data to draw on. HelmUK demonstrated that, for the junctions deemed safe for platooning, the risk to other road users was not increased by platooning operation. However, as the majority of junctions were not platooned through, the risks of platooning operation at these junctions remains unquantified.

Using the HelmUK data and Safety Case as a baseline would enable further assessment of junction safety which could take into account other factors such as traffic flow. This enhanced assessment could help fully determine the nature of the risk at all junctions on English motorway-standard roads.

- ✔ No reliance on real time traffic information or V2I communications
- ✔ Captures risk based on traffic flow as well as static factors (junction type and geometry)
- ✔ Builds on HelmUK research
- ✔ Would provide evidence for use cases such as night-time operation (see below) which could provide improved fuel benefits without requiring changes to the road infrastructure
- ✔ Would provide evidence on a 'status quo' scenario in which platooning is not regulated
- ✘ It is unclear who would take responsibility for the assessment of junction safety for platooning and share this information with all required stakeholders
- ✘ Would require further research and an assessment of all junctions on English motorway-standard roads
- ✘ Would require investment, though less than many other options
- ✘ Only captures static risks and would be less effective in allowing platooning through junctions than a C-ITS solution

### Night-time operation only

The risk around junctions is proportional to the number of vehicles attempting to merge with the main carriageway; limiting platooning operation to times of low flow could allow platooning through most junctions at minimal risk. An example of this is overnight operation.

- ✔ Low investment – no requirement for communication infrastructure
- ✔ Matches patterns of HGV movements
- ✔ May allow longer platoons
- ✘ Would require further junction assessment based on traffic flows (see above)
- ✘ Limits which freight operators make use of platooning
- ✘ May still require automated gap-widening at junctions (see Section 4.1)
- ✘ Little or no benefit to congestion / traffic flow from closely spaced platooning vehicles

### Dedicated platooning lanes

A possibility to maximise platooning on-road would be to create platooning-only lanes which do not come into conflict with merging traffic at junctions and therefore allow longer periods of platooning operation regardless of junction frequency and type.

- ✓ Maximises platooning benefits, likely to provide largest fuel benefit of these options
- ✓ High safety (once in lane)
- ✓ Enables longer platoons
- ✓ Could synergise with other dedicated lane initiatives such as electric road systems
- ✗ Large investment required
- ✗ Fuel benefits likely to be at most a 4.1% saving for a three-vehicle platoon, which may not justify such a large investment
- ✗ Unknown risk around HGVs getting into the dedicated lane and crossing other lanes (e.g. during a breakdown)
- ✗ Reduces road capacity for all other traffic
- ✗ Opposition from other motorists

### Changing lane at junctions

The platooning system used in HelmUK did not support lane changing; doing so would disengage the platooning functionality of the system.

- ✓ Could allow platoons to avoid conflict at junctions
- ✗ Lane changing with two or more HGVs in concert is hard to achieve in high flow situations
- ✗ Unknown risk with these manoeuvres using a platooning system
- ✗ No guarantee this would eliminate the need for automated gap-widening at junctions (see Section 4.1)

The effectiveness of each of these measures in increasing the number of 'platoonable' junctions is summarised against the likely cost and complexity of these measures in Figure 4.2. Of the measures listed here, based on HelmUK's findings the best balance for fuel benefits and investment is likely to be night-time operation supported by enhanced junction assessment. This is expanded on in recommendations in Section 4.3.

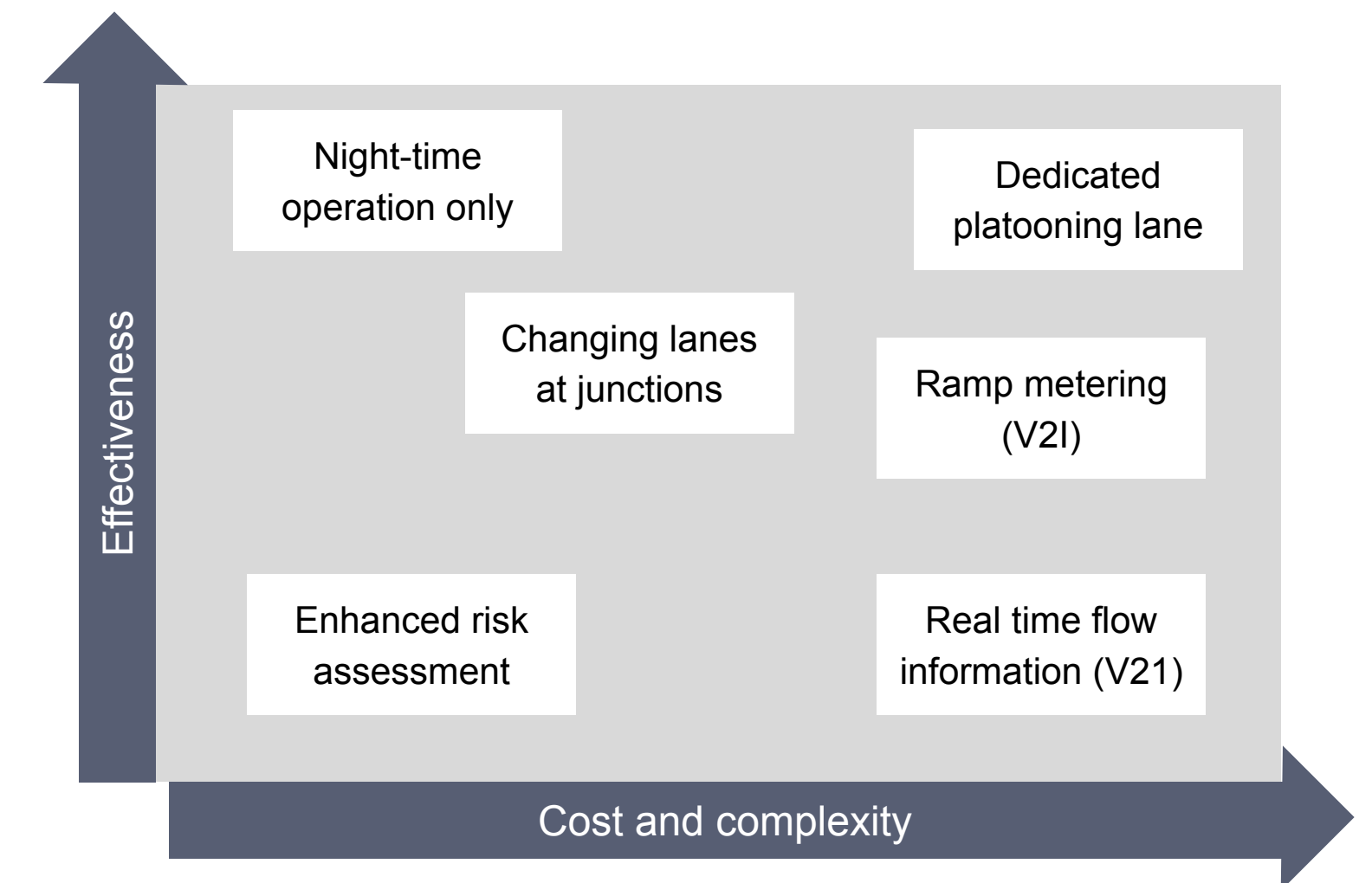


Figure 4.2: Effectiveness versus cost for a number of methods to increase the number of 'platoonable' junctions



## 4.2.2 Adding more vehicles to the platoon

During platooning operation, vehicles following the lead experience a greater fuel benefit from slipstream effects than the lead; this is shown in HelmUK's results (see Section 3.2.1). In this trial three vehicles were operated in a platoon, but it is expected that additional vehicles added to the platoon would see similar fuel benefits as the following and trailing vehicles in HelmUK. Therefore, one method to increase the fuel savings from platooning is to increase the length of the platoon. However, this will increase the likelihood of conflict with other road users at junctions as the length of the platoon increases.

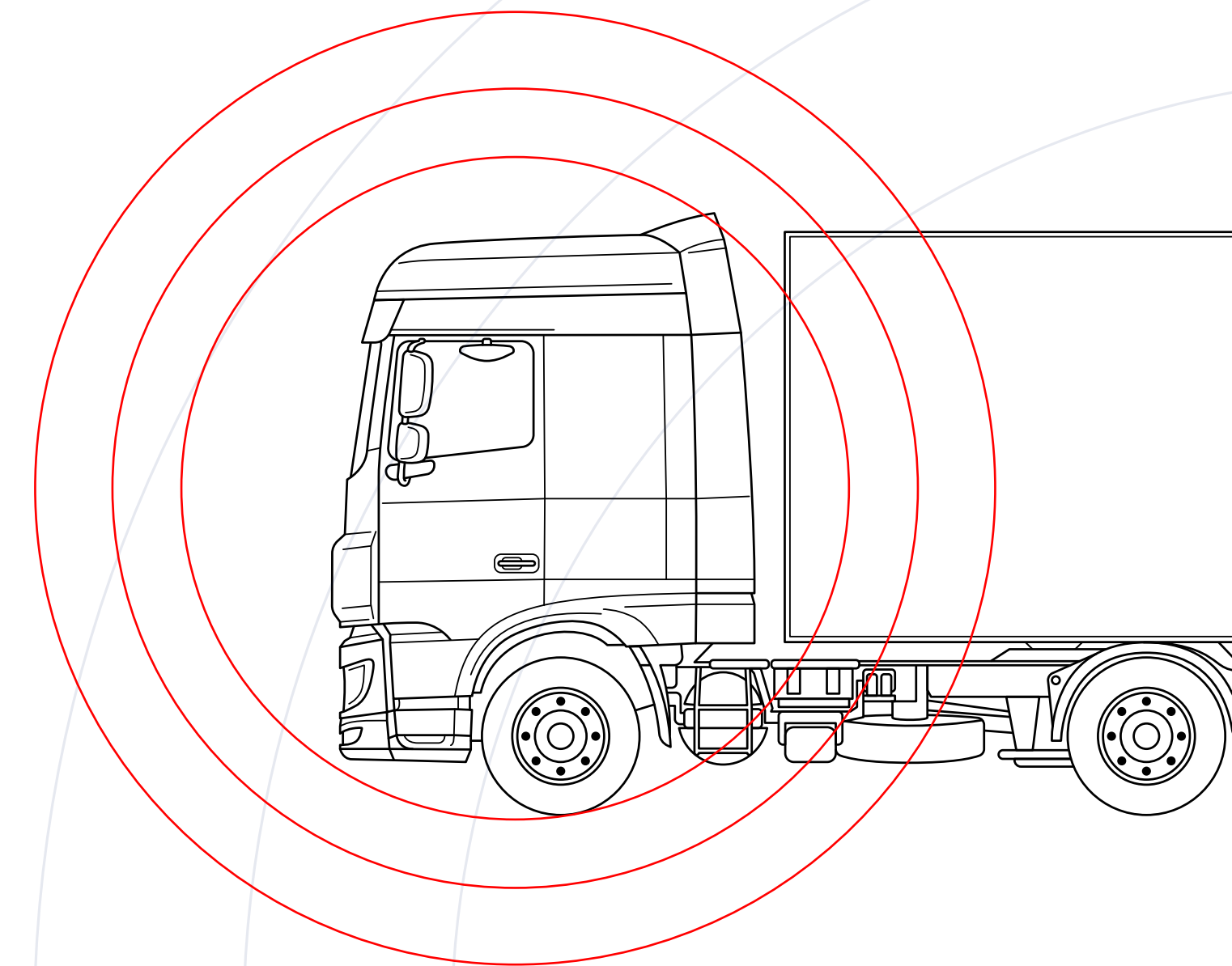
Research on the optimum platoon length as part of this project (see Section 3.4.4) found that for the HelmUK route, and likely the wider English motorway network, the optimum length was 2 to 3 HGVs. This platoon length is likely to offer the best fuel efficiency because it can safely platoon through a greater number of junctions than longer platoons.

Several of the methods outlined above may allow platoon lengths to be increased safely beyond 3 HGVs, in turn saving more fuel. It is worth considering that adding more vehicles to the platoon also increases operational complexity and hence the cost of trying to schedule deliveries into longer platoons. It is unlikely to be possible within a single fleet and would require widespread adoption of platooning technology to ensure that there are enough equipped vehicles on the road at the same place and time to form a longer platoon.

## 4.2.3 Reducing headway between the vehicles

In the HelmUK platooning trials, the maximum benefit achieved by platooning (the theoretical maximum) across three vehicles was 4.1%. This was achieved at 0.8 seconds time-headway between each vehicle in the platoon. The original aim of HelmUK was a 0.5 second headway, but this was not possible due to variability in brake performance of the articulated combinations which did not allow safe platooning at this close headway.

Further technical development may allow closer following distances which can be expected to produce greater fuel benefits. For closer following than 0.8 seconds to be safe in real-world conditions it is likely that this will require advances in braking technology which could pose challenges with operating platooning at lower headways than 0.8 seconds in mixed age fleets.



## 4.3 Platooning and National Highways

Platooning technology is designed for operation on motorways and other motorway-standard roads, which, in England, are part of the Strategic Road Network (SRN). The SRN comprises motorways and major A roads (some of which are built to motorway standards) in England and is the responsibility of National Highways. This section looks at how National Highways and other road operators in the UK should respond to platooning, what actions and investments they may make to support platooning's deployment and what they can expect from the technology based on the results of the HelmUK road trials.

### 4.3.1 How platooning will impact the English SRN

The impacts on the English SRN of platooning technologies will change if significant market penetration is achieved. The HelmUK project has identified possible future impacts of the widespread use of platooning technology which are summarised in Figure 4.3. Mitigations for the future disbenefits in this figure are described in Table 4.1.

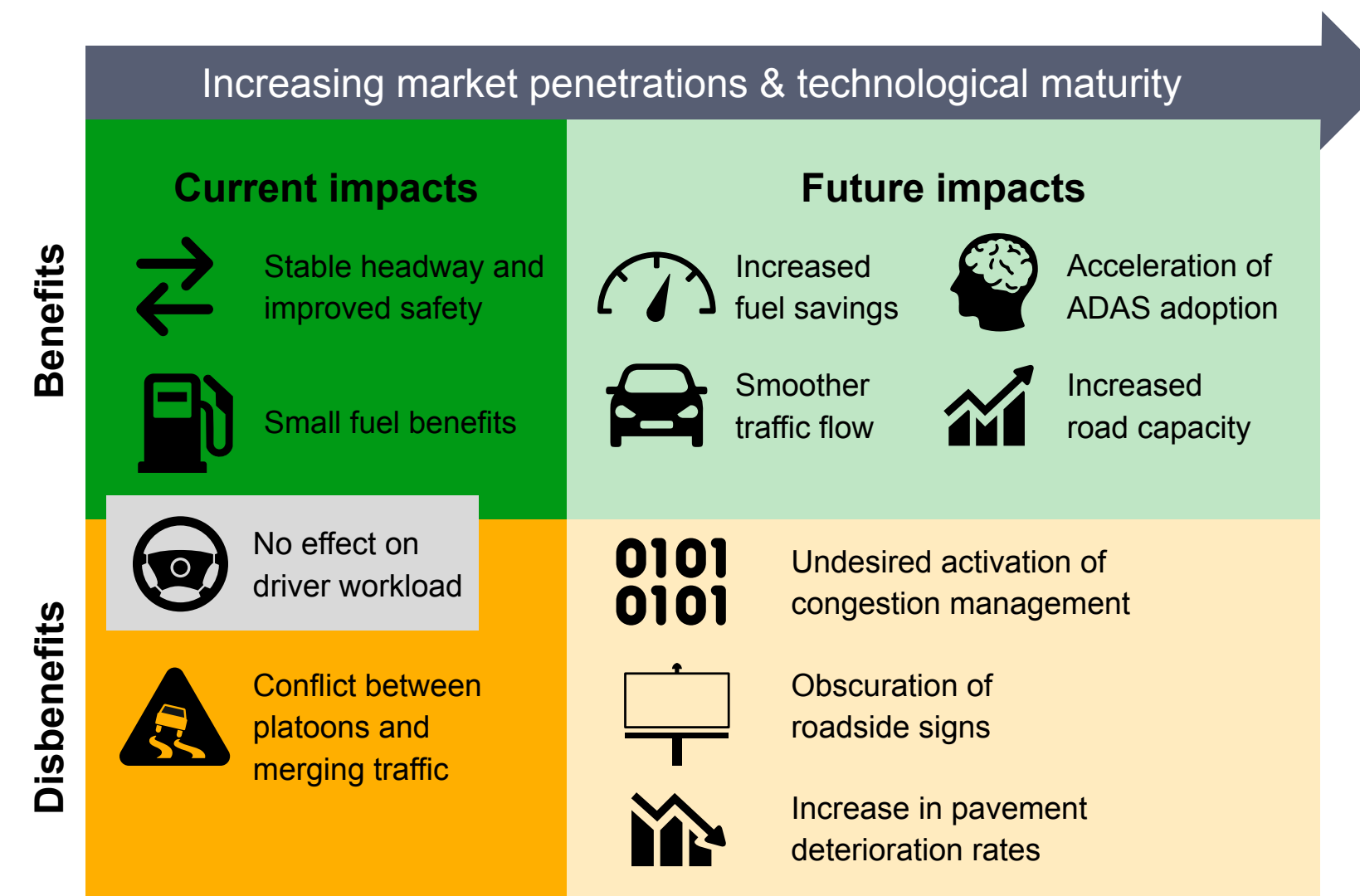


Figure 4.3: Impact of platooning on the English SRN including possible future impacts at high market penetration rates

This project found that a short-term deployment of HGV platooning would provide benefits for the English SRN including stable headways between platooning vehicles and small fuel benefits.

The disbenefits of platooning in the short term are at junctions. The small headway between platooning HGVs will increase risks to merging traffic joining the main carriageway as discussed in previous sections. HelmUK applied a set of criteria based on junction type and geometry to determine which junctions were safe for platooning operation. The trials demonstrated that these junctions were safe for platooning. However, the risk at junctions where the HelmUK trucks did not platoon through remains unknown.

This was a primary driver behind the modest fuel benefits for platooning found in the real-world trials.

The HelmUK trials have shown that, if the platoon is disbanded at 'non-platoonable' junctions, platooning is at least as safe as ACC despite travelling at half the time-headway of a typical ACC setting. Disbanding at junctions as part of a commercial operation (as outlined in Section 4.1) is likely to require data on junction 'platoonability'. It is not currently clear who would provide this, but it is a key consideration for road authorities and is discussed further in Section 4.3.2 below.

**Avoiding or mitigating the risk of conflict at junctions is key to maximising the benefits of platooning.**



Other possible future disbenefits of platooning can be mitigated as summarised in Table 4.1.

Potential impact	Recommended mitigation
If future platooning technologies control steering as well as longitudinal acceleration there is a possible increase in pavement degradation because the vehicles will follow the same path.	If future systems control steering, conduct pavement surveys in areas of high platooning to quantify the potential impact.
Congestion management algorithms may be triggered by high levels of platooning operation as the density of HGVs in certain lanes is increased.	In future this may require recalibration of the algorithm to account for changes in effective capacity of parts of the English SRN to ensure congestion management algorithms continue to perform.
Verge-mounted signs (including variable message signs and advance direction signs) can be obscured by platooning HGVs, both for drivers of vehicles within a platoon and for other road users. The effect is much larger for the drivers within a platoon and becomes more pronounced at very short following distances.	Before commercial deployment of platooning systems with close following, assess whether all information displayed on variable message signs can safely be acted upon by the lead driver of a platoon alone or if alternative arrangements need to be made.

Table 4.1: Potential future impacts of Platooning on the English SRN at high market penetration rates

**Recommendation: Platooning as a driver assistance system**

The main disbenefit of platooning in Figure 4.3 above is the risk of conflict at junctions. This is caused by the low time-headways used in platooning (in HelmUK the time-headway was 0.8 seconds). This functionality generates fuel savings by reducing aerodynamic drag for following vehicles in the platoon. However, HelmUK has shown that large fuel savings are hard to achieve in real-world operation.

This result raises the possibility of adopting the systems which enable platooning but not travelling at short time-headways. Such a system would operate at similar headways to ACC (typical minimum ACC time-headways range between 1.4 seconds and 1.6 seconds) and would remove potential risks around junctions. Such a deployment as a driver assistance system would still deliver benefits:

- Cooperative Adaptive Cruise Control has been shown in HelmUK to ensure stable following distances for vehicles connected to one another:
  - Reduces the risk of rear collisions
  - Potential benefit to the stability of traffic flow.

- Cooperative braking between vehicles could positively impact road safety. Using the technology which enables platooning without travelling at low time-headways would help reduce any activations of the Cooperative Collision Avoidance function which present a risk to following traffic (discussed in Section 3.1.1).
- As discussed in Section 3.2.1, HelmUK’s fuel baselining results show that running HGVs in a convoy using ACC at typical time-headways of 1.6 seconds produced fuel savings of 2.9% over solo HGVs in idealised conditions. Fuel savings over solo HGVs are still achievable when not traveling at low time-headways to other platooning vehicles.

This approach would allow platooning to be rapidly deployed safely on the network as an ADAS technology and would have other advantages:

- No investment from National Highways required.
- Safety requirements would sit with manufacturers (similar to other ADAS systems).
- Removes the need for automated gap-widening at junctions and reduces the requirement for a brake performance estimator.
- Time-headways of less than 2 seconds are common on motorways<sup>32</sup>, widespread platooning technology could significantly reduce the risks posed by this through improved longitudinal control.

<sup>32</sup> Previous TRL research has shown that at typical motorway speeds (60–70 miles per hour) ~50% of all vehicles on the M1 had a gap less than 2 seconds (~20% were less than 1 second). However, for HGVs the percentage following closer than 2 seconds was lower at ~27% (with ~7% less than 1 second). See Appendix C: Previous research on close following for excerpts from this report.

## 4.3.2 When and where on the English SRN should platooning be permitted?

- ▶ **Restrict platooning to motorways (or roads which conform to the same standards) to manage risk**
- ▶ **Platooning through junctions could also be restricted to manage risk**
- ▶ **National Highways would require the UK government to regulate platooning as they have no mechanisms for enforcement**
- ▶ **Junction suitability for platooning should be assessed for motorway-standard roads, and National Highways could consider leading on this**
- ▶ **This information on junction suitability needs to be made available to freight operators and vehicle manufacturers**
- ▶ **Night-time operation may offer a low investment case to support platooning rollout**

Platooning is best suited for motorway operation as these roads provide the highest potential for uninterrupted platooning. Non-motorway road types will often have priority- and signal-controlled junctions which are likely to interrupt platooning operation. Risks of platooning on other road types are mostly unknown but benefits for both fuel and safety are likely to be low. Key road features which should be considered for platooning operation include:

- Segregated carriageways with low radius of curvature.
- No priority or signal controlled junctions, only merge junctions.
- Restrictions on Vulnerable Road User (VRU) traffic.

Platooning should be limited to suitable motorways (or roads which conform to the same standards) with these features, at least initially. This can be done in a number of ways:

- Placing this requirement on vehicle manufacturers, similar to standards around Automated Lane Keeping System (ALKS).
- Road Operators could support a geofencing approach by defining where platooning is permitted. However this would place liability on the road operator and would need to be done in response to a specific risk.

Furthermore, as outlined above a key impact of platooning technology is the risk of conflict at merge junctions. Platooning could be restricted past all junctions on motorways and this restriction left to manufacturers to implement. This is a short-term recommendation of HelmUK outlined in Section 5.3.

To support safe platooning through more junctions in the future, which would in turn increase fuel savings, junctions on English motorway-standard roads could be assessed for platooning risk rather than imposing a blanket restriction on platooning. This would be similar to the approach HelmUK took to assessing junction suitability for platooning based on junction type, slip lane length, and traffic flow.

National Highways may not wish to take responsibility for conducting this assessment to enable platooning. Another approach to making platooning safe at more junctions it would be to make changes to those junctions as discussed in the next Section 4.3.3. However, based on the HelmUK results, a wider assessment of junction safety for platooning could be a relatively low investment step to support the future of platooning.

This assessment would be a key input to any automated disengagement or gap widening system as part of platooning operation, as described in Section 4.1.

Geofencing the English SRN and assessing junction suitability for platooning are complimentary and could be undertaken as part of the same development. The aim of this development would be to provide a 'living map' of motorway-standard roads for platooning technologies to ensure road safety but also to help increase fuel benefits for HGV platooning.



Actions which could be taken to support platooning geofencing:

- Define geographical areas of the network where platooning is permitted based on road features and type.
- Build on HelmUK’s junction assessment criteria to define platooning and non-platooning junctions for English motorway-standard roads.
- This information could be available in a database which is accessible for vehicle manufacturers and fleet operators.
- Such a database would help enable automatic disengagement at ‘non-platooning junctions’ and geofencing of platooning systems.
- Define limits on platooning length for junctions based on risk.
- Refine the junction assessment methodology used in HelmUK to include traffic flow as well as geometry to start to define risk probability as well as severity.
  - Use microsimulation or other ‘risk-free’ ways to determine risk relationship with flow.
- Consider how roadworks and other temporary conditions such as weather could be included in geofencing of platooning.
- Combine this with wider initiatives around CAV so the mapping activity aligns with other National Highways initiatives.

### Should platooning be restricted?

Platooning could be left unrestricted as many ADAS are currently. However, it is recommended that platooning is (initially) limited to motorway-standard roads where the risks are better understood because of HelmUK’s research.

### How can platooning be restricted?

National Highways cannot restrict platooning directly. The best way of platooning operation being controlled is for the UK government to regulate certain functionality such as where platooning can take place and how systems must respond to junctions.

### Recommendation: Night-time only platooning operation

The risk of conflict between platoons and merging traffic at junctions is proportional to traffic flow, so by allowing platooning only at times of low flow, such as night-time, the likelihood of conflict is reduced. The level of risk reduction would need to be quantified and this could be done through an enhanced junction assessment as discussed in Section 4.2.1. This could also be part of a wider approach to determining where platooning can take place as outlined above.

Night-time only platooning is likely to increase the amount of the network which is ‘platoonable’ and therefore increase the fuel savings from platooning operation towards 2.6% (average across three vehicles) and possibly beyond to a maximum of 4.1%.

This model would provide similar or better results than C-ITS solutions or changes to the English SRN while requiring significantly less investment in both time and money.

This model of operational ‘curfews’ also has an added advantage that other interruptions to platooning such as congestion and vehicle cut-ins are less likely. Freight industry engagement also highlighted night-time operation as the most viable application of platooning.

## 4.3.3 Should the English SRN change to facilitate platooning?

- ▶ **Investment could be required by National Highways to make the English SRN more ‘platoonable’**
- ▶ **Limited case for investment to support platooning because the fuel benefits are small, the technology is not yet mature**
- ▶ **However, platooning should be a use case considered in broader changes to the English SRN to support CAV development**
- ▶ **The business case could be strengthened by focusing on creating ‘platooning corridors’ and integrating with existing C-ITS rollout**

As discussed in Section 4.2.1, there are several approaches which could increase the fuel benefits from platooning operation by increasing the number of junctions which can be platooned through. Of the six measures identified in Section 4.2.1, the majority require changes to infrastructure or communications on the English SRN and will require investment from National Highways or UK government to achieve. The relevant measures are:

- Increase rollout of C-ITS to support platooning.
  - Equip existing ramp metering sites with V2I capability for coordination with platoons.
  - Expand the number of ramp metering sites on the English SRN; there are currently ~50 ramp metering sites out of over 1000 motorway junctions so the scale of any rollout to support platooning would be significant
  - Equip junctions with V2I communication capability to inform platoons if it safe to proceed.
- Creation of dedicated lanes (not lane 1 as used in HelmUK) on the English SRN for platooning to maximise uninterrupted platooning operation.
- Changes to junction types or lengthening slip roads to reduce risk to merging traffic:
  - An example could be reducing the number of lane gain/drop junctions as based on the HelmUK Safety Case these could not be platooned past.

- Several types of junction were deemed to be safe for platooning by design (dependent on slip lane length), examples include ‘Taper Merge’ and ‘Parallel Merge’ junctions.
- HelmUK’s assessment of junction ‘platoonability’ is covered in more detail in Appendix B: Junction type classification.

The business case for these interventions is weak based on HelmUK findings. Section 3.2.1 covers the fuel benefits which could be achieved in several future scenarios, including platooning through most junctions or optimising the network (up to 2.6% fuel savings), and the theoretical maximum fuel savings from platooning operation (up to 4.1% fuel savings). The measures listed above are grouped by potential fuel benefit in Figure 4.4 below.

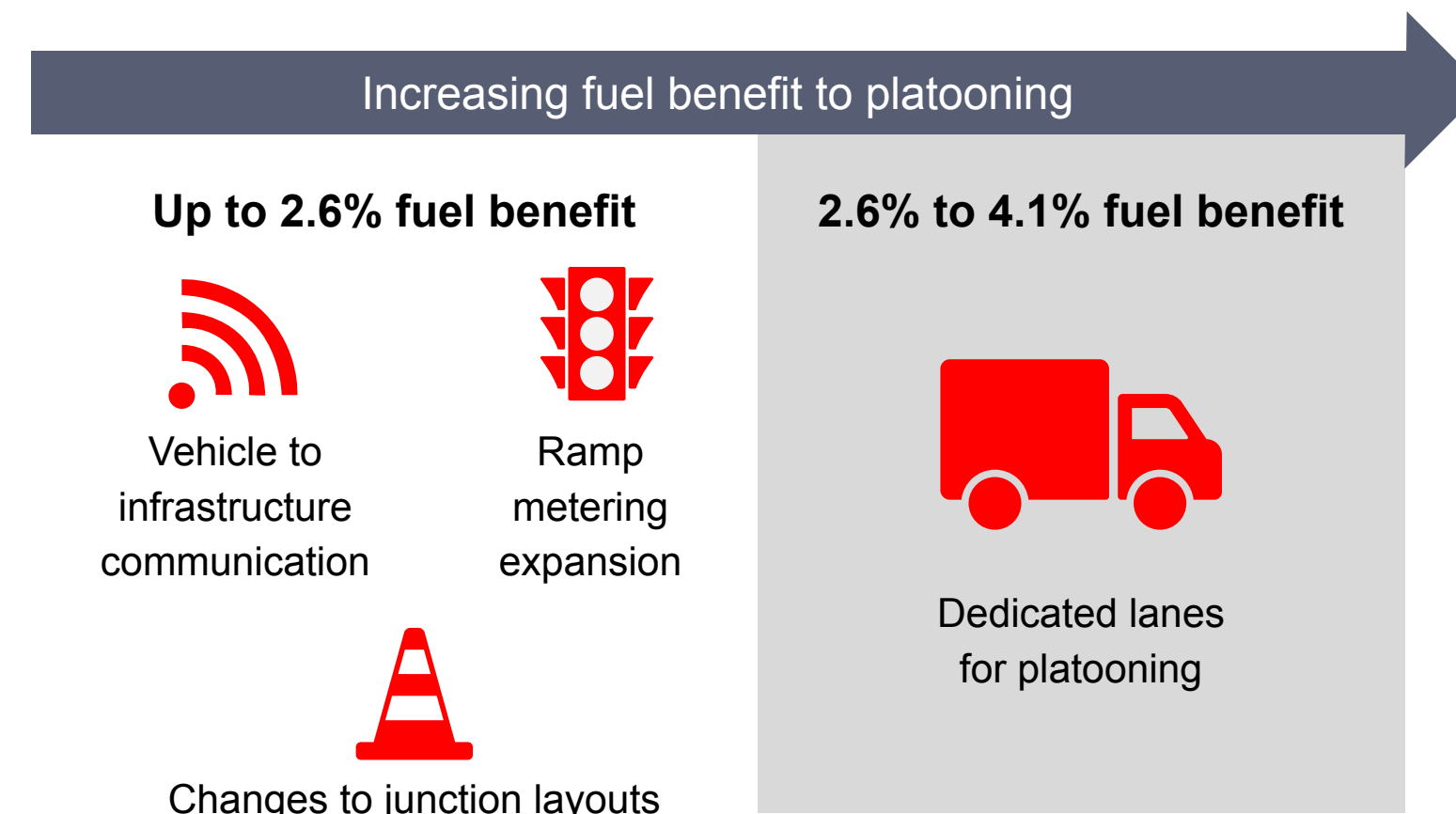


Figure 4.4: Potential fuel benefits enabled by National Highways investment in changes to the English SRN to support platooning

The overall business case for any or a combination of these investments is currently weak based on maximum fuel savings and the unknown complexity and drawbacks of some of the solutions (described in Section 4.2.1). Focus could instead be on measures which realise benefits from platooning without changing the English SRN such as platooning without close following and night-time operation.

### Recommendation: **Platooning corridors and wider CAV rollout**

Rather than network-wide investment, National Highways could focus any potential investment on key routes to create ‘platooning corridors’. This would maximise the impact of investment to support the operation of platooning technology but limit its geographical scope.

Platooning corridors would focus investment on C-ITS implementation and ramp metering upgrades on critical routes on the English SRN (for example between ports and distribution centres). This investment could create a ‘corridor’ down which platooning could be maintained for longer periods of time and offer increased benefits. However, National Highways should only consider investment in ‘platooning corridors’ when platooning technology is mature and is being taken up by the freight industry. Based on HelmUK’s findings this is unlikely to happen in the short term.



Additionally, changes to the English motorways to facilitate CAVs could also be beneficial for platooning. This creates a stronger case for enabling platooning through investment in C-ITS functionality and changes to road (and especially junction) design. CAV will have challenges around merging at junctions and interacting with other road users. When considering how junction design could change to facilitate CAV, this should take into account a use case of enabling safe platooning through junctions.

Platooning is one of many ADAS or CAV systems which could be supported on the English SRN in the future and will spread the cost of potential investment in V2X communication and other intelligent infrastructure.

### 4.3.4 What role do National Highways have in facilitating platooning?

- ▶ **Platooning must be safe to operate on the network without input or management from National Highways**
- ▶ **Stakeholder engagement within National Highways has shown that operations staff have concerns over platooning as a novel technology**
- ▶ **To offset these concerns there needs to be clear communication and safety assurance around platooning operation**
- ▶ **At the moment, there is no case for National Highways becoming a platooning service provider**

The previous sections outline the types of information or ITS services National Highways could provide to platooning vehicles to enable their operation and ensure safety. The findings of the HelmUK project do not make the case for an operational involvement in platooning on the network.

HelmUK has identified some areas of concern where National Highways operations staff want to capture and log information on platooning activity on the English SRN. This is mainly driven by safety concerns as to how local conditions such as weather or roadworks are communicated to platooning vehicles.

There were also concerns that specialised risk assessments may be required if elements of the platooning system are non-standard from a collision response point of view.

Based on the findings of the HelmUK trials, we believe that the technology requires the same level of monitoring as other ADAS and does not require additional monitoring. Internal manufacturer standards and the industry-wide accepted and applied functional safety standard ISO 26262 resulted in the development of a functionally safe platooning system. Based on HelmUK's work in ensuring that platooning technology can be deployed safely on motorways it is unlikely that a specialised response from Emergency Services would be required. This needs to be clearly communicated to key stakeholders so that they understand how platooning works. National Highways should play a role in amplifying this message.

### Recommendation: National Highways should not become a platooning service provider

For a multi-operator model of platooning there is a potential need for a Platooning Service Provider (PSP) to coordinate journeys between operators, maximise benefits and share benefits impartially between operators.

The case for National Highways becoming a PSP is weak and it is not recommended that it is pursued at this time. The key reasons are:

- Fuel benefits to platooning in real-world scenarios are small and this is unlikely to offset the cost of providing a PSP role.
- Such a model would require high market penetration of platooning technology to be most beneficial.
- Currently, National Highways do not have the right expertise to operate as a PSP.
- Industry engagement also highlighted that freight operators do not see a role for a PSP in future multi-operator platooning models.

If future developments demonstrate a need for a PSP, National Highways could contract a third party to act as a PSP and provide relevant data on traffic flow and vehicle movements.

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## → 4.4 Platooning and UK Government

### 4.4.1 Type-approval

The platooning system used for the HelmUK trials was developed by DAF Trucks and their suppliers in the absence of system-specific technical regulation. The development processes were governed by internal manufacturer standards and the industry-wide accepted and applied functional safety standard ISO 26262. This resulted in a platooning system that was safe to use (with trained drivers who were aware of permissible platooning locations), was functionally safe, and had sufficient self-test capabilities to detect any system failures that occurred during the trials and react appropriately to them. Therefore, the experience gathered by HelmUK did not highlight a strict need to regulate platooning systems if manufacturers follow thorough internal safety procedures.

Type-approval regulation could, however, establish a minimum performance threshold across manufacturers for a system with safety implications and ensure that restrictions on the use of platooning (such as platooning only on permissible road types, not platooning through certain junctions or limits to the number of vehicles travelling in platoon formation) are automatically enforced by the system rather than relying on driver adherence.

This appears particularly pertinent with a view to avoid unsafe platooning through junctions; if disbanding or increasing the headway before selected junctions, as required by the HelmUK Safety Case, is left to drivers in broad commercial deployment, there is large potential for non-compliance and increased risk of traffic conflicts. Should the introduction of type-approval regulation be considered by the UK government<sup>33</sup>, best practice established during the HelmUK trials could provide a basis for further aspects to be considered for implementation in technical requirements. The relevant aspects identified fall into four groups: on-board safety functions, platooning restrictions, human-machine interface and system design; overviews are provided on pages 104 to 107.

<sup>33</sup> Note that the European Commission is expected to develop a type-approval regulation for platooning systems based on their obligations defined in Regulation (EU) 2019/2144; it is not known whether this will contain requirements to ensure interoperability, system safety, or both. Note further that the ENSEMBLE project has developed a proposal for a regulatory framework regarding platooning systems, including draft contents for type-approval regulation Deliverable 6.13; [click here](#)



## On-board safety systems

Considerations for on-board safety functions for a potential type-approval regulation:



### Cut-in detection

Other road users cutting in between vehicles in platoon formation was expected and observed during the HelmUK trials. The platooning system should ensure that such vehicles are reliably detected and the system automatically increases the time-headway to not create hazardous close following situations with other road users. The HelmUK safety tests highlighted that the automatic detection of vehicle cut-ins was not absolutely reliable, in particular in the case of motorcycles. Potential requirements and tests should therefore also put emphasis on detection of small vehicles, including motorcycles.



### Cooperative collision avoidance (CCA)

Standard AEB systems might trigger at platooning following distances. For HelmUK, the standard AEB system was replaced during platooning operation by a CCA system which relies not only on radar but also evaluates the V2V communication signals from vehicles ahead. The AEB regulation should permit automatic deactivation of the standard AEB system while platooning is active.



### Stationary obstacle detection

Stationary vehicles in lane one present a substantial collision risk on motorways. At close following distances during platoon operation, this could be exacerbated in situations where the lead driver reacts late and swerves around the obstacle, leaving too little time for the following driver to react. AEB systems are required by regulation to detect stationary vehicles, provide a warning and reduce the impact speed by at least 10 km/h or 20 km/h (depending on vehicle category and permissible maximum mass). AEB systems which exceed the regulatory requirements and are capable of reacting early enough to avoid collisions with stationary vehicles entirely, could increase the safety of platoons.



### Lane keeping assistance (LKA)

The lateral control task is more difficult at close following distances because the view of the road and lane markings ahead is limited. To support the driver, the HelmUK vehicles were equipped with an LKA system which corrected the course by applying a small torque to the steering wheel if lane boundaries were about to be crossed. LKA systems of lane-centring type, i.e. performing gradual support to remain centred rather than correction before line crossing, could further improve the lateral alignment of platooning vehicles, but may increase road surface deterioration (see Section 3.3.6).



### Headway adjustments in response to weight differences

The braking distance of HGVs is influenced by their laden weight. This could create a risk of collisions in harsh braking manoeuvres when heavier vehicles follow lighter vehicles at minimum following distance. The platooning system should ensure that intra-platoon collisions are reliably avoided irrespective of the loading factors and order of the platooning vehicles. This could be achieved by allowing a large enough safety factor to account for all loading conditions when determining the system's minimum following distance or by evaluating the loading status and associated brake performance of each vehicle and dynamically adjusting the headway to safe levels if necessary.

The latter approach is recommended because it maximises the fuel saving potential in real-world operation with varying platoon compositions, which requires axle load monitoring systems fitted to the trailers to allow platooning vehicles to evaluate their relative weight ratios. In HelmUK, the headway adjustment was performed by the Brake Performance Estimator (BPE) function of the platooning system.

## Platooning restrictions

Considerations for automated functions to increase adherence to potential platooning restrictions:



### Motorway junctions

Depending on the junction layout, passing junction entry slips in platoon formation may create difficulties for other road users attempting to merge onto lane one. For junctions where this is the case, the platoon should disband or increase the time-headway (e.g. to ACC following distance). In HelmUK this was a manual process to be performed by the drivers, which proved a challenging aspect even for well-trained drivers because of the high frequency of junctions and the need to remember which junctions are 'platoonable' or 'non-platoonable'. The project experience shows that for a commercial deployment of the system it would be desirable to automate headway increases before 'non-platoonable' junctions. This could be realised as a location-based system function.



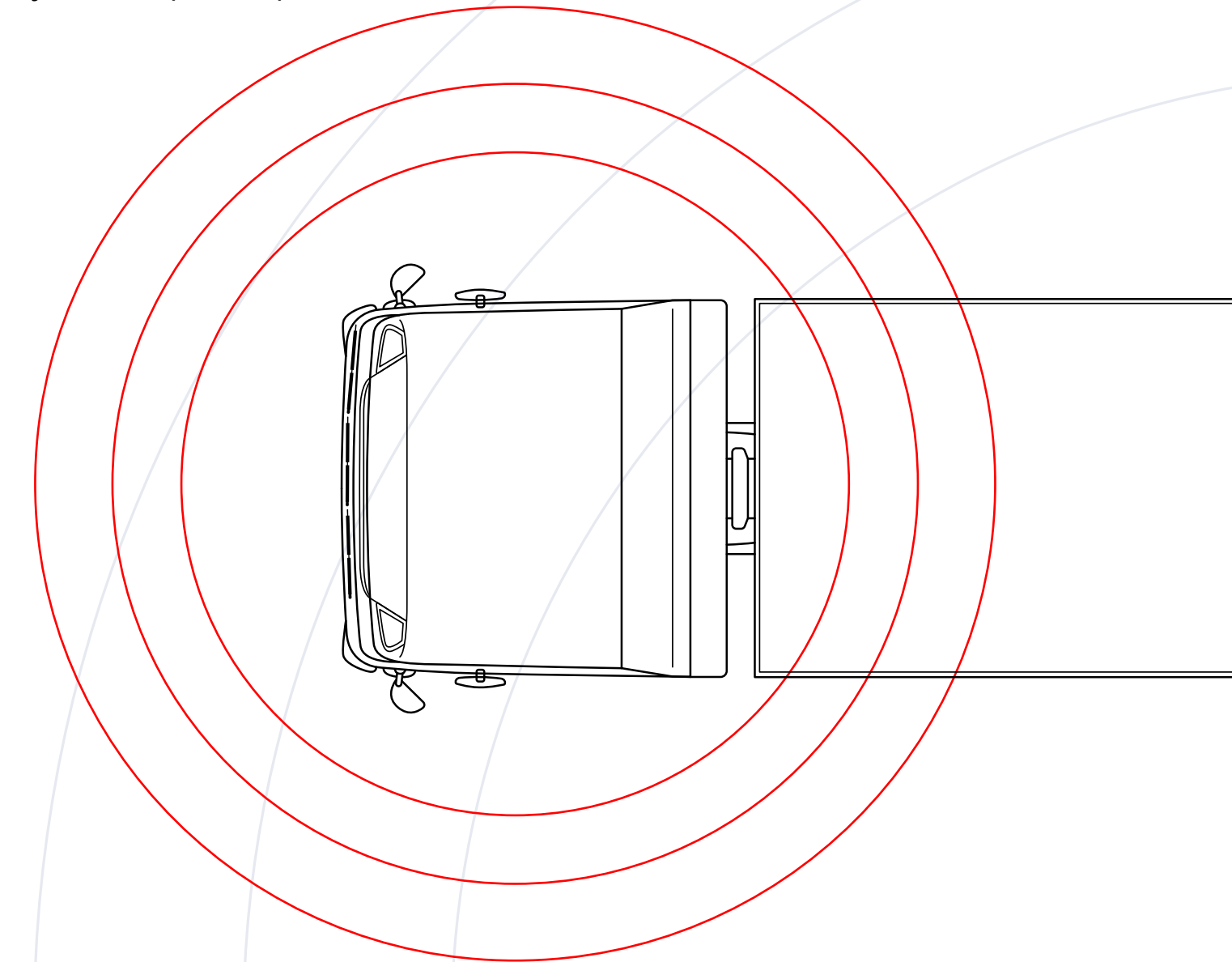
### Platoon length

HelmUK trialled a three-vehicle platoon, but it was shown that addition of more vehicles could increase overall fuel benefits which might therefore be preferred by operators in commercial deployment, if logistics schedules allow. Should maximum permitted platoon lengths be set by regulators in the future to limit traffic conflicts, this could be automatically enforced by an integrated function of the platooning system.



### Road types

HelmUK has trialled platooning exclusively on motorways, which is the most suitable road environment to enable safe operation at close following distances. Any restrictions regarding permissible road types, which may be set by regulators in the future, could be automatically enforced by a location-based system function to avoid misuse. Similar prescriptions exist in UN Regulation No. 157 for Automated Lane Keeping Systems (ALKS).





## Human machine interface

Considerations on relevant HMI aspects from HelmUK experience:



### Voice communication

In HelmUK, a permanent hands-free voice-communication link between all three vehicles was available to aid co-ordination for platoon formation. The experience during driver track training showed that co-ordination via voice communication required a specific protocol to facilitate effective communication and avoid misunderstandings. After the trials, drivers' opinions were split about whether voice communication would be a necessary requirement beyond the trials with the HMI design trialled. Voice communication, even with hands-free headsets, also has the potential to distract drivers. Systems for wider commercial deployment should feature HMI designs which do not rely on a voice link between vehicles.



### Signalling to other road users

The HelmUK vehicles were not specifically marked and did not communicate to other road users that they were operating in a platoon. The trials did not highlight safety critical incidents with other road users which were attributed to this fact. In commercial deployment, however, a standardised way of signalling could be useful to allow platooning vehicles to be exempt from enforcement activities by police forces relating to tailgating.



### Level of automation

The research project ENSEMBLE<sup>34</sup> defines two levels of platooning functionality which may be adopted into future standards or regulations: a support function (driver always responsible, able to overrule system) and an automated function (driver can be out of the loop). It will be important that HMI designs do not lead to misinterpretation about the level of driving automation offered and the associated responsibilities of the driver. The platooning system used in HelmUK was designed as a support function, i.e. it did not allow the driver to perform secondary tasks while driving in platoon formation. The HelmUK HMI was implemented as additional time-headway steps of the ACC systems, which the driver could select via the same control. No issues were encountered during the trials.



### Visual signals

The HelmUK vehicles relied on text-based messages in the instrument cluster (for example: Accept platooning request? Platooning request pending. Platooning request accepted. Disengaging platooning. Platooning decoupled.) and visual indication of the current time-headway step (2 platooning steps; 3 ACC steps). During the trials, instances occurred where lane changes were performed before the platoon was fully decoupled. In these cases, CCA was still active leading in some cases to unwanted automatic brake interventions. An explicit message to drivers when it is safe again to perform lane changes could be considered, but this would need to be weighed against potential hazards created by drivers delaying necessary manoeuvres.

<sup>34</sup> ENSEMBLE research project website [click here](#)

## System design

General system design aspects relevant for potential type approval regulation:



### Functional safety

To limit risks due to hazards caused by malfunctioning behaviour of the platooning system, the ISO 26262<sup>35</sup> standard was followed when developing the HelmUK system. This standard is widely accepted and applied throughout the industry. A future regulation could address the safety of complex electronic systems with similar prescriptions as used for advanced driver assistance systems.



### Cyber security

HelmUK's cyber security requirements were based on guidance from the DfT Code of Practice for Automated Vehicle Trialling and HM Government Key Principles of Cyber Security for Connected and Automated Vehicles. Normative cyber security requirements for vehicle systems in general, and thereby also covering platooning systems, could be implemented through UN Regulation No. 155 (Cyber security and cyber security management systems).



### Software updates

For the duration of the trials no specific experience was gathered with software updates. For commercial deployment of systems that allow software updates, implementation of UN Regulation No. 156 (Software update and software updates management system) could be considered to ensure reliable identification of the software used and safe execution of updates.



### Interoperability

HelmUK used three HGVs from the same brand, equipped with the same platooning system using the same V2V communication protocol. For wider commercial deployment, interoperability of platooning systems from different brands would be desirable to maximise opportunities for platooning on the network. ENSEMBLE is developing solutions for multi-brand platooning that are aligned between the major European HGV manufacturers.

<sup>35</sup> ISO 26262 Road Vehicles – Functional Safety



## 4.4.2 Construction and Use regulations

The HelmUK vehicles were assessed for their compliance with the Road Vehicles (Construction and Use) Regulations 1986, as last amended by S.I. 2017 No. 881, after being modified to integrate the platooning system. The vehicles were found to be in compliance, except for their dimensions, which exceeded the maximum permitted width of 2.55 metres due to the WiFi antennae installed in ‘side wings’ to ensure a stable vehicle-to-vehicle connection between the platooning vehicles. Consequently, a vehicle special order had to be acquired to operate the vehicles on road.

The definition of ‘overall width’ in Regulation 3(2) already provides exceptions for certain items, such as mirrors or lamps, which do not count towards this measurement. It could be considered to add an exception for V2V-communication antennae in order to allow their installation in the technically most suitable location thus enabling stable connections.

## 4.4.3 On-road use

Rule 126 of the Highway Code advises drivers that they “should [...] allow at least a two-second gap between you and the vehicle in front on roads carrying faster-moving traffic [...]”. Drivers in platoon formation disobey this rule with, in the case of HelmUK, a minimum time-headway of 0.8 seconds. While this rule is not a legal requirement, non-compliance might have consequences for drivers when liability is established in court proceedings. Legal analyses are outside the scope of HelmUK, but if it is intended to enable platooning with close following, this aspect might warrant further investigation and potential clarification.

<sup>36</sup> Driver & Vehicle Standards Agency (2020) Guide to maintaining roadworthiness – Commercial goods and public service vehicles.

This also raises the question whether enforcement of safe following distances generally will become more difficult for police forces if it cannot be seen whether a group of vehicles is part of a platoon or following dangerously close without automated cooperative braking capabilities. A standardised way of signalling platoon operation to other road users, as discussed in Section 4.4.1, might help resolve this issue.

Note that the aspects of when and where platooning should be permitted and potential limits on the maximum length of a platoon are discussed in Section 4.3.2.

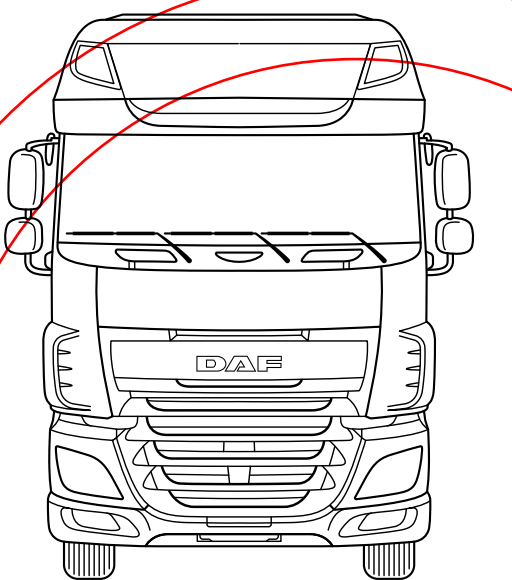
## 4.4.4 Roadworthiness

The HelmUK trials did not identify increased vehicle wear and tear or specific issues relating to, for example, engine contamination or uneven tyre wear, due to platooning operation. The trials involved just three vehicles and could only cover a fraction of their working lifespan, which is why the results cannot be used to rule out such effects authoritatively, but from the project findings there is no indication that the frequency of routine vehicle servicing and maintenance or periodic technical inspections needed to be adjusted for platooning-enabled vehicles.

The platooning system components themselves do not require regular maintenance. During the trials, the platooning system’s self-test routines identified relevant faults and failures reliably and reacted appropriately by not offering platooning functionality while in error state. The limited experience of trialling a single system implementation, did, therefore, not highlight a specific need to include platooning systems in periodic technical inspection routines.

It should be considered that the functionality of ADAS can be compromised by relatively minor interactions when environment perception sensors are affected. This may be damage to the front of a vehicle where a radar sensor is located, or simply replacing a component that affects a sensor, such as a windscreen holding a camera. The relevance of sensor alignment and calibration is not limited to platooning, but applies to many ADAS systems, including advanced emergency braking (AEB), lane departure warning (LDW) and adaptive cruise control (ACC).

Thatcham have developed UK Insurance Industry Requirements (IIR) for the safe repair of ADAS-equipped vehicles, which aim to ensure that inspection, realignment and calibration requirements are adequately considered, performed and documented if a repair includes ADAS sensors, parts likely to affect their functionality or vehicle geometry. Thatcham member insurers require repairers to meet these IIRs. It could be considered to include information on the repair of ADAS-equipped vehicles in government guidelines, such as DVSA’s Guide to maintaining roadworthiness<sup>36</sup>.

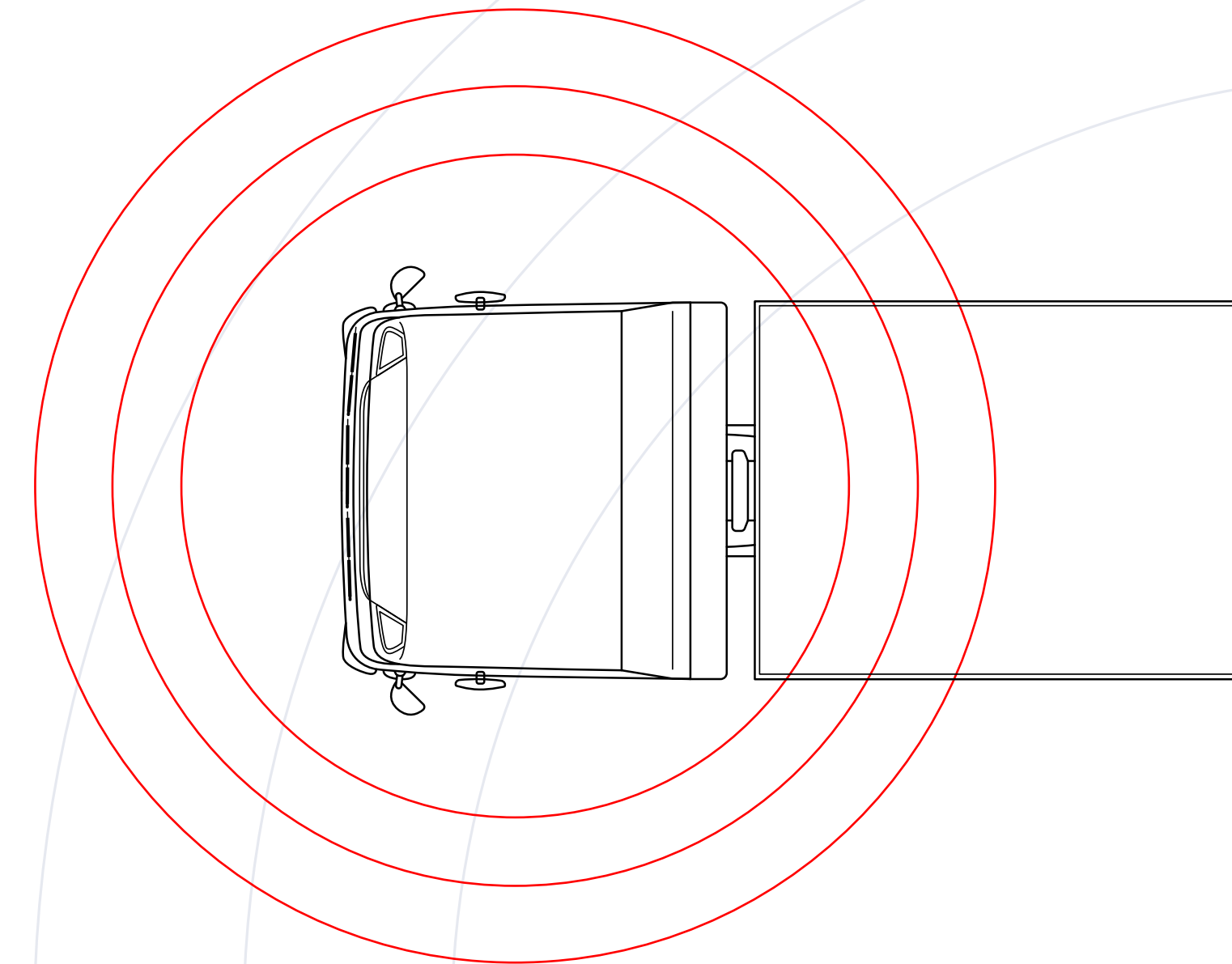


## 4.4.5 Communication with the public

HelmUK highlighted the potential for misunderstandings regarding the system capabilities associated with the term ‘platooning’. In initial conversations, this was often assumed to be SAE Level 4 or 5 driverless vehicle technology, rather than the driver assistance function trialled. The ENSEMBLE project, where the major European HGV manufacturers define common standards, defines two levels of platooning functionality: a support function (driver always responsible, able to overrule system) and an autonomous function (driver can be out of the loop).

It will be important for system users to have a clear understanding of their responsibilities in monitoring the driving environment, the vehicle performance and/or the platooning system performance. Activities to achieve clear understanding could focus on ensuring that suitable information is given to drivers in training, in instruction manuals and through marketing of the systems.

In addition, informing the wider public may help to ensure their support when deploying platooning: The motoring public could be informed how platooning might improve their lives, with benefits and safety aspects clearly communicated. They could also benefit from information about how the technology works as well as guidance on how to act around a platoon. The Frequently Asked Questions (FAQs) developed by HelmUK could form the basis for information material, see Appendix A: Frequently asked questions about platooning.

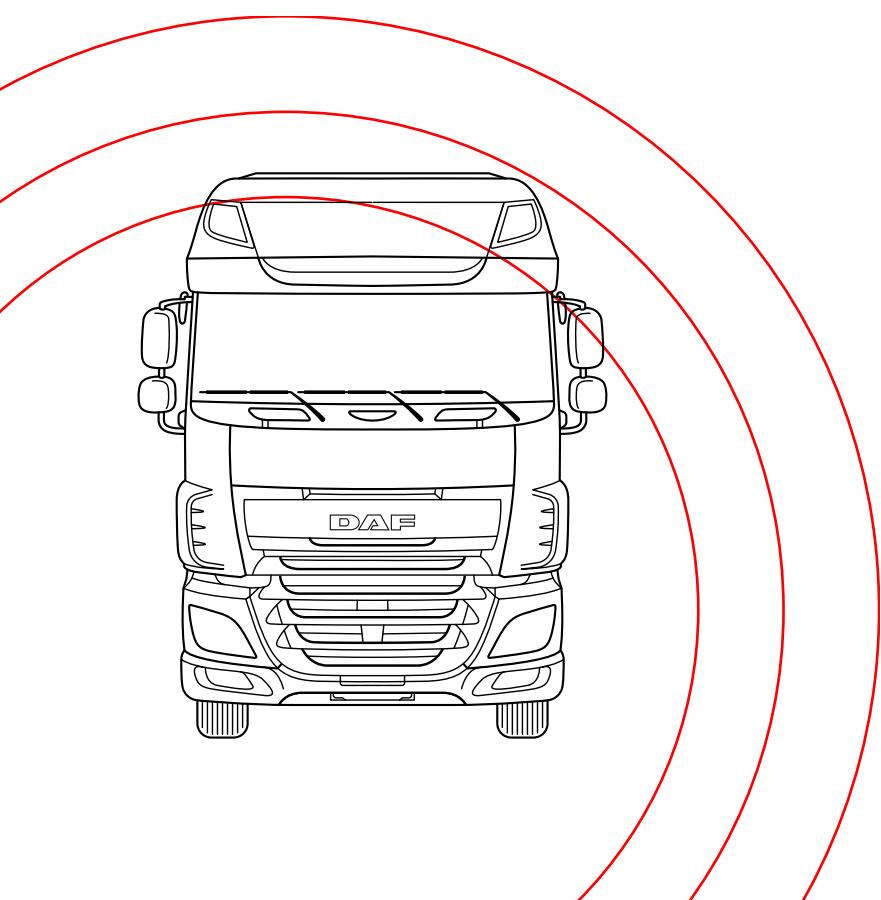




## → 4.5 Platooning and the freight industry

Platooning technology has the potential to provide the freight industry with benefits in terms of fuel savings and safety.

As discussed in previous sections, HelmUK has found a number of benefits and some disbenefits to operating platooning technology in the real world. This section looks at these findings from the perspective of a freight operator who may be looking to incorporate platooning technology into their fleets and includes a series of recommendations for the future of platooning.



### 4.5.1 Platooning business case

- ▶ **The current case for investment in platooning, without subsidies, is weak based on fuel benefits alone**
- ▶ **If more of the network was ‘platoonable’ (increasing fuel savings) then research indicates that some larger operators may be willing to invest at around 2% fuel savings**
- ▶ **Priority for platooning deployment should be on routes with few interruptions to platooning – a key metric is junction frequency**
- ▶ **Platooning would suit night-time operation because of the lower traffic flow and volume allowing more uninterrupted platooning**
- ▶ **Initial platooning deployments are likely to be large, single operator with multi-operator models coming later in the technology lifecycle**

#### Fuel savings

The results of the HelmUK trials, in terms of fuel efficiency, are covered in detail in Section 3.2.1. In brief, these results show that platooning’s fuel benefits over use of Adaptive Cruise Control (ACC) are:

- The on-road trials data showed a small benefit of 0.5% fuel savings
- Modelling of future scenarios, where all junctions are suitable for platooning, achieved up to a 2.5% fuel benefit
- Maximum fuel savings could be up to 4.1% in perfect conditions

These numbers are average savings for a three-vehicle platoon. For longer platoons, savings will be higher because each additional vehicle benefits more from the slipstream effect than the lead vehicle.

Previous sections cover how fuel savings could be improved to get closer to get from 2.5% fuel saving closer to a maximum 4.1% fuel saving (see Section 4.2). These improvements are important for freight operators to be aware of, but most cannot be implemented directly by the freight industry.

HelmUK’s industry engagement found that most operators would want to see a fuel benefit of 5% to invest in platooning – but some operators with larger fleets may invest at around 2% fuel savings (see Section 3.4.1 for more details). There is an overlap between the trials results and this window for investment, which means platooning uptake by industry is possible, but depends heavily on maximising fuel savings.

This places the freight industry in a position where future investment decisions would be heavily influenced by work done by National Highways, DfT, or vehicle manufacturers to increase the amount of platooning possible on the English SRN. In the short term, this limits the business case for platooning outside of larger operators with big fleets who may be willing to invest in platooning for lower fuel savings.

There are two strategies that fleet operators can adopt to improve fuel savings from platooning towards a 2% threshold:

1. Only operate platooning on routes with a combination of:
  - a. Large numbers of 'platoonable' junctions
  - b. Less frequent junctions than the HelmUK route
2. Only operate at night-time when risks are likely to be lower and more junctions can be platooned through.

The next section discusses how these routes can be identified and selected.

### **Route selection and criteria**

Platooning, as implemented by HelmUK, is a concept intended for motorways (and potentially some A-roads) and should not be used on minor roads for safety reasons. Additionally, to allow safe merging of other vehicles onto the road, the short gap between platooning vehicles will need to be widened before some or most motorway junctions. To support the drivers of platooning vehicles, it is a recommendation from HelmUK that platooning systems automatically implement these restrictions i.e. the system would only allow activation on suitable road types and would automatically widen the gap before pre-defined junctions.

The limitation to certain road types means that for fleet operators who do not make extensive use of motorways, platooning will provide no benefit. Industry engagement showed 72% of operators conduct operations on the SRN, and the larger the fleet, the more likely they were to do so.

When planning the use of platooning as part of fleet operation, the highest fuel benefit will be achieved by operating on roads with fewer interruptions to platooning. These routes are also likely to be safer for platooning operation. Key considerations for a fleet operator are:

- How much of a route permits platooning?
- How frequent are junctions along the route? Specifically, junctions which require automatic gap-widening from the platoon?
- Are roadworks present on the route?

To be able to make these decisions the freight industry would need access to any data on platooning restrictions. Any future junction assessment framework could support the creation of a route planning tool to highlight areas where platooning is permitted and junctions which are 'non-platoonable'. Such a framework is discussed further in Section 4.3.2.

These considerations feed into the overall business case:

- Investment in platooning-capable vehicles needs a business case built on viable journeys and routes which minimise the interruptions to platooning and therefore maximise the fuel benefits.
- For this reason, platooning suits night-time operation because the low traffic volume means:
  1. There is less risk of conflict at junctions and therefore more junctions could be 'platoonable', increasing fuel savings on a route.
  2. There is a wider choice of viable routes for platooning journeys.
  3. The chance of other interruptions to platooning, such as congestion and vehicle cut-ins, are reduced.
- However, roadworks are more common at night which may disrupt platooning.

This will mean that some freight operators are in a better position to take advantage of platooning than others. HelmUK's industry engagement highlighted that parcel delivery companies and pallet networks may be suitable for this type of operation.



## Business models

There are broadly 3 business models which could be used for platooning (see Section 3.4.1 for more details):

1. Platooning within a single company's fleet.
2. A platooning alliance between several companies who 'pool' fleets for platooning.
3. Connected platooning where any vehicle can participate in a platoon on an 'ad-hoc' basis.

At the national level the third model has the most potential to provide benefit as it is open to more operators. However, based on the HelmUK findings we believe that the first model is the most likely for early adoption of platooning technology because it does not rely on wider market penetration of platooning technology. The second model could also be of interest to a consortium of businesses with similar operations, but work would need to be done to identify these shared operations and set up a platooning alliance.

In both model 1 and 2, the key is for operators to be willing to coordinate platooning journeys, i.e. to get two or more HGVs in the same place at the same time. Consideration should also be given to the order of vehicles in the platooning based on weight, so that the headway between the vehicles can be as low as possible.

These considerations needed to deploy platooning within a fleet of vehicles will require additional investment in logistics operations, moreover the fuel savings will have to offset any costs of coordinating vehicles in this way.

The 3rd business model also raises a question about how benefits may be distributed across multiple operators if one is leading a platoon and not saving fuel. HelmUK looked at the role of a platooning service provider to facilitate this, but the overall complexity and resultant cost are not likely to be offset by the modest fuel savings of platooning deployment in the real world.

## Technology readiness

Platooning systems are not yet commercially available as original equipment from vehicle manufacturers and planned timescales for commercial deployment are not available publicly. However, HelmUK successfully used a prototype system in live traffic which shows that the technological building blocks for platooning already exist.

The major European HGV manufacturers DAF, Daimler Truck, Iveco, MAN, Renault Trucks, Scania and Volvo Trucks are working collaboratively on the research project ENSEMBLE<sup>37</sup> to develop a standardised protocol that will allow multi-brand platooning. This work also indicates that platooning functionality might be released at two different levels of automation:

**A support function, where the driver remains responsible and is able to overrule the system** – time-headways would not be shorter than 1.5 seconds, i.e. similar to current ACC systems but ensuring coordinated speed and collaborative braking; the fuel benefits measured in HelmUK were based on a system at 0.8 seconds time-headway, so would not be realised with a support-type system.

**An automated function, where the driver is not responsible for the dynamic driving task** – time-headways of less than 1.5 seconds would be possible with the automated function.

All major European HGV manufacturers have shown an interest in platooning technology, but it is not known which are planning to release systems eventually and what price premium they will set for a platooning-enabled vehicle. A prerequisite to commercial deployment is the introduction of a multi-brand communication standard, which can be expected to happen within the next two years.

## Trailer requirements and load order

As part of the safety systems, the HelmUK platooning system used a Brake Performance Estimator which regulates the distance between vehicles based on the load carried by each vehicle. This is an important part of enabling vehicles to travel at low headways safely during platooning, how such systems should operate is described in more detail in Section 4.4.1.

There are two key requirements of this system which the freight industry should be aware of when considering the future of platooning:

1. Trailers are likely to require a weight monitoring system to be compatible with platooning technology which can achieve low headway operation and save fuel.
2. The order of the loads in a platoon will vary the headway and may require coordination. This is easier within a single fleet than as part of an ad-hoc platooning model.

<sup>37</sup> ENSEMBLE research project website [click here](#)

### Vehicle maintenance

The components of the platooning system do not require regular maintenance. A previous platooning trial had, anecdotally, reported potentially increased wear and tear on standard vehicle components due to platooning operation, including damage to body panels due to grit, engine contamination and uneven tyre wear. However, during the HelmUK trials, no evidence was found to indicate increased wear and tear and no meaningful differences were identified whilst conducting routine servicing and maintenance of the vehicles. Based on the information available, there is no indication that the maintenance and inspection intervals for platooning vehicles needed to differ from those of non-platooning vehicles.

### First platooning adopters

Based on the findings of the research conducted in HelmUK, if a freight operator wanted to adopt platooning technology pro-actively, rather than waiting for high market penetration, their business would likely have a number of key features listed here.

In combination, these features are likely to limit initial uptake of platooning technology with UK freight operators, but there is no requirement for other operators to have platooning technology which allows early adoption. From a national perspective however, this lower uptake limits the overall fuel savings UK wide.



Large vehicle fleet or willingness to 'partner'



Operates primarily on the SRN



Willing to invest for fuel savings of ~2%



Can coordinate multi-vehicle journeys



Common origins or destinations for loads



Business is suitable for night-time operation

Figure 4.5: Key features of an early platooning adopter

## 4.5.2 Road safety and effect on drivers

- ▶ **Platooning operation is as safe as current HGVs with ADAS as long as future systems automatically widen the gap at junctions**
- ▶ **The ADAS and cooperative technologies enabled by V2V technology can improve safety even when not platooning at low headway**
- ▶ **Formal driver training is unlikely to be a requirement, but best practice would be to provide drivers with a clear understanding of their responsibilities in monitoring driving environment and system performance, including rules to not perform secondary activities while platooning, and orientation on vehicle cut-ins, junction navigation and cooperative braking**
- ▶ **Driver workload isn't impacted positively or negatively by platooning and driving a following vehicle in a platoon is similar to 'normal' HGV driving**



## Road safety

The full results from HelmUK for road and driver safety are covered in detail in Section 3.1. For a freight operator the key results are:

- In the way the HelmUK trials were conducted, platooning is, broadly speaking, as safe as using current generation ADAS such as ACC. This assumes disengaging at junctions assessed to be 'non-platoonable'.
- The platooning system combined a number of ADAS, such as LKA and cooperative ACC (CACC), as well as cooperative collision avoidance (CCA). LKA fitment as part of platooning systems will improve safety for HGVs even when not platooning.
- Key to platooning is the CACC functionality which maintains excellent longitudinal control of the vehicles in a platoon and, in doing so, allows vehicles to follow each other at low headways without increasing the risk of collisions.
- HelmUK has seen that CCA can reduce risk of collisions but in the HelmUK trial, CCA was sometimes activated in a way which could have increased risk to following traffic. As this is a prototype system, it is assumed that further improvements would reduce this risk.
- In order to actively manage risk at junctions, for most junctions on the HelmUK trial route, the vehicles widened the headway between them to allow vehicles to merge.
- The recommendation in this report is that future platooning systems should automatically widen the gap between platooning vehicles at junctions where there is a similar risk. This is needed until this risk is better understood or mitigations are in place at the junction level which could remove the need for gap widening behaviour (see Section 4.2.1).

The above points are likely to be true of most first-generation platooning systems. Platooning will not increase risk to HGVs, HGV drivers or other road users as long as high-risk junctions are handled automatically by the system.

## Effect on drivers

**Driver training** - as part of HelmUK there was extensive training in the classroom, on track and finally on road. As part of this project, it was found that widening driver training outside of the small pool of experienced DAF test vehicle drivers had several challenges, including the intensity and complexity of the training. However, this level of training is unlikely to be a requirement of a first-generation platooning system if it is going to be commercially successful. Key to successful adoption of platooning technology is for manufacturers and operators to clearly communicate to their drivers what the technology can do. A first-generation system is likely to:

- Not in any way be 'driverless'.
- Only control acceleration and braking (for the following vehicles).
- Require steering from all drivers.
- Require all drivers to be ready to take full manual control at any time.

While drivers may not need formal training, some orientation for drivers would be best practice. Based on our experience of HelmUK this should be focused around:

**Platooning operation** – company guidance and policies on when to engage platooning and when to abort. An example would be weather conditions such as heavy rain or below certain speeds.

**Degree of automation** – first platooning system releases might be driver support functions where drivers will remain responsible for monitoring the driving environment and react if necessary (see above). Until higher levels of automation are achieved, it will be important that drivers have a clear understanding of their responsibilities and the fact that distracting secondary activities must not be performed while platooning.

**Vehicle cut-ins** – how to handle vehicles cutting between the platoon including any specific risks around harder to detect VRUs such as motorbikes.

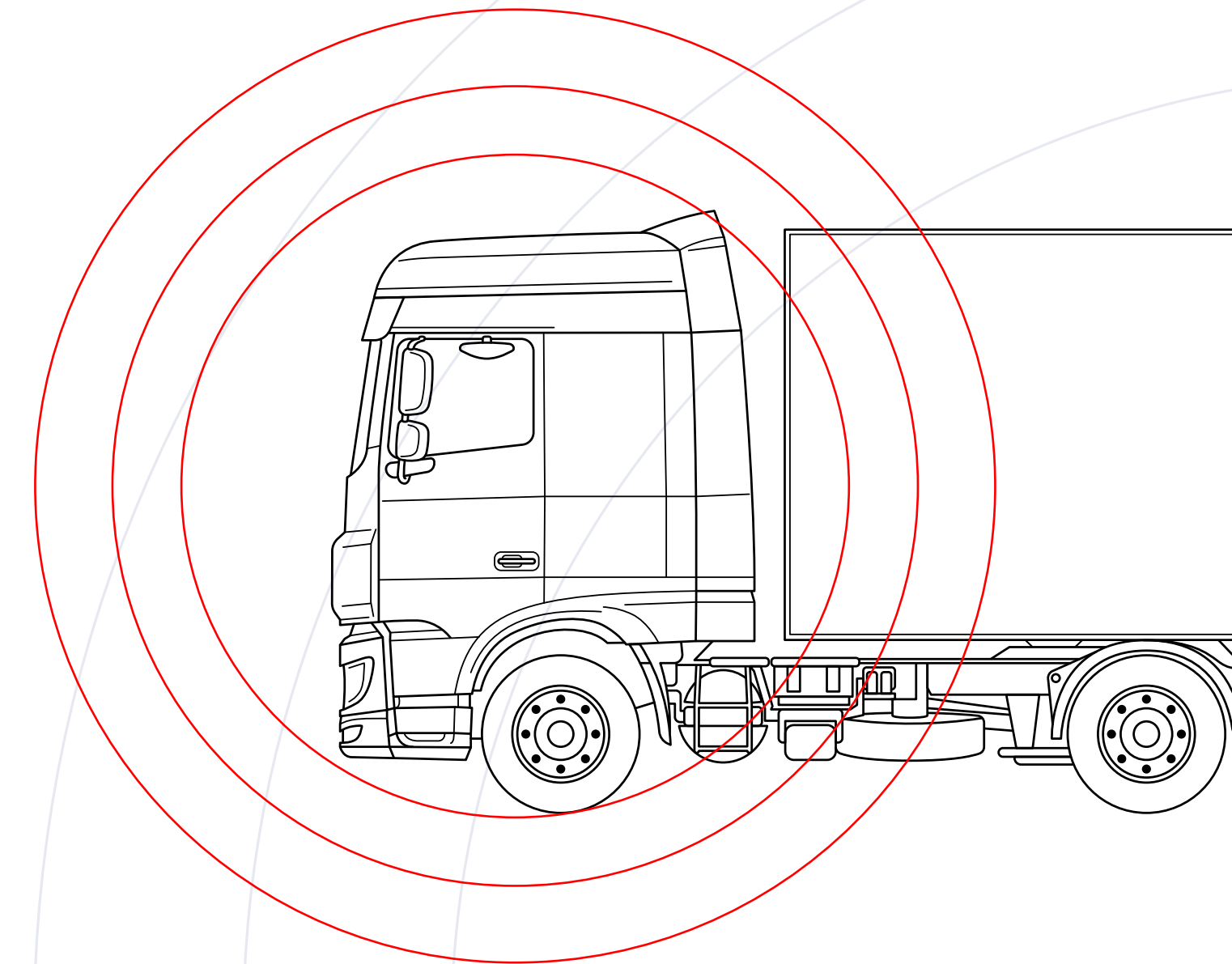
**Junctions (automatic gap widening)** – to anticipate the activation of this functionality, and the risk around junctions as well as being aware that drivers can override any system functionality manually as needed.

**Cooperative Collision Avoidance** – when this is likely to activate and how to respond correctly.

**Driver workload and hours** – platooning as deployed in HelmUK is a driver assistance system (it is not automation) and first-generation systems are likely to be similar to this. Our research shows these systems do not have a large impact on driver workload. This means that while there is no risk from platooning to drivers, it will not reduce their driver hours or enable longer driving.

**Driver communication** – as part of HelmUK, voice communication was used between the vehicles to coordinate platooning engagement. However, it is recommended that future platooning systems do not rely on voice communication to operate safely on-road. The Human Machine Interface (HMI) of the vehicles should support platoon formation and disbanding without the need for voice communication. Section 4.4.1 covers the HMI elements of a future platooning system in more depth.

**Future automation** - future systems could increase the level of automation and control steering as well as headway. This may reduce the workload for drivers or, in the longer term, fully automate the driving task.





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# Conclusions and recommendations



# 5 Conclusions and recommendation

## 5.1 Overall conclusions

HelmUK was the UK's first public-road trial of platooning technology and has provided valuable data and insights into the real-world operation of platooning. These insights enabled an assessment of the potential future of platooning and the effect it may have on various stakeholders, including Road Authorities, UK Government, and Freight Industry (Section 4). The final conclusions and recommendations from the HelmUK project are based on the key findings which are shown in Figure 5.1.

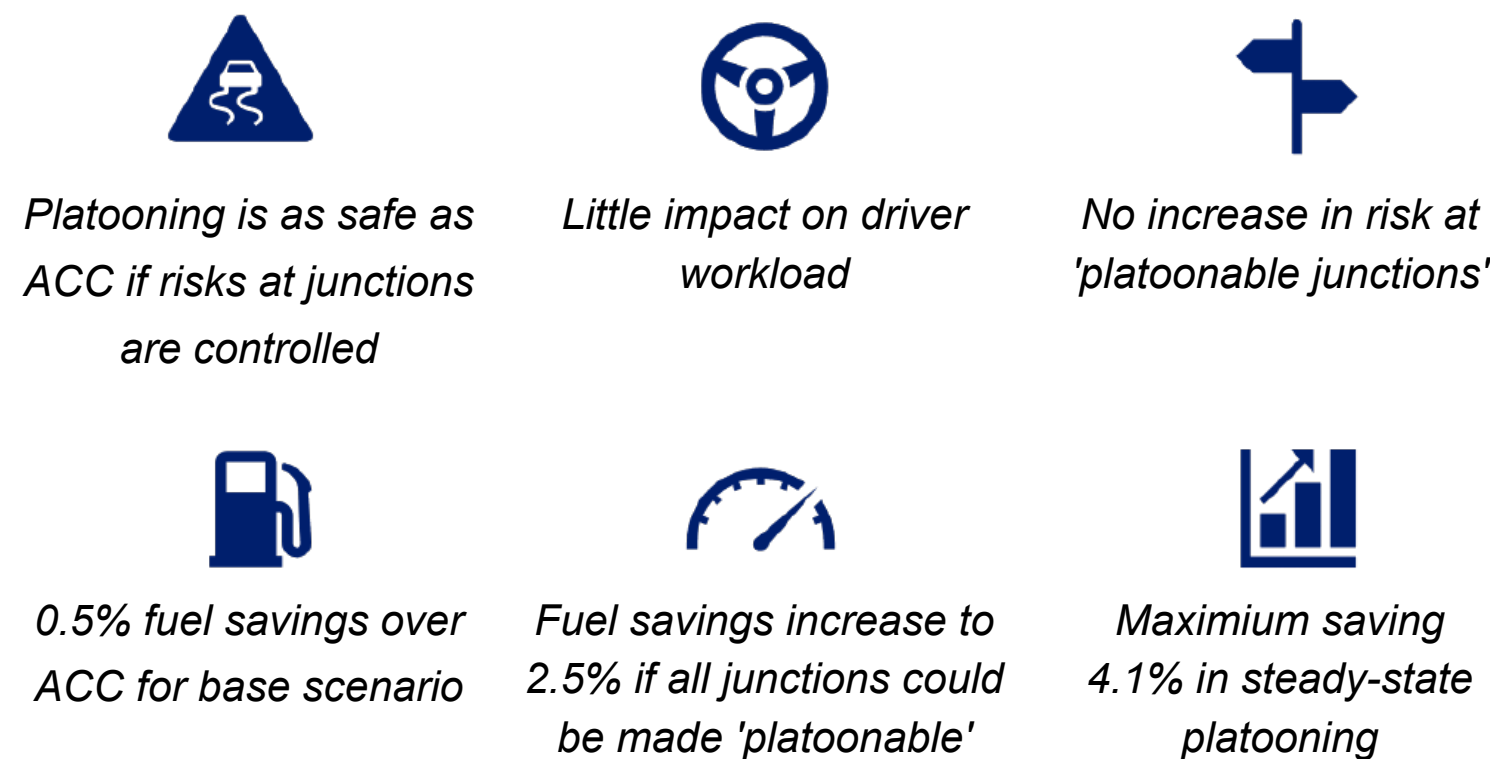


Figure 5.1: Key findings from HelmUK

Based on these findings, the short-term business case for platooning is limited. Figure 5.2 summarises the overall case for platooning based on HelmUK's research and includes a 'Red Amber Green' assessment of each element of platooning operation.

Green	Amber	Red
<b>Platooning technology</b> HelmUK system was functional and safe	<b>Road compatibility</b> Platooning was compatible with 10% of junctions	<b>Fuel efficiency</b> Negligible savings in real world
<b>Driver acceptance</b> No effects on driver workload	<b>Operational controls</b> Safe operation requires controls at junctions	<b>Industry uptake</b> Initial uptake limited

Figure 5.2: The overall case for platooning from HelmUK

The conclusions from this project are:

- Across a three-vehicle platoon, in real-world conditions, fuel savings were 0.5% over current technologies such as Adaptive Cruise Control (ACC); there was no evidence this difference was statistically significant.
- A key cause of low fuel savings is that only 10% of junctions along the trial route were assessed as safe for platooning as part of HelmUK's Safety Case.

- Platooning poses a potential risk at many motorway junctions because of the low headway between the vehicles.
- Changes to infrastructure, or even junction design, could increase the percentage of 'platoonable' junctions on motorways, but the business case for platooning doesn't support significant investment.
- Even if all junctions were safe for platooning, HelmUK has shown that 2.5% fuel savings could be realised.
- In perfect conditions this figure could rise to 4.1% across three vehicles.

The core challenge of platooning can be summarised as the need to balance road safety at junctions with realising fuel savings. The rest of this section is devoted to recommendations which could help achieve this balance.

Firstly, Section 5.2 looks at the potential of platooning technology as a driver assistance system. HelmUK has shown that several of the novel technologies deployed as part of the trial can provide benefits to road safety. Moreover, the main safety disbenefit to platooning is caused by traveling at low-time headways (below ~1.4 seconds). Therefore, deploying these systems at higher time-headways in line with ACC operation can provide benefits.

Section 5.3 then looks at three options to deploy a full platooning system in the UK and makes recommendations about how this should be approached.

Finally, Section 5.4 summarises recommendations for the future of platooning.



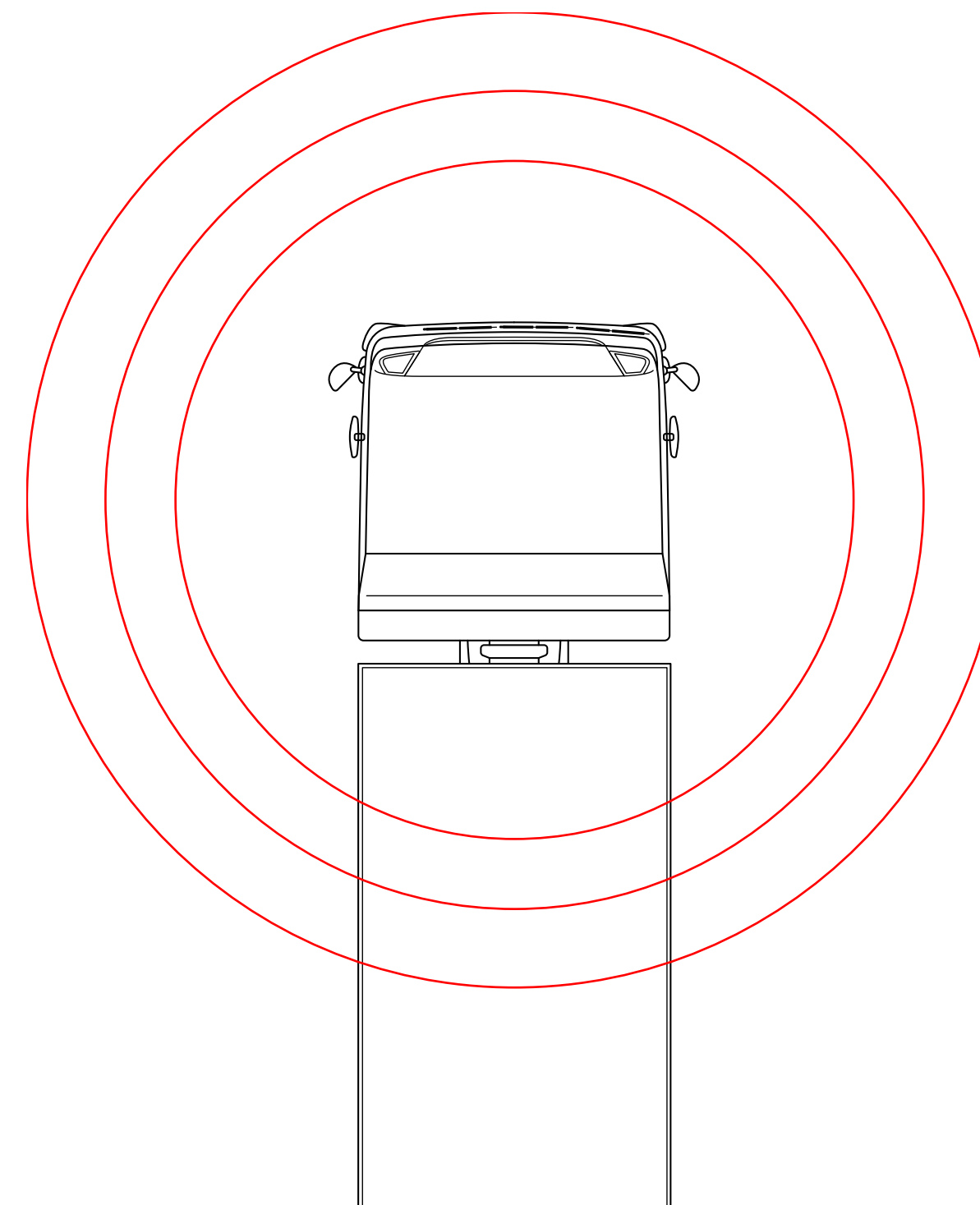
## → 5.2 The potential for platooning as a driver assistance system

HelmUK conducted real-world trials using a platooning system which incorporated several novel ADAS, along with existing technology, to achieve platooning operation. HelmUK was the first on-road trial of platooning in the UK and is also believed to be the first on-road trial of cooperative adaptive cruise control and cooperative collision avoidance. The trials have demonstrated not just the functionality and benefits of the overall platooning system, but also the discrete elements which make up the platooning system. These elements are:

- Cooperative Adaptive Cruise Control, which keeps the distance between the vehicles constant using short-range vehicle-to-vehicle (V2V) communication.
- Brake Performance Estimator, which adjusts the distance between the vehicles based on weight to ensure safety no matter the load or order of the trucks.
- Cooperative Collision Avoidance, which ensures coordinated automatic emergency braking.
- Lane Keeping Assistance, which supports the driver's steering to prevent vehicles from veering out of lane.

Together, these elements enable the vehicles to travel at time-headways lower than the lowest settings commonly offered with ACC today which are typically 1.4–1.6 seconds. The primary reason for this in platooning systems is to reduce fuel consumption for following vehicles. However, this is also the cause of the main potential risk from platooning technology.

This research has shown that the elements above provide benefits to road safety and this finding is valid regardless of the success of the broader platooning concept. Indeed, these benefits are enhanced if deployed at time-headways greater than 1.5 seconds in-line with current ADAS. This section explores how mature these technologies are and how they can be implemented on-road in the near future.



### Technology readiness

The prototype system successfully and safely deployed on real roads during HelmUK demonstrated that the technological building blocks for platooning exist:

- Vehicle-to-vehicle communication for coordinated acceleration and braking, including emergency braking.
- Radar detection of cars and larger vehicles cutting into the platoon.
- Axle load monitoring for automatic adjustment of headway to weight distribution across the platoon.
- Lane keeping assistance to support the driver's steering.

For commercial deployment, an ideal platooning system should also:

- Be interoperable with other manufacturers' systems.
- Automatically enforce use restrictions, such as maximum length of platoon or road type.
- Automatically increase the headway before junctions not suitable for platooning.
- Feature an HMI implementation that does not rely on voice communication between drivers.
- Be capable of reliably detecting motorcycles cutting-in.

Platooning systems are not yet commercially available from vehicle manufacturers and planned timescales for commercial deployment are not available publicly. A prerequisite to commercial deployment is the introduction of a multi-brand communication standard, which can be expected to happen within the next two years.

In the short term, technological maturity may limit the deployment of platooning. One of the largest technical hurdles is ensuring safety at low time-headways. This is a challenge which the HelmUK project is familiar with, having originally targeted a 0.5 second time-headway and having revised this to 0.8 seconds based on the variation in brake performance between vehicles in real-world conditions.

Another key technical challenge of a platooning system is V2V communication between different manufacturers. The HelmUK project has demonstrated that this functionality performs safely in a real-world environment using DAF vehicles. The European ENSEMBLE project also demonstrated this functionality along with inter-operability across multiple HGV manufacturers on real roads but at 1.5 seconds time-headway. This successfully demonstrated that V2V communication technology can enable multi-company platooning business models. Importantly, this also demonstrates that connected vehicle applications, such as cooperative braking and cooperative adaptive cruise control, are viable inter-vehicle driver assistance systems.

For coordination of the platoon, HelmUK maintained a voice communication link between the drivers, which, even with hands-free headsets, has the potential to distract drivers and might not be practicable due to language barriers. For wider commercial deployment, HMI designs without reliance on a voice link between vehicles would need to be developed.

The vision laid out by the ENSEMBLE project is of platooning first being deployed as a 'driver support' system at time-headways above ~1.5 seconds with negligible fuel savings. As the technology matures, this is anticipated to evolve into a full platooning system including HGVs traveling at time-headways lower than current ACC systems (i.e. below ~1.4 seconds) to save fuel.

Broadly speaking the results of HelmUK support this two-stage vision – the case for using elements of platooning technology at minimum time-headways comparable to ACC is strong and requires very little intervention or investment. By contrast there are several steps required to implement platooning and realise fuel savings without increasing risk (as discussed in 5.3).

### Regulation of close following

To avoid any risks from automated close following through junctions, DfT could consider regulating to ensure that low headway settings (below currently established ACC headways) are not made available in UK vehicles. This could be implemented, for instance, via a Construction and Use regulation. However, this would prevent use of platooning as a fuel saving technology, unless a specific exemption was made in the future.

### Recommendations

HelmUK has shown that platooning at low time-headways produces modest fuel savings in a real-world environment but poses a potential risk at junctions.

This strengthens the case for deploying elements of the platooning system as a driver assistance system without travelling at low time-headways. With this approach, road safety benefits are enhanced and the risk at junctions is removed. The only disbenefit is the loss of already small fuel savings over ACC.

However, HelmUK's fuel baselining results show that running HGVs in a convoy using ACC at typical time-headways of 1.6 seconds produced fuel savings of 2.9% over solo HGVs in idealised conditions. Fuel savings, over solo HGVs, are still achievable even when not traveling at low time-headways to other platooning vehicles.

Based on HelmUK's trials, if ADAS technology incorporating CACC, CCA and LKA were implemented without traveling at time-headways lower than current ACC minimums, these systems would increase road safety and would integrate safely with the current network. There is no indication that additional technical regulation would be required<sup>38</sup>.

<sup>38</sup> This is under the expectation that cyber security will be addressed in a wider context by application of UN Regulation No. 155. Interoperability of platooning systems across manufacturers is being worked towards by industry in the ENSEMBLE project.



## Overview

The main benefits and disbenefits to deploying the technologies proven through HelmUK as driver assistance systems without platooning at low time-headways are as follows:

### Main benefits:

- Quicker route to market for elements of platooning functionality.
- CACC provides enhanced longitudinal control of the vehicles which improves safety and (at high market penetration) could also improve traffic flow.
- Cooperative braking provides enhanced reaction times and prevents collisions within the platoon.
- LKA, which will likely be fitted as part of most platooning systems, provides a benefit even in non-platooning operation.
- Risks at junctions would not increase over the current baseline because following distances would be in the same range as current ACC systems.
- Little or no investment or action would be required from National Highways or DfT.
- Fuel baselining results indicate that operating an HGV convoy at higher time-headways comparable to ACC can still save fuel over solo truck operation (2.9% in perfect on-road conditions).

### Main disbenefits:

- Without platooning at closer time-headways, fuel savings over ACC will not be realised, which weakens the business case for the freight industry. However, based on the findings from HelmUK, the business case is limited and therefore the lost benefit is small in comparison to the potential disbenefit at junctions.
- The willingness of operators to pay extra for safety benefits and increased driver convenience from platooning as a driver assistance system is unknown.
- Drivers will need to have a clear understanding of what the system can and cannot achieve and that they continue to be responsible for.
  - In first generation systems, this is likely to be steering, manual braking or acceleration (as needed), monitoring the road environment, and responding to other road users or hazards etc.

### Recommendation

HelmUK has demonstrated in a real-world environment that cooperative braking and cooperative adaptive cruise control provide tangible benefits to road safety. If they are implemented independently of low time-headway operation (under ~1.4 seconds) they are unlikely to require regulation and may increase road safety over existing ADAS.

## → 5.3 Managing platooning deployment in the UK

Low headways are a key feature of the platooning concept; by travelling at shorter headways, fuel savings are possible due to a reduction in air resistance. The main potential risk associated with this identified through HelmUK is at junctions. This risk occurs when other road users are unable to merge with the main carriageway because of the presence of platooning vehicles and either overrun the slip road or must join a free-flowing carriageway at low speed.

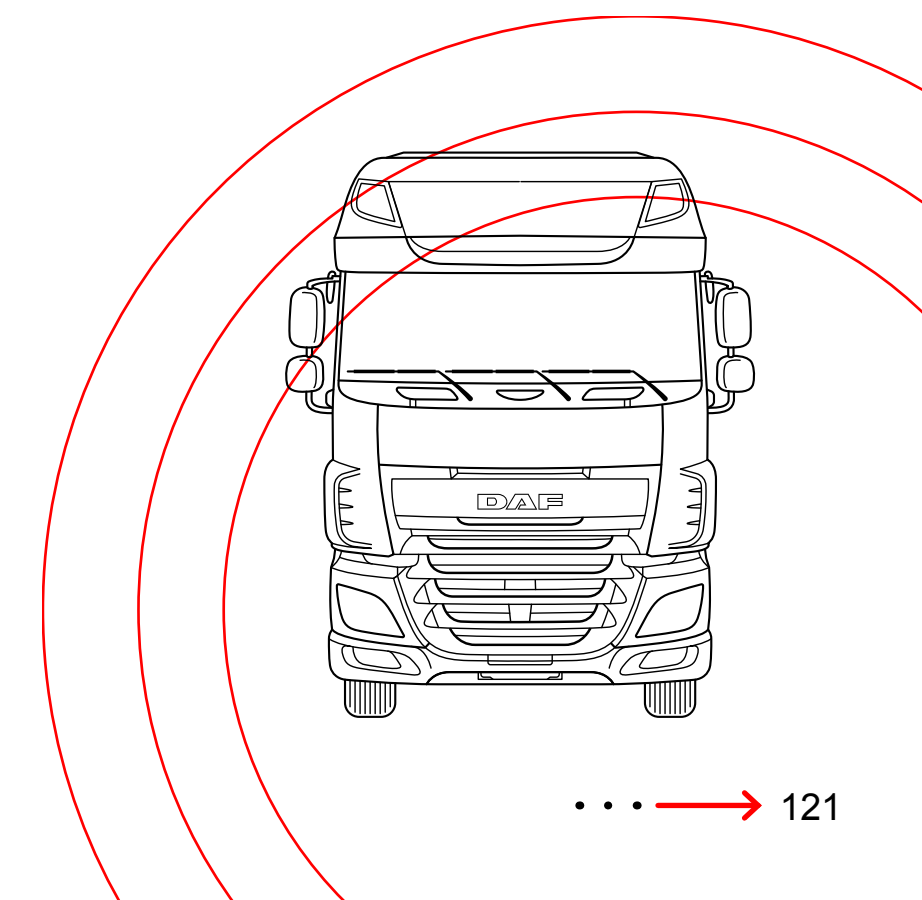
Considerable time and effort within the programme was required to mitigate this potential risk as part of the HelmUK Safety Case development. Junctions along the trial route were assessed and deemed to be 'platoonable' or 'non-platoonable' based on their type, the slip lane length, and other characteristics. During the road trials, vehicle data and video footage were analysed every day and used to inform a 'go' or 'no-go' safety decision for the next day's operation. A key part of this process was reviewing junction footage.

The trial results have shown that for those junctions which were 'platoonable', the presence of platooning vehicles did not increase risk. Moreover, with mitigations in place for the risk at junctions, HelmUK found that platooning was as safe as ACC operation despite platooning operating at half the headway of ACC. This validates the criteria HelmUK used for junction safety but the potential risks at 'non-platoonable' junctions as defined by the HelmUK Safety Case remain.

Only a small number of junctions (10%) were assessed as 'platoonable' on the trial route and the platoon had to disband at all other junctions. This had a significant impact on fuel savings as the platoon had to reform often which expends additional fuel.

Based on HelmUK's findings, the key to deploying platooning on-road successfully is to balance fuel savings and road safety. There are three possible approaches to deploying platooning in the short term:

1. Maintain the 'status quo' with current ADAS deployment, i.e. where platooning development is left to the market and risks are not controlled.
2. Control the risks related to platooning through regulation.
3. Take steps to maximise the benefit from platooning while controlling the risks by building on HelmUK's findings.





## Maintaining the status quo

Currently, few ADAS systems are regulated by the UK Government. Platooning could be treated in the same way as ACC and allowed to evolve in the market without intervention or encouragement. The broader transportation landscape is becoming more connected and more automated with every passing year and by the time platooning systems are commercially available, it may be only one among many similar technologies.

It is therefore important to consider what happens if platooning is neither regulated nor enabled by government and road authorities.

This approach has a number of benefits and disbenefits:

### Main benefits:

- Platooning development and uptake would be entirely industry-led; there would be no need for government investment.
- Market pressures are likely to maximise time spent platooning to save the most fuel, which could mean that fuel savings would be around 2.5%<sup>39</sup> but could, in certain situations like night-time operation, be higher (to a maximum ceiling of 4.1%).
- DfT would not need to regulate platooning systems and National Highways would not need to invest in enabling platooning 'up-front' (or at all) and could wait to see if the technology is successful before defining a business case for further investments.

### Main disbenefits:

- The key risk identified in the development of the Safety Case for HelmUK was conflict at merge junctions caused by close following (low time-headways) in platooning; this option cannot guarantee mitigation of that risk.
- The HelmUK trials found that platooning at 0.8 seconds time-headway was as safe as ACC driving at 1.6 seconds time-headway if the risk around junctions was controlled.
- In the 'status quo' case, this risk would not be controlled and would potentially expose other road users to dangerous situations.
- There would be little to no control over the risks from the technology; currently, the only mechanism to curtail close following at low time-headways would be through dangerous driving charges.
- Liability in case of collisions might be unclear, because platooning drivers are following much more closely than recommended in the Highway Code and follow-on collisions might be unavoidable if the lead driver causes a collision.

### Recommendation

This approach makes it the responsibility of freight operators or HGV manufacturers to control risks with platooning operation. This places an increased burden on drivers and operators to identify risks (such as at junctions) and to remember to take action to mitigate these. This approach cannot be enforced except through existing road traffic laws which is not a practicable route for enforcement. Based on HelmUK's Safety Case and subsequent results, this approach is not recommended. The risk at junctions with 'non-platoonable' characteristics remains a key concern for platooning technology.

## The role of the driver

As part of the Safety Case development for HelmUK, it was explored whether drivers could choose whether to platoon past each junction as they approached. However, for the vehicles to reach a safe following distance before arriving at a junction, the platoon would have to start disbanding early. For HelmUK it was not thought that drivers would be able to reliably detect potential conflicts in sufficient time to do this.

<sup>39</sup> All fuel figures quoted in this section are average fuel savings across three vehicles.

## Restriction of platooning operation to manage risk

To mitigate the potential risk at junctions from platooning vehicles, several steps could be taken.

Road use regulation could be introduced which only permits platooning on suitable road types. Similarly, regulation could be introduced to restrict platooning past junctions. Both of these responsibilities could either be pushed to vehicle manufacturers through type-approval legislation (i.e. require platooning systems to automatically adhere to the applicable restrictions, most likely by 'geofencing' based on location data) or be enforced by police forces like other road rules<sup>40</sup>. Experience gathered during the trials showed that manual disengagement before each junction could be difficult to adhere to even for well-trained drivers.

Such restrictions would actively manage safety and reduce the potential risk at junctions. HelmUK has shown that with similar restrictions in place platooning is as safe as ACC operation.

However, HelmUK has also shown that with low percentages of 'platoonable' junctions the fuel savings are around 0.5% for platooning operation (over ACC). This means that if junctions were restricted in this way there is a limited business case for platooning.

## Type-approval regulation

The experience gathered by HelmUK did not highlight a strict need to regulate platooning systems if manufacturers follow thorough internal safety procedures. Type-approval regulation could, however, establish a safe minimum performance threshold and ensure that functionalities such as increasing the headway before junctions and restricting the use to motorway-standard roads become automated and don't rely on driver adherence. See Section 4.4.1.

### Main benefits:

- Risks at junctions would be controlled and platooning would be at least as safe as ACC operation.
- This regulation would still allow platooning systems to operate as a driver assistance when not travelling at low time-headways and would not impact on the use of these systems outside of platooning operation (see Section 5.2).
- Minimal investment from public sector.

### Main disbenefits:

- Fuel benefits are likely to be around 0.5% which is too low to support a business case for platooning based on today's market conditions.
- Vehicle manufacturers might have to develop systems for automatic disengagement or headway increase at junctions and for detecting road types to enable platooning.

### Recommendation

Restriction of platooning operation past junctions would eliminate the main risk from platooning identified through the HelmUK project and ensure platooning was at least as safe as ACC operation at 1.6 second time-headway. However, the fuel results demonstrate that such restrictions are likely to eliminate fuel savings and undermine any business case for platooning.

Based on the HelmUK findings this option is recommended for consideration. This option would allow platooning's deployment as a driver support system as a minimum while preserving road safety. It would also keep the door open to operation on routes with lower junction density and to future platooning developments by manufacturers to provide fuel benefits despite this restriction.

<sup>40</sup> The practicality of enforcing this is expected to be low based on the difficulty visually distinguishing between low time-headways and the current lack of enforcement technology aimed at this issue.



### Enabling platooning operation to maximise benefits

This scenario looks at maximising the fuel and safety benefits available from a platooning system through both enabling and controlling platooning functionality.

As discussed above, HelmUK found that if most junctions require the platoon to disband or increase headway then the fuel savings from platooning operation are small at 0.5%. In an optimised network, where most or all junctions could be platooned through, these savings could rise to 2.5%.

There are interventions which could improve the number of junctions on the network which could be platooned through safely; these are covered in detail in Section 4.2. However, the business case for most of these is weak because they require significant investment or changes to the English SRN for a fuel saving of around 2.5% over ACC operation. Nevertheless, enabling safe platooning through junctions should be a use case considered in broader changes to the English SRN to support CAV development. This section focuses on a short-term option to enable platooning while controlling risks.

To increase fuel benefits while protecting road safety, a key action could be to develop a framework for managing junction safety. HelmUK saw no increase in risk at junctions which were identified to be safe for platooning through the Safety Case development process. This is the recommended starting point for managing safety at junctions, based on the HelmUK Safety Case methodology.

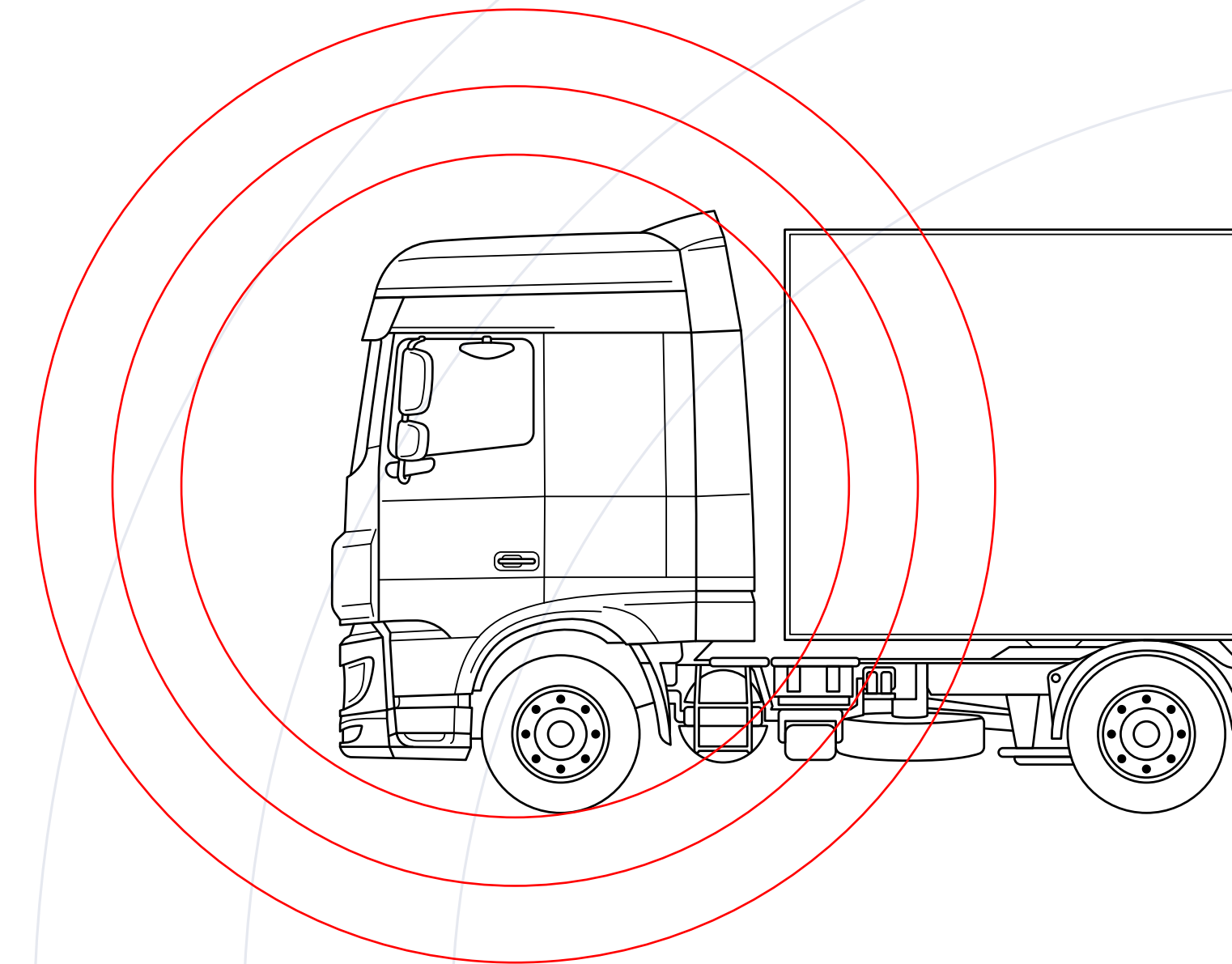
The aim of this framework would be to allow an increasing number of junctions to be platooned through based on an assessment of risk at those junctions. However, this would require National Highways, DfT, vehicle manufacturers, or fleet operators (or a collaboration of these stakeholders) to conduct this assessment and share the outcomes.

Another challenge is the difference in technological maturity or safety performance of various commercial platooning systems which may be developed by different manufacturers. HelmUK had the advantage of only needing to assess junction safety for one platooning system.

The key outcomes needed from this framework would be:

- Further quantify risk for junctions deemed 'non-platoonable' by HelmUK methodology.
- Relate junction risk to traffic flow.
- Create a database of 'platoonable' (or 'non-platoonable') junctions across English motorways (and possibly other roads built to motorways standards) using this information.
- Platooning system capabilities would need to be captured.

Building on HelmUK's junction assessment criteria could allow identification of use cases which would allow the majority of junctions to be platooned through safely, for instance at times of low typical vehicle flows, which reduces the risk at junctions. Night-time platooning is likely to provide the highest percentage of 'platoonable' junctions (and therefore maximise fuel benefit) without requiring any changes to the road infrastructure.



## Enabling platooning operation to maximise benefits

### Main benefits:

- An initial risk management framework for platooning at junctions could be based on the junction selection criteria in HelmUK's Safety Case. The trials have shown that there was no increased risk at junctions assessed as 'platoonable' using these criteria.
- It may be possible to make the case for a 'status quo' scenario or platooning at a wider range of junctions than were proven to be safe in HelmUK by refining the assessment to include traffic flows.
- Fuel savings of 2.5% could be achieved if the majority of junctions are 'platoonable' under certain conditions – a realistic example is likely to be night-time operation which could start to approach the maximum 4.1% fuel saving in perfect conditions.

### Main disbenefits:

- For a framework to be effective, platooning systems would have to have a standard set of safety features common to all systems covered by the framework.
- For this option to support platooning, one or more stakeholders would have to take on a role to create or administer a framework for assessing junction safety.
- The information from these assessments would be most beneficial if it was publicly available which requires further investment and maintenance.
- Freight operators can improve fuel benefits by operating at times of low flow which will limit the uptake to suitable industries and operators and therefore limit the overall benefit to the freight industry.

### Recommendation

For platooning operation to achieve modest fuel savings without increasing risk will require National Highways, DfT, vehicle manufacturers, or fleet operators to take responsibility for managing risk at junctions.

This could be in the form of a framework to support risk assessments of different junctions initially based on the HelmUK junction selection criteria. Such a framework may support the case for platooning at night, where more junctions can be platooned through (as the risk is lower due to lower traffic flows) allowing platooning operations to save more fuel.



## → 5.4 Summary of recommendations for platooning deployment

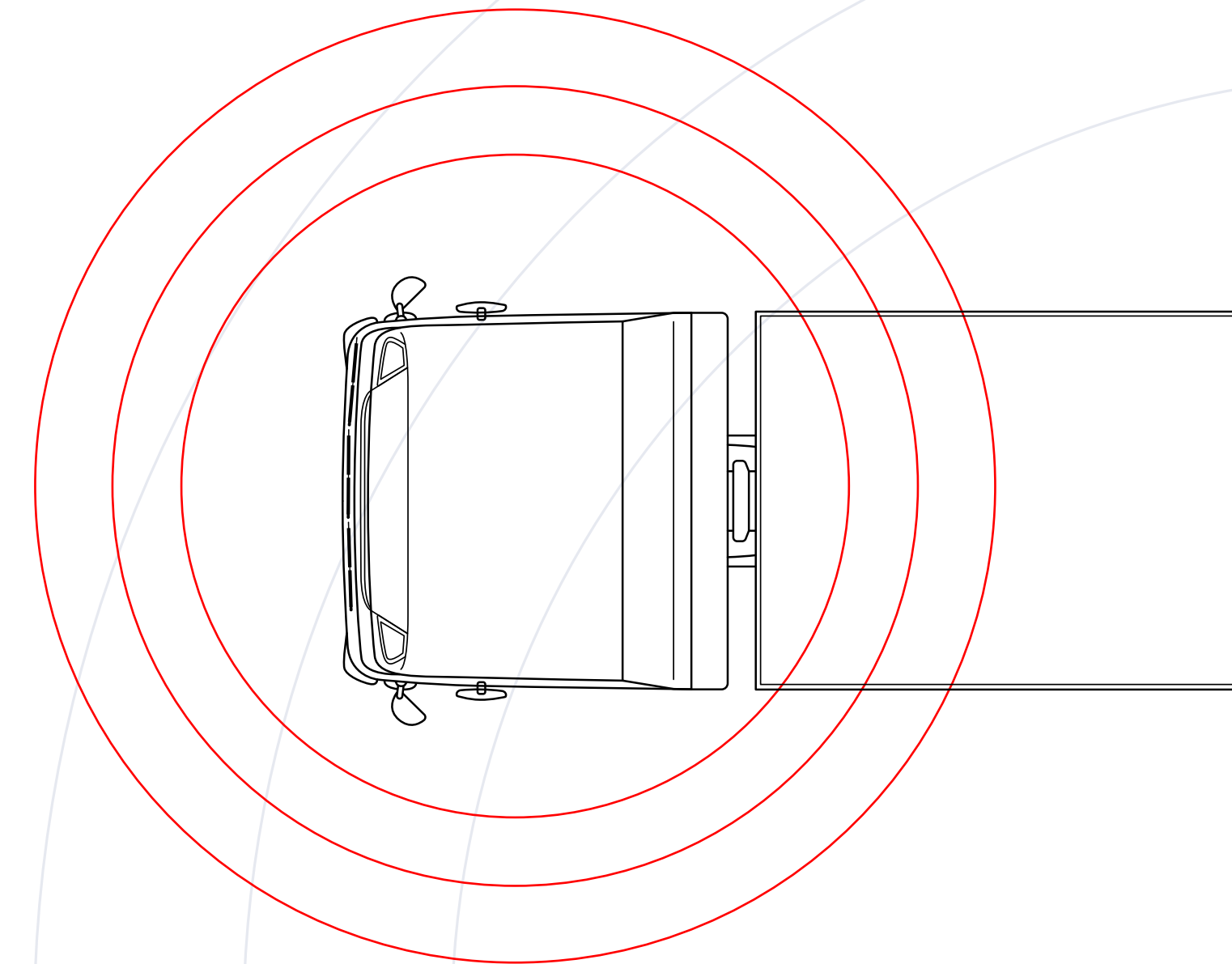
Based on the findings and project experience of HelmUK, the driver support systems which enable the overall platooning concept would provide safety benefits if they were deployed at headways above current ACC minimums (approximately 1.4 seconds). It is also likely that platooning at larger headways would still save fuel over solo truck operation. This approach will enable a limited form of platooning on the motorways without risks at junctions being uncontrolled. Furthermore, any such deployments would not be affected by regulation of the full platooning concept.

HelmUK has shown the main risks from platooning are related to low headways. For closer following distances, as used in HelmUK, consideration should be given to regulating platooning at junctions over an unregulated approach to platooning which aligns with the 'status quo' for driver assist systems. Regulation of platooning through junctions at close following distances will have a negative impact on the economic case for platooning but will mitigate the largest risk from platooning i.e. conflict with merging vehicles.

Currently the technological maturity of platooning and the low fuel savings from real-world operation mean that there is not a short-term case for making changes to the road network to support platooning.

The longer-term future of platooning would benefit from National Highways, DfT or the freight industry (or a collaboration of these stakeholders) creating a risk management framework which would allow platooning through some junctions on English motorways. Initially, this would be based on the HelmUK junction assessment criteria but could be expanded to cover use cases which are likely to present a low-cost way of reducing the risks of platooning while increasing the fuel savings, such as night-time operation.

Beyond this, platooning should be considered as a use case for wider adaptations of English motorways (and the wider SRN) to CAV, especially with regards to 'CAV friendly' junction designs.





# Appendix





## → Appendix A: Frequently asked questions about platooning

The following tables contain a copy of the FAQs about platooning developed for the HelmUK website<sup>41</sup>.

### Trial overview

Question	Answer
<b>What is HGV platooning?</b>	<p>Heavy Goods Vehicle (HGV) platooning is the use of technology to allow HGVs to travel safely in close proximity at speed, with the driver of the lead vehicle controlling the speed, acceleration and braking of the whole 'platoon'.</p> <p>Platooning is not driverless technology; all HGVs in a platoon have a driver who is responsible for steering as normal and is ready at all times to take over manual control or leave or dissolve the platoon if necessary. The platooning vehicles are connected using vehicle to vehicle communication and the following vehicles adapt their acceleration and braking to the movements of the lead vehicle.</p>
<b>Is HGV platooning the same as a single lorry pulling two or more trailers?</b>	<p>No. The concept consists of multiple truck drivers wirelessly connecting their HGVs for a certain period of their journey in order to be as efficient as possible. Trucks, or lorries in the platoon are able to disconnect from the platoon in order to reach their own specific delivery destination.</p>
<b>What was the UK's platooning road trials and what was the aim?</b>	<p>International research suggested that HGV platooning has the potential to deliver significant savings in fuel and efficiency, reduced emissions and road safety improvements. What was unknown was whether these benefits could be achieved in the real world on UK roads. HelmUK is the name of a research project which aimed to independently evaluate the potential benefits of HGV platooning in a real-world commercial environment on UK roads to help inform future decision making.</p> <p>Three lorries were specially adapted with platooning technology to enable them to travel in a platoon, with speed and braking of following lorries reacting to the actions of the lead lorry. The technology allowed the space between the lorries to be substantially decreased without increasing the risk.</p> <p>Extensive off-road testing was done to verify the safety and operational performance of the system before any on-road trials took place.</p> <p>A control group of HGVs carrying the same loads and following the same routes, but with the platooning technology turned off, was used to measure any differences.</p>
<b>Who was running the trials and who funded the trials?</b>	<p>HelmUK was run by a consortium of partners led by TRL on behalf of the Department for Transport and National Highways.</p> <p>Partners involved in the project included:</p> <p>Apollo Vehicle Safety, Connected Places Catapult, Costain, DAF Trucks, DHL, fka, Fusion Processing, Ricardo, TNO, TransportPR, Transport Research Laboratory, UTAC, VisionTrack, ZF.</p>

<sup>41</sup> HelmUK research project website [click here](#)

## Trial overview

Question	Answer
<b>Are these the first trials of their kind?</b>	No. HGV platooning technology has been extensively trialled across other parts of Europe and in the USA to demonstrate the technology. These UK trials, however, were the first to investigate on-road operation.
<b>What is the timescale for the trials?</b>	HelmUK began in September 2017. The technology development, extensive safety testing, and driver training were undertaken without the use of the road network. On-road trials and the associated driver training sessions were delayed by Covid-19 restrictions and took place from mid-2021 through to early 2022. The project aims to report its findings in early 2022.
<b>Where will the trials take place?</b>	Off road trials were undertaken virtually using TRL's high fidelity DigiCar and DigiTruck simulators as well as at Millbrook's Proving Ground. The on-road trial route was selected after in-depth consideration and risk assessment between the partners involved: TRL, Department for Transport and National Highways. The road trials took place on motorways M5 and M6. Road authorities and emergency services were informed in advance of the trials.
<b>How many lorries will there be in a platoon and what will the spacing be?</b>	The platoons in this trial consisted of up to three HGVs. The distance between lorries was tested during off-road trials. When platooning the lorries were travelling 0.8 seconds apart.
<b>Will the lorries be transporting real goods?</b>	During the early stages of the trials the lorries were run without a load. After thorough testing, the lorries ran with loads to represent commercial operations. A control group of journeys involving lorries carrying the same loads over the same routes without using the wireless platooning technology was used as a comparison to test effectiveness. This trial did not involve the transportation of hazardous goods.
<b>When will the results of the trial be published?</b>	TRL will publish its report to the Department for Transport and National Highways in Spring 2022. The publication of results will be confirmed by the Department for Transport and National Highways.



## Benefits

Question	Answer
<b>What are the benefits of HGV platooning to road hauliers and the public?</b>	<p>Platooning technology has the potential to deliver a wide range of benefits, not only to the logistics industry, but to provide safety benefits to all road users and the environment.</p> <ol style="list-style-type: none"><li>1) Road safety: instantaneous automatic braking between the lorries could improve road safety in the event of an unexpected deceleration.</li><li>2) Congestion: The reduced distance between lorries means that lorries take up less road space, potentially increasing traffic capacity and traffic flow. As platooning is limited to lane 1 of the motorway, there are expected to be fewer HGVs in the middle lane which is expected to help traffic flow.</li><li>3) Environmental: In previous trials significant savings in fuel efficiency have been identified, with corresponding reductions in emissions. This is due to the lorries travelling closer together and decreasing wind resistance.</li><li>4) Business efficiency: This has the potential to deliver significant cost savings to the logistics industry, which will ultimately be reflected in the price of goods transported by road. The hauliers in the Advisory Group are helping ensure that the benefits and constraints of using platoons for their businesses are correctly identified and assessed.</li><li>5) UK as an industry leader: this real-world trial shows the UK is supportive of applying advances in technology to support the logistics industry, the wider economy as well as improvements in road safety.</li></ol> <p>The information gathered by HelmUK will help to understand the scale of these potential benefits as well as any disbenefits to assist with future decision-making on platooning technology.</p>
<b>How much fuel could HGV platooning technology save and what is the impact on emissions?</b>	<p>When high-sided HGVs travel closely together, the airflow around the leading vehicle envelops the vehicles in its slipstream, so the following vehicles use less fuel to maintain the same speed. The vehicles following the lead vehicle benefit the most; however, the lead vehicle also experiences reduced aerodynamic force, therefore saving fuel. Various studies carried out in other countries have identified fuel savings between 4% and 30%; however, the UK trials determined if savings can be realised on UK roads when operating with loads and in traffic representative of commercial operation. Using less fuel directly reduces exhaust emissions including carbon dioxide and nitrogen oxide.</p>

## Safety

Question	Answer
<p><b>Is the technology safe, roadworthy and reliable?</b></p>	<p>Off-road safety testing of the trial lorries was on-going throughout trial and had to satisfy stringent standards set by the Department for Transport, National Highways and TRL before any on-road trials.</p> <p>The vehicles were compliant with all legal and safety requirements. The project ensured that trials complied with the Department of Transport's Code of Practice for the testing of automated vehicle technologies at all times.</p> <p>The lorries used in the trial were fitted with the latest safety equipment in addition to the wireless platooning technology. Each lorry had a driver in the cab who could take manual control of the lorry at any time.</p> <p>The drivers chosen for the trial were highly experienced and received comprehensive training in the new technology and safety procedures before the trial began. The project used simulation technology to determine driver training needs.</p>
<p><b>Can the wireless technology be hacked?</b></p>	<p>The wireless communications are secured, and the project had the support of the UK's cyber security experts. Regardless of technology fitted to the trial lorries, the drivers were always in control and operated the lorry normally when necessary. Cyber security is an important aspect that was considered by the consortium. Adequate protection measures were ensured before on-road trials commenced.</p>
<p><b>How can we rely on the drivers to pay attention if the driving is automated?</b></p>	<p>The lead driver controlled the acceleration and braking and drove in the normal way. Drivers of the following lorries retained steering control for their lorries. This together with the specialist driver training ensured that drivers maintained concentration and alertness and thus were ready to take full control if necessary.</p>
<p><b>What happens if the lead driver has an emergency, or the lead lorry breaks down?</b></p>	<p>In the event of any emergency, any of the platoon drivers could disengage and take full manual control of their lorries.</p>
<p><b>What speed can HGVs in a platoon travel at?</b></p>	<p>HGVs in the platoon had the same speed limit as other commercial vehicles and travelled at a maximum speed of 56mph.</p>
<p><b>What happens in roadworks?</b></p>	<p>HGVs passing through roadworks will not be engaged in platooning.</p>
<p><b>Is there the risk of more dangerous incidents taking place?</b></p>	<p>The platooning technology reduces human error from the driving task, meaning that it is likely there will be a reduction in overall safety risk.</p>



## Other road users

Question	Answer
<b>How will other drivers know what to do?</b>	All drivers should continue to comply with existing road traffic law and there was no expectation that drivers of other road vehicles need to do anything differently when driving in the presence of platoons. This is relevant to the trial and interactions with platooning technology in the future. This study carefully monitored the interaction between the platoon, HGVs and other road users to fully capture and understand all potential issues that could arise.
<b>How will we know if lorries are in a platoon?</b>	During off road testing it was decided that the lorries would not be marked to identify them as a 'platoon'. As they were not marked, they looked like normal lorries on the road and behaved in the same way, except for travelling closer together than usual.
<b>How can a car overtake a platoon of three lorries?</b>	Trials took place only on motorways where there was an overtaking lane for other road users to use in the usual way.
<b>Will the HGV platoon be able to use the overtaking lane?</b>	The trial explored the best procedures for situations such as overtaking.  In situations where overtaking could cause serious inconvenience to other road users, platoon drivers had the option to disengage from the platoon and proceed independently, reengaging further ahead.
<b>What happens if I get trapped and can't join or exit at my junction?</b>	All the trial lorries were driven by specially trained drivers who were aware of the potential problems and were able to take control and disengage from the platoon if it was causing a difficulty to other road users. The optimal way to deal with junctions and slip roads was tested during the trials. In most instances, HGVs did not engage in platooning when passing junctions, therefore vehicles were able to merge as normal.
<b>What happens at roundabouts?</b>	Lorries travelling in a platoon on the HelmUK trial did not use any roads with roundabouts, as they were trialled on motorways only.
<b>What happens if a motorist tries to squeeze into the gap between two lorries?</b>	If any driver in the platoon believed that safety in the platoon was compromised, they immediately disengaged from the platoon and moved to a safe distance.  The platooning system also had a built-in capability to detect intercepting cars and automatically react by increasing the following distance or disengaging the platoon. This was successfully tested throughout the trials.
<b>Who would be liable in the result of an accident?</b>	Every lorry had a driver present throughout the trials who had complete responsibility for the safe operation of the lorry. The driver was specially trained and legally responsible, just as they would be if the lorry did not have platooning technology.
<b>How do the platoons affect visibility of reading road signs?</b>	Provided that other road users are driving at a safe distance behind a platoon, they will be able to see roadside signs as normal. Overhead gantries will be visible to other road users, particularly with the use of other lanes that platoons will not use.

## Appendix B: Junction type classification

The images shown in this appendix are taken from Design Manual for Roads and Bridges, Volume 6, Section 2, Part 1 (TD22/06) published by National Highways. This information is licensed under the terms of the Open Government Licence v3.0 <https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/>.

### Type A – Taper merge

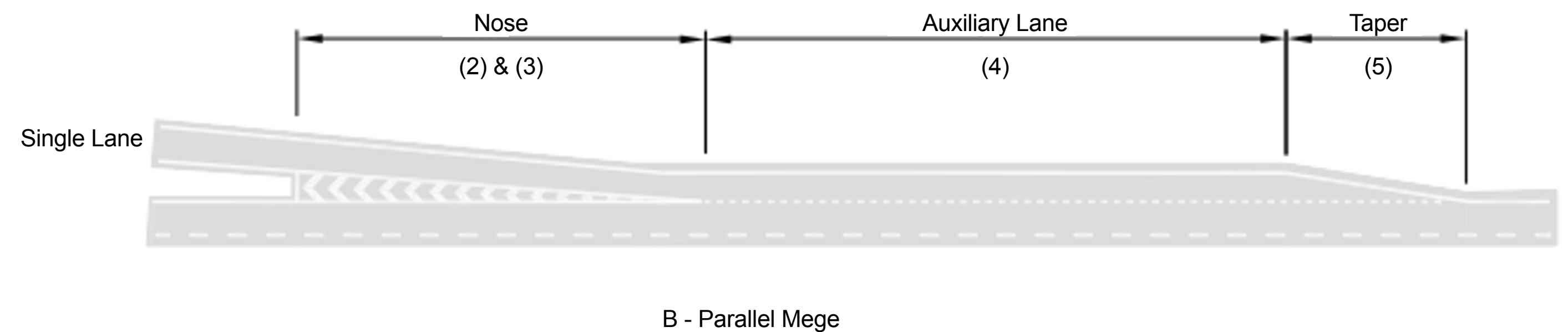
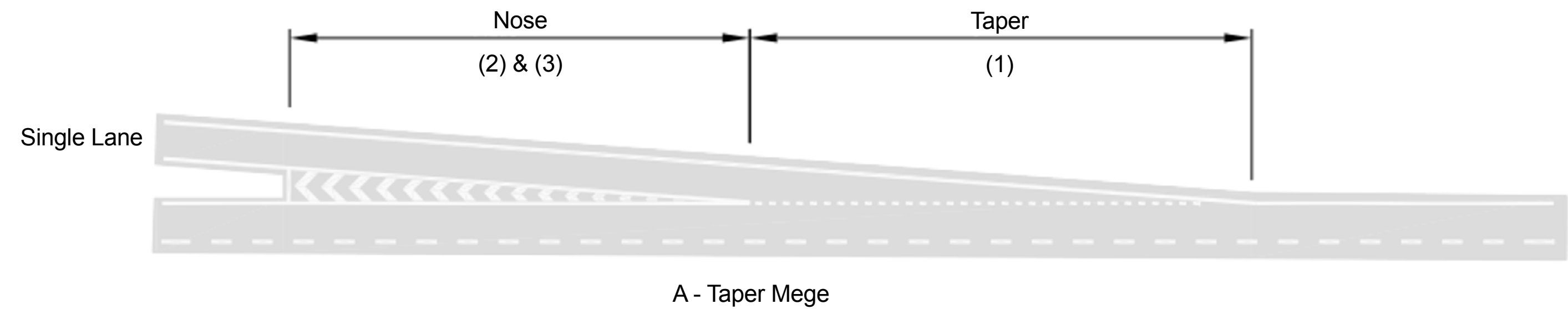
Single lane slip road merging with the mainline via use of a merging taper.

This is the simplest type of junction and is suitable for platooning provided that the calculation shows sufficient space for merging vehicles to adjust.

### Type B – Parallel merge

Single lane slip road merging with the mainline via use of a parallel merge auxiliary lane, meaning there is a longer distance over which vehicles can merge with the mainline compared to a standard taper but used where merging and mainline flows are higher.

The conflicts at these junctions are similar to those of Type A, but the auxiliary lane provides additional room to merge. Therefore, these junctions are expected to be suitable for platooning.

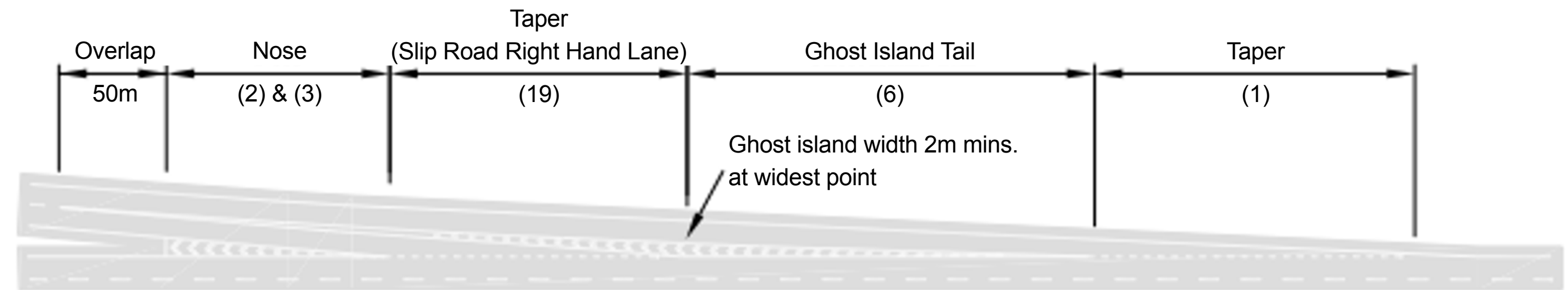




### Type C – Ghost island merge

Higher flow on the merging lane that requires use of two lanes and the use of two merging tapers. This type will only be used where mainline flows are relatively light with 3 or more mainline lanes.

These junctions are not suitable for platooning. The available room for drivers merging from the right lane is almost always too short and platoon drivers would need to be aware of two sets of interactions.

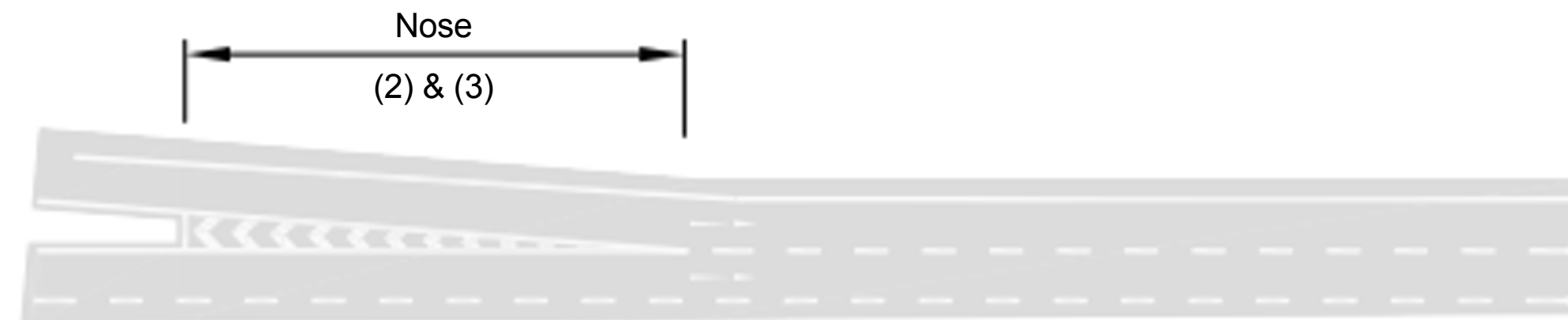


C - Ghost Island Merge  
(Only used where design flows on mainline are light, there are 3 lanes or more on mainline and merging flow is over one lane capacity, see paragraph 2.30).

### Type E – Lane gain

Simple single lane gain that would require platooning vehicles to change lane.

Platoon drivers will be trained to disengage before any non-emergency lane change. As there is no conflict point (where merging drivers are required to fit into the mainline flow) platooning does not normally need to be disengaged in advance.

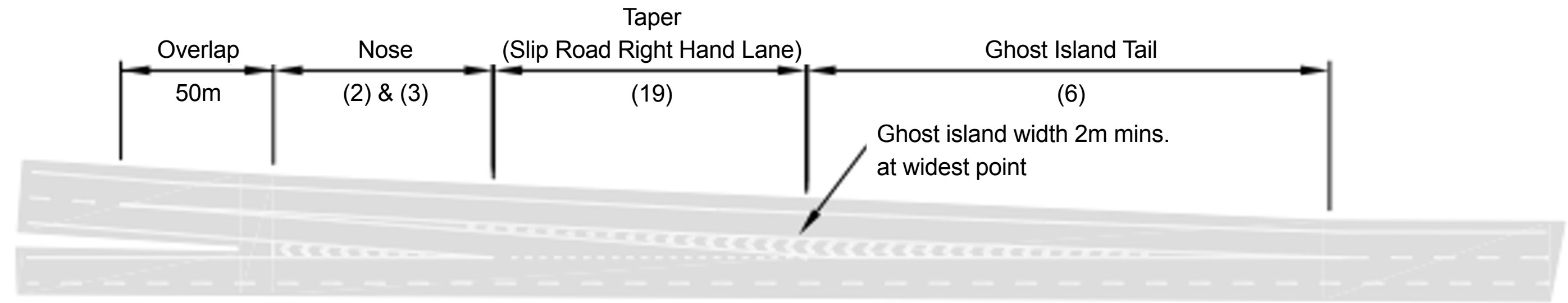


E - Lane Gain

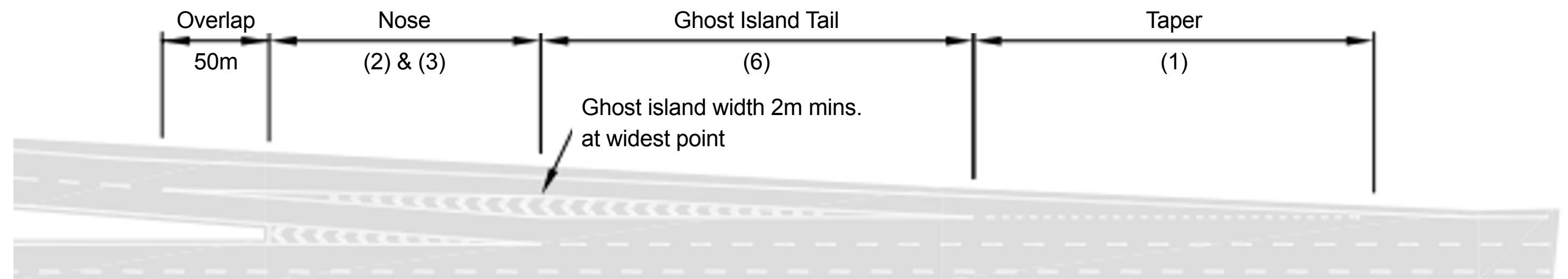
### Type F – Lane gain with ghost island merge

Mixture of Type A and Type E with a merging taper followed by a lane gain scenario that would require platooning vehicles to change lane.

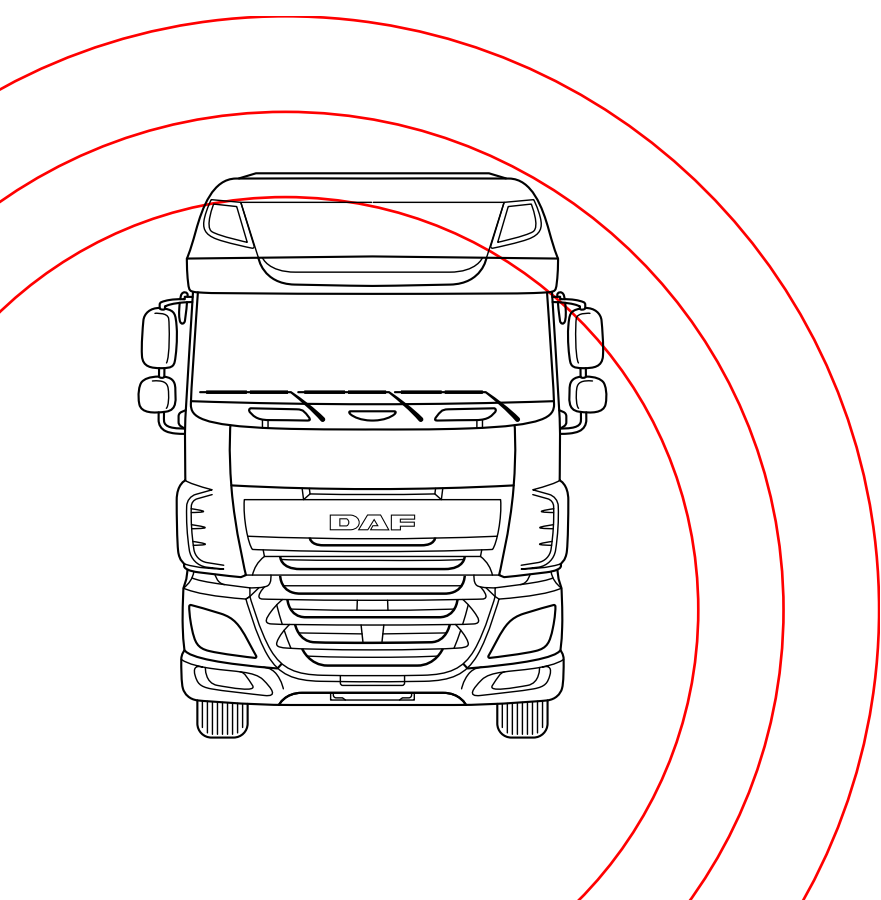
These junctions are not suitable for platooning. The available room for drivers merging from the right lane is almost always too short and platoon drivers would need to be aware of two sets of interactions.



F - Lane Gain with Ghost Island Merge (OPTION 1 - PREFERRED)



F - Lane Gain with Ghost Island Merge (OPTION 2 - ALTERNATIVE - See Paragraph 2.30)





### Type G – 2 Lane gain with ghost island

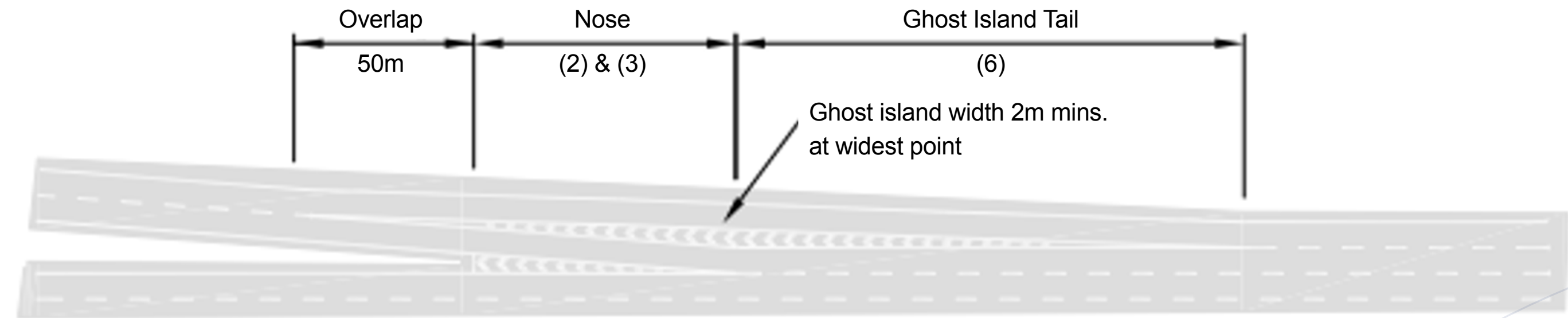
2 lane gain scenario that would require platooning vehicles to change lanes twice.

These junctions are not suitable for platooning. The available room for drivers merging from the right lane is almost always too short and platoon drivers would need to be aware of two sets of interactions.

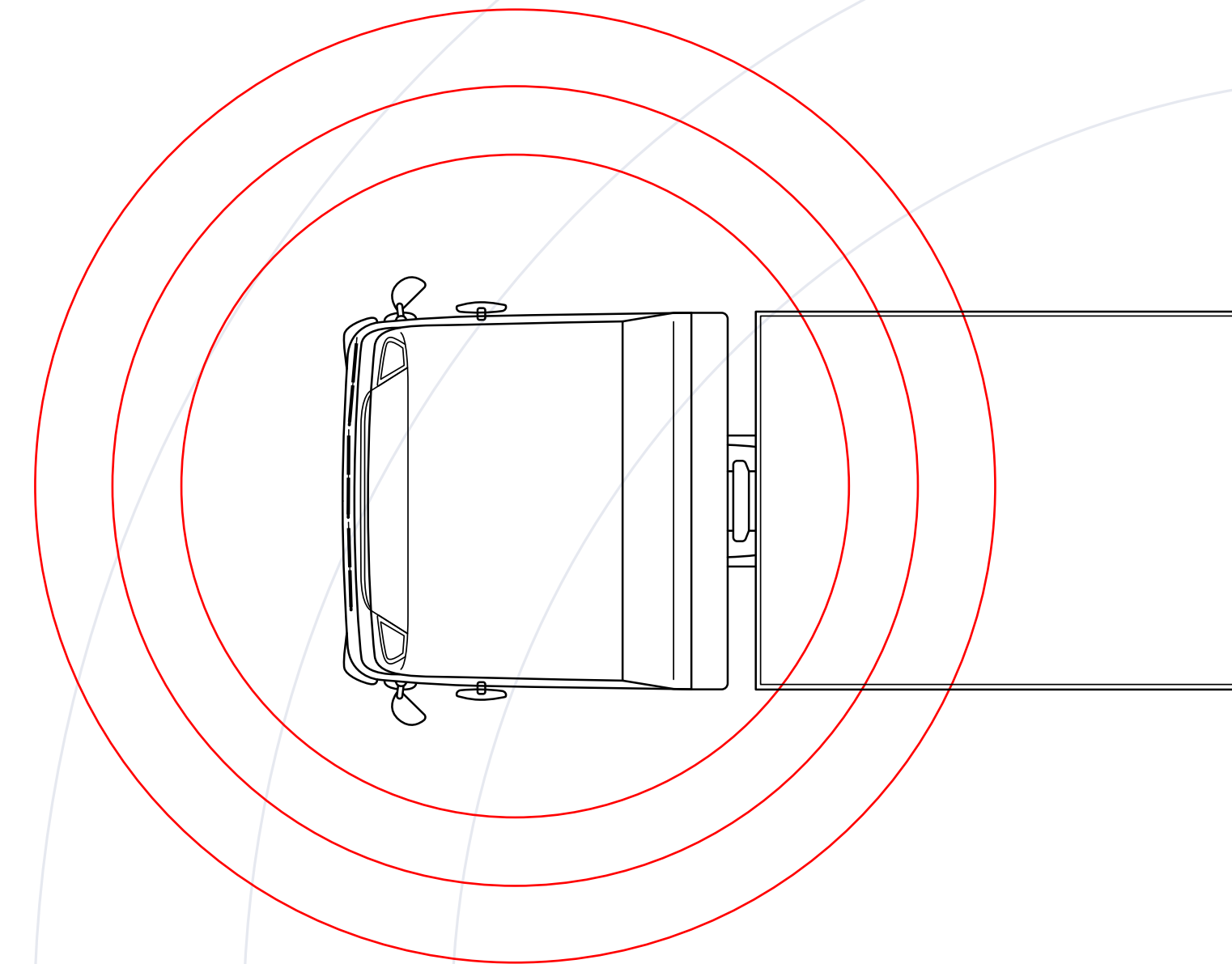
### Type H-1, H-2: Two lane merge upstream or within nose

These are an older type of junction that are no longer installed on the network by likely to still be present. For these layouts the slip lane merges / terminates as a two-lane marked slip on approach to the taper.

There is the possibility of conflict between merging vehicles, as the two lanes merge close to the taper. These junctions are considered generally suitable for platooning, though consideration should be given to typical flows at the time of the trial.



G - 2 Lane Gain with Ghost Island



## Appendix C: Previous research on close following

This appendix contains a figure and a table from previous TRL research on close following for National Highways (then the Highways Agency) conducted in 2010 on the M1 motorway in England. This figure and table are reproduced here with the permission of National Highways.

Figure 2.8: Percentage of gaps (between vehicles) of less than 1 and 2 seconds by vehicle type

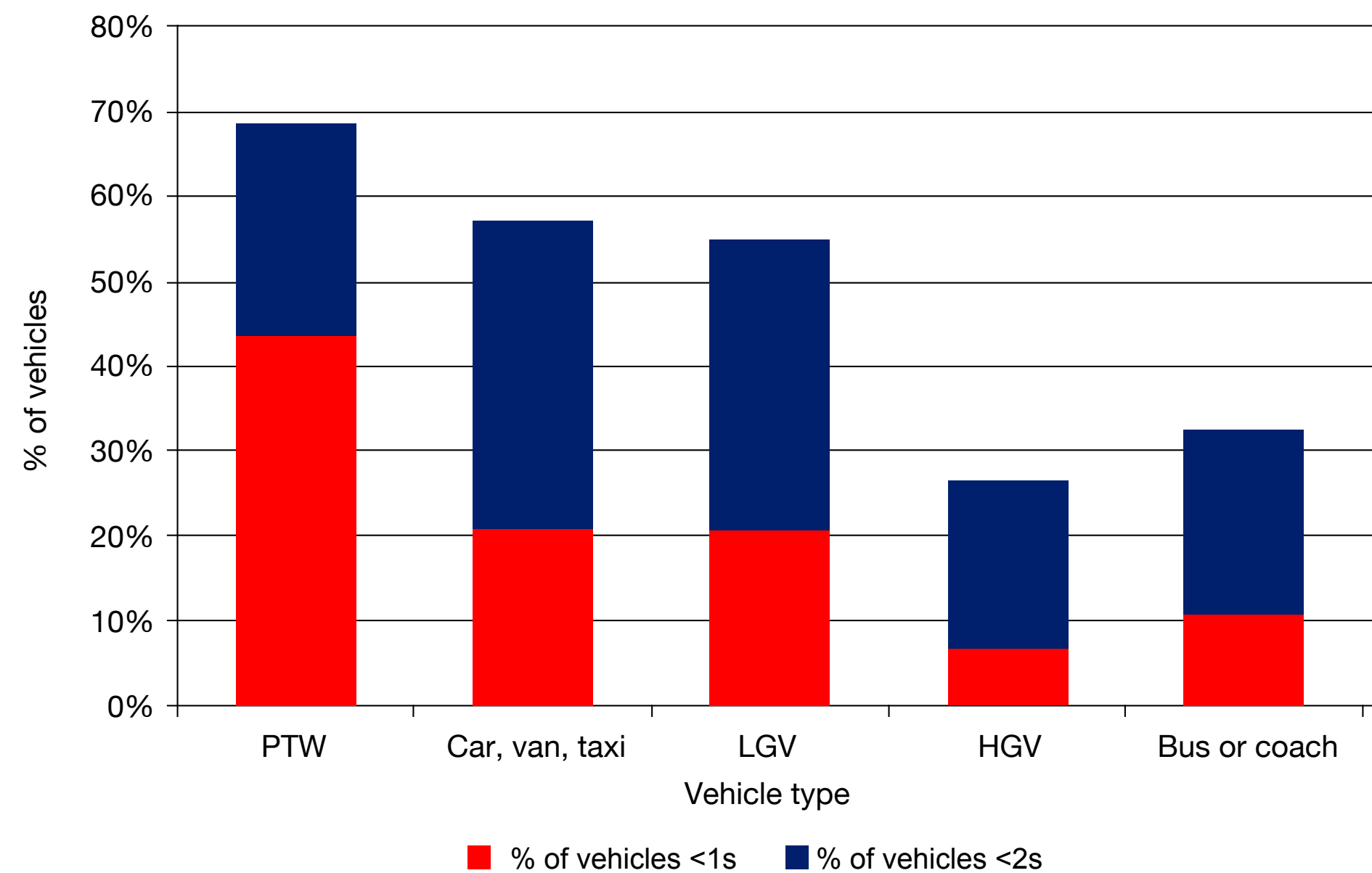


Table A 6: Mean time gap (s) by vehicle type

Vehicle type	Number of vehicles	Mean time gap (s)	% of vehicles <1s	% of vehicles <2s
PTW	121	2.6	43.80%	68.60%
Car, light van, taxi	141,028	4.2	20.90%	57.00%
LGV	34,829	4.2	20.50%	55.10%
Car or LGV with trailer	526	3.5	12.50%	38.40%
HGV	53,095	6.1	6.80%	26.60%
Bus or coach	2,558	6.9	10.80%	32.50%
Unclassified	4	3.7	0.00%	25.00%
<b>Total</b>	<b>232,161</b>	<b>4.7</b>	<b>17.50%</b>	<b>49.50%</b>



# HelmUK final report

## → Abstract

HelmUK was the UK's first real-world trial of HGV platooning which ran between 2017 and 2022. The concept of platooning is to use advanced driver assistance systems to enable HGVs to safely travel close together to save fuel via a slipstreaming effect. This concept has never been tested in a real-world environment in the UK.

HelmUK ran for 5 years and through exhaustive analysis of real-world trials found that platooning saved small amounts of fuel over Adaptive Cruise Control (ACC) in the real-world. Further analysis found that in a road network optimised for platooning, fuel savings could increase to between 2.5% and 4.1%. HelmUK also found that platooning was as safe as ACC operation, if risks with merging vehicles at junctions are managed.

This report describes the purpose, approach, design, and results of the HelmUK trials covering road safety, fuel savings, effects on the road network, and economic benefits.

The HelmUK final report also discusses the future of platooning for National Highways, the UK government, and the freight industry. Finally, the report makes a series of recommendations for platooning development and deployment. These include consideration of regulation of low headways at junctions and a strong recommendation to deploy the underlying systems enabling platooning at more typical larger headways where they offer safety benefits with no increase in risk.

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