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Review of Technology for Undertaking Mobile Phone and Seatbelt Surveys on the SRN

Phase 1

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Executive summary

The Department for Transport (DfT) currently monitors various road user behaviours, such as seatbelt and mobile phone use, by means of roadside observations. The aim of these surveys is to gather behavioural metrics to use as safety performance indicators, as part of a proactive approach to managing road safety. However, these surveys are costly, geographically restricted and may not be representative of behaviours across the network as a whole. For example, the current methodology is not well-suited to gathering data on higher speed roads, such as many of those managed by Highways England.

Highways England and the DfT therefore commissioned TRL to investigate:

- technologies which can help produce robust metrics of behaviours, such as seatbelt and mobile phone use by vehicle occupants, that do not suffer from the limitations of the current approach;
- the possible timelines associated with implementing revised methodologies which incorporate these technologies.

Information to support this research has been sourced from published commercial documents, academic literature, expert knowledge (both within TRL and externally) and contact with relevant businesses.

The most promising approach identified is based on the use of roadside cameras. These could be used to produce statistics based on the vehicles passing a number of sites on the road network. As they could be left in place, they offer the possibility of monitoring trends over time. Near infra-red cameras (as used in ANPR systems) are likely to be the most suitable technology, as the light used is invisible to human eyes and windscreen reflections can easily be removed. Some development will be required to capture clear images of the inside of the vehicle: we propose that this is investigated further in Phase 2 of this research.

Once clear images have been captured of the inside of the vehicle, they must be processed and classified. Various levels of automation have been proposed. The most advanced systems use deep-learning algorithms, which are ‘trained’ to classify images based on a large set of example images (where the seatbelt or phone wearing status must already be known). While systems such as this have the potential to achieve high levels of automation (and hence low on-going costs) the investment required to generate a training set of images may be considerable. A semi-automated system, where coders manually review still images, could be considered and would have considerably lower technical risk and initial cost.

Companies in Spain and Australia have been identified which may have developed relevant technology, though it is unclear at this stage as to the specific capabilities of these systems. Phase 2 should investigate further the cost and effectiveness of various levels of automation (and the precise details of the technology).

Two other types of approach were identified: the use of data from existing in-vehicle sensors, and the monitoring of mobile phone radio emissions. These were found to be less promising options for producing behavioural metrics as there are barriers to the collection of telematics data which will be difficult, if not impossible to overcome.

The majority of cars are equipped with seatbelt sensors, which are used to produce a warning to drivers if the vehicle is used without seatbelts fastened. However, the data from these are not stored or transmitted outside the vehicle. Even if it were, there would be major legal and political barriers to overcome before these data could be shared with the DfT or Highways England.

It is feasible to determine whether a mobile phone is being used in a vehicle based on its signal. Two possible approaches were identified: use of a roadside phone detector or analysis of mobile network meta-data (which gives information on the time and place of calls). Both share the same fundamental flaw: they do not distinguish between phone use by drivers and passengers. It may be possible to use these technologies to supplement another system, but they cannot replace it. Phase 2 will investigate further whether a useful metric could be produced by fusing the data from multiple sources, which will include a review of the potential of meta-data.

1 Introduction

This project focuses on high-risk driver behaviours which are prohibited by law such as travelling in a vehicle without a seatbelt and driving while using a mobile phone.

1.1 Background

The Department for Transport has carried out surveys of mobile phone and seatbelt use on UK roads since 2002. These consist of manual observations, made by people working at the side of the road, in areas with low speed or stationary traffic. As part of the 2017 survey project, TRL was asked to evaluate a methodology for surveying the Strategic Road Network (SRN) on behalf of Highways England. This consisted of cameras mounted on a moving vehicle, observing the drivers of overtaking vehicles. The technique was only partially successful and it was considered that there were too many limitations for a wider roll out to be desirable. A report evaluating this methodology has been produced (Myers, et al., 2017).

The sections below summarise the relevant legislation and the variables currently observed for both seatbelts and mobile phones.

1.1.1 Seatbelts

The Road Traffic Act 1988 (sections 14 and 15) requires drivers and passengers in motor vehicles to wear a seatbelt. Certain exemptions apply, including:

- Delivery drivers making very short journeys between drop-off points
- Drivers performing a reversing manoeuvre
- Holders of a medical certificate
- Drivers of licenced taxi drivers who are carrying a passenger or plying for hire
- Drivers of vehicles too old to be fitted with seatbelts

Existing surveys look at whether the driver and passengers are wearing a seatbelt, and the type of vehicle they are driving. This does not precisely correspond to legal compliance in all situations, as it is not possible to assess (for example) whether a driver holds a valid medial certificate. However, it is probably reasonable to assume that legal compliance is closely correlated with the results of these surveys.

1.1.2 Mobile phones

Use of 'hand-held mobile telephones' while driving is prohibited by the Road Vehicles (Construction and Use) (Amendment) (No. 4) Regulations 2003. As with seatbelt use, this legislation does not prohibit every behaviour which could be considered dangerous: in particular, it allows the use of phones which are not hand-held (e.g. mounted in a holder) even though the use of hands-free phones has been shown to present risks only slightly lower than the use of hand-held phones (McEvoy, et al., 2005). The existing surveys record instances of drivers using a phone held to their head; therefore, as well as not capturing hands-free calling, they do not capture all illegal behaviours relating to the use of mobile phones (e.g. texting).

1.2 Purpose of this task

Following the delivery of the feasibility study report, it was agreed that a more thorough investigation of potential methodologies for producing metrics of seatbelt and mobile phone use on the SRN should be carried out. The aim of this technology review is to identify promising technology for providing such measures, with a particular focus on identifying non-compliant behaviours. . It focuses on technologies that might be deployed for measures on the SRN, and identifies some of the potential issues around deployment. It does not cover the issues around study design e.g. approach to sampling. While finding a methodology which can be used on the SRN remains a key objective, it is likely that any technique identified would also be practical on local roads, although the approach to deployment may differ.

This review focuses on technology which is at least partially automated. The existing methodology used on DfT surveys is a manual process involving roadside observers. While this method is considered to provide a high level of accuracy, the labour intensive nature has cost implications and constrains the data which can be collected. A more automated approach has the potential to allow surveys to be carried out more frequently and on a larger sample of vehicles, with cost savings accruing over time (following an initial investment required for development and capital costs). An automated approach also reduces the exposure of workers to risks associated with roadside working.

Figure 1 shows the steps required to develop and implement a new methodology to produce metrics of dangerous/illegal behaviours. This report covers Phase 1, which was designed to identify credible technologies. These were identified through a combination of expert input, literature research and contact with relevant companies/organisations (discussed in more detail in Section 2). In Phase 2, a technology (or technologies) will be evaluated in more detail to contribute towards a business case for further development. This will involve more detailed analysis of the technology and the work which would need to be done to implement it.

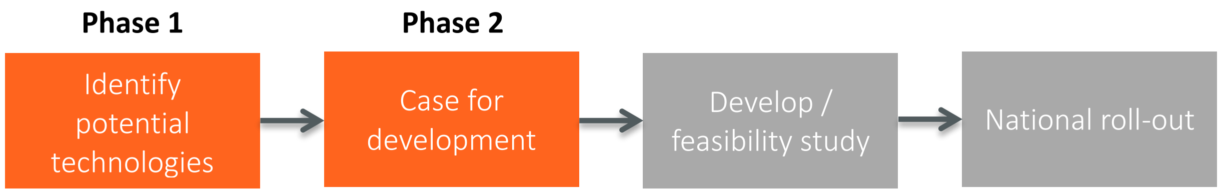

Figure 1: Steps to developing a new survey methodology. The first two steps, in orange, form part of this project

2 Methodology

2.1 Overview

The aim of Phase 1 was to identify credible technologies which could be used to deliver a metric of seatbelt and mobile phone use in the future, both on the SRN and on local roads. There are three main parts to this phase:

- A technology status review, incorporating a search of published and unpublished literature and a web based search. The aim was to ensure that we had a comprehensive understanding of existing research and to identify technologies or systems which are commercially available.
- Consultation with internal TRL experts from a variety of technical backgrounds.
- Consultation with experts from other organisations (both potential suppliers and other research organisations) to gather their views on the capability of current and future technology.

These exercises ran in parallel, with results from each informing the direction of others as they progressed. An agreed set of evaluation criteria was used throughout to inform the assessment of the technologies considered in a consistent way. The assessments were made drawing on empirical evidence (where available), expert knowledge opinion and the expert judgement of the authors.

2.2 Technology status review

Systematic searches of the TRID (Transport Research International Documentation) and Science Direct databases were carried out. Search terms are given in Appendix A.

In some cases the number of results produced by these terms was excessive. In these cases, researchers made a judgement to refine the terms (as shown in A.2), consider the most recent results only, or consider the results ranked as most relevant by the search engine.

Searches were also made of:

- Unpublished TRL reports since 2008
- Published TRL reports since 2004
- Google Scholar
- Journals known to researchers (e.g. *Sensors:*)
- General web search

A rapid search of the TRIMIS (Transport Research and Innovation Monitoring and Information System) database was also carried out. The majority of the projects listed by TRIMIS were not relevant to the monitoring of seatbelt and mobile phone use, and no fundamentally new methodologies were identified.

2.3 Expert consultation

Contact was made with relevant experts both within TRL and externally. These individuals were identified through three routes:

- Previous contacts of researchers involved in the project
- Organisations identified from the technology status review and web search
- Contacts suggested by others involved in the review

The content and style of discussion varied depending on the individual's specific area of expertise. Individuals to be contacted and areas to discuss were informed by the technology status review.

2.4 High level evaluation criteria

Each technology identified was evaluated against high level criteria agreed with the client at the inception meeting. These criteria are based on the ability of the technology to be used to produce a robust metric. The most important aspects to be considered fall under the categories of quality, cost, and availability and practicality:

- Quality relates to the ability to produce a large, repeatable sample of data suitable for statistical analysis.
- Cost addresses up-front development costs, costs associated with rolling out the technology (e.g. in manufacturing and installation), and the amount of human input which is needed to run a survey.
- Availability and practicality considers non-financial barriers to deployment, including the amount of development required and technical risk.

The tables below show the questions to be considered in each category and outline the level of detail included in Phase 1 (this report) and in Phase 2 (if the technology is selected for further analysis).

Results of the Phase 1 evaluation are shown in the Technology Factsheets.

Table 1: Quality evaluation criteria

Aspects	In Phase 1	In Phase 2
Applicability Does the technology capture seatbelt use, mobile phone use and other dangerous/illegal behaviours? **Accuracy** Are the observations consistently made correctly? **Reliability** Is the equipment vulnerable to failure, or does it only work under certain conditions? **Replicability** Can we expect similar results if the survey is repeated under the same conditions? **Representativeness** Does the technology capture relevant information for all relevant road users, and are there any biases in the road users for which the information is captured? For example, does the technology capture data from all types of vehicles or are drivers travelling above the speed limit likely to be over-represented in the sample? **Scalability** Does the technology lend itself to simultaneous uses at multiple locations?	Based on their understanding of the proposed technique, subject matter experts make an informed judgement on how well it is likely to perform against the evaluation criteria. For example, whether the technique is likely to be able to monitor a representative sample of drivers.	Investigate whether the technique (or similar technique) has been used previously, and assess the results of any trials. Assess whether the technology could provide added value in the future, and what the potential benefits could be.

Table 2: Cost evaluation criteria

Aspects	In Phase 1	In Phase 2
Development cost Are there likely to be substantial costs in developing the technology in such a way as to be able to use it for this purpose? **Unit capital cost** What sort of cost would be associated with each unit and how many might be required? **On-going data collection cost** Including maintenance costs, data processing requirements and any human input required for data entry and analysis.	Information on capital cost is provided where it is readily available. Any features of the technique known to lead to an especially high cost (e.g. labour intensive processes, requirement for specialist staff) are highlighted.	Quantify (if possible) cost in comparison to existing techniques. This could include obtaining quotes from suppliers or estimating the amount of staff time required once the system is operational. Consider the amount of time required for any pre or post-processing of a given quantity of results.

Table 3: Availability and practicality criteria

Aspects	In Phase 1	In Phase 2
Level of development For example whether the system uses off-the-shelf components or requires customised development **Barriers to deployment** Including technical, legal and practical (e.g. means and security of installation, data transmission requirements) **Ethics and acceptability** For example, will the methodology be seen as too intrusive? **Stakeholder engagement requirements** Does the development of this technology for this purpose require the buy-in of multiple other stakeholders? **Safety of researchers and the public** Does the installation and/or operation of the technology require operators to be exposed to additional risk? Could the technology cause drivers (or other road users) to be distracted in some way? **Data protection issues** Does the means of operation result in the collection of personal data? What level of consent might be required?	The product factsheet states whether the product is currently in the market or under development/at prototype stage. Any immediately apparent barriers to deployment are highlighted.	Assess the level of development required before the system can be used, and technical risk involved. Discuss short- and medium-term barriers to deployment. These could be technical, legal (e.g. privacy), or protection of technology by intellectual property owners.

3 Results

This section summarises the information learnt from the technology status review and expert consultation. Four areas discussed in this exercise were selected for evaluation in factsheet format (Sections 4 to 7). The factsheets summarise the feasibility of these technologies, while this section looks in more detail at the opinions of stakeholders and active areas of academic research.

3.1 Expert consultation

3.1.1 List of consultees

The following experts with relevant knowledge were consulted during this phase of the project:

- Dr David Hynd (Safety expert, TRL) on gathering seatbelt usage data
- Dr Jolyon Carroll (Vehicle expert, TRL) on harvesting of vehicle data using telematics
- Mike Maskell (Automotive and telecoms expert, TRL) on use of cellular networks to gather vehicle-based data
- Alan West (Freight and fleet expert, TRL)
- Chrys Stevenson (Defence technology expert, TRL) on relevant defence technologies
- Transport Systems Catapult, (TSC) on relevant experience at TSC
- Thames Valley Police on current police practice and use of ANPR cameras
- Experts at five different organisations with relevant expertise in gathering data from vehicle sensors, processing of data from Cellular operators, video analytics using deep learning, video analysis for seatbelt detection and existing techniques and technologies for seatbelt and mobile phone detection
- Members of the International Traffic Safety Data and Analysis Group (IRTAD), contacted by the DfT

In addition, two of the authors of this report have relevant expertise. Peter Vermaat has extensive experience in video image processing and Saket Mohan has an in-depth knowledge of communications and vehicle technology: the findings here reflect their experience. Other experts such as DSTL (formerly the Home Office Scientific Development Branch) have been contacted, but either have not yet responded, or were unavailable in the timescale. These experts could be consulted during Phase 2 of the project.

3.1.2 Seatbelt usage

Key Findings
• Many vehicles have seatbelt sensors installed, but their use is unlikely to be viable due to limited fitment, privacy concerns, and technical barriers to receiving and collating the data • Roadside cameras exist which are capable of producing clear images of a driver • Video analytics systems capable of detecting seatbelt use do not yet exist, but there have been recent

developments in technology which may make them feasible

- Mid and far infra-red (thermal) cameras are likely to perform worse than normal cameras and are very expensive

There is a wide consensus that in-vehicle sensors are available which are able to detect whether seatbelts are worn. At present, a high level of coverage is only available for the driver's seat of the newest vehicles, which are required by law to have seatbelt warnings. However, many manufacturers voluntarily fit sensors to other seats and the European Union is currently considering widening this regulation to include all seats in the vehicle. These regulations, assuming they are mandated, will be only for newly introduced models, and then some years (typically 3-5) after the regulation is announced, so it will be some years before the majority of the vehicle fleet is likely to be equipped with seatbelt sensors on all seats.

Even if appropriate sensors are installed, detecting usage in the vehicle still requires that information to be transmitted to a monitoring system. The legality of gathering these data for the purpose of monitoring non-compliance levels requires further investigation given the requirements of the EU General Data Protection Regulation (GDPR) which is currently coming into force.

There are also no consistent standards governing the gathering of these data from vehicles. Some motor manufacturers may already store these data for short periods of time (well under a minute) in an event data recorder, but they are unlikely to be transmitted outside the vehicle. In the future, it is expected that increasing amounts of data will be transmitted through built-in telematics capabilities and stored by motor manufacturers. These data are, however, regarded by the motor manufacturers as valuable and proprietary: the experts consulted believe that they would be extremely reluctant to release them. This view is not shared by the European Union, who have expressed the view that all data generated in a vehicle are the property of the vehicle owner/driver (suggesting that their permission may be required to collect them). In either case, a representative sample of data will not be easily accessible to third parties unless this was to be mandated by regulation, which is unlikely.

The combination of a lack of on-board sensors for some years, privacy considerations, a lack of standardisation, and questions of data ownership mean that, for the time being, using on-board sensors to capture data for a metric on seatbelt wearing is unlikely to be feasible.

The only other technology considered feasible for measuring seatbelt wearing on the SRN is the use of roadside cameras, potentially supported by video analytics technology (which is described in more detail below). It is likely that this approach would be able to capture images of only front seat drivers and passengers.

Experts indicated that equipment capable of capturing images of moving vehicles is already available and used for enforcement purposes in some areas, though not on high speed roads. Previous work for the DfT has shown that using standard CCTV cameras for this purpose presents challenges due to poor image quality, particularly at night. Artificial visible lighting cannot be used as this will point directly at the driver. Using near infra-red cameras (i.e. cameras sensitive to light just outside the visible range, typically at about 900nm wavelength) allows the use of off-the-shelf cameras with artificial lighting which is not visible and hence does not dazzle drivers. The image quality from these cameras makes detection of seatbelt usage feasible, though only for front seat passengers, including on high speed roads.

To allow larger scale surveys to take place economically, it would be desirable to partially or completely automate the analysis of images/video. The set of digital analysis techniques which can be used for this are known as video analytics, and have been investigated as part of this project. Experts consulted in this project have indicated that previous attempts to use video analytics techniques for the purpose of monitoring seatbelt wearing have shown that it is difficult and unreliable. However, several also suggested that recent advances in image classification using deep-learning techniques have made detection of seatbelt usage from images far more feasible. Further consultation will be required to examine to what extent this can now be achieved and how this compares with what is achieved via traditional means.

A further possible solution is to use thermal cameras which work in the mid and far infra-red spectrum. These cameras are sensitive to infra-red heat radiated by warm bodies, so are able to detect live bodies. In principle a seatbelt worn across the body may shield a small amount for heat, and hence could be detected as a “dark” line in an image of a driver/passenger. However, the heat-shielding effect of seatbelts is marginal at best, so the detection will be very difficult, particularly if the driver is wearing thick clothing. Thermal cameras are also extremely expensive in comparison to near infra-red or visible light cameras; for example, a camera with a resolution of 464*388 pixels costs some £10,000[1]. This solution is therefore not considered feasible at this stage.

Thermal cameras work in the deep infra-red spectrum. There are also sensors which work in the millimetre-wave spectrum (i.e. hundreds of gigahertz), between thermal infra-red and radar. These are used to detect hidden weapons and are deployed in places such as airports. This is military-grade equipment, and consequently is very expensive. It is possible that it could be commercialised, though this would require volume orders to significantly reduce prices.

3.1.3 Mobile phone usage

Key Findings

- No in-vehicle sensors suitable for the detection of mobile phone usage were found in this review
- Roadside sensors for detecting phone use are more viable, but will not indicate whether the phone use is by a driver or a passenger. A system which supplements a mobile phone detector with a camera has been proposed by a manufacturer.
- Data from mobile networks can identify the volume of mobile phone use on a particular road, but it is not immediately obvious how this could inform a robust metric due to confounding factors.

No in-vehicle sensors suitable for the detection of mobile phone usage were identified in this review. There is an increasing trend for smartphones to connect into the vehicle’s

[1] FLIR E95 Thermal Camera (https://www.pass-thermal.co.uk/flir-e95-thermal-camera)

infotainment system, allowing the phone to be controlled from the dashboard display/touchscreen; the vehicle would therefore be aware when a call is being made. As with seatbelt sensors, sourcing these data from the vehicle would be challenging given the same privacy and data ownership etc. reasons. In addition, if drivers were to know that their phone usage via the infotainment system was being monitored through the vehicle, they may be tempted to use a hand-held phone instead, with associated risks.

Detection of mobile phone usage using external sensors is somewhat more viable. Local (roadside) radio wave analysers can in principle detect that a phone is being used, and if it is being used for speech, data or SMS (text message) by analysing the radio wave patterns. Similar equipment has been extensively used in war zones, particularly in insurgency wars where combatants often use mobile phones instead of secure military radios. This allows phone usage to be detected without needing to access the actual call data (voice, data or messaging). By using directional antennas pointing at roads, the use of phones in vehicle can therefore be detected. However, this does not in any way indicate if the phone is being used by the driver or a passenger in the vehicle or in what way (e.g. hand-held or not). One expert consulted suggested that one UK safety camera manufacturer is exploring the possibility of a mobile phone enforcement system, though was not able to share further details with us given a confidentiality agreement they have in place.

Another possibility discussed was making use of existing mobile phone records held by the Mobile Network Operators (MNOs). An expert stated that this call meta-data (i.e. data about the call, without the call contents) can be post-processed and used to identify whether the call was made from a road vehicle, pedestrian, train etc. As above, this does not provide information of whether the in-vehicle callers were drivers or passengers, or whether the phones detected were hand-held or not.

It is possible, however, to envisage a scenario where the above technique could be used to estimate the effectiveness of a campaign targeting driver mobile phone usage. If before and after surveys were carried out, a reduction in the number of calls from moving vehicles could be partially attributable to a reduction in driver mobile phone usage due to the campaign, based on the assumption that the campaign does not result in a reduction in passenger mobile phone usage. However, there are many other reasons why phone usage could vary over time and it is unlikely that this would provide a robust measure of campaign effectiveness, particularly given the changes in usage are likely to be small.

As with seatbelt usage detection, the most promising detection technique is likely to be camera detection supported by automated video analysis. One expert has had some success in detecting drivers holding their hands near to their ear, but was not able to reliably detect a mobile phone being held.

As with seatbelt detection, a major issue is coping with widely varying lighting conditions, windscreen glare etc. These issues make it unlikely that much success is possible using standard CCTV cameras as the image source; however, near infra-red cameras with suitable lighting are far more likely to be feasible as an image source.

Fleet operators may use in-cab CCTV to monitor driver behaviour. We did not find any evidence of automated or systematic monitoring systems being used: experts indicated that operators generally use the cameras for incident investigation.

3.2 Technology status review

Key Findings

The purpose of the review was to identify any technologies which had been used in the past for detection of seatbelt and mobile phone use, or where a system is in development. The key findings were:

- Camera systems which produce suitable images of the occupants of moving vehicles are highly practical. Some commercially available systems may exist, but the extent of their capability is hard to establish.
- Video analytics is an area of active research. The task of identifying seatbelt or mobile phone use has been attempted with some success in research projects.
- There are substantial practical barriers to using in-vehicle sensors to monitor seatbelt or phone use directly. However, it may be more feasible to produce a generalised 'distracted driving' metric based on 'black box' data.
- Mobile phone detection could supplement a camera system but not replace it, since it has no way of distinguishing between use by drivers and passengers.

In total, 55 relevant documents were identified by the review. The systems proposed fell into seven categories:

- Roadside camera systems
- Video analytics technologies
- Use of data from in vehicle systems
- Mobile phone detectors
- Installation of additional sensors in vehicles
- Systems which could gather data on additional dangerous driving metrics
- Others

3.2.1 Roadside camera systems

Six sources were identified which related to roadside camera systems: two websites of potential equipment providers, three reports and a news article discussing the use of seatbelt enforcement technology in Finland. No academic research which specifically related to cameras to detect mobile phone or seatbelt use was identified: this was not unexpected given the highly specialised nature of the technology and the subsequent commercial interests in this area. However, the principles are well understood, and development of a camera system will consist of an adaptation of existing technology.

Reflections from windscreens can cause poor image quality, which was a particular problem for the technique applied in the earlier feasibility test using cameras mounted on moving vehicles (Lot 3 of this project). The only known method to overcome this is to prevent (reflected) natural light reaching the camera sensor, which can be achieved using a principle applied in ANPR cameras. These use an infra-red light source combined with a filter in front of the camera which only allows light from this source to pass.

The concept of taking interior photos using infra-red light has been proven (Lawton & Hutchins, 2010). Some further development of the system would be necessary before it could be used on road, such as incorporating a mechanism to trigger the camera as a vehicle passes and ensuring the system can work in daylight: the system developed worked in darkness, but there was too much ambient infra-red light for the same technique to work in daylight. It is likely that the system could be modified to work in all lighting conditions using the ANPR-style technology described above.

Figure 2: reproduced from earlier TRL report: Image taken by stills camera in controlled conditions

One other report (Parliamentary Advisory Council for Transport Safety, 2005) contained a brief mention of an automated camera-based system under development in the Netherlands, which was to detect seatbelt use. We were not able to find any other references to this system.

TRL reviewed the content of two identified camera manufacturers' websites. Tradesegur (Tradesegur SA, n.d.) manufactures cameras currently used for enforcement purposes in Spain. Images are collected by 225 cameras and processed using software which selects those likely to contain evidence of seatbelt and mobile phone violations. They are used for enforcement purposes and are semi-automated: the images are first automatically processed then manually reviewed.

One Task (oneTASK, n.d.), has produced a system in Australia which appears to have similar capabilities.

We approached both organisations with further questions about the capability of their technology. However, we were not able to make contact with One Task before the finalisation of this report and Tradesegur were could not comment due to a confidentiality agreement. Areas where we would like more information include:

- The sensitivity (whether all violations are detected) and specificity (whether false violations are recorded) of the automated seatbelt detection system. Requirements for a survey may be more stringent than for law enforcement, since a achieving a representative sample is more important.

- Whether the system works in all lighting and weather conditions
- Whether the system can be used on high speed roads

In the later stages of the preparation of this report, an additional system was identified in Finland, which was described as being in development in 2010. This system is referred to by a European report on enforcement policy (Kallberg, et al., 2008) and in an industry news article (ITS International, 2010). TRL will investigate this system further in Phase 2.

3.2.2 Video analytics technologies

Five academic papers were identified relating to video analytics systems to detect seatbelt and mobile phone use, as well as the two potential technology providers mentioned above in Section 3.2.1. This demonstrates that it is – or at least has been – an area of active academic research. The technology is relatively immature: four of the papers propose potential algorithms for processing roadside images but none of these have been used in large scale trials. Chen, et al. (2018) and Xu & Loce (2015) propose the use of machine learning approaches: this is consistent with the feedback in the expert consultation, which suggested that this was a promising field where much progress is being made. A machine learning approach was also used in Seshadri, et al. (2015), though this used cameras located inside a vehicle. Encouragingly, one paper (Artan, et al., 2016) discusses the analysis of images taken using an infra-red camera. Finally, Lim, et al. (2000) includes a relatively complicated method of identifying the driver based on their position relative to the number plate, which could be helpful but would be likely to require significant further development as well as the on-going management of a database of accurate number plate positions for every car model.

3.2.3 Data from in-vehicle systems

There are a considerable number of recent academic sources relating to the use of in-vehicle data (one published report, eight research papers, one active project and four unpublished reports identified).

There are two main areas of interest:

- Using data on general driving behaviour to detect distraction. These systems use inputs such as steering angle and throttle position and match them to known profiles of drivers experiencing particular types of distraction, for example talking on the phone. The technology is experimental, and while some studies have had success in simulator trials none have applied it on-road.
- Extracting data from in-vehicle systems, such as seatbelt warning sensors. It was noted that eCall[2] systems obtain these data, but it is only transmitted in an emergency.

TRL has previously carried out an evaluation of seatbelt warning systems for the European Commission (McCarthy & Seidl, 2014). Section 4.4.4 of that report contains information on

[2] A system, fitted to new vehicles, which automatically calls the emergency services in the event of a crash

the rates of sensor fitment to cars tested by Euro NCAP, and shows that the fitment of warning sensors rose substantially in the period 2002-2013. In the final year (2013), all 22 vehicles presented for test had a driver's seat sensor, 21 had a front passenger seat sensor, and 17 included sensors for the rear seats. It should be noted that Euro NCAP generally test new models as they come onto the market: this means that the fitment of vehicles available for purchase will lag several years behind, as older models stay in production. There are substantial challenges in using data from these sensors, which are discussed in Factsheet 3: data from in-vehicle systems.

Research papers:

Mousel, et al. (2015), Ishak, et al. (2017), Ye, et al. (2017), National Advanced Driving Simulator (2015), de Waard & Brookhuis (2001), Wahlström, et al. (2015), Ye, et al. (2017), Li, et al. (2015)

Active project:

Technologies for Safe and Efficient Transportation University Transportation Center (2014)

3.2.4 Mobile phone detectors

Several products are available which can detect mobile phone use. The commercial product identified by this review (Westcotec, 2017) identifies the presence of a mobile phone transmission but does not produce a different output depending on whether it consists of a voice call, data transmission or text message. By the nature of this type of system, a secondary check to determine whether the phone use was from a driver or passenger is required. A patent (Rosen, 2007) for a system combining two phone detectors and a camera has been filed in the USA.

Watkins, et al., (2011) successfully used software on phones to distinguish between texts sent while driving and those sent while not distracted. This required modification to the operating system of the phone and characterisation of each driver's texting habits in advance, so is unlikely to be feasible for producing metrics. Systems have also been made for enforcement purposes which require access to the phone (Cellebrite, 2016).

3.2.5 Installation of additional sensors in vehicles

A number of studies have installed additional sensors in vehicles, such as cameras (for example in Masood, et al. (2018)) and antennae (Shabeer & Wahidabanu , 2012), to detect mobile phone use, seatbelt use, or distracted driving. We have not investigated these in detail since they are impractical for capturing data to support a metric. Notably, the installation of such sensors may, in themselves, result in drivers changing their behaviour in such a way that they are no longer representative of all drivers.

3.2.6 Systems for related applications

Some papers were identified which discuss methods that have the potential to produce safety metrics unrelated to seatbelt and mobile phone use. The most practical are summarised briefly below:

- Use of video to identify hazardous driving patterns (Zhijun, et al., 2017), such as abrupt double lane changes. These systems consist of image processing software analysing footage from CCTV cameras.
- Risk assessment of cornering events based on GPS data (Wahlstrom, et al., 2014). These data could be collected from telematics devices or mobile phone apps.
- Detecting reckless driving based on speed and acceleration data (Zeeman & Booysen, 2013).

3.2.7 Other systems

A few papers were identified which suggested that various types of driver behaviour could be monitored using methods other than those above. Techniques included EEG (electroencephalogram, sensors attached to the scalp) and eye tracking in order to monitor variables relating to distraction. None of these systems were considered to be feasible for collecting data for producing metrics relating to driver behaviour across the population, as they are likely to be far too intrusive to be used outside of a trial setting, so were not investigated further.

4 Factsheet 1: roadside camera systems

This factsheet focuses on the technology required to produce consistently acceptable quality images from a camera mounted at the side of the road. This is the first step to be carried out before any automated processing of images.

4.1 Variations

4.1.1 Use of ANPR cameras

Use of ANPR cameras was briefly considered, as they use an infra-red photography process effective in eliminating reflected light (see section 4.1.3). Most installations consist of two cameras: an infra-red camera designed for number plate recognition and an overview camera for evidential purposes.

The number plate recognition camera is highly specialised and uses low levels of infra-red light. Images from these cameras appear almost entirely black, with only the (retroreflective) number plate visible, so are unsuitable for other analysis.

Overview cameras are similar to CCTV cameras. While they provide a good view of the exterior of the vehicle, they will not produce high quality images of the interior of moving vehicles.

All ANPR results created by police forces in the UK are stored at the National ANPR Data Centre, including a wider image of the scene as well as the image of the number plate alone. If access could be gained to this database, the wider images could be used to manually check whether vehicle occupants are wearing seatbelts, or whether the driver is using a hand-held mobile phone; however, the quality of these wider images may not be sufficiently clear to detect seatbelt and mobile phone usage. Access to this database is strictly controlled, so a powerful case would need to be made.

4.1.2 Commercially available products

Two commercially available products were identified, as discussed in Section 3.2.1. Neither manufacturer was able to provide information on the capability of their technology which could assist this investigation.

The capability of existing commercial systems will be investigated further in Phase 2.

4.1.3 Infra-red photography

Any camera system for taking interior photographs must capture clear images of the vehicle occupants which is difficult if cameras working in the visible spectrum are used. The core issue with natural light image capture is that the lighting source, i.e. the ambient light from sunshine, is uncontrolled in terms of intensity and direction, leading to inconsistent lighting levels and uncontrollable reflections and shadows. The way to overcome this is to use artificial lighting, though shining bright light directly at drivers would clearly be unsafe. One solution to this is to use light outside the visible spectrum, and the easiest to use is infra-red.

There are two types of infra-red camera which may help with this: near infra-red and thermal infra-red.

Near infra-red cameras are already used in ANPR systems. They work with artificial lighting for 24 hour use and use a filter to cut out any ambient light: this can be used to remove reflections. Near infra-red cameras use normal sensors and optics, so are of similar costs to existing CCTV cameras.

Thermal or mid and far infra-red cameras are widely used in military applications where their ability to covertly detect the heat given off by living beings is very valuable. The use of these types of cameras is unlikely to be productive as their characteristics are not suited to detection of seatbelt and mobile phone usage, and their costs are prohibitively high due to the special sensors and optics required.

The focus of the assessment below is on near infra-red photography.

4.2 Assessment against evaluation criteria

4.2.1 Quality

Aspect	Notes
Applicability	Seatbelts – Yes Mobile phones – Yes Other – Potential to record images of other distractions, e.g. eating, drinking. Close following could be detected by measuring the time between camera triggers, red-X or other prohibited lane non compliance by detecting vehicles in prohibited lanes.
Accuracy	Potentially high, with correct camera angle and video analytics technique. Quality of images cannot be known with certainty until a feasibility study has been carried out: it is possible that a proportion of images will not be sufficiently clear. Specialist hardware should substantially improve image quality when compared to Lot 3.
Reliability	The principle of manufacturing robust camera equipment for use at the roadside is well proven. Theft, damage and vandalism are risks wherever equipment is left in a public place.
Replicability	Good. It may be possible to install a system semi-permanently, logging all vehicles passing a point.
Representativeness	Dependent on the number of locations where the system is installed. A suitable camera location and angle will need to be found to cover all lanes/vehicle types.
Scalability	Can easily produce a large number of observations from a single point. Additional equipment required to add extra locations.

4.2.2 Cost

Aspect	Notes
Development cost	Unknown. It may be possible to modify a commercially available system, or a new system may need to be developed.
Unit capital cost	Depends on exact technology chosen. Likely to consist of a modified commercially available camera with additions for waterproofing, security and data transmission.
On-going cost per survey	The human input required is highly dependent on the level of automation which can be achieved (see Factsheet 2: video analytics technology).

4.2.3 Availability and practicality

Aspect	Notes
Level of development	Commercially available camera systems exist which are likely to be suitable for this technique, though the quality and technology (i.e. use of infra-red) is unknown. A bespoke system could be built using off-the-shelf hardware if required. Image recognition technology has until recently not been able to reliably detect seatbelt/mobile phone usage. Newer techniques such as deep learning have promise but may not be immediately able to automate detection, especially of mobile phone use.
Barriers to deployment	Appropriate locations to mount the cameras would need to be identified. As surveys are to be carried out over a short period of time using portable equipment then it may be practical to use batteries; otherwise a power supply will be required. A secure data transmission system from the roadside would be required, which could operate over GSM networks, using the same approach as the DfT uses for collating automatic traffic counts.
Ethics and acceptability	Potential to collect personally identifiable data with evidence of illegal activity. Taking interior photos of vehicles may be seen as unacceptably intrusive.
Stakeholder engagement requirements	Anticipated to be internal to Highways England/DfT only if used on the SRN. There will be a requirement to involve the relevant highway authority if used on other roads.
Safety of researchers and the public	Installation required at roadside Use of a light source (e.g. flash) with camera could distract drivers. However, if an infra-red source is used then the light is dim or invisible to the human eye.
Data protection issues	Personally identifiable data may be collected without consent. The legal framework for this would require investigation in Phase 2. The data controller may be Highways England, the DfT or a contractor.

4.3 Relevant technology trends

Capability has been continually improving for some time.

- Cost has fallen
- Light sensitivity has improved: this is important when taking pictures of moving vehicles due to the short exposure times

- Resolution has improved. High resolution images make it easier to identify seatbelt/phone use
- Infra-red LEDs which can produce sufficient light to see through windscreens are now commercially available.

4.3.1 Impact of these trends

- High performance camera systems for moving vehicles are increasingly practical and affordable
- Infra-red technology is now well proven and affordable

5 Factsheet 2: video analytics technology

This factsheet discusses the possibility of automatically processing the images taken by a roadside camera (see Factsheet 1: roadside camera systems). This could have cost and consistency advantages over manual coding.

Three possible levels of automation have been identified. These are outlined below:

- The lowest level of automation consists of 'assisted manual' coding. This would use relatively straightforward video processing algorithms to detect frames which contain a vehicle: these single images could then be analysed by human operators through a computer interface. It is likely that this would be considerably more time efficient than a fully manual process, with a minimum level of development cost and technical risk. Table 4 compares the inputs required for this technique to those required for the fully manual process used in Lot 3.
- An intermediate level of automation. In this system, an image recognition programme would make a 'first pass': labelling some images as clearly compliant or non-compliant while referring others for manual review, though more work would be required to develop a methodology which would give a measure of confidence in the classification of any image.
- A high level of automation, where all (or almost all) images are labelled automatically.

Table 4: Comparison of human input required for the lowest level of automation with the fully manual process used in Lot 3

	Lot 3	Roadside camera
Data collection	Specialist vehicle and driver, four observations per mile	One time device installation to capture vehicles passing a location
Data analysis	Watching vehicles overtake on video: approximately one observation per minute	Analysis of static images with dedicated interface: five to ten seconds per observation

We have contacted several industry stakeholders to discuss this technology. Their consensus is that, with the latest advances in video analytics and good quality images, it is likely to be possible to achieve at least some level of automation.

5.1 Assessment against evaluation criteria

5.1.1 *Quality*

Aspect	Notes
Applicability	Seatbelts – Yes Mobile phones – Yes Other – Could produce metrics for close following based on the time between vehicles. In the future, video analytics could also be used to detect other risky behaviours (e.g. erratic driving), though this is likely to require different camera angles and processing algorithms.
Accuracy	Unknown. It is possible that a proportion of images will require manual analysis.
Reliability	Unknown until a system is in operation
Replicability	Good. Automated systems are intrinsically consistent.
Representativeness	Unknown. There may be particular situations where an automated system makes consistent errors, e.g. for vehicles with low interior light levels.
Scalability	Very high: once the system is set up it can be fed any number of images.

5.1.2 *Cost*

Aspect	Notes
Development cost	Unknown. Some commercial providers are working on this technology, though none have been identified as having a market-ready solution and, for commercial reasons, none are willing to be named in this report in relation to their work in this area. There are likely to be substantial costs associated with producing a 'training set' of images showing compliant or non-compliant behaviour.
Unit capital cost	Once cameras have been installed (see Factsheet 1: roadside camera systems) and a processing algorithm developed, the cost of rolling automated processing out on a larger scale is expected to be low. For this to be achieved, it is highly desirable that all cameras store data in a standard and open format.
On-going cost per survey	The human input required is highly dependent on the level of automation which can be achieved. It is likely that some manual analysis would be required to achieve a high level of accuracy, at least initially.

5.1.3 Availability and practicality

Aspect	Notes
Level of development	Some commercially available systems exist, though it has not been possible to assess their performance due to commercial confidentiality concerns.
Barriers to deployment	Barriers associated with deploying a camera system at the roadside are covered in Factsheet 1: roadside camera systems.
Ethics and acceptability	Requires processing of personally identifiable images with evidence of illegal activity. Holding interior photos of vehicles may be seen as unacceptably intrusive. However, automated processing may be seen as more acceptable.
Stakeholder engagement requirements	Anticipated to be internal to Highways England/DfT only.
Safety of researchers and the public	No known risks
Data protection issues	Personally identifiable data may be processed without consent. The legal framework for this would require investigation in Phase 2. If the images are processed by a third party then there may be additional considerations relating to data transmission and storage. In the context of this project, the data controller may be Highways England, the DfT or a contractor.

5.2 Relevant technology trends

Image and video processing technology is developing rapidly:

- Deep learning algorithms are becoming increasingly practical and widely used. These ‘learn’ whether an image contains a particular feature based on a ‘training set’ – images which are known to contain (or otherwise) a given feature (e.g. a driver holding a phone). Images coded manually would be a typical training set. These algorithms have become feasible through a combination of advanced image analysis theory, and making use of the graphics engines, originally developed for computer gaming applications, in training of the deep neural networks.
- These algorithms are becoming increasingly tolerant of poor quality images, as might be produced by a roadside camera.

5.2.1 Impact of these trends

- The practicality and reliability of systems based on automated image analysis are improving, a trend which can be expected to continue, though it unclear if and when it will develop to the point where it is good enough for this purpose.

6 Factsheet 3: data from in-vehicle systems

Modern cars contain many sensors which collect data about the behaviour of the occupants. These include systems built into the vehicle, such as seatbelt warnings, and those installed by 'black box' telematics providers for fleet management and insurance purposes.

Extracting data from in-vehicle systems can be challenging. Some of the issues to be overcome with gathering data from in vehicle sensors are summarised below:

- Data recording. Not all cars are fitted with (for example) seatbelt warning systems: it has only been required on new car models since 2015, and then only for the driver's seat. The European Union is currently considering extending this to all seats in the vehicle.
- Data transmission. In the majority of cases, data are collected from the vehicle only when it is serviced or repaired, and it is unlikely that information about seatbelt use is stored. A few manufacturers may transmit more detailed data in real time, but this is unlikely to cover the majority of the fleet in the near future.
- Data format. As there is no requirement to collect or supply these data externally, data collected by each manufacturer is likely to be in a different format. This would make any data analysis very challenging.
- Data ownership. There are on-going discussions between manufacturers and regulators about who owns the data: it is thought to be either the vehicle owner or the manufacturer. In either case, the co-operation of the data owner would be required for any analysis to take place.
- Privacy. Any detailed data collected from vehicles can easily become personally identifiable if it includes information such as the routes of frequent journeys.

In our opinion, the technical, legal and organisational hurdles mean that the use of in-vehicle sensors is unlikely to be a practical methodology in the medium term, and hence recommend that this methodology is not pursued further. More information on the potential for gathering anonymised data is discussed in a recent TRL report for the European Commission (McCarthy, et al., 2017).

The review of published literature identified several studies which propose techniques to identify 'distracted driving' based on vehicle behaviour. These techniques could be capable of detecting a reduction in driver performance caused by the use of a mobile phone and/or other distractions, rather than identifying phone use directly. Since these use general driving data, rather than specific vehicle sensor data, it may be possible to gather the required variables from data collected by 'black box' suppliers.

There are fewer barriers to gathering these data than there are for seatbelt sensor data:

- Some data, such as speed and acceleration (including braking and cornering) can be gathered directly by a 'black box' without the need to interface with the vehicle.
- The format for engine data, such as throttle position, is defined in the OBD2 standard used by almost all vehicles. Some telematics devices read these data as standard.

- Data are already transmitted and stored centrally and permission for anonymised use may have been routinely obtained.

The assessment below covers the potential for measurements based on 'black box' or OBD2 data only. The most immediately relevant of these is a general 'distracted driving' measure, produced by identifying the signature of distraction in the way that the vehicle is driven.

6.1 Assessment against evaluation criteria

6.1.1 Quality

Aspect	Notes
Applicability	Seatbelts – No, see above Mobile phones – Not directly, but the effect on driving can potentially be identified Other – Potential generalised metric for distracted driving
Accuracy	Some studies have produced promising results but the processing algorithms are experimental.
Reliability	Likely to be good, as it is based on well proven sensors already installed in vehicles
Replicability	Will depend on how the mix of vehicles with a black box installed changes over time.
Representativeness	At present, these systems are fitted to only a small proportion of the fleet. Any sample is likely to be biased towards high risk drivers (with telematics insurance) or fleet vehicle users. Some vehicle types may be better represented than others: for example the majority of HGV fleets now gather data.
Scalability	High. Once a general approach is established the approach could be rolled out across all vehicles monitored by a co-operating telematics supplier.

6.1.2 Cost

Aspect	Notes
Development cost	No hardware development required. The general analytics methodology is known based on published research but is likely to require some further calibration and software development.
Unit capital cost	Low, since sensors are already fitted.
On-going cost per survey	Little human input required to gather data, but may require specialists to interpret. Ideally, telematics companies would provide anonymised data free of charge for road safety purposes, but this is not guaranteed.

6.1.3 Availability and practicality

Aspect	Notes
Level of development	Experimental/prototype stage
Barriers to deployment	Requirement to obtain data from telematics providers. Different providers may hold the data in different formats. Unproven methodology.
Ethics and acceptability	Anonymised data should be supplied
Stakeholder engagement requirements	Requirement to secure cooperation of one or more telematics providers
Safety of researchers and the public	No addition risks – uses equipment already fitted to vehicles
Data protection issues	Personal data are already held by telematics providers: this should be anonymised before research is carried out on it.

6.2 Relevant technology trends

- Vehicles are becoming increasingly connected, and some manufacturers are choosing to transmit data in real time.
- Some vehicles will soon (2019 or 2020) transmit data to others nearby, through CAM (Common Awareness Message, in Europe) or BSM (Basic Safety Message, in the USA). The specifications for these messages do not provide for the transmission of seatbelt warning data.
- An increasing number of vehicles are fitted with devices which transmit data about the vehicle and its behaviour to a third party, such as an insurer. Seatbelt status is transmitted in over the CAN bus (which some telematics systems may link to), but the format is not standardised. This means that it is unlikely that commercial telematics providers will hold data on seatbelt use.

6.2.1 Impact of these trends

- While data on seatbelt use exist within vehicles, its collection to support a metric is unlikely to become practical for the foreseeable future.
- In general, data on vehicle behaviour and use are likely to become more readily available.

7 Factsheet 4: mobile phone signal detection

Two types of system have been identified which rely on the identification of a signal from a mobile phone:

- Roadside detector systems, which recognise the signals emitted by active phones in passing vehicles. These are available commercially.
- Mobile network data analysis: looking at the pattern of movement of phones connected to a network. This approach consists of counting the number of phones making a call or text while moving at traffic speed along a road.

Both approaches suffer from the same limitation: they cannot determine whether any phone use was by a driver or passenger. Two possible strategies for working with this were suggested:

- Simply monitoring trends in the overall rate of mobile phone use in vehicles, and assuming that the rate of usage by drivers follows a similar trend.
- Supplementing the data from a mobile phone detector with a secondary source, such as a camera. This is likely to require a roadside detector, as position information from network analytics is not precise enough.

As discussed in Section 3.1.3, monitoring trends of mobile phone use in vehicles is not considered likely to produce a useful metric on its own. As a result, the assessment below considers a possible system where a roadside detector is supplemented by a camera.

7.1 Assessment against evaluation criteria

7.1.1 Quality

Aspect	Notes
Applicability	Seatbelts – No. Supplementary camera would capture seatbelt data, but requires separate analysis Mobile phones – Yes Other – None
Accuracy	Requires a supplementary sensor, such as camera. The system may pick up phone use some distance away or on the opposite carriageway, which would lead to a high false positive rate.
Reliability	Unknown
Replicability	Initial detection of mobile phone use is expected to be highly consistent as the system is automated. Analysis of images is likely to be the limiting factor (see separate fact sheet).
Representativeness	High.
Scalability	Can easily produce a large number of observations from a single point. Additional equipment required to add extra locations.

7.1.2 Cost

Aspect	Notes
Development cost	Some hardware development will be required to link a video recording system to a mobile phone detection system.
Unit capital cost	This will depend on the exact system selected and the level of development required. As an example, Westcotec manufactures a mobile phone detection system with a price of approximately £4,500 which detects call and texts being made in passing vehicles, though it cannot differentiate between drivers and other users who may be in the vehicle. This does not include a secondary verification system (i.e. camera).
On-going cost per survey	Less labour intensive than a fully manual survey, since not all images need to be analysed for mobile phone use. The ultimate level of input depends on the level of automation of image analysis.

7.1.3 Availability and practicality

Aspect	Notes
Level of development	Experimental/prototype stage
Barriers to deployment	Technology is unproven. The practical issues relating to the installation of electrical equipment identified in Factsheet 1: roadside camera systems also apply to this system.
Ethics and acceptability	Main ethical considerations relate to camera system (see separate factsheet).
Stakeholder engagement requirements	Anticipated to be internal to Highways England/DfT only if used on the SRN. There will be a requirement to involve the relevant highway authority if used on other roads.
Safety of researchers and the public	Risks associated with installation and maintenance.
Data protection issues	No additional considerations as a result of detector installation; mobile phone data are encrypted, so the detector will only be able to identify that a call or text was made. The content remains secure.

7.2 Relevant technology trends

- Data on the movement and use of mobile phones are already collected and sold by networks. This could be used to identify phones which are making calls from moving vehicles.
- There is no foreseeable method of identifying whether a phone call was made by a driver (rather than a passenger) based on mobile phone signal detection alone.

8 Conclusions and next steps

This project has identified technologies which could be used to measure the rate of non-compliant behviours of vehicle drivers and other vehicle occupants, focussing on, but not restricted to seat belt and mobile non-compliance. This was done in two phases:

- Technology review, which identified the current state-of-the-art in relevant technologies;
- Technology evaluation, which was used to gain an understanding of the capabilities of current technologies;

By far the most promising technologies identified, based on likely performance, closeness to market and feasibility, are based on the use of roadside cameras.

Camera technology is well proven and commercial systems are available which capture images of front seat vehicle occupants. However, the ability of these systems to capture images reliably in a range of conditions and from a representative sample of vehicles is unclear. Earlier work (Lot 3 of this project) showed that variation in lighting conditions can cause inconsistent image quality: this could be overcome by using infra-red cameras. Previous research has demonstrated this approach under experimental conditions, and the technique is widely used in ANPR cameras, but it is not yet proven in 'real world' conditions for seatbelt and mobile phone use.

As a minimum, video processing or camera triggering technology could be used to select still images for a human to review. This is likely to result in a substantial reduction in cost when compared to the existing manual methodology used in the DfT surveys: researchers could quickly review images using a coding interface, eliminating the need to travel to site and transcribe data. A full analysis of the relevant capital and operating costs will be needed to provide evidence of actual cost savings which may be achieved.

Ideally, the analysis of images would also be completed automatically. Substantial improvements in algorithms for video analytics have taken place in recent years, meaning that this may be much more practical than in the past. Much recent development has involved 'deep learning' techniques: these are 'trained' based on a set of images which have already been manually assessed. At least one technology provider has expressed an interest in working on such a system, though emphasised that a high level of technical risk is involved. Potential costs of future developments will be considered in Phase 2.

The same video-based technologies could be used for the detection of other non-compliant behaviours such as close following, red-X compliance etc.

In-vehicle sensors could be used to detect non-compliance, particularly the wearing of seatbelts which is already done in many newer vehicles. However, gathering the information from vehicles has significant and possibly insurmountable obstacles relating to data privacy and ownership, to the extent that this cannot be recommended as an approach.

Roadside sensors have been used as a method for detecting that mobile phones are being used in passing vehicles, but it is very difficult to identify whether the phone usage which is detected is by the driver rather than other vehicle occupants, or whether the phone was hand-held or hands-free. This method may be useful when the data are used with other sensor data, though this will require further research to validate.

It is possible to use meta-data from mobile phone operators to identify possible mobile phone usage at particular locations (for example on or near a road), but as with roadside sensors it is difficult to identify whether the phone was being used by a driver, and that it was hand-held.

Key findings	Next steps
A roadside camera system to produce images of drivers appears likely to be practical. Basic video processing techniques can convert videos to still images for faster manual review. It may be possible to automate the processing of these images, though this is much more technically challenging. Other technologies (in-vehicle sensors, roadside sensors, meta-data processing) are capable of detecting non-compliant behaviours, but there are significant barriers to their usage. Fusing data from multiple sensors has promise, but requires further investigation.	A detailed investigation of the potential for the use of camera and image analysis technology should be carried out in Phase 2. This should consider in more detail: • Technologies for image capture, including commercially available systems and the use of near-visible infra-red light • The cost and feasibility of a semi-automated system, where researchers review still images using a coding interface • How the design of any semi-automated system can facilitate the production of training data for use in a deep learning algorithm • Use of in-vehicle and roadside sensors, particularly the potential of fusing data from multiple sources

Key findings	Next steps
Mobile phone detectors could supplement a camera system, but not replace it They cannot assist with the collection of data on seatbelt use	We do not recommend that Highways England commission the development of a mobile phone detection system in the immediate future. However, data from a detector could improve the reliability of an automated image analysis system for mobile phone detection: its use should be reconsidered if this proves especially challenging.

Direct measurement of seatbelt or mobile phone use from in-vehicle sensors is unlikely to be viable in the foreseeable future. While seatbelt use is sensed by many vehicles, it is not stored or collected in any standardised format. Even if this changes in future, legal barriers and privacy concerns are likely to prevent a roll out.

Indirect measurement of driver distraction based on telematics data may be possible. However, at the moment, these drivers represent only a small and non-representative proportion of the fleet. The processes required to interpret these data are in their experimental stages. While this may become a viable option in the future, it is much less promising in the short to medium term than the use of a camera-based system.

Key findings	Next steps
Direct measurement of seatbelt or mobile phone use from in-vehicle sensors is unlikely to be viable in the foreseeable future Indirect measurement of driver distraction may be possible. However, there are technical challenges and limitations in gathering a representative sample.	We recommend that the use of vehicle-sourced data for the detection of seatbelt and mobile phone use should not be considered further at this time.

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Appendix A Database search terms

A.1 Initial search terms

Set 1
“Seatbelt” OR “seat belt” OR “safety belt”
AND
“violation” OR “infringement” OR “not wearing” OR “not on” OR “not deployed”
AND
“detection” OR “recognition”

Set 2
“mobile” OR “mobile phone” OR “cellphone” OR “cell phone” OR “smartphone” OR “handheld” OR “handy”
AND
“use” OR “usage” OR “using”
AND
“detection” OR “recognition”
AND
“while driving” OR “driver”

Set 3
“texting” OR “SMS” OR “surfing” OR “browsing” OR “internet” OR “distracted” OR “distraction”
AND
“detection” OR “recognition”
AND
“while driving” OR “driver”

Set 4
“unsafe” OR “dangerous” OR “hazardous” OR “compliant” OR “compliance”
AND
“driver” OR “driving”
AND
“detection” OR “recognition”

Set 5
“driver” OR “driving”
AND
“image processing” OR “image recognition”

A.2 Refined search terms

Set 2a
(“mobile*use")
AND
(“detection” OR “recognition”)
AND
(“while driving” OR “driver”)

Set 2b
(“seatbelt*use")
AND
(“detection” OR “recognition”)
AND
(“while driving” OR “driver”)

Set 3a
“distracted”
AND
(“detection” OR “recognition”)
AND
(“while driving” OR “driver”)

Set 4a
“dangerous”
AND
“driving”
AND
“detection”

A.2.1 Terms used in databases not supporting complex searches

seatbelt detection

mobile phone detection

dangerous driving detection

"dangerous driving" detection

"image processing" driving

mobile phone detection

Review of Technology for Undertaking Mobile Phone and Seatbelt Surveys on the SRN

This study identified technologies with the potential to be used for monitoring seatbelt and mobile phone use by vehicle occupants. A review of published and unpublished literature was undertaken, as well as consultation with subject matter experts and relevant businesses. Use of roadside cameras, supported by video analytics technology, was felt to be the most promising of the options identified and further investigation of this option was recommended for Phase 2 of this project. Each technology was assessed against criteria relating to quality, cost, availability and practicality. Systems involving data from in-vehicle systems or from detecting mobile phone emissions were also considered.

Other titles from this subject area

In press	Feasibility study: Seatbelt and mobile phone use surveys on the SRN. R Myers, L Croft, L Durrell, S Chowdhury. 2017
PPR871	Mobile Phones and Seatbelts Technology Review (Phase 2). P Vermaat and R Myers. 2018

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