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1 Introduction

An amendment to the United Kingdom Construction and Use Regulations (HMSO (1986a)) came into operation in 1983 that required the fitment from various dates of lightweight sideguards to new goods vehicles and trailers over certain weights and to some of the larger existing semi-trailers. These sideguards are designed to protect pedestrians and cyclists from falling under the trailer wheels, rather than prevent underrun of other vehicles, although they do provide some protection against this particularly when the angle of impact is acute.

At the same time, regulations came into force that required the fitment of rear underrun protection (European Union (1970)) to prevent cars that collide with the rear of goods vehicles running underneath the structure of the larger vehicle. A similar regulation requiring front underrun protection came into force in 2003 (European Union (2000)).

Regulations also require the fitment of spray suppression equipment to goods vehicles. These devices consist of wheel guards, mudflaps and matting (European Union (1991), British Standards Institution (1984a & b) & HMSO (1986d)).

To-date each of the above issues has been considered individually but it is possible that if they were considered together cost effective improvements could be identified in each area. The UK Department for Transport (DfT) has commissioned TRL to investigate the benefits of taking an integrated approach to these three topics. If further improvements to these systems are considered individually the improvements in each area may appear small. However, an integrated approach to the design of the front rear and side of HGVs may yield much greater combined benefits at less apparent cost than considering the elements individually.

The main objective of this project is to assess the benefits of integrating front, side, and rear underrun protection in terms of:

- Improved protection for other road users in collision with an HGV
- Allowing the use of improved aerodynamics to control spray emission in wet conditions, including the development of a regulatory test procedure.
- Improved fuel efficiency as a result of improved aerodynamics.

The work on safety guards in this project has focussed more on side protection than front or rear because improvements to these features were being considered in a parallel project commissioned by the European Commission (EC): Vehicle Crash Compatibility (VC_COMPAT).

This report describes all of the work carried out for this project and draws the final conclusions and recommendations.
2 Literature review – safety guards

Below is a brief summary of the findings of the literature review with respect to safety guards.

The safety guard literature review was intended to update a previous review carried out by TRL, on behalf of the DfT, in 1995, and to attempt to identify any research to demonstrate any benefits of, or difficulties with, an integrated approach to underrun protection.

The review revealed that there had been little new research into the safety aspects of sideguards since the previous review in 1995 and the principles of good design remained the same, that is, low ground clearance and minimising gaps.

More recent research showed that substantial additional benefits can be gained by replacing the traditional rail type sideguards with solid flat panels enclosing as much of the space between the wheels as possible. Research by De Coo et al (1994) suggested that with the appropriate ground clearance, run over by the rear wheels could be eliminated in overtaking manoeuvres. Research by Stöcker (1990) suggested that other injury criteria can also be reduced by removing the possibility of entanglement with the guard, collision between the victim and any protruding structure and a more gentle collision with the floor.

The only major development in the approach to sideguard design involved the Krone SafeLiner trailer, which is constructed using a chassis frame around the outside of the vehicle, rather than a traditional central chassis beam. The benefits of this approach are that the:

- Sideguard is not an addition to the vehicle but an integral part of it
- Whole side of the vehicle is enclosed, including the trailer wheels
- Side of the vehicle is much stronger than a traditional sideguard such that car underrun can be prevented at moderate speeds in side collisions.

The main difficulties with sideguards that were identified are well established. The first is that reduced ground clearance is important for optimum safety performance, but this can cause manoeuvrability problems in some circumstances. Ground clearance is important on vehicles that are required to take part in manoeuvres over raised obstacles such as ferry-ramps or uneven terrain. There were no papers identified that proposed full solutions to these difficulties. The second problem is that the sideguards represent additional weight, which in turn reduces the vehicle payload. Further problems with enclosed sideguards were identified; these include access to load securing points, side-mounted handbrakes, chain connections for securing on ferries, twist-lock levers and spare wheels. Brake cooling was also considered a problem for some vehicles. Research supporting the Krone SafeLiner trailer showed that many of the difficulties associated with the additional weight can be overcome by the use of innovative designs. The Krone trailer is shown to have integrated side and rear protection with greater capabilities than required by legislation without substantial weight penalties or problems associated with access to wheels or ancillary devices. No specific research into the fitment of sideguards to unconventional vehicles was identified.
3 Review of underrun regulations

The current regulations (European Union (1970), HMSO (1986b), European Union (1989), HMSO (1986c) and European Union 2000)) relating to underrun protection have been reviewed in detail to highlight any differences and inconsistencies between them and to identify any requirements that might prevent or limit an integrated approach to their design. The main findings and arguments are reported below.

The UK regulations for front, side and rear underrun protection have been developed over a period of time and are increasingly similar to the EC Directives. The UK sideguard Regulation (HMSO (1986d) is very different to the EC Directive (European Union (1989)). whereas the UK Regulation for front underrun refers directly to the EC Directive (European Union, (2000)). In future it is likely that European Whole Vehicle Type Approval will mean that EC Directives will form the basis of all of the UK national regulations for underrun protection.

3.1 Test forces

One of the inconsistencies noted in the Regulations is that the test forces that the front underrun barrier is required to withstand, are higher than for those used for the rear. At first glance this situation might appear logical. Front and rear underrun guards are primarily designed to protect car occupants that collide with an HGV when it is the front of the car that is involved in the collision. Front underrun guards may also provide some additional protection when the front of an HGV collides with the rear of a slower moving or stationary car. However, this is not their prime objective because the rear of a car is not subject to the same stringent levels of crashworthiness that the front is and it is not known whether eliminating underrun of the rear of a car structure would provide substantial additional benefits.

Where a collision occurs between the front of a car and the front of an HGV the vehicles are usually travelling in opposing directions prior to the impact. When the car strikes the rear of an HGV they are usually travelling in the same direction. For this reason closing speeds are typically much greater in accidents involving the HGV front than those involving the HGV rear. The typical front accident, therefore, applies a greater force to the HGV than the typical collision with the rear of the HGV, which is consistent with the different forces required by the different Regulations. This approach means that both front and rear underrun guards are capable of protecting a similar percentage of the fatalities that collide with the front and rear respectively.

However, cars are designed to offer protection at or below certain impact speeds, for example 56km/h (EU frontal impact directive 97/27/EC). It can, therefore, be argued that both the front and rear underrun barriers should be designed to withstand forces associated with a survivable impact, that is, an impact with a closing speed of 56km/h or less. As stated previously, the closing speeds, and therefore the forces applied to the underrun guard, in frontal collisions are typically greater than in collisions with the rear. Therefore, if both front and rear underrun guards are designed to withstand the same forces then the rear underrun guard will protect a greater percentage of the fatalities that collide with it than the front underrun guard will. This approach would maximise the benefits that could be obtained from rigid underrun protection.

It is likely that the reason for the difference in test forces is not as a result of a deliberate choice of approach to the problem of accidents with the front and the rear of an HGV. The Regulation for the rear underrun guard was introduced in 1983 and the Regulation for the front was introduced in 2003. A more likely reason for the difference is simply that cars are, in general, now heavier and stiffer than they used to be. The success of EuroNCAP in improving crashworthiness standards is considered to have been a substantial influence on this change. These changes to car structure mean that a modern car is likely to impose much higher loads on an underrun device than a car that was modern at the time that the rear underrun regulation was written, more than 20 years ago. In addition to this, the research tools available to quantify the forces involved have also improved. For example, many crash tests are now carried out using recently developed “load cell walls”, which can quantify the force imposed by any particular part of the interacting structure. The front underrun standard is, therefore,
more likely to be an appropriate standard for today’s vehicle fleet. If an integrated approach to underrun protection aimed at maximising the number of people protected is taken, then it is clear that the forces required by the rear underrun regulation should, at least, be brought into line with those required for the equivalent front underrun guard.

Although they could substantially affect the relative protection offered by the different guards, none of the differences described would prevent a manufacturer from producing a vehicle where the underrun protection was integrated all of the way around the vehicle. However, the differences do demonstrate that the Regulations themselves haven’t been designed from an integrated or harmonised point of view and this is unlikely to encourage an integrated approach to meeting the requirements.

3.2 Test methods

The geometry of the surface used to apply forces to the sideguards to test their strength is different to that used to test the front and rear underrun devices. The sideguards are tested using a circular ram with a maximum diameter of 220mm. Front and rear underrun devices use a rectangular ram 250mm high (exact height specified by the manufacturer) and 200mm wide with a radius of curvature of 5mm at the vertical edges. The reason for this difference is not known but it should be noted that the magnitude of forces involved differs widely. For example, 1kN for sideguards compared with 100kN for rear guards.

The way in which the ram applies the test force is also different between the Regulations. For rear and side underrun the rate of application of the force is not specified and it has always been interpreted as a quasi-static test. Equally there is no time period specified for which the rear or side protection must withstand the force. However, in the front underrun Regulation (European Union (2000)) it is required that the test force is applied “as quickly as possible”, although there is no further guidance on what sort of rate is implied by this statement. It is not known why the front Regulation is worded in this way or whether it leads to any significant problems. However, it does leave the Regulation open to interpretation.

When a force is applied very rapidly it can generate “shock loading”, which can result in much greater stresses within the structure. In such a case a dynamic test would be more difficult to pass than a static test. Some materials exhibit “strain hardening” behaviour and appear stiffer when forces are applied more rapidly to them than when they are applied slowly. With this sort of material it would be easier to pass a dynamic test than a static test. This allows the possibility that the test method could be tailored to suit the material used in order to pass the requirement. However, it also true that rapid application of force is more realistic when considering real crashes. This is supported by the requirement that the guard must withstand the force for at least 0.2 seconds, which is typical of the duration of a car frontal crash into a barrier. When considering the suitability of the test methods, it is worth noting that for all of the underrun regulations the test loads are applied sequentially which is not representative of what happens in real impacts. In real impacts the forces applied to the underrun guard are all applied within the same 0.2 second period.

Again, none of these differences prevent an integrated approach to safety guard design but neither do they encourage such an approach.

3.3 Dimensional requirements

The ground clearance of underrun protection is one of the key parameters affecting its performance. The maximum ground clearance for rear and side protection is 550mm. However, for the front it is 400mm. There are operational reasons for this associated with the shorter overhang of the body at the front compared with the often large rear overhang and wheelbase. Larger overhangs are more likely to result in ground clearance problems for underrun protection. However, it is worth noting at this stage that not all HGVs have a large rear overhang, but all HGVs are required to have an underrun guard that can have a ground clearance suitable for a large rear overhang. Also, many HGVs that do have...
relatively large rear overhangs are voluntarily fitting side and rear guards that are much lower than required by the Regulations. A series of examples is shown in Figure 1, below.

![Figure 1. Examples of low ground clearance HGVs](image)

It can be seen that the ramp and departure angles permitted by these designs will be very small, yet they were all HGVs easily found in-service on UK roads. The photographs show no evidence of damage to suggest that grounding of the vehicle had been a problem in service. However, the photos only represent one fixed point in time for these vehicles and it is possible that they had been damaged previously and repaired before the time of the photograph.

The sideguard Regulation states that for a trailer (other than a semi-trailer) the maximum distance from the leading edge of the sideguard to a vertical tangent to the rearmost part of the tyre in front is 500mm. This requirement is sensible for a full trailer that is equipped with one or more axles at the front and the rear but it is not possible to apply it to a trailer with centre axles as shown in Figure 2 below. This is because the distance to the tyre in front of the leading edge of the sideguard will depend on the design of the towing vehicle and the separation between towing and towed vehicles, both of which will vary greatly.
However, Figure 2 illustrates the gap that can be left as a result and clearly shows that it is still possible for vulnerable road users to fall under the wheels of such a trailer if there are no sideguards fitted in front of the trailer axles. It can also be seen that for a vehicle combination such as this the fitment of sideguards behind the rear wheels of the towing vehicle could also offer substantial benefits.

Again, the anomalies and differences noted in this section can have a substantial affect on the performance of the protection but do not prevent an integrated design. However, as before, there is little to encourage an integrated approach.

3.4 Installation

In order to integrate the side and rear safety guards, additional sideguards must be fitted behind the rear wheels. This is not prevented by the Regulations and is, in fact, expressly permitted by the European Directive. However, it is in excess of the current requirements and, as such, there is no regulatory control on the structures that might form part of an integrated guard. The sideguard behind the rear wheels may also have to be angled. A requirement of the rear underrun Regulation is that the device must not protrude past the outer surface of the tyre. If the sideguard is designed to cover the wheels, then the rear section must be angled to meet the rear underrun device. A regulation that includes all the requirements to design a vehicle with integrated guards may encourage more manufacturers to take this approach.

The wording of the rear underrun Regulation is prescriptive in at least one place and could potentially stifle innovative solutions such as integrated safety guards. The Regulation requires that the rear underrun device is mounted to the chassis side members or whatever replaces them. It is assumed that this is to ensure the mounting points have sufficient strength to withstand the possible load and it also implies a traditional central beam chassis construction. However, the Regulation already contains a test requirement that certain loads should not result in the rearguard moving or crushing such that it is more than 400mm from the rear of the vehicle. If the rearguard can meet this requirement, a further constraint should not be necessary.

A number of vehicle and trailer manufacturers have seen the potential aerodynamic and styling or image benefits of having glass fibre panelling around the vehicle. However, for many of these the end product still falls a little short of a fully integrated safety guard concept, as shown in Figure 3, below.
It can be seen that although the glass fibre panel type sideguards extend behind the rear wheels and around the rear of the trailer there is still a separate rear underrun guard constructed in the traditional manner and not linked to the integrated guard. One of the benefits of an integrated approach is that the sideguard behind the rear wheels can be used to strengthen the rear guard at its edges. Another benefit is that there is a smooth surface for the vulnerable road user to contact all the way along the length of the vehicle. This design of trailer misses out on these potential benefits because the rear guard is not connected to the sideguard and the sideguard behind the rear wheels tapers in-board of the vehicle, which leaves the rear guard as a sudden protrusion, which could cause injury to a vulnerable road user in contact with the side panelling.
4 Review of exemptions to underrun protection

When the rear underrun and sideguard Regulations were introduced there was strong opposition from industry, with the main concern being the effect of smaller ground clearances on operations. This opposition was overcome by exempting some vehicles from the regulations. Accident studies have suggested that a number of fatalities could be prevented if such vehicles were not exempt from the Regulation. The exemptions from the UK Regulation for rear underrun are as follows:

- A motor vehicle with a maximum speed not exceeding 15mph
- A motor car or heavy motor car constructed or adapted to form part of an articulated vehicle
- An agricultural trailer
- Engineering plant
- A fire engine
- An agricultural motor vehicle
- A vehicle fitted at the rear with apparatus specially designed for spreading material on the road
- A vehicle so constructed that it can be unloaded by part of the vehicle being tipped rearwards
- A vehicle owned by the Secretary of State for Defence and used for naval, military or air force purposes
- A vehicle to which no bodywork has been fitted and which is being driven or towed-
  - For the purpose of a quality or safety check by its manufacturer or a dealer in, or distributor of, such vehicles; or
  - To a place where, by previous arrangement, bodywork is to be fitted or work preparatory to the fitting of bodywork is to be carried out; or
  - By previous arrangement to premises of a dealer in, or distributor of, such vehicles;
- A vehicle which is being driven or towed to a place where by previous arrangement a device is to be fitted so that it complies with this regulation
- A vehicle designed and constructed, and not merely adapted, to carry other vehicles loaded onto it from the rear
- A trailer specially designed and constructed, and not merely adapted, to carry round timber, beams or girders, being items of exceptional length
- A vehicle fitted with a tail lift so constructed that the lift platform forms part of the floor of the vehicle and this part has a length of at least 1m measured parallel to the longitudinal axis of the vehicle
- A trailer having a base or centre in a country outside Great Britain from which it normally starts its journeys, provided that a period of not more than 12 months has elapsed since the vehicle was last brought into Great Britain
- A vehicle specially designed, and not merely adapted, for the carriage and mixing of liquid concrete
- A vehicle designed and used solely for the delivery of coal by means of a special conveyor which is carried on the vehicle and when in use is fitted to the rear of the vehicle so as to render its being equipped with a rear underrun protective device impracticable
- An agricultural trailed appliance
The exemptions from side underrun regulations are similar but not identical. The exemptions from EC Directives are much more generic as shown below:

- **Sideguards**
  - Tractor units for semi-trailers
  - Trailers specially designed and constructed for the carriage of very long loads of indivisible length
  - Vehicles designed and constructed for special purposes where it is not possible, for practical reasons, to fit such lateral protection
  - Any motor vehicle or trailer designed for use on the road, with or without bodywork and with a maximum speed less than 25km/h

- **Rear underrun protection**
  - Tractors for semi-trailers
  - “slung” trailers and other similar trailers for the transport of logs or other very long items
  - Vehicles for which rear underrun protection is incompatible with their use

- **Front underrun protection**
  - Off-road vehicles of category N₂ and N₃
  - Vehicles such that their use is incompatible with the provisions of front underrun protection

This section of the report investigates whether the exemptions for sideguards and rearguards are justified. Many of the exemptions relate to the use of the vehicle and a certain amount of subjective opinion is inevitable in discussions of the subject. TRL has attempted to tackle this problem by collecting evidence of both the use that vehicles are put to in-service and the construction of vehicles with and without safety guards in order to try to determine what likely and extreme situations will be encountered in-service and whether the fitment of a current regulatory minimum underrun device would have an adverse affect on the vehicles ability to operate in those environments.

The review found that for vehicles that claimed exemption due to problems with ground clearance during operations that could occur off road there was considerable evidence to suggest that many off road operations did not cause a problem and many such vehicles had structures other than sideguards that limited ground clearance just as much as underrun protection would have. Some examples are shown in Figure 4, below
However, it was found that some extreme examples of off-road use did exist and some exemptions would continue to be required for some specialist applications. The review proposed some alternative methods of granting exemptions and these are described below.

4.1 Potential alternative approaches to exemptions

The evidence shown in the review strongly suggested that many of the exemptions to safety guard regulations are not justified. Part of the problem may well be the wording of the Regulations and exemptions themselves. For example, the UK Regulations exempt a series of specific vehicles based on criteria such as the body type and/or the type of load carried. The EC Directives tend toward the opposite extreme where most exempt vehicles will obtain their exemption through a subjective interpretation of how one generic exemption applies to any particular vehicle or operation. Both of these approaches allow the possibility that vehicles or operations that do not strictly require an exemption can gain one. It is, therefore, important to consider what design or operational factors are truly limited or affected by the fitment of safety guards and to re-structure the exemptions based upon these factors independent of vehicle type or load.

Analysis of the exemptions in the UK and EC Regulations/Directives (European Union (1970), HMSO (1986b), European Union (1989), HMSO (1986c)) suggest that the basic factors determining whether a vehicle is exempt are as follows:

- The off road capability (e.g. tippers, agricultural vehicles, military vehicles etc)
- The use of ancillary equipment essential to the vehicle function (e.g. road sweepers, concrete mixers etc)
- The presence of chassis/body structure in the areas covered by the safety guard requirements

The following sections will discuss possible approaches to defining whether such factors are relevant to any particular vehicle and whether they merit an exemption.

Figure 4. Examples of use of vehicles
4.1.1 Off-road performance

At present, it is considered that many of the exemptions from safety guard regulations have been based on the requirement for that specific type of vehicle to be able to travel “off-road”. However, with the possible exception of front underrun regulations, the exemption tends to be awarded based on vehicle type such that the “off-road” use is never objectively defined.

It is possible to consider a number of levels of “off-road” performance:

- On-road – that is roads made of hard surfaces such as concrete or asphalt
- Unmade road – clearly travelled roads, tracks or trails, constructed from packed earth and/or gravel
- Completely off-road – travel where no road, track, or trail exists. Surfaces and profiles can be anything that naturally occurs from rock through to deep mud or water and can involve steep gradients

Initial consideration of how to define vehicles that should be exempt was based upon the definition of off-road vehicles contained in EC Directive 70/156. This definition (Type G) specifies a range of criteria such as ground clearance, ramp angles, number of driven wheels etc, which must be met in order to qualify.

According to the definition it is not possible for articulated vehicles to be officially classified as a Type G off-road vehicle if they are considered as a whole (i.e. tractor and semi-trailer together). This is because to travel off-road a vehicle needs to be able to offer much better traction than many HGVs and, therefore, the Directive specifies that at least half of the wheels must be driven. No current road going trailer uses powered axles, to the best of the authors’ knowledge, and so this requirement cannot be met. Even if the vehicle combination is considered as a single vehicle, of current configurations, only a 6*4 tractor towing a single axle trailer has half of the axles driven. Therefore, if it is argued that exemptions are justified for off-road vehicles, then using the EC Directive definition of a type G off-road vehicle in the underrun protection regulations could end the exemptions to all the requirements for articulated vehicles.

However, many rigid tippers are capable of meeting the requirements described above, particularly those with only two axles and a Gross Vehicle Weight (GVW) in excess of 12 tonnes where standard two-wheel drive is sufficient to meet the traction requirement of half of the wheels being driven. If the definition of a type G vehicle were used to justify exemptions from safety guards regulations then all 6*2 and 8*2 tippers would lose their exemption as would all 4*2 tippers with a GVW<12 tonnes. However, many other rigid tippers (e.g. 4*2 with GVW>12 tonnes, 8*4) would retain their exemption and it is likely that over time more, or even all, rigid tippers would be designed to meet the criteria and maintain their exemption.

It appears that the type G definition is not particularly demanding. Traction can be an issue on unmade roads and is likely to be a major issue in serious off-road use but a vehicle can still be classified as an “off-road” vehicle when equipped with only two wheel drive. Also, the minimum ground clearance required to meet the ramp angle requirement for a typical tipper studied is only 432 mm. This could be comfortably achieved by a vehicle equipped with sideguards, which suggests either that the minimum level of off road use considered by the regulation is not very demanding or that sideguards do not restrict off-road use. If the rear ground clearance is reduced to 550mm, as if a rear underrun device had been fitted, the departure angle is reduced to 26º, which also still allows the vehicle to be classified as off road.

It can be seen that using the type G classification to define the exemptions from safety guards regulations would offer substantial benefits by reducing the number of exempt vehicles on the road. However, the definition would need to be made considerably more demanding to end the exemptions for many other vehicles that do not get used in very severe off-road operations.

An alternative approach to this problem would be to require adjustable or demountable safety guards for off-road vehicles such that they are equipped when travelling in areas of risk (on-road) and can
move or remove them when required to travel off road. Guards that were adjusted manually could potentially be achieved relatively simply with little cost or weight implications but would require enforcement action to ensure that drivers always deployed them on-road. Guards that could be adjusted automatically from switches in the cab would be more likely to be used but would be more complex and would therefore increase cost and weight.

### 4.1.2 Ancillary equipment

The use of ancillary equipment can create genuine difficulties installing underrun guards. However, in many cases it would still be possible to fit guards that improved safety without compromising operational performance, although in some cases this may require innovative design and increase cost. In the EC Directives, vehicles with extensive ancillary equipment are exempt under the condition that protection need not be fitted where it is impractical or inconsistent with its use. A suitable approach to this particular problem may be to keep a generic exemption but then to issue guidelines or a code of practice for type approval agencies that helps them to define what constitutes “impractical” or “inconsistent with its use”. This could be based upon a variety of specific criteria relating to the type of vehicle and its use as well as more generic criteria perhaps associated with certain percentage cost or weight increases if safety guards are fitted. Guidelines or a code of practice also have the advantage that they are easier to amend and update than regulations such that it will be relatively easy to keep them up to date in light of new technology or vehicle designs.

### 4.1.3 The presence of chassis/body structure

The presence of chassis or body structure in areas where underrun protection is required can potentially remove the need for underrun protection. However, there are a number of vehicles currently exempt from the Regulations, for example fire engines or dustcarts, that do voluntarily have body structure in the areas covered by the safety guard regulations. For these vehicles the structure does not have to conform to any of the strength or protrusion requirements of the Regulations and, therefore, may not offer the protection intended by the regulations.

An appropriate way to deal with such vehicles may be to end any specific exemptions and to amend the regulation such that vehicle or body structure may replace the safety guard provided that it can be demonstrated that it fulfils the principal requirements for dimensions, strength and presenting a smooth surface to vulnerable road users. A vehicle such as a fire engine could still be exempt from the requirements if it can be categorised as an off-road vehicle and vehicles such as a dustcart could still be exempt if it can be shown that the use it is put to makes it impractical to do so under the guidelines system discussed above.
5  Review of spray suppression exemptions and regulations

Spray suppression equipment in the UK is governed by EC Directive 91/226/EEC, British Standard BS AU 200 and Road Vehicles (Construction and Use) Regulations 1986 Regulation 64. These standards are reasonably similar and specify the performance of two distinct types of spray suppression material to be used in the construction of mud-guards and wheel valances. They are defined as “energy absorbing” materials and “air/water separators”. Approval is obtained through component testing of the materials that involves spraying a defined quantity of water at the materials and expressing the water collected by them as a percentage of the water sprayed at them. This is then combined with prescriptive minimum and maximum dimensions of the wheel guards.

These regulations are a significant barrier to the concept of integrated safety guard and spray suppression systems. They are wholly design prescriptive rather than performance-based and therefore do not permit innovative solutions such as the use of aerodynamics to control spray.

The exemptions permitted by these regulations are almost identical to those permitted by the safety guards regulations reviewed above and the arguments for such exemptions are almost the same as for the safety guards. However, there is one important difference. When off-road use was discussed in relation to safety guards the argument was all about ground clearance and manoeuvrability on uneven terrain. In this respect it was shown that safety guards often did not reduce the ground clearance and manoeuvrability of many exempt vehicles because of the presence of other structures. In addition to this, it was also shown that much of the claimed “off-road” use of such vehicles was actually on flat well maintained “unmade roads” of packed earth or gravel where the terrain was such that large ground clearances were not required. However, one of the main difficulties when considering the same vehicles and the same use in relation to spray suppression is that use on such “unmade” roads will result in extensive mud and debris being thrown from the vehicle wheels onto the spray suppression material resulting in the material quickly becoming clogged and ineffective. It was, therefore, concluded that although the presence of spray suppression equipment may not hamper the operation of many of the vehicles with off-road exemption, it would in practice be ineffective and, therefore, there would be little benefit in ending the exemptions. It is possible that the use of aerodynamic spray suppression devices may be less susceptible to this performance degradation but that is likely to be design specific and cannot be quantified at this time.

The review did also conclude that it may be beneficial to end the exemptions for road going fire engines, refuse vehicles and some military vehicles and that this was likely to be achievable without significant operational consequences.
6 The benefits of improved sideguards

Two methods were employed to assess the benefits of improving sideguards such that they presented a continuous smooth surface with low ground clearance:

- Computer simulation
- Accident data analysis

Computer simulation using the proprietary Madymo code was carried out in order to investigate the physical improvements possible, in terms of loading applied to a vulnerable road user (VRU) injury criteria, and the kinematics of the VRU. These results were then combined with an analysis of accident data in order to try to predict the benefits of improving sideguards as modelled for the computer simulation and of ending the current exemptions to sideguard regulations.

6.1 Computer simulation

A model based investigation was completed to assess and compare the potential injury risk that integrated safety guards and traditional rail type side guards pose to vulnerable road users, such as pedestrians and cyclists, when fitted to heavy goods vehicles (HGVs). For the purposes of the investigation the following three models were developed:

- A heavy goods vehicle (HGV) model
- A vulnerable road user model
- A bike (pedal cycle) model.

These models were used in combination with standard human body models of various sizes either seated on the bicycle or standing as a pedestrian. Images of all four models can be seen in Figure 5, below.

![Figure 5. Models used in the computer simulation exercise](image-url)
With these models a series of vulnerable road user to HGV impacts were simulated. Injury predictions from these simulations were compared in order to assess the comparative influence that the integrated and traditional guards have on the injury risk to vulnerable road users during vulnerable road user to HGV impacts.

An example comparison of the results from the modelling is shown in Figure 6 and Figure 7, below.
The objective of this work was to complete a model based comparative investigation of the potential injury risk that traditional side guards and integrated side guards fitted to HGVs pose to vulnerable road users, such as pedestrians and cyclists. Based on a series of model predictions the general findings are that injuries and high body loads are more likely during vulnerable road user impacts.
with HGVs if the vehicle is fitted with a traditional rail type side guard rather than a smooth integrated guard that covers the trailer wheels.

The nature of collisions between vulnerable road users and the side of HGVs is chaotic, particularly for the traditional sideguard. It is, therefore, not possible to model all of the possible interactions between the vulnerable road user and the HGV exhaustively. All of the HGV structures have been assumed to be perfectly rigid and all deformation during vulnerable road user contacts with the ground and the HGV models was assumed to occur in the vulnerable road user model only. In reality sideguards will permit some deformation, which is likely to reduce the magnitude of injury criteria and loads predicted. In addition to this the design of the vulnerable road user model and the injury criteria designed for use with the model are intended for frontal impact in cars. This does limit the ability of the modelling to predict absolute injury risk. However, accepting these limitations, the model does offer a valid comparative analysis of the influence of the geometrical properties of sideguards on relative injury risk. These limitations must be taken into account when considering the conclusions of this work.

Many of the high injury predictions and high body loads predicted by the models in this work were more a consequence of resulting interactions with the ground rather than a consequence of direct impacts between vulnerable road users and the HGV structures. This was the predicted behaviour despite the fact that both the HGV models and the ground simulated in the model runs were both represented as rigid bodies. An additional point is that in reality the cyclist might also be wearing protective head gear. This feature was not explicitly modelled but may reduce the magnitude of the head loads and HIC values predicted in this work.

For collisions with the HGV model fitted with a smooth integrated guard, the general finding was for the vulnerable road user model to slump and fall close to the moving HGV model. This provided greater potential for the upper appendages of the vulnerable road user model to fall under the guard and be crushed by the trailer wheels. Furthermore, for cycle impacts into the integrated guard, there was a greater likelihood of the cyclist falling onto their bike and suffering injuries from the bike. In contrast the impacts with the traditional rail side guard generally resulted in at least the upper torso and appendages being thrown clear of the HGV. However, the possibility of the legs being run over by the trailer wheels of the HGV remained.

6.2 Accident data

Accident data from three sources, STATS19, Heavy Vehicle Crash Injury Study (HVCIS) Fatals and Truck Crash Injury Study (TCIS). has been analysed. The objectives of this accident analysis were:

- to provide a context for the future predictions of benefits
- to provide data upon which to estimate the benefits of changes to regulations

In order to provide a context against which predictions of future benefits could be compared accident data from before the original introduction of sideguards was compared with data from ten years later when sideguards would have been standard on most of the UK fleet.

The number of accidents has fallen substantially (18.7%) during the ten years between the two samples. When increases in traffic are considered, the accident rate has fallen by 31.8%. This suggests that road safety, driver behaviour and/or vehicle primary safety have improved. However, in relation to the performance of sideguards, it is the severity of injuries received by those that are involved in accidents that is important.

Table 1 shows the distribution of the injury severity for pedal cyclist casualties involved in all types of collision with an HGV and how the distribution has changed since the introduction of sideguards.
Table 1. Summary of pedal cyclist casualties

<table>
<thead>
<tr>
<th>Severity</th>
<th>1980-1982</th>
<th>1990-1992</th>
<th>% Change in proportion of casualties of each severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>165</td>
<td>127</td>
<td>-5.7%</td>
</tr>
<tr>
<td></td>
<td>7.0%</td>
<td>6.6%</td>
<td></td>
</tr>
<tr>
<td>Serious</td>
<td>661</td>
<td>465</td>
<td>-13.2%</td>
</tr>
<tr>
<td></td>
<td>28.0%</td>
<td>24.3%</td>
<td></td>
</tr>
<tr>
<td>Slight</td>
<td>1533</td>
<td>1322</td>
<td>+6.3%</td>
</tr>
<tr>
<td></td>
<td>65.0%</td>
<td>69.1%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2359</td>
<td>1914</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(100%)</td>
<td>(100%)</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 shows that for those pedal cyclists that are still involved in accidents, there has been a reduction in the proportions that are fatally or seriously injured. This suggests that there have also been improvements in secondary safety during this period.

Sideguards are primarily designed to be effective in only a very specific type of accident where a cyclist falls against the side of a passing HGV in the region between the wheels. This type of accident cannot be specifically identified in STATS 19 but dividing the data into categories where both the cyclist and the HGV were going straight ahead in the same direction and the impact was to the nearside of the HGV is close. The change in injury distributions either side of fitment of sideguards for this more specific accident type is shown in Table 2.

Table 2. Injury distribution for accidents where the HGV was “going ahead other” and was impacted on its nearside

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>23</td>
<td>11</td>
<td>-61%</td>
</tr>
<tr>
<td></td>
<td>14.7%</td>
<td>5.7%</td>
<td>14.7%</td>
</tr>
<tr>
<td>Serious</td>
<td>51</td>
<td>55</td>
<td>-12.8%</td>
</tr>
<tr>
<td></td>
<td>32.7%</td>
<td>28.5%</td>
<td>32.7%</td>
</tr>
<tr>
<td>Slight</td>
<td>82</td>
<td>127</td>
<td>+25.1%</td>
</tr>
<tr>
<td></td>
<td>52.6%</td>
<td>65.8%</td>
<td>52.6%</td>
</tr>
<tr>
<td>Total</td>
<td>156</td>
<td>193</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(100%)</td>
<td>(100%)</td>
<td></td>
</tr>
<tr>
<td>KSI</td>
<td>74</td>
<td>66</td>
<td>-28.3%</td>
</tr>
<tr>
<td></td>
<td>47.4%</td>
<td>34.2%</td>
<td>47.4%</td>
</tr>
</tbody>
</table>

It is clear that the proportion of pedal cyclists involved in this type of accident that were fatally or seriously injured has been substantially reduced since the introduction of sideguards and that the effect on the proportion of fatalities is much greater than on the serious injuries. If this information is compared with that shown in Table 1, which was for all pedal cyclist casualties in collision with an HGV, it can be seen that the change in the distribution of injury severity is much greater in this
specific circumstance than it was in general. The large reductions in killed and seriously injured pedal cyclists in an accident situation where sideguards might be expected to influence injury severity suggests that the introduction of sideguards has offered substantial benefits to cyclists. However, it is interesting to note that Table 1 shows that the total number of all collision types between HGVs and pedal cyclists has decreased in the time period, while Table 2 shows that in the specific accident type where an HGV overtakes a cyclist the total number of collisions has increased substantially. The frequency of this type of collision has increased, suggesting either pedal cyclists and HGVs mix in traffic more frequently or that primary safety measures (such as mirrors, education etc) may have not been effective. However, the likelihood of being killed or seriously injured once involved in this type of accident has substantially decreased.

In other manoeuvres studied, it could be seen that the proportion of Killed or Seriously Injured (KSI) cyclists was broadly similar before and after sideguard introduction, or even increased slightly. This suggests that nearside impacts with an HGV that is “going ahead other” is the only category that sideguards have substantially affected.

In accidents involving pedestrians colliding with the side of an HGV going straight ahead there was also a reduction (20%) in the proportion that were fatally injured when sideguards were fitted but no reduction in serious injuries. Again, other accident mechanisms did not show comparable reductions.

A separate analysis was carried out to assess whether vehicles that were exempt from fitting sideguards were over represented in the later accident statistics (when most vehicles in the fleet would have been fitted with sideguards). Table 3 shows the results for accidents where the HGV was travelling straight ahead and impacted on the nearside.

<table>
<thead>
<tr>
<th>Exempt</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
<th>Total</th>
<th>KSI</th>
<th>Vehicle Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exempt</td>
<td>6</td>
<td>18</td>
<td>22</td>
<td>46</td>
<td>24</td>
<td>92.3</td>
</tr>
<tr>
<td>Not Exempt</td>
<td>5</td>
<td>34</td>
<td>103</td>
<td>142</td>
<td>39</td>
<td>317.8</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>52</td>
<td>125</td>
<td>188</td>
<td>63</td>
<td>410.1</td>
</tr>
<tr>
<td>% Exempt</td>
<td>54</td>
<td>35</td>
<td>18</td>
<td>24</td>
<td>38</td>
<td>23</td>
</tr>
</tbody>
</table>

It can be seen that the proportion of exempt vehicles increases in accidents of increasing severity and that the proportion involved in KSI accidents is much greater than the vehicle stock suggests should be the case. These differences are statistically significant, again demonstrating the benefits of fitting sideguards in this type of collision.

These statistical analyses were supported by case studies from the TCIS database and the HVCIS fatal database.

6.3 Analysis

The introduction of sideguards was intended to prevent pedal cyclists from falling into the space between the axles of a passing HGV and being run over by the rear wheels. It was also thought there may be additional benefits for pedestrians that fall into the same region of the HGV. The analysis in this report has, therefore, focused on types of accidents where these situations may arise.

The computer simulation compared the loads transmitted to, and injury criteria sustained by, pedal cyclists and pedestrians falling against the side of an HGV moving in a straight line and equipped with either traditional rail type sideguards or smooth integrated sideguards. The results of the simulation showed that a traditional sideguard design was very effective at preventing the upper body of vulnerable road users from being run over by the rear wheels. However, it also showed that it was
possible for the vulnerable road user to still receive severe injuries which could prove fatal, particularly head injuries resulting from contact with the ground.

When studying the national accident data there was considerable evidence to support the simulation findings that current sideguards prevent cyclists being run over by an HGV travelling straight ahead. The injury severity distribution for cyclists colliding with the nearside of an HGV has changed substantially with a 61% reduction in the proportion of casualties killed. In addition to this it was shown that exempt vehicles were statistically over-involved in accidents of this type.

The findings of the simulation study can be further supported by case studies from the HVCIS fatal database and the TCIS. The TCIS contained two cases where the presence of a sideguard had prevented a fatality but had still allowed the cyclist's legs to be run over by the rear wheels causing severe long term impairment. The simulation runs showed that while the upper body was thrown quite violently away from the vehicle the legs often remained quite close to the wheels.

However, there was much less accident evidence of the effectiveness of sideguards in other manoeuvres and where pedestrians were involved. There were suggestions that exempt vehicles might be over-involved in these accident types but those suggestions were not statistically significant at the 95% confidence interval. The changes to the injury severity distribution were much smaller than for cyclists colliding with the nearside of HGVs going straight ahead and in some cases small increases in the proportions of serious injuries were evident. Case studies from the fatal and TCIS databases suggested that the reason for this might be that the accident mechanisms are different. For example, the pedestrians in these databases were typically walking into the side of vehicles rather than falling against them.

The simulation of the integrated guard designs predicted that vulnerable road users would typically receive much lower loadings and reduced injury criteria compared with the traditional rail design. However, translating the predicted benefits in terms of load and injury criteria to predicted reductions in the number of fatal and serious casualties in road accidents is complex and necessarily involved a number of assumptions resulting in a range of estimated benefits. The analysis was divided into two parts:

- The benefits of ending exemptions to current regulations
- The benefits of fitting smooth integrated sideguards to HGVs

The benefits of ending the exemptions from the sideguard regulations were estimated based on the enhanced STATS19 data. The proportion of registered vehicles that are not exempt and are involved in accidents was calculated. This proportion was then applied to the total number of registered vehicles in the fleet to estimate the number of casualties there would be if the exemptions were ended. For example, for fatalities where the HGV was overtaking a moving vehicle there were nine fatalities caused by vehicles fitted with sideguards, this is equivalent to 0.0028% of vehicles in the fleet fitted with sideguards. If this rate of involvement is applied to the whole vehicle fleet of 410.1 thousand vehicles, it is anticipated that there would be a total of 12 fatalities. When compared with the total of 14 fatalities involving all HGV types from the accident data, this equates to preventing 2 fatalities over the three year period. Table 4 shows the estimated number of casualties that may have been prevented between 1990 and 1992 if there were no vehicle exemptions.
Table 4. Estimated change in number of casualties as a result of ending exemptions to sideguards

<table>
<thead>
<tr>
<th>Vehicle stock values</th>
<th>Change in number of casualties</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedal cyclists (HGV going ahead other)</td>
<td>Mid</td>
<td>-2.4</td>
<td>+1.2</td>
<td>+12.6</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>-3.0</td>
<td>-1.8</td>
<td>+27.4</td>
</tr>
<tr>
<td>Pedal cyclists (HGV overtaking moving vehicle)</td>
<td>Mid</td>
<td>-4.5</td>
<td>-5.8</td>
<td>+7.9</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>-4.9</td>
<td>-10.6</td>
<td>+0.4</td>
</tr>
<tr>
<td>Pedestrians (HGV going ahead other)</td>
<td>Mid</td>
<td>-0.7</td>
<td>-3.1</td>
<td>-11.4</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>-2.6</td>
<td>-12.4</td>
<td>+94.8</td>
</tr>
</tbody>
</table>

Table 5 shows the estimated percentage of pedal cyclist and pedestrian casualties that may be prevented by ending exemptions

Table 5. Estimated percentage of casualties prevented by ending exemptions to sideguards

<table>
<thead>
<tr>
<th>Vehicle stock values</th>
<th>Percentage change in number of road user casualties</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedal cyclists</td>
<td>Mid</td>
<td>-5.5%</td>
<td>-1.5%</td>
<td>+1.5%</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>-6.3%</td>
<td>-2.3%</td>
<td>+2.1%</td>
</tr>
<tr>
<td>Pedestrians</td>
<td>Mid</td>
<td>-0.3%</td>
<td>-0.3%</td>
<td>+0.7%</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>-0.9%</td>
<td>-1.4%</td>
<td>+6.3%</td>
</tr>
</tbody>
</table>

The number of pedestrians and pedal cyclists injured in accidents involving HGVs in the year 2000 is shown in Table 6 (DfT. Road Accidents Great Britain, 2001)

Table 6. Actual and predicted casualties for 2000.

<table>
<thead>
<tr>
<th>Road user</th>
<th>Actual number of casualties (2000)</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedal cyclist</td>
<td>30 100 373 503</td>
<td>30</td>
<td>100</td>
<td>373</td>
<td>503</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>97 169 454 720</td>
<td>97</td>
<td>169</td>
<td>454</td>
<td>720</td>
</tr>
</tbody>
</table>

Predicted number of casualties (zero exemptions)

<table>
<thead>
<tr>
<th>Road user</th>
<th>Mid</th>
<th>Lower</th>
<th>Mid</th>
<th>Lower</th>
<th>Mid</th>
<th>Lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedal cyclist</td>
<td>28.35</td>
<td>28.11</td>
<td>98.5</td>
<td>97.7</td>
<td>378.6</td>
<td>380.8</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>96.7</td>
<td>96.13</td>
<td>168.49</td>
<td>166.63</td>
<td>457.2</td>
<td>482.6</td>
</tr>
</tbody>
</table>

Predicted change in number of casualties

<table>
<thead>
<tr>
<th>Financial value of change (£)</th>
<th>Total change</th>
<th>-1.95</th>
<th>-2.76</th>
<th>-2.01</th>
<th>-4.67</th>
<th>+8.8</th>
<th>+36.4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-2,328,768</td>
<td>-2,507,410</td>
<td>-3,296,102</td>
<td>-3,546,029</td>
<td>626,667</td>
<td>91,080</td>
<td>376,740</td>
</tr>
</tbody>
</table>
It can be seen that this analysis predicts a reduction of approximately two fatalities per year if exemptions are ended. When all injury severities are considered it can be seen that, based on published values per casualty (DfT, 2001), there is a predicted net benefit of between approximately £2.5 million and £3.5 million per year.

An analysis of the HVCIS database used a probability method to assess the benefits of sideguards on a case by case basis. This analysis predicted that ending exemptions to sideguard regulations could prevent 4% of pedal cyclist fatalities and 1% of pedestrian fatalities. This is equivalent to a saving of 2.17 fatalities per year based on the above figures, which falls within the range predicted above.

The effect of smooth integrated sideguards on injury severity was assessed by considering injury risk data. The injury predictions from the modelling were used to estimate the risk of injury of different severities based upon published injury risk curves. The analysis considered only head injury criteria. This is because the forces that are applied to the chest and legs are not in the directions for which the model is designed. For example, the chest of the Hybrid III model is designed to be compressed from the front. The impacts with the HGV loaded the chest from the side so the injury predictions were low. Likewise, the legs are intended for axial loading, which did not occur in these types of HGV impact.

Injury risk curves for skull fracture and AIS≥3 brain injury were published by Prasad and Mertz (1985) and Mertz et al (1996a, 1996b). Adult cadavers were used to obtain biomechanical data, but were not normalised for size and mass effects and therefore the curves are representative of injury risk of the adult population. NHTSA (1999) expanded the Prasad and Mertz data, as shown in Figure 8.

![Figure 8. Probability of each specific injury level for a given HIC15](image)

Figure 8 was used to estimate the probability of the road user receiving injuries that are fatal (AIS 5 and 6), serious (AIS 3 and 4) or slight (AIS 1 or 2), or receiving no injury. The AIS levels associated with fatal, serious or slight injuries were assumed for the purposes of this analysis. It is possible that a
person receiving a single AIS 5 injury could live and also possible that a different person receiving one or more AIS 4 injuries could be killed but this has been ignored for the sake of simplicity.

The HIC values for comparison are based on the highest, the lowest and the average of all of the relevant model runs in order to enable a range of comparisons to be made. Using Figure 8 the probability of each injury severity has been estimated, as shown in Table 7, for all model runs where the cyclist collided with a passing HGV while initially positioned 0.75m from the HGV. The actual distribution of injury severity recorded in STATS 19 for the equivalent manoeuvre is included for comparison with the model predictions based on current designs of sideguard. STATS 19 does not contain information on uninjured persons. For that reason the predicted data in the table have been normalised to show the probability of injury of each severity as a percentage of all injuries, thus excluding uninjured persons.

<table>
<thead>
<tr>
<th></th>
<th>Actual STATS 19 data</th>
<th>Traditional Guard</th>
<th>Integrated Guard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Best run</td>
<td>Worst run</td>
<td>Mean all runs</td>
</tr>
<tr>
<td><strong>HIC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slight</td>
<td>64</td>
<td>1294</td>
<td>720</td>
</tr>
<tr>
<td>Serious</td>
<td>30</td>
<td>0</td>
<td>66</td>
</tr>
<tr>
<td><strong>Fatal</strong></td>
<td>6</td>
<td>0</td>
<td>8</td>
</tr>
</tbody>
</table>

It is clear from the results that the best case run for both designs of guard does not represent all of the collisions occurring on the road because for both guards it is predicted that there will be no chance of serious head injury. The HIC results varied quite considerably between model runs depending on the exact location of the impact on the sideguard. If head injury were the only injury that occurred in real life, and the mixture of impact positions used in the modelling was perfectly representative of the collisions that occurred in real life, then it might be expected that the predicted distribution from the average of all of the traditional guard simulations would match the actual distribution exactly. In reality, a number of factors that cannot be quantified will influence the real figures. For example, not all HGVs are fitted with sideguards, there are a wide variety of designs in service, collisions will have occurred in areas of the side not protected by the sideguard, some cyclists may have worn helmets and it will not always have been the head that was the most severely injured body region. However, despite this, the actual injury distribution in STATS 19 is very close to that predicted by averaging all of the relevant model runs and is within the range predicted by the average and worst case runs. In addition to this, case studies from in-depth databases studied have suggested that head injury is one of the most common injuries received in this type of accident.

It can also be seen that the predictions for head injury with the integrated guard predict a very impressive performance. The results are much less variable than for the traditional guard as might be expected given the uniform structure of the integrated guard. For the reasons described above it is not possible to make absolute firm predictions of benefits based on the data available because many other factors could be involved in the accidents. For that reason a range of predictions have been made based on:

- The change from predicted worst case traditional guard to predicted worst case integrated guard (Method A)
- The change from predicted average traditional guard result to predicted average integrated result (Method B)
• The change from actual injury distribution (going ahead other) to predicted worst case injury distribution. (Method C)
• The change from actual injury distribution (overtaking moving vehicle) to predicted worst case injury distribution. (Method D)
• Previous estimates from the HVCIS project based on case analysis (Method E)

The predicted injury distributions were applied to the STATS 19 figures from the year 2000 for the specific accident configurations (i.e. only the two manoeuvres and nearside impacts) to estimate the annual casualty reduction potential.

The analysis showed that Methods B and D formed the outlying estimates of the range. Table 8 summarises the results.

### Table 8. Predicted benefits of an integrated guard for cyclists

<table>
<thead>
<tr>
<th></th>
<th>Method B</th>
<th>Method D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
<td>Serious</td>
</tr>
<tr>
<td>Average traditional</td>
<td>3%</td>
<td>28%</td>
</tr>
<tr>
<td>Average integrated</td>
<td>0%</td>
<td>13%</td>
</tr>
<tr>
<td>Change</td>
<td>-3%</td>
<td>-15%</td>
</tr>
<tr>
<td>Number of P/C casualties (2000)</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>Proportion in Manoeuvre of interest</td>
<td>21.5%</td>
<td>25.7%</td>
</tr>
<tr>
<td>Percentage of all P/C casualties</td>
<td>-0.65%</td>
<td>-3.9%</td>
</tr>
<tr>
<td>Change in number of casualties</td>
<td>-0.2</td>
<td>-3.9</td>
</tr>
<tr>
<td>Financial value (£)</td>
<td>-238,848</td>
<td>-523,341</td>
</tr>
</tbody>
</table>

It can be seen that the predictions range from preventing one fatality every five years to saving three fatalities every two years. When the financial values are considered the benefits range from a saving of £0.581 million to a saving of £2.134 million per year, if the effect on serious and slight injuries for the upper boundary, where no information is available, is assumed to be the same as that for the lower boundary.

It is considered that the predictions based on the work in this report formed a pessimistic estimate because they ignored the benefits of integrated guards seen in the modelling, in terms of reducing the forces through other parts of the body that can also, reasonably, be expected to reduce injury severity. It has also been assumed that vulnerable users that collide with the side of an HGV will always receive at least slight injuries, so no benefits from reducing slight injuries to uninjured are considered. It is also possible that the integrated guards will have some benefit in other manoeuvres such as turning left, going ahead on a bend or reversing and at other impact points such as the offside. These possible benefits have also been ignored.

The previous estimates made in the HVCIS project considered the possible benefits in all situations on a case by case basis. However, at the time of that analysis the benefits had not been quantified so well in physical terms because no test or simulation data was available. It is, therefore, reasonable to expect these to be optimistic estimates such that the actual benefits will lie somewhere between the two.

The simulation work suggested that there should be very substantial benefits to pedestrians that fall against the side of HGVs. However, the comparison of actual injury severity distribution in STATS 19 before and after the introduction of sideguards suggested that this more fundamental change had
only resulted in a moderate decrease in the proportion of pedestrians fatally injured and no substantial change to the proportion that were seriously injured. Case studies from the TCIS and fatal databases suggested that pedestrians tended to suffer different accident mechanisms to pedal cyclists and did not often simply fall into the side of a passing HGV. This research, therefore, suggests that the benefits to pedestrians when they do suffer a simple fall against the side of an HGV are greater than they are for pedal cyclists, but that they suffer that accident mechanism less frequently than pedal cyclists such that the overall benefits of sideguards is less for pedestrians compared with pedal cyclists.

For the purposes of this study, the safest assumption to make for a prediction of a lower boundary for the benefits of integrated guards for pedestrians is that they will have zero benefit. This is because, although it is clear from the simulation that they have the potential to offer substantial benefits to pedestrians it is not so clear from the accident analysis that this potential is likely to translate into casualty savings. An analysis of fatal accidents estimated that fitting such integrated sideguards could prevent up to 3% of pedestrian fatalities. This can be assumed to be the upper boundary of likely benefits. Based on the STATS 19 data for 2000 this would result in a saving of approximately two or three fatalities per year.

Table 9 summarises the predicted benefits of ending exemptions and using integrated smooth sideguards.

### Table 9. Summary of casualty savings

<table>
<thead>
<tr>
<th>Measure</th>
<th>Change in number of casualties</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fatal</td>
<td>Serious</td>
<td>Slight</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower</td>
<td>Upper</td>
<td>Lower</td>
<td>Upper</td>
<td>Lower</td>
</tr>
<tr>
<td>End exemptions</td>
<td>Pedal cyclist</td>
<td>-1.65</td>
<td>-1.89</td>
<td>-1.5</td>
<td>-2.3</td>
<td>+5.6</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>-0.3</td>
<td>-0.87</td>
<td>-0.51</td>
<td>-2.37</td>
<td>+3.2</td>
<td>+28.6</td>
</tr>
<tr>
<td>Fit smooth sideguards</td>
<td>Pedal cyclist</td>
<td>-0.2</td>
<td>-1.5</td>
<td>-3.9</td>
<td>-3.9</td>
<td>+17.5</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>0</td>
<td>-2.91</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>-2.15</td>
<td>-7.17</td>
<td>-5.91</td>
<td>-8.57</td>
<td>+26.3</td>
<td>+53.9</td>
</tr>
</tbody>
</table>

Financial value (£) (RAGB, 2001)

|                                |       |       |       |       |       |       |
| Total                          | -2,567,616 | -8,562,701 | -793,063 | -1,150,083 | +272,205 | +554,760 |
| Net benefit (Lower)            | -3,088,474 |       |       |       |       |       |
| Net benefit (upper)            | -9,158,024 |       |       |       |       |       |

It can be seen that there are benefits to refining the design of sideguards. However, this analysis has shown that these estimated benefits are small in comparison with the benefits that were obtained by introducing sideguard regulations.
7 Height compatibility between tractor and trailer

It has been found in a previous study and in other surveys that the ground clearances of trailer sideguards in service are sometimes greater than the 550mm maximum required. It has been suggested that this may be because the wording of the sideguard regulations is such that they specify that the ground clearance is measured when the load bed of the trailer is flat and level. However, the height of the fifth wheel and the height of the trailer king pin can vary such that when some vehicles are combined the load bed of the trailer is higher at the front than it is at the rear.

The work on this aspect of the project has involved studying the regulations and standards controlling the compatibility of tractors and trailers and the design of sideguards to identify the scope of the problem. Three potential solutions are proposed:

- Introduce adjustable sideguards
- Reduce the allowable ground clearance
- Rerword the regulation

The feasibility of these options has been assessed based upon analysis of the physical problems and consultation with industry and recommendations of the most cost-effective way to solve the compatibility problem have been made.

7.1 Regulations and standards

The current sideguard regulation (UN/ECE Regulation 73) states that the ground clearance of the sideguard should be measured when fitted to the vehicle and the vehicle should:

- be unladen
- be positioned on a horizontal and flat surface
- have semi-trailers positioned on their supports in an essentially horizontal manner

Therefore, for every vehicle combination where the trailer is travelling in a horizontal condition the ground clearance of the sideguard should conform to the 550 mm maximum imposed by the Regulation. However, the trailer of an articulated vehicle does not always travel in a horizontal condition in service. The height of the 5th wheel of the tractor unit and the height of the trailer king pin at the point where the trailer is horizontal will determine the angle of the trailer and the resulting ground clearance of the sideguard. These heights will be determined by vehicle design but are also affected by the load condition of the vehicle.

The height from the ground of the 5th wheel is governed by ISO 1726, which regulates the Interchangeability of tractor and trailer units. There are also European Regulations (Regulation 55) regarding the strength and dimensions for 5th Wheel couplings, but this is irrelevant to sideguard heights. To understand the issues with the tractor and trailer compatibility these standards were investigated.

Interchangeability means that any tractor unit should be able to hitch up to, and pull any trailer. In order to facilitate the interchangeability there is an International Standard, ISO 1726. This standard places requirements on the fifth wheel’s height above the ground, the trailer’s front overhang and its gooseneck, as well as the free clearance between the tractor and trailer when manoeuvring. The tractors and trailers that comply with the requirements of this standard in theory can be combined with each other and meet the regulatory requirements.
7.1.1 The fifth wheel’s height above the ground

The standard specifies heights for the 5th wheel in both the laden and unladen states. With the trailer loaded the fifth wheel is required to have a height of 1200 mm above ground level, with a permissible variation of 100 mm higher or 50 mm lower. However, with the trailer unloaded the height of the fifth wheel should not exceed 1400 mm above ground as shown in Figure 9 below.

![Figure 9. Diagram of laden and unladen 5th wheel height requirements](image)

If the trailer has been built to meet the lateral protection regulation (UN ECE regulation 78) then there should be no issues with the ground clearance of the side guards. However there is the scope of the setups of the tractor and trailer to potentially exceed the side guard clearance requirement. For example, if a tractor unit is designed such that when unladen the 5th wheel is 1400 mm from the floor is coupled to a trailer (as shown in Figure 10) that is horizontal when the king pin is 1250 mm from the floor then the king pin height will be 150 mm higher when attached to the tractor unit. If the sideguard is 550 mm from the ground when horizontal and the king pin to front of sideguard length is approximately 2750 mm and the king pin to trailer bogie (centreline of middle wheel) length is 7900 mm, then the height of the leading edge of the sideguard will be \((150 \times (7900 - 2750))/7900 = 97.8\) mm higher than the 550 mm requirement. This was calculated as follows

Before

\[
\tan \alpha = \frac{1250}{7900}
\]

\(X = 2750\) mm from king pin therefore

\(X = (7900 - 2750) \tan \alpha\)

\(X = 5150 \times (1250/7900)\)

Increase in height = \((150/7900) \times 5150 = 97.8\) mm

After

\[
\tan \beta = \frac{1400}{7900}
\]

\(Y = 2750\) mm from king pin therefore

\(Y = (7900 - 2750) \tan \beta\)

\(Y = 5150 \times (1400/7900)\)
7.1.2 The trailer’s front overhang and gooseneck

The greatest distance from the king pin to a point on the trailer in front of the king pin must not exceed 2040 mm. This corresponds to a front overhang of 1612 mm on a trailer which is 2500 mm wide. On an ISO trailer, the length of the gooseneck from the king pin and rearwards (G) is 2300 mm. The detailed measurements are given in Figure 11. However, for non ISO trailers these dimensions may be different and under certain conditions this may result in the sideguard exceeding the maximum required 550 mm ground clearance.

7.1.3 Free clearance when manoeuvring

If the vehicle is driven on an uneven surface, depressions or crowns, the tractor and trailer are angled in relation to each other. The lengthways angle $\alpha$ between the tractor unit and the trailer is referred to as the trailer inclination forwards ($\alpha_1$)/rearwards ($\alpha_2$) and the sideways angle $\beta$ is referred to as the sideways inclination of the trailer. The manoeuvre angle $\gamma$ is the angle horizontally between the tractor and trailer when the vehicle turns. The manoeuvring requirements are shown in Figure 12.
Manoeuvring requirements

The tractor unit and trailer must clear each other in the following manoeuvres, assuming the following definitions of free space:

- When travelling straight ahead, the trailer must be able to lean 6° forwards ($\alpha_1$) or 7° backwards ($\alpha_2$).
- When travelling straight ahead, the trailer must be able to lean 3° sideways ($\beta$).
- When turning (manoeuvre angle $\gamma$) between 0° and 25°, the trailer must be able to lean backwards ($\alpha_2$).
- From inclination 7° backwards ($\alpha_2$) in a 25° turn (manoeuvre angle $\gamma$) the demand that the trailer should be able to lean backwards falls off progressively to 3° rearwards inclination ($\alpha_2$) in a 90° turn (manoeuvre angle $\gamma$).
- For turns (manoeuvre angle $\gamma$) from 25° up to 90°, inclination angle ($\alpha_2$) falls off from 7° to 3°, so that it should be able to lean 5° backwards in a 57.5° turn.

Different tyre sizes, spring rates or fifth-wheel heights between tractor unit and semi-trailer reduce these angles so that they no longer comply with the standard.

Figure 12: Manoeuvring requirements

7.1.4 Location

The fifth wheel’s location is controlled by the permitted axle load, permitted vehicle length as well as whether interchangeability is required. To achieve the permitted axle loading, the fifth wheel shall be located in a set position following a set of calculations.

For international transport, the location often needs to be adapted to suit the interchangeability requirements above. The vehicle’s total length must not exceed the current regulations governing length.

On vehicles with a fixed fifth wheel delivered from the factory, you can select location in 25 mm steps from the final drive/leading rear axle. Hole centres are spaced at 50 mm. Increments of 25 mm can be obtained by turning the fifth wheel round, since its centre is 12.5 mm offset from the king pin.

7.2 Options

It is proposed that there are three feasible options to address the problems with sideguard clearance exceeding the maximum ground clearance. These options have been discussed with industry to get an idea of their feasibility and practicality. The options are:

1. Provide adjustable side guards.
2. Reduce the allowable side guard clearance for trailers.
3. Adjust the wording in the Regulation
There is a potential 4th option and that is to do nothing. This option will be the least disruptive to the industry but will not ensure that all the side guards meet the required regulation.

7.2.1 Option 1 - Provide adjustable side guards.

Adjustable side guards are a potential way to allow the side guards to always meet the maximum ground clearance. Most side guards have been found to be made of aluminium alloy channel and consist of two rails and three supports. However, there are other sideguard constructions such as panel guards that may make adjusting the height very difficult. A simple option of providing the adjustability is to have a simple locking pin idea, as shown in Figure 13. This would allow the driver to adjust the sideguard once the trailer is loaded so that the ground clearance is within the permitted tolerance.

![Figure 13. Diagram of a simple adjustable sideguard.](image)

As Figure 13 shows the concept is very simple, however in practice it will be very difficult to ensure that all the side guards are adjusted correctly. Also the truck operators may not tolerate the extra time for checking and adjusting the side guards. To ensure that the side guards are set correctly for the tractor and trailer setup, without the need for driver interaction, an ‘intelligent’ system could be used. Intelligent systems could be hydraulic/pneumatic such that it adjusts itself once the vehicle is loaded by having a sensors along the length of the sideguard that detect inclination of the trailer and then feedback to a control unit that then adjusts the guards to set clearance if required. Such systems would be more expensive to implement, but would ensure that the side guards are always within the regulatory ground clearance, despite any tractor/trailer compatibility issues or irregular loadings on the trailer.

7.2.2 Option 2 - Reduce the allowable side guard clearance

To ensure that the sideguard clearance is satisfactory in all situations the allowable sideguard clearance could be reduced to say 400 mm. Reducing the clearance will result in safer vehicles and provide a potential benefit to pedestrians and cyclists. Knight (1998) concluded that fitting side guards with a reduced ground clearance, 350 to 400mm, to all HGVs would increase savings to 13% and 2% for pedal cyclists and motorcyclists respectively. Another paper by Stöcker (1990) concludes that a ground clearance of 550 mm (as permitted by EC Directive and UK Construction and Use Regulations) is too high - it should be no more than 300 mm unless special operating conditions require it to be greater than this. The justification for lowering the requirement would be the potential benefits in the reduced number of casualties.

7.2.3 Option 3 - Adjust the wording in the regulation

A simple solution is to adjust the wording in the Regulation such that it requires side guards to always have less than 550 mm clearance in service. The current sideguard regulations (UN/ECE Regulation 73) states that the checked vehicle should:

- be unladen
be positioned on a horizontal and flat surface

- have semi-trailers positioned on their supports in an essentially horizontal manner

In theory if the regulations are followed, a semi-trailer can be checked and passed with appropriate clearance, but as soon as the trailer is attached to a tractor unit then the sideguard clearance could then be outside the regulatory requirements. To solve this particular problem for semi-trailers the third clause could be replaced by one that states

- when the height of the trailer from the ground, measured immediately adjacent to the king pin is 1400 mm

This would, therefore, position the trailer in the condition that would be represented by the highest 5th wheel height permitted by the ISO standard. An additional clause may be required that states that the ground clearance may not exceed 550 mm at any point along its entire length in order to avoid measurements being taken at the lowest point of a sloping sideguard.

Such a requirement will have the effect that where a tractor unit with a 5th wheel at the lower end of the tolerance permitted by the ISO standard tows a laden trailer the ground clearance of the sideguard will be lower than the 550 mm permitted. An example of this can be seen by looking at the trailer in Figure 10 and as long as the kingpin height does not exceed the 1250 mm then the sideguards should not exceed the ground clearance requirement.

One advantage for such an option is that once the tractor and trailer have been checked there are no requirements for the driver to adjust anything. This option will also not involve any great additional costs, except that the checking process may take a little longer.

7.3 Discussion

The ideas have been devised around options that were deemed as appropriate to ensure that the sideguard clearance of 550 mm is always met. There may be a number of other options to ensure that the 550 mm requirements is met, however for this study only the three presented in section 3 were considered. Alternative options were requested from manufacturers however, no new ideas were presented.

7.3.1 Consultation with industry

To gauge the feasibility and practicality of the ideas highlighted in section 3, tractor and trailer manufacturers were contacted. Although a number of contacts were made, the amount of useful comments was limited, with the general response stating that there is no real problem. However the feedback gained from some manufacturers has highlighted a number of different views on the ideas. The following is an opinion from one trailer manufacturer and it sums up the general ‘no problem’ response:

‘Interesting subject and not really controversial from my window....

_The world has turned for many years with no side guards. The Dutch invented the side guard as a tube long before the EEC stepped in; the French are still using a single bar but will change to comply with EEC Directive 89/297 in 2005._

_Where is the problem? are we trying to raise a problem which only exists perhaps in the UK because the fifth wheel is generally higher than in most European countries ...the reason being : wings are fitted to the tractors and therefore a sub-frame has to be built to raise the fifth wheel up to a traditional figure of 52” as far as I can read we have one law and it is the EEC Directive 89/297 this in my opinion supersedes even in some way ISO references and local or regional laws...._
Is 30 mm higher or lower going to kill more cyclists than today..... or stop the nose of a car to go under the trailer ????

....ISO is a practical and generally accepted guideline but it is not a law at all. The EEC directives are applicable laws across the whole of Europe. Are we trying to solve a situation which is perhaps just a UK situation?’

This is a very strong opinion against introducing change and demonstrates the tough opposition that may be faced if changes were to be introduced. However, such strong opinions are not held by all the manufacturers and some gave constructive feedback on the options. There is perhaps a valid point about the cyclists however it is also important to have a regulation that can be enforced in service.

7.3.1.1 Option 1

Providing adjustable side guards was not accepted as a suitable solution and those consulted believed that although it seems good on paper, it probably would not work in practice. The following are two opinions from industry on having adjustable side guards:

- ‘Adjustable side guards are not an option, it will never be accepted due to the extra time/work required for the operator of the truck. And the cost for a hydraulic/pneumatic device is not acceptable. If it would become a requirement anyway, the guards will in real life always be positioned in its upper-most position and hence no positive effect is achieved.’
- ‘Side guards have to survive in a rather harsh environment - vibration due to road surfaces and most of all having to survive knocks from loading equipment. I really do not see that side guards could be made cost effectively and robust enough and be able to be adjustable in this way.’

As the feedback shows the feasibility of such an idea is very low. There would be a number of issues to overcome such as cost, time to adjust, robustness etc. The issue with robustness may be overcome as the fixings could be just as strong as the current guards that are often bolted in place.

7.3.1.2 Option 2

As previously discussed, Option 2 involves reducing the allowable clearance. This idea had the most feedback as it is simple; however it does involve minor design changes for the trailer manufactures. Some of the opinions received are shown below:

- ‘A reduction of allowable clearance is a more feasible way, although it will not be met with enthusiasm (as any new requirement).’
- ‘There is no stated legal minimum clearance and in practice 400 mm would not be a problem. Having a range of 400 mm (a sensible minimum) and 550 mm (the legal max) allows plenty of tolerance to allow for the variations in tractor fifth wheel heights. The only problem can be if manufacturers assume (incorrectly) that the 550 mm is a minimum as well as a maximum setting.’
- ‘To lower the maximum lower height to 400 mm would be a real problem for trucks and trailers when going over humps in roads and worse hump back bridges. Are side guards really so badly out of alignment with the regulations that such complex solutions need to be considered?’

The feedback shows that this option was met with mixed feelings, although it seems more feasible than Option 1. The ground clearance of sideguards remains a contentious issue, although there is considerable evidence to show many trucks and trailers do voluntarily have sideguards with clearances of 400 mm or even less.
7.3.1.3  Option 3

This option seemed to be the easiest to implement and the feedback produced no negative comments. The feedback on this option was limited, however the following comment provides a view from industry on how the regulation could be changed:

- ‘…wouldn’t it be more correct to state that the requirement (550 mm) should be met regardless of loading condition etc, like the requirements on FUP We cannot make regulations tougher than needed due to some that do not fulfil the requirements.’

It is essential that any changes to the wording of the regulation are absolutely clear and unambiguous. The wording could be based on the worst case permitted by the ISO standard or could simply state that it must always be less than 550 mm. The EC Directive for front underrun protection does offer a precedent in this respect and similar wording could be used. The EC Directive (Regulation 96) states:

‘The maximum ground clearance with respect to the underside of the FUPD shall be no more than 400 mm, as specified in Paragraph 2 of annex , between the two points P1 in the installed condition.

Annex 5 Paragraph 2:

Dimensions shall be taken as if the vehicle was in the following condition:

- The vehicle was unladen
- The vehicle was at rest on a level, flat, rigid, smooth surface.
- The front wheels were in the straight-ahead position
- The tyres were inflated to the pressure recommended by the vehicle manufacturer
- Vehicles equipped with hydropneumatic, hydraulic or pneumatic suspension or a device for automatic levelling according to load were in their normal running condition specified by the manufacturer.’

7.3.2  Feasibility of the ideas

From the feedback received it is possible to see that different manufacturers see the options in different ways and it will be impossible to ensure that any change is met with enthusiasm. Some of the options will be less disruptive to industry, but the exact impact is currently unknown. To get an idea of the feasibility of each option the ideas were rated against various criteria to get an overall rating. The options were scored on a scale of 1 being poor, 2 being OK and 3 being good and the final results of the assessment are shown in Table 10 below. The cost of implication is a very basic assessment of the estimated costs of having to implement a change in design and refitting current vehicles. The cost does not consider any legal costs or costs due to delay in business due to refitting or cost to manufacturers for new tooling.
Table 10. Feasibility rating of the options

<table>
<thead>
<tr>
<th></th>
<th>OPTION 1</th>
<th>OPTION 2</th>
<th>OPTION 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of implementation</td>
<td>1 Expensive will require substantial design and construction investment</td>
<td>2 May require additional design costs for manufacturers</td>
<td>3 The cheapest option, but there may be small design costs for manufacturers</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>2 Adjustable sideguards are good, but effectiveness is reduced due to the operator not necessarily using them</td>
<td>3 Will mean that the current requirements are met</td>
<td>3 Would ensure that the clearance is met, however will take time to implement</td>
</tr>
<tr>
<td>Ease of implementation</td>
<td>1 Difficult to get operators to use and would be expensive to implement</td>
<td>2 Would be difficult to implement due to opposition to changes in regulation</td>
<td>3 Is the easiest to implement, but may be met with opposition</td>
</tr>
<tr>
<td>Potential benefits</td>
<td>2 Would be good but the rating is reduced to the potential lack of use</td>
<td>3 This option has the highest benefits to cyclists and pedestrians</td>
<td>2 Would ensure that the 550mm is met, but not give the added protection of option 2</td>
</tr>
<tr>
<td>Effect on regulatory requirements (are the options making the requirements tougher?)</td>
<td>3 no change</td>
<td>1 new requirements on sideguard clearance, tougher to meet.</td>
<td>2 changes are not compulsory but may be required for certification</td>
</tr>
<tr>
<td>Feasibility Rating</td>
<td>9/15</td>
<td>11/15</td>
<td>13/15</td>
</tr>
</tbody>
</table>

3 = Good, 2 = OK and 1 = Poor

By comparing the relative options it can be seen from Table 10 that Option 1 is the least feasible. Option 1 would be too expensive to implement and it would involve a number of modifications to be made by the trailer manufacturers and a range of adjustment to be specified in the regulation. The idea would also require the drivers to ensure that the setup is correct, which in practice is very unlikely to happen and hence the option have very little effect. However Options 2 and 3, appear to be better in terms of the lack of disruption they will cause, but as previously discussed they too will not be greeted with enthusiasm within the industry. Table 10 shows that Option 3 is the best as it will not involve manufacturers to change any designs unless issues arise with certain 5th wheel setups. If Option 3 was to be considered then the correct rewording of the regulation would have to be discussed. If changes were to be made to the regulation then changing the sideguard clearance height should also be considered as the feedback from industry and previous research has shown that this will provide additional benefits to pedestrians and cyclists. As well as the options presented there is also the option to do nothing, so before any decision on the feasibility of implementing any of the options, the cost/benefits of each option and benefits to road users needs to be investigated.
7.4 Conclusions on height compatibility

1 International Standard (ISO 1726) specifies heights for the 5th wheel in both the laden and unladen states. The standard is designed to make tractors and trailer interchangeable allowing any trailer to be hitched to any tractor unit and still meet the regulations.

2 Providing adjustable side guards is the least feasible option as it would be too expensive to implement and would involve a number of modifications to be made by manufacturers. Adjustable side guards may also require the drivers to ensure that the sideguard is adjusted correctly, which in practice is very unlikely to happen and hence the solution is ineffective.

3 Reducing the minimum clearance provided a number of mixed feelings from the consultation. Previous studies have shown that lowering the sideguard clearance will provide an increase benefit to the road users they are designed to protect.

4 Rewording the regulations is the most feasible option from those investigated, however if it was to be considered then the correct rewording of the regulation would have to be agreed.
8 The potential use of alternative materials

Creating an integrated safety guard and spray suppression system that improved impact protection to other road users, reduced aerodynamic drag, and using aerodynamics to control spray is likely to involve increasing the area that current safety guards occupy such that smooth flat surfaces are presented all around the vehicle with minimum gaps. In some areas, increased structural stiffness may also be required to improve impact protection. If this solution is applied as a traditional bolt-on extra to the vehicle using traditional materials it will increase vehicle weight and reduce payload and productivity, implying a cost burden to industry. The objectives of this part of the project were to consider whether the use of alternative materials in the construction of safety guards could reduce the weight penalty associated with that improvement in performance, thus minimising the costs to industry from reduced productivity. This part of the work is summarised in this section.

The work involved reviewing existing literature and data concerning the materials currently used in safety guards and using theoretical analysis of material properties and guard designs to identify alternative materials that could be used in future designs. Issues regarding the feasibility of using alternative materials including weight, strength, cost and recycleability were all considered as part of this study.

The work began by reviewing existing data on the dimensions and properties of sideguards in order to develop a typical current guard made from steel and another made from aluminium.

The force applied to sideguards in various collisions was also considered. These ranged from the current legislative requirements to protect pedal cyclists through to the forces that would be required to prevent a medium sized car from running underneath the trailer when colliding with it at angles of up to 90 degrees.

The properties of various materials were analysed in order to define those that might be suitable for safety guard construction and to identify their advantages and disadvantages. The analysis considered:

- Steel
- Aluminium alloys
- Advanced metals
- Glass fibre reinforced plastic (GFRP)
- Carbon fibre reinforced plastic (CFRP)
- Advanced composites
- Sandwich construction
- Recyclability of materials
- Costs
- Consideration of integrating guards of different materials
- Use of alternate vehicle designs

This strength and weight information was then combined with the geometries of typical sideguards to calculate the weight of the guards required for different materials and strength requirements. The results of this analysis are shown in Table 11, below.
## Table 11. Alternative materials summary table

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight of guard based on ‘typical’ dimensions (kg)</th>
<th>Weight of guard minimally compliant to 2kN load (kg)</th>
<th>Weight of minimally compliant full length semi-trailer guard (kg)</th>
<th>Weight of vehicle impact resisting guard</th>
<th>Weight of panel covering ‘typical’ guard (kg)</th>
<th>Approximate cost of materials (GBP/kg)</th>
<th>Approximate cost ratio of typical component</th>
<th>Recycleability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>33.1</td>
<td>7.5</td>
<td>18.2</td>
<td>14.7</td>
<td>103.1</td>
<td>19.5</td>
<td>0.30</td>
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<td>Aluminium alloy</td>
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<td>7.6</td>
<td>18.6</td>
<td>14.8</td>
<td>119.6</td>
<td>6.7</td>
<td>1.15</td>
<td>1 – 2</td>
</tr>
<tr>
<td>Magnesium alloy</td>
<td>7.6</td>
<td>7.2</td>
<td>17.7</td>
<td>13.9</td>
<td>134.0</td>
<td>4.5</td>
<td>2.75</td>
<td>2</td>
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<tr>
<td>Titanium alloy</td>
<td>19.1</td>
<td>7.6</td>
<td>18.5</td>
<td>14.8</td>
<td>109.2</td>
<td>11.2</td>
<td>3.60</td>
<td>10</td>
</tr>
<tr>
<td>GFRP</td>
<td>6.8</td>
<td>11.9</td>
<td>29.1</td>
<td>22.5</td>
<td>217.5</td>
<td>4.2</td>
<td>2.15</td>
<td>1.5</td>
</tr>
<tr>
<td>CFRP</td>
<td>7.2</td>
<td>2.8</td>
<td>6.9</td>
<td>5.5</td>
<td>40.8</td>
<td>4.0</td>
<td>6.25</td>
<td>1.7 - 4</td>
</tr>
</tbody>
</table>
It was found that the weight of the ‘typical’ current sideguard was calculated to be 33.1kg and 11.4kg for steel and aluminium respectively. This was compared to the weights of guards designed to be minimally compliant with the UK sideguard regulation, where a guard made from steel weighs 7.5kg and one made from aluminium is 7.6kg. This indicates that at present sideguards tend to be substantially over-engineered and are much heavier than they are required to be in order to meet the strength requirements in the regulations.

Steel guards have many features that make them the most common type currently in use. The primary reason is production cost, with steel guards being the cheapest to produce. Steel is very strong, which is able to counteract the major drawback of its high density. Another benefit is that it is easily recycled. Where the strength benefits of steel are not utilised it is a poor choice of material. This is illustrated by its high weight as a non-structural panel fitted on top of a conventional sideguard.

Aluminium sideguards are also commonly used for current vehicles. A ‘typical’ guard constructed from aluminium is considerably lighter than the steel equivalent but the minimally compliant aluminium guard is actually slightly heavier than its steel equivalent because of its lower strength properties. The low density of aluminium makes it suitable for the non-structural panel guard cover. Aluminium alloy is slightly more expensive than steel. As with steel, aluminium is easily recycled.

The other alternative metals considered, magnesium and titanium alloys, were found to provide few benefits in this application. Magnesium can offer only a very small weight saving over steel, while a titanium guard is heavier than the steel equivalent. Magnesium may be useable as a non-structural panel guard cover, however manufacturing such a panel may not be cost effective. Magnesium and titanium alloys can be readily recycled, but lack the infrastructure that is in place for steel and aluminium meaning the amount recycled at present is lower.

Glass fibre reinforced plastic (GFRP) was found to be a very ineffective material for constructing sideguards because of its very low strength requiring a large section size. However, it is ideal as a non-structural panel mounted on top of a sideguard and in the vehicle survey this was the most common material used for this purpose.

The high strength and low density of carbon fibre reinforced plastic (CFRP) were found to allow substantial weight savings over steel. This saving was found for all load cases considered, from a 4.7kg saving for the minimally compliant UK regulation guard to a 62.3kg saving for a guard designed to withstand a perpendicular car impact, when compared with the steel equivalent. CFRP also provides the lightest option for non-structural panels. Panels constructed using only carbon fibres and resin fail in a brittle manner which is unsuitable for safety guards. Therefore, it is necessary to include aramid fibres which are less strong but more ductile and prevent the brittle failure mechanism, increasing the complexity and cost of construction. CFRP can also suffer damage, such as delamination of the layers, when subjected to low energy impacts. Again, correct selection of the fibre and resin properties can prevent this. The cost of CFRP is highly dependent on the constituent materials but is up to 4 times more expensive per component than steel. Technology is currently being developed to use mass production techniques for CFRP with the intent of decreasing production costs.

Currently recycling GFRP and CFRP is not economically viable because it is difficult to separate the fibres from the resin matrix. The processes to recycle the thermoset polymer resin are also very expensive. Advances in recycling technology are required before recycling of these composites becomes economically viable.

When considering the results of this study the assumptions made in the calculations of guard strength must also be considered. By assuming constant EI material, yield or ultimate failure is not accounted for. The assumption of basic beam bending rather than more complex behaviour has also been made. For a more comprehensive analysis methods such as finite element analysis would be required.

The effect of integrating side and rear guards cannot be fully evaluated in terms of the materials used and the weight penalties or savings at this time because it is likely that a separate research project (VC-COMPAT) will recommend changes to the properties of front and rear underrun protection but the full findings are not yet known. However, a preliminary review identified that some problems could be encountered with corrosion and joining if different materials were used for side and rear.
These were not considered to be insurmountable. There could also be benefits in terms of weight if guards are integrated by allowing the sideguard structure to form part of the strength required for the rear underrun protection.

Alternative design strategies can also be used to provide an integrated solution using current and/or alternative materials. By placing the trailer frame structure at the outer edges the Krone SafeLiner is able to provide an integrated guard with increased lateral protection which is constructed from steel without a substantial weight penalty compared with traditional trailer designs.
9 Literature review – spray suppression

Below is a brief summary of the findings of the literature review with respect to safety guards.

Research into the effect of spray on other road users suggests that accidents due to spray are relatively rare or, at least, rarely identified. Research has found that cars are subject to dense spray from lorries for less than one percent of their driving time. However, spray from lorries has been ranked very highly as a nuisance factor in surveys of car drivers, this suggests that when spray does occur it presents a very serious nuisance and/or risk. Various researchers have attempted to quantify the contribution of spray to accidents but their estimates vary widely. Table 12, below, summarises these estimates.

Table 12. Summary of spray related accident research.

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Roads Studied</th>
<th>Length of Study</th>
<th>Severity of Accidents</th>
<th>% of wet weather accidents with splash/spray contribution</th>
<th>% of total accidents with splash/spray contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maycock (1966)</td>
<td>M1, M10, M45 Great Britain</td>
<td>3½ years</td>
<td>Casualty &amp; some damage only</td>
<td>1.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Forbes (1962)</td>
<td>A quarter of all accidents in Michigan State, including towns, cities and rural areas</td>
<td>1 month</td>
<td>Not specified</td>
<td>-</td>
<td>0.12</td>
</tr>
<tr>
<td>Forbes (1962)</td>
<td>All fatal accidents on Michigan State roads</td>
<td>2 years</td>
<td>Fatal</td>
<td>-</td>
<td>0.16</td>
</tr>
<tr>
<td>Casella &amp; Vivari (1973)</td>
<td>Connecticut roads</td>
<td>1 year</td>
<td>Fatal</td>
<td>-</td>
<td>0.36</td>
</tr>
<tr>
<td>Casella &amp; Vivari (1973)</td>
<td>Connecticut roads</td>
<td>5 years</td>
<td>Casualty &amp; damage only</td>
<td>-</td>
<td>0.012</td>
</tr>
<tr>
<td>Sabey (1973)</td>
<td>All roads in Great Britain</td>
<td>1 year</td>
<td>Casualty</td>
<td>18.5% (in rain) 9.5% (on wet roads) (Indirect estimates)</td>
<td>2.7</td>
</tr>
<tr>
<td>Storie (1984)</td>
<td>All motorways and A(M) roads in Great Britain</td>
<td>6 months</td>
<td>Casualty &amp; damage only</td>
<td>-</td>
<td>1.7</td>
</tr>
</tbody>
</table>

It can be seen that there are a wide range of estimates of the influence of spray, from 0.012% to 2.7% of all accidents. However, it must also be considered that the lowest four estimates are all based on USA data. It is possible that in the areas these studies were carried out the weather and/or road construction are different, which could affect the contribution of spray to accidents. In addition to this, many US states impose a speed limit of 55 mile/h, potentially changing the typical difference in speeds between HGVs and other road users. If only the UK studies are considered the estimates range from 0.4% to 2.7% of all accidents.
Currently spray suppression equipment is defined by regulations and standards and consists of one of two types of defined materials to be used around the wheel arch and mudflap area. However a number of papers related to the use of aerodynamics to control spray all agreed that substantial improvements could be gained in relation to the current suppression devices. However it was considered that in order to assess the benefits of aerodynamic spray control it would be necessary to develop a whole vehicle performance test.

The literature review identified a number of aerodynamic spray suppression devices. Air Fenders Systems have designed a wheel guard (Figure 14) that has a side shield to enclose the wheel. It uses and controls the flow of air around the wheel to suppress spray formation.

![Figure 14. AirFender™ wheel guard](image)

The Krone SafeLiner trailer is an example of a vehicle design that claims to improve spray suppression as well as the aerodynamics of the vehicle and the protection offered to other road users in collision with it. The SafeLiner has a space frame with load bearing external chassis members and enclosed axle housing which forms an aerodynamic, fully enclosed chassis (Figure 15).

![Figure 15. Krone Safe Liner trailer](image)

A British company manufacture a device called QuickWing (Figure 16). It is a moulded mudguard that partially covers the wheel. It is claimed that it can be removed in 5 seconds to enable quicker removal and refit of road wheels, whilst also improving fuel economy and reducing spray emissions.

![Figure 16. QuickWing spray suppression device](image)
Researchers generally agree that little spray is generated below speeds of 30 mile/h (48 km/h). Beyond this speed, the amount of spray generated increases with speed. The results of past research disagree on the effect of tread design and depth on spray generation. Some believe that tread depth has little effect but others believed the effect could be quite substantial. Past research showed that the vehicle load has a negligible effect on spray generation.

All of the literature agrees that water depth has a substantial effect on spray generation until a critical depth is achieved when the tyre is already saturated with water and cannot pick up any more to throw off as spray.

Research suggested that the nature of the road surface has a considerable effect on the depth of the water film, and thus spray generation, for a given volume of water. The spray generated on impervious surfaces is considerably greater than that generated on pervious surfaces where the water can drain away.

Weather conditions, particularly wind speed and direction, can have a significant effect on the spray measurements. Effects can be minimised by only testing under certain conditions, and by careful positioning of measuring equipment.

A variety of techniques for measuring the effects of transmission loss, veiling luminance, contrast change and narrow angle scattering were assessed in the literature review. Each of these techniques can be broken down into three main parts:

- Measurement configuration
- Type of sensor
- Analysis of data

The literature reviewed described three main configurations for measuring spray; longitudinal, cross-track and on-board measurement. Each method has both advantages and disadvantages. The longitudinal test method has the advantage of measuring the spray in the position that poses the greatest risk, that is, where a passing car might be. However the results are strongly influenced by the lateral position of the vehicle relative to the measuring station. The cross track method measures a larger quantity of spray and is less sensitive to the lateral position of the vehicle. It cannot, however, be directly related to the effect on human drivers because it measures spray at right angles to the direction of travel. The on-board measurement has the advantage of recording a constant spray measurement because the position of the sensor relative to the vehicle always remains the same, unlike for the longitudinal and cross-track methods where the spray changes as the vehicle passes the measuring station. The disadvantage of this method is that all sensors mounted on a moving vehicle are subject to vibration and shake from the vehicle, which may affect the accuracy of the results.

The sensor most commonly used in past research to measure spray is the laser transmissometer. It has the advantage of being very accurate and is not susceptible to the influence of ambient light levels. However it must be very accurately set-up and aligned accurately, plus it only uses a narrow beam of light and so only measures a very small proportion of the spray cloud at any one time.

Telephotometers can be used in the same way as transmissometers if used in conjunction with a calibrated light source. They can be used to measure veiling luminance and transmittance. Similarly to the transmissometers they require very accurate alignment and only measure a small portion of the spray cloud.

Video images have been used by a number of researchers to measure the spray cloud. The main advantage is that a much larger area of the spray cloud can be assessed simultaneously. Transmittance, luminance contrast and veiling luminance can all be measured simultaneously, allowing a greater range of analysis options. One of the main disadvantages of this approach are that modern cameras are usually not designed as measurement devices, therefore many of the user friendly features can have an adverse affect on the accuracy of the recording. This can be overcome by using cameras designed specifically for monitoring purposes, where certain key parameters can be manually controlled.
10 Spray measurement

10.1 Introduction

The literature review suggested that using aerodynamics to control vehicle spray emissions could be beneficial but that a whole vehicle test to measure spray would be required to demonstrate this and to allow such aerodynamic spray suppression devices to be type approved. This element of work aimed to develop such a method.

The work was divided into two elements; wind tunnel testing and full scale testing. The aims of the wind tunnel testing were to identify whether cross winds had an effect on the full scale test methods used to measure spray and to identify the type of device offering the greatest potential for spray reduction for later use in comparative tests. The objective of the test work was to develop a method of measuring spray that was sufficiently representative, reliable and repeatable to be used in a regulatory environment.

10.2 Wind tunnel model tests

The shape and position of an HGV spray cloud controlled using aerodynamic modifications can be adversely affected by cross winds. Such wind conditions are difficult to simulate in full scale track tests due to the dependency on the weather and wind at the time of the test. Therefore TRL commissioned a series of 1/8th scale model tests in the controlled conditions of a wind tunnel to investigate, in a qualitative manner, the effect of cross winds on the airflow around HGV scale models fitted with aerodynamic spray control devices.

10.2.1 Work specification

10.2.1.1 Model configuration

TRL specified four model configurations to be modelled and tested, as shown in Table 13.

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Tractor Unit Details</th>
<th>Semi-Trailer Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base vehicle</td>
<td>Normal mudguards over wheels on rear axle. No side skirts</td>
<td>Normal mudguards over wheels on all axles. Double rail sideguards.</td>
</tr>
<tr>
<td>2</td>
<td>Wheel Covers</td>
<td>Spray suppressing mudguards over wheels on rear axle. No side skirts</td>
<td>Spray suppressing mudguards over wheels on all axles. Double rail sideguards.</td>
</tr>
<tr>
<td>3</td>
<td>Sculpted Body</td>
<td>Flat panel side skirts between front and rear axles.</td>
<td>Aerodynamic package comprising flat panel side skirts and rounded rear skirt.</td>
</tr>
<tr>
<td>4</td>
<td>Flat Body</td>
<td>Normal mudguards over wheels on rear axle. Flat panel side skirts between front and rear axles as fitted on Krone vehicles.</td>
<td>Aerodynamic package with flat underside and flat panels enclosing wheels and rear, similar to Krone SafeLiner.</td>
</tr>
</tbody>
</table>

The base model is an articulated HGV comprising a two axle tractor unit with sleeper cab coupled to a three axle box semi-trailer. This is typical of long haulage vehicles commonly found on UK motorways, travelling at high speed and generating spray in wet conditions. It is fitted with the basic
minimum regulatory spray suppression requirement and no aerodynamic skirts. Figure 17 shows the scale model of the base vehicle.

![Figure 17. Base Model for 1/8th scale wind tunnel tests](image)

The Spatz and Quickwing mudguards identified in the literature review are similar with respect to their aerodynamic properties. The Air-Fender system is more advanced, but it was decided that it would be unlikely that the air inlets and side blades could be modelled accurately and effectively at smaller scale required. Therefore model 2 was based upon the Spatz and Quickwing style of mudguards, as they represent the cheapest possible retro-fitted spray reduction system. Figure 18 shows the 1/8th scale model with the retro-fit mudguards in place.

![Figure 18. Base vehicle with retro-fit mudguards (model 2)](image)

Model 3 is based on the Don-Bur Air Management System which, unlike most other flat panels, is streamlined at the rear end. This system represents a more comprehensive aerodynamic and spray reducing package that could be fitted either as new or retro-fitted, in conjunction with enclosing the wheels with the Spatz or Quickwing mudguard, to the current trailer design.

Model 4 is based on the Krone SafeLiner design. This design represents the most comprehensive package identified with the vehicle having flat sides, a flat underside and almost fully enclosed wheels. Figure 19 shows the scale model of the Krone SafeLiner.
10.2.1.2 Test configuration

The airflow visualisation test was carried out at one test speed (5m/s), which was high enough to ensure that the fully developed airflow occurs, yet low enough to ensure good smoke visualisation.

The tests are being completed with each model positioned at three yaw angles relative to the direction of flow within the wind tunnel:

- 0°
- 5°
- 12°

The flow around the vehicle was identified using a multi-jet smoke rake. The smoke rake was held horizontally at five evenly distributed positions across the entire height of the model, as shown in Figure 20.

The qualitative analysis of the tests was derived from video analysis of the tests. Footage was recorded from the following three positions, as illustrated in Figure 21:

- A longitudinal view recorded from a position behind the model showing the airflow in the wake behind the vehicle. (Position A).
- A longitudinal view recorded from a position offset to either side of the model showing the airflow along the side of the vehicle around the wheels. (Position B).
- A transverse, wide angle view recorded from a position level with the rear of the model showing the airflow along the side of the vehicle and in the wake behind the vehicle. (Position C).
The wheels are the key area of spray generation, therefore, smoke was released around the wheels to simulate spray leaving the wheel at the simulated test speed. A laser light sheet was used to illuminate five different planes in the wake alongside the model, as shown in Figure 22.

### Figure 21. Camera positions

The wheels are the key area of spray generation, therefore, smoke was released around the wheels to simulate spray leaving the wheel at the simulated test speed. A laser light sheet was used to illuminate five different planes in the wake alongside the model, as shown in Figure 22.

### Figure 22. Spray illuminated by laser light sheet on 1/8th scale model

10.2.2 Results and analysis

This section describes a brief summary of the findings of the wind tunnel model testing. In terms of general airflow around the vehicle there was no visible difference between the baseline model and the model with the spray suppressing wheel covers. It is likely that the small physical differences between the models were not significant enough to change the airflow for a 1/8th scale model. The airflow around the model with sculpted side skirts showed a slight improvement in airflow and a small reduction in turbulence as the air passed the vehicle. Fully enclosing the sides and underside of the vehicle (like the Krone SafeLiner) had a greater effect in improving the airflow as a more laminar airflow was evident from the video footage.

Both the sculpted skirts and flat bodied models generated significantly less “spray” (simulated by the smoke released at the wheels) than the baseline model. As the yaw angle of the models was increased the smoke appeared to be lifted up and over the vehicle, creating an area of clear air alongside the vehicle. The model with sculpted side skirts and the flat bodied model produced a larger area of clear air which would improve the visibility for a following driver compared to the baseline vehicle.
For all the model configurations there was a significant reduction in “spray” from the wheels as the yaw angle was increased to 5° and then 12°. Although the amount of “spray” was reduced the relative performance of the models remained the same with the fully enclosed model producing the least amount of “spray” at the three yaw angles tested.

The wind tunnel tests identified the worst model configuration as the baseline model with normal wheels guards. Therefore, based on this finding, TRL specified that the initial full scale testing as part of the development of the spray test procedure was to be carried out using a standard vehicle fitted with normal mudguards over all the wheels and a double rail sideguard on the trailer. The reason for this is that it was considered desirable to generate reasonably large quantities of spray to develop the test method.

10.3 The development of a whole vehicle spray measurement test – Phase 1

The literature suggested that video offered several potential advantages over traditional laser methods for spray measurement. These were principally that a larger area of the spray plume could be measured thus allowing a much wider range of analysis options to be used on the data developed, with the potential to significantly reduce the run-to-run variation found in previous work using lasers. For this reason, it was decided that the basis of the investigative test work to be carried out would be a video analysis method.

10.3.1 Choice of camera

An extensive review of the cameras available and the factors influencing the performance of a camera in relation to spray measurement was carried out. All of the cameras identified would give a good quality image based upon the number of pixels available and the quality of modern optics. It should be noted that even the current lower specification cameras with 800,000 pixels will typically have 750 lines vertically and 1000 horizontally available from the raw sensor.

Using a modern camera to output data down the PAL composite video interface would not improve the image quality compared to past research by TRL. The best solution was found to be to abandon analogue interfaces and use a digital one now readily found on virtually all cameras. Two choices for the digital interface were found, USB and Firewire (IEEE 1394). The Firewire method was chosen, which has the highest data transfer rate without compression and has been designed specifically for digital video communication.

In order to examine the type of camera sensor needed for this project, it is useful to consider the human eye response. After all, the objective is to measure the level of spray generated by road vehicles such that it can be reduced in order to improve the vision available to the drivers of other vehicles. If the potential eye response to the level of illumination found during spray conditions is considered then, as a rule of thumb, it can be estimated that the eye response will be in the range of 0.06 seconds to about 0.7 seconds. Considering the phenomenon of image blurring, work by Scher-Zaiger (1995) as shown that the human eye responds between 0.12 and 0.125 seconds. Combining these data about the eye response suggest that a camera system that can capture images at a rate of about 16 frames per second was required in order to match the human eye response for the range of lighting conditions required.

The camera chosen for the track tests was the PixeLINK PL-A662 colour mega-pixel digital camera, as shown in Figure 23.
Figure 23. PixelLINK PL-A662 colour mega-pixel digital camera

It was chosen because it is an industrial-grade camera specifically designed for colour machine-vision applications. It has a high-speed FireWire (IEEE 1394) digital interface (400Mbits/second), and is capable of still and video imaging. It offers a good compromise between resolution and frame rate. There is a trade-off between these two factors: the higher the resolution, the slower the frame rate. This camera has a maximum resolution of 1280 × 1024 pixels. It has a frame rate of up to 12.7 frames/sec (fps) at 1280 × 1024 resolution, or 60 fps at 640 × 480. There is full software control over camera settings and a software development kit available for custom applications.

The camera lenses were chosen to have sufficient zoom to focus on the target ensuring that at minimum there was 1 pixel per 10mm of target. Lens hoods were constructed of sufficient length to prevent direct sunlight from entering the lens, reduce reflections and prevent contamination misting of the lens from stray spray. The lens hood approximate dimensions were:

- diameter: 100mm
- length: 350mm

The track-based cameras were securely mounted to tripods, with metal weights attached to the tripods to ensure that the position was fixed throughout the experiment and that camera position was not affected by the wind caused by the passing test vehicle. The tripods were height adjustable to permit the camera to be positioned directly opposite the centre of the target.

10.3.2 Test configuration

The literature review suggested that the test procedure should be carried out at a closely controlled speed to minimise variation in the results and recommended that tests are carried out at 90km/h. However, the research agrees that the quantity of spray generated is related to speed so it was decided that tests at lower speeds would be performed so that the results can be correlated to the amount of spray generated.

The literature was ambiguous in relation to the effect of tyre tread depth on spray generation. Regardless of the facts of this effect, tread depth will have no effect on the development tests because the objective will simply be to accurately measure whatever spray is generated. However, in the later comparative tests one of the objectives was to quantify the amount of improvement that can be offered by aerodynamic spray suppression systems. If the tread depth of the tyres fitted to one of the vehicles was different to the other there was a risk that this may have some effect on the amount of spray generated in comparison with the other vehicle. In this case the measured difference between the vehicles may be partly related to the tread depth rather than the performance of the suppression system. For this reason, any comparative tests must be carried out with equivalent tread depths.

The literature suggested that spray generation was not dependant on load so it was decided that testing should be carried out in an unladen condition in order to minimise effort and cost.
Water depth is known to substantially affect spray. The TRL test track used spray bars mounted along both sides of the test lane, to produce upward jets of water which were directed to fall on the wheel tracks of the test vehicle. The quantity of water directed onto the surface could be varied. The equipment used to wet the track surface was operated continuously during the test and was capable of maintaining an evenly distributed covering of water over the entire testing surface. TRL used an electronic water depth measuring method, developed by TRL, to monitor the water depth and tested in several water depth conditions to identify the appropriate control for the final test protocol.

Road surface texture depth was also shown, by the literature study, to affect the quantity of spray generated. For this reason, it was decided that all tests carried out for this project would be performed out on the same surface having a known and accurately measured texture depth. However, this variable will need further consideration before a method is suitable for use during type approval.

Environmental conditions, particularly wind, can have a strong effect on how quickly the spray generated is dispersed, which will affect the spray measurements. For this reason TRL specified testing in only low wind conditions. A weather station was used to monitor ambient conditions with the ability to record:

- Windspeed and direction
- Temperature
- Humidity

A range of measurement configurations had been tried in the literature. TRL carried out tests incorporating all three measurement configurations (longitudinal, cross-track and on-board measurement). This was in order to identify whether one method was more reliable than the others or whether a combination of the methods is required to generate repeatable results.

The work on video methods carried out in the nineties, proposed a technique to measure spray using a black and white target in the form of a checker board or simply two vertical columns, one black and the other white. The basic principle is that, in bright conditions, the white targets will reflect approaching 100% of light towards the camera whereas the black will reflect almost none. When spray is present the amount of light from a white square received by the camera can be compared with the amount of light received before the vehicle passed when no spray was present. This is defined as the transmittance. In addition to this, when spray is present and light is scattered some light will appear to come from the black squares, thus enabling measurements of contrast to be used. An example of the effect is shown in Figure 24, below.
Figure 24. Example of effect of spray on a chequerboard target.

This type of target was chosen to allow a range of techniques to be tried and to permit averaging of results over a large area to try to reduce the natural variation inherent in spray clouds.

The cameras and chequerboards were aligned such that there was one cross-track measurement, one track based longitudinal measurement on each side of the vehicle and one on-board measurement on either side of the vehicle, giving a total of five separate measurements of spray.

10.3.3 Analysis procedure

Data from the trials was collected in Audio Video Interleave (AVI) format which is an uncompressed video format. The AVI file was subsequently converted into a format that was readable by the Matlab Image Processing Toolbox for analysis. The format chosen was the Tagged Image File Format (TIFF), which is also an uncompressed image format. While using an uncompressed format leads to larger file sizes, and as a result longer data transfer times, it is essential for this method because using compressed files can lead to changes in the data, dependant on the compression format, and the analysis suite can manipulate uncompressed files more easily.

The video capture was recorded for 100 frames at a frame rate of 25 frames per second, resulting in four seconds of recorded data. The video capture is timed to begin just before the lorry passes between the camera and the target in order to obtain at least one image of the target before spray is generated.

Once the data for a particular run were converted from the AVI format into 100 TIFF images, the frames of data were analysed to find:

- The first frame after the lorry has passed beyond the target
- The location of top left pixel of the target (a, b)
- The location of the bottom right pixel of the target (c, d)
The values a, b, c and d were subsequently used to define the location of the target in such a way that no pixels from the red border of the target were included.

The locations of the edges between each of the light and dark square were found in the first image recorded (before the lorry passes between the target and camera) using the Prewitt edge finding algorithm. These edge points were stored in a matrix (E) for later use in transmittance calculations.

The transmittance is defined as the amount of light that reaches the camera lens and is defined as being 1 when there is no interference, that is, when 100% of the light leaving a target reaches the camera. Before the lorry passes between the camera and the target there is assumed to be no interference and, thus, a transmittance of 1.

Once the lorry has passed the target the transmittance will be reduced due to the presence of spray from the vehicle. The transmittance is calculated using the following equation:

\[ T = \frac{B_{ls} - B_{ds}}{B_{lc} - B_{dc}} \]

where \( B_{ls}, B_{ds}, B_{lc}, \) and \( B_{dc} \) were defined as the light and dark squares under clear and spray conditions, with the conditions being before and after the lorry passes the target respectively. The transmittance value \( T \) was calculated for each vertical edge pixel defined in the matrix E calculated earlier. The light and dark squares, \( B_{ls}, B_{ds}, B_{lc}, \) and \( B_{dc} \), are defined as being displaced 5 pixels horizontally from the actual edge pixel itself because the nature of digital images causes a blurring around the actual edge points in the image due to resolution limitations.

50 matrices of transmittance values were recorded for each lorry pass, representing a timeline of 2 seconds worth of data.

Once the transmittance values were recorded a number of measures were calculated, these are defined below.

10.3.3.1 Colour maps

The data for each edge in each transmittance matrix are averaged to create \( n-1 \) by \( m-1 \) matrices (where \( n \) and \( m \) are the height and width of the target, measured in light and dark squares) of transmittances. These matrices are subsequently displayed using a colour coding to give a visual indication of the level of transmittance loss.

10.3.3.2 Transmittance plots

Each matrix used to create a colour map is averaged to create a single value, this produces 50 values which can subsequently be plotted to display the change in Transmittance over time.

10.3.3.3 Two second integrals

In order to obtain an overall value for the spray generated (modelled by the loss in transmittance) an integral is calculated over the two second timeline generated in the transmittance plots.

10.3.4 Results and discussion

The test results indicated that a video camera set up to measure cross track spray had potential to be used as part of a formal test method. The other camera angles were discarded as unsafe or impractical. The longitudinal camera method was found to be impractical for safety reasons whilst the on-vehicle camera method was discarded due vibration issues causing unacceptable blurring of the images. Several significant issues were identified during the test phase:
Colour cast – a blue tint was seen in video images collected in low lighting conditions. This was due to a combination of the video camera response and the colour temperature of the ambient light on overcast days, for which the camera image white balance would need to adjusted. This could be avoided by using the camera as if it were monochrome (black & white) in the final test protocol.

Colour graduation – Increased brightness was perceived at the top of the test target compared to the bottom and was measured as a real effect. It was found that this can be cancelled out by the analysis of images before and after the test vehicle has passed. Such an analysis must be incorporated into a final test protocol.

Camera exposure control – this is important because it allows the effective measuring range of the camera to be adjusted. The response range of the camera is limited to output values in the range 0 - 255, where 0 is “black” and 255 is “white”. The amount of light reaching the camera image sensor through the lens needs to be adjusted such that the image sensor outputs values within the range 0-255, otherwise “clipping” of the output signal occurs. In the resulting image, clipping is seen as over-exposure and lost detail in the lighter parts of the image as shown below. The lens aperture refers to the size of the opening of a diaphragm in the lens, which may be adjusted in f-stops as marked on the lens. Each step change in f-stop will double (or half) the amount of light passing through the lens.

![Figure 25. 90km/h – water depth C - run 1 - example of normal spray effect](image)

![Figure 26. 90km/h – water depth C - run 1 - example of clipping spray effect](image)

The results showed that use of the exposure control provided by the camera software was not suitable for achieving the required luminance range. This was evident in variable lighting conditions, produced by broken cloud cover, when the range of the camera was exceeded. The anticipated solution to this effect was to conduct future testing in near constant ambient lighting conditions and changing the lens aperture (or f-stop) setting to keep within the operating range of the camera. The values for transmittance fell into two distinct categories for this set of trials, those where the dynamic range of the camera was exceeded (clipping of the video signal) and those that were not affected.

Figure 27, shows the results from all the 90 km/h runs at water depth C.
Values where the clipping problem did not occur are shown in the group of five traces at the top of the chart, while the runs in which clipping was apparent showed greater variability and erroneous transmittance values. These results are shown in order to demonstrate the importance of setting up the peak white level so as to avoid clipping.

10.4 The development of a whole vehicle spray measurement test – Phase 2

A number of issues were identified in Phase 1, which needed to be addressed in order to develop an effective spray measurement protocol. The test procedure was modified from that used in Phase 1 to try to improve the performance in respect of the camera exposure control and to retain just the cross track recording method. The revised procedure was tested on a limited number of vehicle runs.

Figure 28 shows the recorded transmittance for a two second interval after the lorry had passed the target at 50 km/h, 70 km/h and 90 km/h, for runs that do not have lighting irregularities. Clearly a distinction between speeds is visible with greater transmittance loss at the higher speeds as would be expected.
Figure 28. Transmittance loss against time

The integral of the transmittance is calculated by using 1 minus the measured value. As described above, a transmittance value of unity represents complete light transmission with no loss. Table 14 shows the integral values of the transmittance calculated for the first 2 seconds of the test run for each of the three speeds.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Integral of the transmittance</th>
<th>Sample</th>
<th>Mean</th>
<th>s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.05 0.06 0.04 0.05 0.04</td>
<td>5</td>
<td>0.05</td>
<td>0.01</td>
</tr>
<tr>
<td>70</td>
<td>0.10 0.14 0.11 0.12 0.11</td>
<td>6</td>
<td>0.12</td>
<td>0.02</td>
</tr>
<tr>
<td>90</td>
<td>0.18 0.18 0.21 0.21 0.28 0.29</td>
<td>6</td>
<td>0.23</td>
<td>0.05</td>
</tr>
</tbody>
</table>

These results show good consistency between the runs with increasing mean values and also standard deviations as the speed increases. Even using this small sample, performing a simple t-test on the data set showed that the 50 km/h runs were significantly different at the 99% level to the 70 km/h set and the 90 km/h runs also significantly different to the 70 km/h runs at the 99% level.

Previous work by TRL has recorded measurements using 20 runs at each speed. It would be expected that using 20 runs should provide a reasonable degree of statistical significance for the results. The results from Table 14 confirm that a series of 20 runs should provide statistically significant results and with the latest test method it may be possible to reduce the number of test runs. However, it was decided to continue using a series of 20 runs at each speed to ensure consistency and allow for any runs that might have failures.

The results from this second phase of testing demonstrated that most of the problems using the video camera had been overcome. However, further problems were encountered and specific issues from the second test phase are described below.
Camera timing – the test results showed a slight timing difference between different camera/computer combinations. For future tests it will be necessary to measure the timing response of the particular camera/computer combination in order to compensate for this timing response in the video data analysis. It may be possible to overcome the timing problem using specific software. This issue will need to be resolved before any adoption at type approval.

Camera range – in this test phase the aperture on the camera lens were used to control the image brightness, in order to avoid clipping of the “white” value (attempting to measure a “white” value greater than 255). It was shown that one f-stop of lens aperture adjustment between f5.6 and f8 was too coarse to provide the degree of control needed. The lenses used for this work allowed intermediate aperture values to be set using the f-stop ring although the setting needed to be locked to ensure the level remained fixed.

The results of this phase of testing showed that for future tests the image “white” value will need to be controlled to keep below a peak value of 210. This can be achieved by adjusting the lens f-stop, but only where the lens f-stop can be continuously adjusted in addition to step changes in f-stop, where one step change in f-stop corresponds to a doubling or halving of the light entering the lens. Alternatively, neutral density (ND) filters absorb light evenly throughout the visible spectrum, effectively altering exposure without requiring a change in lens opening and without introducing a colour shift. ND filters are available in values equivalent to change in image brightness of thirds of an f-stop, for example 0.1 ND and 0.2 ND. Another alternative method possible for some cameras such as the one used for these tests is to alter the gain of the video amplifier to adjust the sensitivity or dynamic range of the camera. This control would be achieved using camera functions provided by the software developer’s kit (SDK) supplied with this camera. For this method ND filters or f-stop adjustment would set the approximate white level and the amplifier gain would adjust the white level to the optimum value of 210 units described above.

Lighting levels and lens flare – Lens flare from direct sunlight was apparent from analysis of the results. This introduced an extra variable to the test method and the resulting camera images were over-exposed compared to similar images where lens flare did not occur. In addition to the required fine control of the camera range described in the previous paragraph, it will be necessary to conduct future tests under diffused lighting conditions, i.e. under cloud cover when only small changes in the ambient light occur.

10.5 The development of a whole vehicle spray measurement test – Phase 3

This third and final phase of development testing was conducted to collect data under the controlled conditions identified as a result of the previous phases of testing and to provide confirmation of resolving the various issues concerning the use of digital video cameras to measure vehicle spray.

In this test phase a single laser beam was used to compare with the results of the video test method. The laser was set up to measure transmittance at a point at the side of the video target, at mid-height of the target. It has been shown in previous research that laser measurement provides a reliable method of measuring transmittance, provided care is taken to fix the laser transmitter and receiver firmly in place. The laser system chosen used a modulated beam at 100Hz to eliminate any effects due to ambient changes. The sensor was a light sensitive semiconductor device with built-in signal conditioning. The output voltage of this sensor was directly proportional to luminance and could be connected to a data logging system. Data was collected at 5kHz so that it was possible to demodulate the 100Hz wanted signal using a simple Excel spreadsheet without the need for electronic processing of the sensor output. Both the laser and sensor are readily available devices costing under 200 GBP in total.

This final set of tests was undertaken with two cameras and a laser operating in parallel, providing a validation of the camera results. The two cameras were set to have the same range simply to provide backup. Plotting the transmittance curves as before showed a clear distinction between the 50 km/h, 70 km/h and 90 km/h runs similar to those seen for the Phase 2 tests, the curves are shown in Figure 29.
The integral of the transmittance was calculated as before over a two second period. Figure 30 shows the relationship between the integral of the transmittance and the luminance range for each of the test runs. This shows that the response range of the camera changes over the runs, with the 50 km/h runs showing a small variation in luminance range value (179-198). Similar results were also seen for the 70 km/h run where a changing luminance range value (152-224) was seen but was largely kept under control by the changes to the f-stop performed by the test engineers. The results for the 90 km/h tests showed considerably more variability (80-196) due to the fading light conditions at the end of the day. These tests were completed when it was no longer possible to change the f-stop values of the camera swiftly enough. As a result of this, data produced from a luminance range value below 130 was excluded from the analysis, due to the errors introduced when the dynamic range of the camera is small.

Figure 29. Transmittance curves over a 2 second time frame
The video data results show that when the issues identified in the previous test phases are carefully controlled, the video spray measurement method can clearly distinguish different levels of spray at speeds of 50, 70 and 90 km/h. The results showed that setting a luminance range value for the camera of 130-230 gives a reliable operating range for the camera. However controlling this value exactly would be possible using the software capabilities within the cameras used and obtaining a value of 180-200 would minimise errors while maintaining a range where signal clipping should not occur. Maintaining this operating range by the adjustment of the camera lens using different f-stop values is more difficult as the lighting levels fall at sunset, otherwise this method may be used for research testing purposes. To ensure consistent camera operating range is maintained during a regulation type test, this adjustment should be automated as part of the camera function.

The comparison of the video measurement of transmittance to the laser method of measuring transmittance in Figure 31 showed the video transmittance was approximately 81% of the laser transmittance although there was an excellent linear relationship. The best correlation of the video transmittance occurs at the lower speed of 50 km/h, the correlation reducing as the speed and the corresponding level of spray increases at 70 km/h and 90 km/h. This implies that the video method does provide a suitable measure of the spray but it is measuring other effects as well. The most likely effect is that caused by veiling luminance as described above.

**Figure 30. Change in luminance range plotted against integral of the transmittance**
Figure 31. All speeds comparison of transmittance

The results of two digital video cameras used under the same test conditions during this test phase were compared. The operating range of both cameras had been adjusted to approx. the same luminance range value between the test runs. The cameras results showed 95% agreement. Some of the variation may be due to the physical separation of the cameras, differences in starting time of the video capture and possible differences in the camera response.

10.6 Potential enhancements of the method

10.6.1 Assessment of spray levels by zones

The results showed that spray may be produced by a HGV to the full height of the target board at 1.5m. Under normal driving conditions only spray within a region around the driver’s eye-points and the brakelights of the vehicle in front would be hazardous. For the purposes of an assessment test it would therefore be useful to break the target board into a number of horizontal bands or zones. This would allow a weighting scale to be applied to the density of the spray measured at different heights. For example, to consider spray in the height range 0 to 0.3m as low hazard, in the height range 0.3m to 1.0m high hazard, and in the height range 1.0m to 1.5m as medium hazard. These zones would need comparative testing as outlined in the main report above, to establish suitable height ranges and their hazard weighting. It is interesting that whilst it would appear reasonable to expect that measuring spray over a larger target area would be better than using a narrow beam laser, the results from this test programme show that the differences are minimal. The simple visual presentation using colour maps (see Figure 32). clearly identifies denser areas of spray at the bottom of the target. Further work is needed to establish the best method of analysis and the potential value of zoning the values.
Figure 32. Transmittance plots over a 1.2 second interval - Baseline - 90km/h - run 1 – Phase 3 study

10.6.2 Development of a vertical line laser method

Based on the results of the research, it is thought that developing a line generating laser system matched to an array of sensors would offer all the benefits of a video camera system while reducing the issues related to controlling the camera settings and the effects of ambient lighting and veiling luminance on the data. This method has become feasible due to improvements in laser optics technology and reductions in cost. The capability now exists to spread the laser to a wider beam to project a vertical line pattern similar in height to that analysed using the video technique. One drawback of using such a method potentially comes from the set-up of the equipment, because it is not yet known how difficult aligning the laser projected beam with the sensor array would be. This alignment issue was found to be trivial when using a single laser-to-receiver set-up. Safety issues regarding the use of lasers can be resolved by using a Class 1 laser that is safe to view by the human eye.

The laser line method can be made insensitive to ambient changes and veiling luminance. Modern lasers are extremely stable, the device used for these tests demonstrated no measurable change in response throughout an 8 hour period. By using a vertical line generator and a fast data rate, for
example 5kHz, it is possible to measure the spray plume in greater detail than a single laser beam providing an image comparable with the video method.

### 10.6.3 The effect of different water depths

The spray measurement method relies on a consistent water depth being achieved on the road surface during testing. The current water depth measurement procedure will ensure the water depth is consistent, however it cannot ensure a precise value of depth is attained due to variation in surface texture and impurities present both in the water and on the road surface. Further research is needed to develop the water depth measurement procedure as presented here, to quantify these effects.

### 10.6.4 Automated test procedure for type approval use

This research has demonstrated the feasibility of using video cameras and a single laser/receiver combination to measure spray. The methods presented will need further development to allow a technician without specialised knowledge of video camera techniques and image analysis tools to set-up the equipment, conduct the tests and complete the analysis on the collected data. Automatic control of the video camera dynamic range, to achieve an acceptable luminance range value under varying lighting conditions, would need to be achieved. This could be developed using software to control the camera, with functions provided by the camera manufacturer software development kit. In its current form the test method would not be suitable as a regulation test method and is not yet simple enough to be used as a routine test.

### 10.7 Conclusions from spray development work

To gauge success in the ability to measure vehicle spray using video camera methods, three key objectives were established against which success or failure of the methodology could be tested. These objectives established both the validity of the results and the feasibility of the method.

**Objective 1: To examine the use of modern video camera technology to measure vehicle spray**

Building on previous work, a checkerboard featuring black and white squares was built and used as the target against which the spray could be measured. The luminance differences between these white and black squares were subsequently used to calculate the reflected transmittance from the target. From Phase 1 testing onwards the measurement appeared to give an accurate measure of the spray as seen by the eye. Phase 2 further developed the method and later tests from Phase 3 testing, where confounding factors such as the veiling luminance and other lighting issues were brought under control, showed a clear distinction between different speeds of the test vehicle with runs at 50 km/h, 70 km/h and 90 km/h being statistically distinguishable at the 95% level as required. As a result the video camera technology is considered a suitable medium for the measurement of spray.

**Objective 2: To compare and validate vehicle spray measurements using a video camera with a laser system measuring transmittance directly**

The measure of transmittance using a laser provides a direct and accurate measure. While it was found that the values calculated by the video method were not the same as those calculated by the laser method a linear relationship was seen, with a correlation coefficient (R2) of 0.94 and a linear fit suggesting that the values recorded using the video method were approximately 81% of those from the more direct laser method.

**Objective 3: To develop a test procedure for measuring vehicle spray using a video camera**

A method for conducting the tests has been produced which dictates the set-up of the equipment, execution of the trials and completion of the analysis on the collected data. This test procedure is capable of being performed by research engineers who have specialised knowledge of video camera techniques and image analysis tools. In its current form, the test method would not be suitable as a regulation test method and is not yet simple enough to be used as a routine test.
Having established the feasibility of the measure, there are still limitations on the video camera method. Lighting conditions and camera settings need to be controlled. The texture depth of the road surface and the water depth will also affect the spray measured and although it has proved possible to control these at one test track, how to control them when testing is carried out at a variety of tracks will require further research. However, now that a reliable and repeatable measure for vehicle spray has been produced it would be possible to further investigate this factor with relative ease.

The results indicate that both video and laser methods could be used to accurately measure spray generated by HGVs and that both methods have their advantages and drawbacks. Either of these methods would require further development to reduce the time taken and improve robustness before they could be employed during routine type approval.
11 Comparative testing

This part of the project aimed to compare the spray generated by a vehicle meeting current type approval standards and one that controlled spray using aerodynamics while also providing further validation of the test method. The aerodynamic system was chosen based on the results of the wind tunnel testing. Those tests showed that a vehicle with flat smooth sides, low ground clearance and a flat panel underneath provided the best airflow. For these reasons, a Krone SafeLiner trailer was chosen. The Baseline trailer was a standard tri-axle curtain sided trailer fitted with rail type sideguards and standard “grass matting” spray suppression. These results were intended to provide an indication of the potential benefits from the introduction of a whole vehicle spray measurement regulation. The video method test results had been compared in the previous part of the report to test results using a conventional laser system to measure transmittance directly. In this part of the project, only the video method was used.

The test set-up was as previously developed in the project. A total of 20 runs were performed for each of the two trailers (SafeLiner and Baseline) at three different speeds (50 km/h, 70 km/h and 90 km/h).

11.1 Test results

Using the data from the principal test camera the following issues were encountered:

- The tests were undertaken in direct sunlight, as a result veiling luminance (flare caused by the spray reflecting the sunlight) was noticeable causing total and partial ‘whiteout’ of the video image
- Spray generated directly by the track wetting equipment on occasion entered the video clip
- Camera wobble caused by gusts of wind occurred occasionally
- On a number of test runs (mainly at the slower speeds) there was insufficient data to perform 2 seconds of analysis after the vehicle passed, further analysis could be undertaken at a later date but would not be directly comparable with the other results collected or previous work.

These data issues have resulted in the following data set:

<table>
<thead>
<tr>
<th>Trailer</th>
<th>Speed</th>
<th>Excluded data</th>
<th>Usable data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Flare Wobble Too little data Other</td>
<td></td>
</tr>
<tr>
<td>SafeLiner</td>
<td>90</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Baseline</td>
<td>90</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Baseline</td>
<td>70</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>SafeLiner</td>
<td>70</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>SafeLiner</td>
<td>50</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Baseline</td>
<td>50</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Clearly, with no 70 km/h or 90 km/h data for the Baseline trailer, simple comparisons between the trailers at these speeds cannot be made.

The clean datasets as described above were processed as specified in the test method and as a result the outputs should be comparable to studies undertaken in the same conditions. Considering the
SafeLiner runs, more spray is produced at greater speeds as expected and shown in the results from previous studies. Transmittance curves over a 2 second period can be seen in Figure 33.

Figure 33 clearly shows that the curves for the SafeLiner behave as expected with the 90 km/h causing the greatest loss in transmittance, with 70 km/h and 50 km/h spray having less effect. While some overlap is seen between the different speeds (which is to be expected due to the random effects of spray) this is minimal.

![Figure 33. Transmittance curves - SafeLiner](image)

The same test method procedures used for the Phase 3 testing were used for the comparative testing, as were identical analysis techniques. However one principal difference are the weather conditions under which the tests were conducted. The Phase 3 tests were conducted on an overcast day with diffused lighting conditions while the comparative tests were conducted under clear conditions with resulting beams of light and veiling luminance that this may cause.

It was hoped that the Phase 3 data would be statistically indistinguishable from the comparative data for the Baseline 50 km/h runs. If this was the case then a reasonable step would be to compare the 70 km/h and 90 km/h Baseline data from the Phase 3 studies with the SafeLiner 70 km/h and 90 km/h comparative test data.

Descriptive statistics for the Baseline vehicle at 50 km/h are shown in Table 16, these show that the mean for the Phase 3 tests is lower than the corresponding runs during the Comparative tests. Performing a test for significance rejects the null hypothesis and concludes that there is a significant difference between the two groups.

<table>
<thead>
<tr>
<th>Test</th>
<th>Sample</th>
<th>Mean</th>
<th>s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 3</td>
<td>23</td>
<td>0.10</td>
<td>0.02</td>
</tr>
<tr>
<td>Comparative</td>
<td>14</td>
<td>0.19</td>
<td>0.04</td>
</tr>
</tbody>
</table>
This difference is probably caused by the different lighting conditions that the studies were conducted under, operating under bright conditions can cause veiling luminance when the sun hits the droplets of water that form the spray cloud (light is reflected from the spray into the camera lens), causing a higher level of transmittance loss to be recorded. No comparisons between the comparative study and the Phase 3 study can be reliably made.

11.2 Data comparison – Baseline vs. SafeLiner

The only directly comparable datasets for the Baseline and SafeLiner trailers is for 50 km/h. Figure 34 shows the transmittance curves for each of these vehicles at 50 km/h and clearly shows the SafeLiner vehicle to be causing less of a loss in transmittance (and hence less spray) than the Baseline vehicle.

Table 17 displays descriptive statistics for the two trailers at 50 km/h, clearly the SafeLiner has a lower mean value than the Baseline vehicle when recorded at the same speed. Performing tests of statistical significance indicates that it is statistically unlikely that the two data sets have the same mean.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Sample</th>
<th>Mean</th>
<th>s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SafeLiner</td>
<td>7</td>
<td>0.08</td>
<td>0.02</td>
</tr>
<tr>
<td>Baseline</td>
<td>14</td>
<td>0.19</td>
<td>0.04</td>
</tr>
</tbody>
</table>

However, performing the same tests on the SafeLiner at 70 km/h and the Baseline at 50 km/h indicates that the null hypothesis of the two groups having the same mean cannot be dismissed. Descriptive statistics for these two groups can be seen in Table 18.
Table 18. Descriptive statistics for SafeLiner (70km/h) and Baseline (50km/h)

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Speed</th>
<th>Sample</th>
<th>Mean</th>
<th>s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SafeLiner</td>
<td>70</td>
<td>18</td>
<td>0.17</td>
<td>0.04</td>
</tr>
<tr>
<td>Baseline</td>
<td>50</td>
<td>14</td>
<td>0.19</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Transmittance plots for the Baseline (from Phase 3 tests) and SafeLiner trailers at 90 km/h can be seen at the end of the report, while the Baseline trailer appears to cause less spray in this image it should be noted that the tests were carried out under different lighting conditions and that the SafeLiner results may be showing the effects of veiling luminance.

11.3 Spray zones

Considering the height of the spray cloud between trailer types is not an obvious measure to make as different trailer types generate different levels of total spray and only at 50 km/h do we have directly comparable data. As a result the decision has been made to base analysis on the mean amount of spray obscuring the target into three bands (top, middle and bottom) as a proportion of total spray. So three measures are created:

- Proportion Top
- Proportion Middle
- Proportion Bottom

Where for example Proportion Top (P_Top) would be calculated as follows:

\[
P_{\text{Top}} = \frac{M_{\text{Top}}}{M_{\text{Top}} + M_{\text{Middle}} + M_{\text{Bottom}}}
\]

Where M_Top is the mean loss in transmittance over the top third of the target. Using these proportion values resulted in means as displayed in Table 19.
Table 19. Spray height values

<table>
<thead>
<tr>
<th>Speed</th>
<th>Measure</th>
<th>Trailer</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>P_TOP</td>
<td>Baseline</td>
<td>14</td>
<td>0.29</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SafeLiner</td>
<td>7</td>
<td>0.29</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>P_MIDDLE</td>
<td>Baseline</td>
<td>14</td>
<td>0.33</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SafeLiner</td>
<td>7</td>
<td>0.33</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>P_BOTTOM</td>
<td>Baseline</td>
<td>14</td>
<td>0.37</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SafeLiner</td>
<td>7</td>
<td>0.38</td>
<td>0.01</td>
</tr>
<tr>
<td>70</td>
<td>P_TOP</td>
<td>Baseline</td>
<td>14</td>
<td>0.28</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SafeLiner</td>
<td>18</td>
<td>0.28</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>P_MIDDLE</td>
<td>Baseline</td>
<td>14</td>
<td>0.33</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SafeLiner</td>
<td>18</td>
<td>0.33</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>P_BOTTOM</td>
<td>Baseline</td>
<td>14</td>
<td>0.39</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SafeLiner</td>
<td>18</td>
<td>0.39</td>
<td>0.02</td>
</tr>
<tr>
<td>90</td>
<td>P_TOP</td>
<td>Baseline</td>
<td>15</td>
<td>0.28</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SafeLiner</td>
<td>11</td>
<td>0.28</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>P_MIDDLE</td>
<td>Baseline</td>
<td>15</td>
<td>0.33</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SafeLiner</td>
<td>11</td>
<td>0.33</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>P_BOTTOM</td>
<td>Baseline</td>
<td>15</td>
<td>0.39</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SafeLiner</td>
<td>11</td>
<td>0.38</td>
<td>0.01</td>
</tr>
</tbody>
</table>

No significant difference can be seen for the transmittance proportions at any of the heights between the different trailer types (i.e. the bottom proportion of the baseline at 50 km/h (37%) cannot be seen to be significantly different to top proportion of the SafeLiner at 50 km/h (38%)).

The proportion at the top of the board is significantly less than the proportion in the middle, for all speeds and both trailer types.

The proportion at the middle of the board is significantly less than the proportion in the bottom, for all speeds and both trailer types.

11.4 Conclusions from the comparative tests

The comparative tests were hampered by the bright weather conditions under which they were performed. This testing has served to highlight the limitations of using a video camera for spray analysis, where optical effects caused by lighting conditions have to be controlled, and in this case were not. This has resulted in data being discarded from the affected test runs. The variable response of the video camera to ambient light means the test results cannot be compared with tests performed on other days. Any future testing using video cameras should be performed under overcast (dispersed light) conditions in order to prevent veiling luminance.

Creating a method that utilises technologies that are not affected by lighting conditions would be preferable, although it is still thought that the video method, when operating under suitable (dispersed) lighting conditions, is reliable.
The dynamic range of the camera was again shown to be robust when maintained within the recommended 130-230 range, however making this constant under all lighting conditions would still be preferable.

Due to the ambient light conditions comparisons between the SafeLiner and Baseline trailers can only be made for the Baseline vehicle travelling at 50 km/h, and the spray generated at this speed was seen to be greater than the spray generated by the SafeLiner trailer at 50 km/h, and statistically indistinguishable from the SafeLiner at 70 km/h.

The SafeLiner vehicle was shown to produce more spray with increase in vehicle test speed, similar to results found during the Phase 3 survey for the Baseline trailer. As a result it is believed (but not proven) that the SafeLiner trailer would produce less spray than the Baseline vehicle at each tested speed.

While it is thought that the SafeLiner produces less spray than the Baseline trailer, the proportion of spray covering the top, middle and bottom of the target does not appear to vary with change in trailer type or speed.

There is evidence to suggest that using aerodynamics to control spray could result in a substantial improvement in spray suppression.
12 Fuel economy

12.1 Literature review
There was a substantial volume of literature concerning fuel efficiency so TRL focused only on the literature assessing the benefit of improved aerodynamics. The research showed that aerodynamics can have a substantial effect on the drag coefficient of the vehicle. The use of side skirts around the vehicle forms only a part of that benefit and the greatest benefits can be achieved from modifications to the front of the vehicle. Commercial Motor (Kendall, 1996) stated that 80% of the benefits derived from improvements to the tractor unit and 20% to the trailer. A study by the Energy Efficiency Office (1990) showed a 23% increase in fuel efficiency for two rigid box vans which were aerodynamically modified.

12.2 Comparative fuel economy tests
Potential fuel economy benefits from providing an integrated safety guard and spray suppression system are key to enabling a positive cost-benefit analysis. The literature review showed that appropriate use of aerodynamics can improve fuel economy substantially.

12.3 Test procedure
The testing was carried out on a nominally flat and straight section of the M3 motorway between junctions 4 and 5. The volume of fuel consumed whilst travelling at a constant speed of 80 km/h between marker posts 55.3 and 58.2 was recorded. The test speed was sufficient to obtain results that are likely to be representative of those achieved in normal high speed operation, yet allowed other vehicles using the motorway to overtake and pull away, minimising the likelihood of the results being adversely affected by the aerodynamic disturbance caused by other vehicles. When travelling southbound the heading was 260°, northbound 80°.

The time at which the marker posts were passed was also recorded, facilitating the calculation of mean speeds. Tests in which the mean speed deviated from the nominal value by more than 3.2 km/h were deemed invalid, as were tests that were deemed to be unduly influenced by factors beyond the control of the test team such as traffic or weather conditions.

When starting a vehicle from cold the fuel consumption falls rapidly in the first few kilometres of driving due to the warm up of the engine, transmission and tyres. Previous research (Williams, 1977) has demonstrated that approximately one hour of running time is required before the fuel consumption stabilises. The research also demonstrated that shorts stops of 10 minutes or more tended to increase the fuel consumption when the vehicle was restarted. Therefore to ensure the vehicle was operating consistently a warm up period of at least one hour of driving was specified prior to valid measurements being taken. Measurements recorded during this period were analysed to identify when the fuel consumption had stabilised, after which valid results could be obtained. If the vehicle remained stationary for more than 10 minutes during testing at least one circuit of the test route was completed prior to valid measurements being taken, whilst subsequent measurements were analysed to ensure the vehicle was fully warmed up again and the fuel consumption had stabilised.

The fuel temperature, measured in the fuel tank, was recorded at the beginning, midpoint and end of each test day. To maximise repeatability, testing was carried out on a dry pavement under similar light wind and ambient conditions. The wind speed and direction, air temperature and relative humidity, measured hourly at the weather station in Fleet, Hampshire, were recorded.
Table 20. Analysed results of the fuel tests.

<table>
<thead>
<tr>
<th></th>
<th>Southbound</th>
<th>Northbound</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Renault/York</td>
<td>Renault/Krone</td>
</tr>
<tr>
<td>Mean volume of fuel consumed $\bar{x}$ (l)</td>
<td>0.902</td>
<td>0.881</td>
</tr>
<tr>
<td></td>
<td>Renault/York</td>
<td>Renault/Krone</td>
</tr>
<tr>
<td>Standard deviation $s$ (l)</td>
<td>0.060</td>
<td>0.078</td>
</tr>
<tr>
<td></td>
<td>Renault/York</td>
<td>Renault/Krone</td>
</tr>
<tr>
<td>Number of observations $N$</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Renault/York</td>
<td>Renault/Krone</td>
</tr>
<tr>
<td>Students-t value $t$</td>
<td>2.36</td>
<td>2.36</td>
</tr>
<tr>
<td></td>
<td>Renault/York</td>
<td>Renault/Krone</td>
</tr>
<tr>
<td>95% lower confidence limit (l)</td>
<td>0.852</td>
<td>0.816</td>
</tr>
<tr>
<td></td>
<td>Renault/York</td>
<td>Renault/Krone</td>
</tr>
<tr>
<td>95% upper confidence limit (l)</td>
<td>0.952</td>
<td>0.946</td>
</tr>
</tbody>
</table>

Equation 1 – Confidence limits for mean $\bar{x} \pm \frac{t}{\sqrt{N}} s$

Where $\bar{x}$ is the mean of the data set.

$t$ is the value of Students-t for N-1 observations (determined from statistical tables).

$N$ is the number of observations in the data set.

$s$ is the standard deviation of the data set.

Lower and upper confidence limits at 95% confidence levels are calculated in Table 20.

The upper confidence limit for the Krone semi-trailer is greater than the lower confidence limit for the York semi-trailer for both southbound and northbound tests. Because the confidence limits on the data sets overlap it is possible that the two data sets may have been drawn from the same population. Therefore the results do not indicate a statistically significant difference at the 95% confidence level, although there is a trend showing the Krone semi-trailer offered a small benefit.

It is likely that this variation occurs as a result of the aerodynamic disturbances caused by other traffic using the test section. Although the speed difference between the test vehicle and other traffic was sufficient to allow other vehicles to overtake and pull away, it is likely they would disturb the airflow around the test vehicle for a substantial proportion of the test section. Assuming that another articulated HGV would need to travel at least 60m between pulling out from behind the test vehicle to returning back in front to overtake and a speed difference of 6 mile/h, an overtaking manoeuvre would take a minimum of 22s to complete. Travelling at a constant speed of 80 km/h, the 2.9km test section takes 131s to complete. Therefore an overtaking vehicle is likely to affect at least 17% of the test. Additional disturbances will also be caused as the vehicle approaches, increasing the drag the test vehicle experiences, and therefore the volume of fuel consumed, as it enters the low pressure region behind the test vehicle. The opposite effect will occur when the overtaking vehicle is in front of the test vehicle, reducing the drag the test vehicle experiences. It was not uncommon for two or three HGVs to approach, overtake and pull away from the test vehicle when travelling along the test section on this heavily trafficked route.

Previous research (Williams et al, 1981) has shown that flat panel side skirts alone can offer fuel savings of up to 5% at 80km/h on an unladen rigid vehicle. The savings identified through this testing compare favourably, the difference likely to be a result of the different vehicle type. In practice the fuel savings achieved in normal use are likely to vary from those determined in the testing because:

- The testing was carried out travelling at constant speed on a flat and straight section of road under light wind conditions. In normal operation changes in speed, road gradient, ambient and surface conditions will affect the volume of fuel consumed.
• The tests were completed at 80 km/h (50 mile/h) to minimise the likelihood of the results being adversely affected by the aerodynamic disturbance caused by other vehicles. HGVs normally travel at higher speeds on motorways, governed by speed limiters which are typically set at 90 km/h (56 mile/h). Because aerodynamic drag is proportional to the square of the vehicle speed, the potential fuel savings achieved as a result of improved aerodynamic efficiency are greater the higher the vehicle speed.

• The tests were completed with the semi-trailers unladen. HGVs normally travel at least partially if not fully laden, which increases the rolling resistance and therefore the demand on the engine.

12.4 Effects of introducing Krone type semi-trailers

The test work undertaken was limited to a direct comparison with articulated vehicles at high speed and no equivalent direct comparison was available for rigid vehicles. Previous research has shown that aerodynamic improvements only result in improved fuel economy at high speed. For these reasons a very conservative estimate of the benefits of integrated safety guards and spray suppression on fuel economy has been made. It has been assumed that there will be no equivalent benefits for rigid vehicles because it cannot be objectively quantified in the same way. This is not likely to reflect the true picture because rigid vehicles have similar problems to articulated vehicles in terms of components and airflows and do travel at high speeds on motorways. For articulated vehicles it has been assumed that there will only be benefits on motorways and rural “a” roads because this is where high speed driving is more likely.

Transport Statistics Great Britain (DfT,2004) states there were 116,700 articulated vehicles licensed for operation in Great Britain in 2003. The distances articulated vehicles travelled by class of road are detailed in Table 21.

Table 21. Distances travelled by articulated vehicles by class of road

<table>
<thead>
<tr>
<th>Class of road</th>
<th>Distance travelled by articulated vehicles (billion km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorways</td>
<td>7.38</td>
</tr>
<tr>
<td>Rural major ‘A’ roads</td>
<td>4.79</td>
</tr>
<tr>
<td>Urban major ‘A’ roads</td>
<td>0.82</td>
</tr>
<tr>
<td>Minor roads</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Articulated vehicles travelled a total distance of 13.4 billion km. However, it is unlikely that the speeds at which the distances travelled on urban major ‘A’ roads and minor roads will be sufficiently high to generate an improvement in fuel economy through improved aerodynamics. Therefore, the following calculations are based on the distances travelled on motorways and rural major ‘A’ roads only, a total of 12.17 billion km or 7.56 billion miles, where higher speeds are likely to realise fuel economy benefits as a result of improved aerodynamics.

Dividing by the number of licensed articulated vehicles, yields an average distance travelled of 64,800 miles per vehicle per year on such roads. Assuming an average fuel consumption of eight miles per gallon when laden to the average lading factor, each vehicle will consume 8,100 gallons or 36,800 litres of diesel per year travelling on such roads. With typical diesel prices currently at £0.88 per litre, the average cost of fuelling an articulated vehicle when travelling on high speed roads is £32,400 per year.

The fuel economy tests indicated that on average the tractor unit consumed 2.4% less fuel when drawing the Krone semi-trailer compared to when drawing the York semi-trailer. These tests were
carried out with the vehicles unladen except for ballast used to account for the difference in unladen weights. Previous research by TRL (Gyenes, 1978, Renouf, 1981) states that fuel consumption varies linearly with gross vehicle weight because the energy required to overcome tyre rolling resistance and store potential and kinetic energy varies linearly with weight, whereas other factors affecting energy losses, aerodynamic drag in particular, are not very sensitive to vehicle weight. Transport of Goods by Road in Great Britain: (DfT,2004) states that the average lading factor for articulated vehicles in 2003 was 0.58. Analysis of the TRL research indicates that an articulated vehicle travelling at a high constant speed, laden to the average lading factor of 0.58, will consume 16% more fuel than when unladen. Applying this finding to the test results, it can be estimated that the tractor unit would consume 2.0% less fuel when drawing the averagely laden Krone semi-trailer compared to when drawing the averagely laden York semi-trailer at high constant speed. This equates to a fuel saving of 160 gallons or 750 litres, and a cost saving of 660 GBP per vehicle per year. Krone estimate that the SafeLiner semi-trailer costs a maximum of €uro 2500 or 1750 GBP more to produce than a normal semi-trailer, giving a 2.7 year payback time with current fuel prices.

Table 22 details the potential annual savings achievable as a result of improved aerodynamic efficiency should increasing proportions of the total distance travelled by averagely laden articulated vehicles at a high constant speed be completed using Krone type semi-trailers.

<table>
<thead>
<tr>
<th>Proportion of distance travelled by articulated vehicles on high speed roads completed with Krone type semi-trailers (%)</th>
<th>Annual reduction in volume of fuel consumed</th>
<th>Annual cost savings (£million)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(million gallons)</td>
<td>(million litres)</td>
</tr>
<tr>
<td>1</td>
<td>0.19</td>
<td>0.87</td>
</tr>
<tr>
<td>2</td>
<td>0.38</td>
<td>1.74</td>
</tr>
<tr>
<td>5</td>
<td>0.96</td>
<td>4.36</td>
</tr>
<tr>
<td>10</td>
<td>1.92</td>
<td>8.72</td>
</tr>
</tbody>
</table>

It is estimated that every per cent of the constant high speed distance travelled by articulated vehicles that is completed with a Krone type semi-trailer instead of a traditionally designed semi-trailer could yield an annual reduction of 0.19 million gallons or 0.87 million litres in the volume of fuel consumed and annual cost savings of 0.77 million GBP. There are also the associated benefits resulting from reduced emissions and potentially fewer journeys if the additional volume the Krone semi-trailer offers can be utilised.

An additional consideration is the Krone semi-trailer was 910 kg heavier than the York semi-trailer. Therefore the payload the Krone semi-trailer is able to transport will be less than the York semi-trailer is able to transport in circumstances where the payload is restricted by the maximum gross vehicle weight. Such operations would require additional journeys to transport the same load, consuming additional fuel should the Krone semi-trailer be used. However there is extra storage space within the chassis structure of the Krone semi-trailer, potentially offering increased capacity where the load transported is limited by volume. The greatest benefits of improved aerodynamic efficiency are achieved where large, lightweight vehicles travel at a high constant speed.

12.5 Conclusions

- The Krone semi-trailer was 910 kg heavier than the traditionally designed York semi-trailer. Therefore the payload the Krone semi-trailer is able to transport is less than the York semi-trailer is able to transport in circumstances where the payload is restricted by the maximum
gross vehicle weight. However, there is extra storage space with the chassis of the Krone semi-trailer, potentially offering increased capacity where that payload is limited by volume.

- The mean volume of fuel consumed by the tractor unit when drawing the Krone semi-trailer was 2.4% less than that consumed when drawing the York semi-trailer. However, the results are not statistically significant different at the 95% confidence level.

- Through application of previous TRL research, it can be estimated that when travelling at a high constant speed, a tractor unit would consume 2.0% less fuel when drawing a Krone semi-trailer compared to when drawing the York semi-trailer if the vehicle is laden to the average lading factor.

- It is estimated that every per cent of the constant high speed distance travelled by articulated vehicles that is completed with a Krone type semi-trailer instead of a traditionally designed semi-trailer could yield an annual reduction of 0.19 million gallons or 0.87 million litres in the volume of fuel consumed and annual cost savings of 0.77 million GBP.
13 Discussion

13.1 The benefits of integrating safety guards and spray suppression all around a vehicle.

The main objective of this project was to assess the benefits of integrating front, side, and rear underrun protection in terms of:

- Improved protection for other road users in collision with an HGV
- Allowing the use of improved aerodynamics to control spray emission in wet conditions, including the development of a regulatory test procedure.
- Improved fuel efficiency as a result of improved aerodynamics.

The main premise behind this work was the knowledge that each of these features considered alone may yield a relatively low cost-benefit ratio. However, when considered together it is possible that the same structural changes (i.e. flat smooth panelling around all sides of the vehicle) could be used to improve all three aspects of performance for the same cost, thus improving the cost benefit ratio.

The research has assumed that the strength offered by the panelling approach to front and rear underrun would not change because changes in these areas are being considered separately by an EC framework project entitled VC-COMPAT and the results are not yet fully known.

It was found, through computer simulation and accident analysis that using a flat panel sideguard reduced the forces applied to vulnerable road users that collided with the side of an HGV. This reduction in forces was predicted to translate to a reduction in the number of pedal cyclists killed of between 0.2 and 1.5 per year with serious injuries reduced by 3.9 per year and slight injuries increased by 17.5 per year. It was also predicted that pedestrians may benefit from the changes with a predicted reduction of between 0 and 2.91 fatalities per year. Using DfT casualty cost figures (RAGB, 2001) this translates to a financial benefit of between £0.581 million and £5.609 million per year.

The effect of spray on accidents is difficult to quantify and estimates of its influence vary widely. However, several UK studies were found that quantified the contribution of spray to accidents and the estimates from these studies were that spray contributed to between 0.4% and 2.7% of all accidents. Using data from RAGB (2001). it was shown that the total number of recorded UK accidents in 2001 was 229,014 and that the average value of prevention of accidents was 54,710 GBP. This suggests that if ALL accidents where spray was a contributory factor could be prevented there would be a total financial benefit of between approximately 50,117 million GBP and 338,293 million GBP. However, the improvements shown with respect to the aerodynamic spray suppression system did not fully eliminate spray, only reduce it. Some spray is also generated by passenger cars and other vehicles that would not be included in the scope of the improvements. It is, therefore, likely that the introduction of such systems as standard would prevent only a proportion of those accidents influenced by spray.

Comparative trials were carried out using a Krone Safeliner trailer that had adopted the integrated approach of flat panels all around the sides of the vehicle. These trials showed that there were significant benefits for both spray and fuel economy. Based on the results of these trials it is estimated that every per cent of the total distance travelled by articulated vehicles at high speed that is completed with a SafeLiner type semi-trailer instead of a traditionally designed semi-trailer could potentially yield an annual reduction of 0.19 million gallons or 0.87 million litres in the volume of fuel consumed and annual cost savings of 0.77 million GBP. If all high speed articulated vehicle travel was completed in vehicles adopting a similar integrated design as the Krone SafeLiner then 87 million litres of fuel could be saved, reducing the fuel bills of the haulage industry by approximately 77 million GBP. Associated societal benefits would also be accrued from reduced noxious emissions.

An additional consideration is that the SafeLiner semi-trailer was 910kg heavier than the tested standard York semi-trailer. Therefore the payload the SafeLiner semi-trailer is able to transport will
be less than the York semi-trailer is able to transport in circumstances where the payload is restricted by the maximum gross vehicle weight. Such operations would require additional journeys to transport the same load, consuming additional fuel should the SafeLiner semi-trailer be used. However there is extra storage space within the chassis structure of the SafeLiner semi-trailer, potentially offering increased capacity where the load transported is limited by volume. However, it should be noted that the Krone SafeLiner is just one example of how integrated safety guards and spray suppression systems may be implemented. The review of alternative materials also showed that it may well be possible to mitigate the increases in weight associated with an integrated guard design such that the cost impact of the reduced payload is minimised or even eliminated.

Summing these benefits shows that implementing an integrated safety guard and spray suppression regulation for all vehicles currently subject to the individual regulations could result in a benefit of up to approximately 128 million GBP to 420 million GBP per year, which would be divided between societal benefits through reduced accidents and direct financial savings for the haulage industry through reduced fuel costs.

13.2 Benefits of individual stand-alone changes

Each of the areas described in the previous section could be considered as stand-alone changes but the cost-benefit ratio is likely to be lower. In addition to the changes described above the project also identified a number of other changes that could be considered separately. These are described in the following sections. An initial analysis of the financial benefits of the changes are provided here but a fuller cost benefit analysis can be found in the Partial Regulatory Impact Assessment also produced as part of this project.

13.2.1 Ending exemptions to underrun/spray regulations

Each of the current individual regulations governing safety guards and spray suppression permit a range of vehicles to be exempt from the requirements. Typically, these are vehicles that lay claim to off-road use or those that also carry out complex functions or operations such as street cleaners or refuse vehicles.

The work found that for “off-road” vehicles there was likely to be little benefit from ending exemptions from spray regulations. This was mainly because current spray suppression material quickly becomes clogged with dirt and debris when used off-road, even on relatively flat well constructed “unmade” roads that might be found on construction sites and quarries. This means that if fitted the spray suppression on vehicles that travel in such circumstances is likely to be ineffective. It is possible that the use of aerodynamic spray suppression devices may be less susceptible to this performance degradation but that is likely to be design specific and cannot be quantified at this time.

The accident analysis carried out as part of this project suggested that ending all exemptions to the sideguard Regulations could prevent between approximately two and three fatalities per year with a corresponding reduction in serious injuries and increase in slight injuries. The predicted net financial benefit (based on DfT estimates of casualty prevention values) was between approximately 2.5 million GBP and 3.5 million GBP.

Knight (2000) analysed a large sample of fatal accidents involving trucks and showed that 7% of all car occupants killed in a collision with an HGV collided with the rear of the HGV. It was also estimated that 8% of all the car occupant fatalities arising from such accidents could be prevented by ending all exemptions to rear underrun regulations. In 2001, 180 car occupants were killed in two-vehicle collisions with an HGV. Applying the estimates to the 2001 figures suggests that approximately one fatality per year could be prevented by ending exemptions to the rear underrun regulations with an associated prevention value of approximately 1.365 million GBP.

Front underrun regulations were only introduced in 2003 and, as yet, there is insufficient accident data involving vehicles equipped with the protection to make reliable evaluations of their effectiveness or predictions of the benefits if no exemptions existed. However, as a tentative initial estimate it can be
assumed that the relative benefit of ending exemptions is the same as that for the rear (8%). Knight (2000) showed that in the UK approximately 50% of all car occupants killed in collision with an HGV are involved in a head on collision. Using the assumption of an 8% improvement combined with the 2001 data suggests that approximately 7 fatalities per year could be prevented by ending exemptions to front underrun protection, translating to a financial value of prevention of approximately 9.557 million GBP per year.

In total, the work has suggested that ending all exemptions to all safety guard regulation could potentially prevent up to a likely maximum of 11 fatalities per year with a prevention value of up to approximately 14.4 million GBP.

The review of the vehicles that were exempt suggested that there was potentially significant scope for reducing the number of vehicles that gained exemptions but that some were essential to the operation of the vehicle and would be required for the foreseeable future. Any action taken on exemptions will, therefore, only achieve a proportion of the benefits predicted above, depending on the number and use of the vehicles for which exemptions are ended.

The work recommended that consideration be given to reducing the number of exempt vehicles through several different mechanisms:

- Specifying off road exemptions on the basis of the off-road vehicle definition in EC 70/156 for all safety guards regulations (currently only front underrun).
- As above but increasing the requirements of the off-road definition such that only vehicles capable of use completely off of a road are eligible rather than allowing vehicles that would not be capable of travelling on any terrain more difficult than an “unmade” gravel road.
- Developing and introducing guidelines for the interpretation of the generic exemption where fitting safety guards is “incompatible with the use” of the vehicle.

13.2.2 Amending sideguard requirements for centre axle trailers

The review identified a potential weakness in the current sideguard regulations with respect to rigid vehicles towing drawbar trailers where all the trailer axles are positioned at the centre of the trailer. The wording of the regulations means that a large gap, where no sideguards are required, can exist between the rear axle of the tow vehicle and the first axle of the trailer into which a cyclist could fall. This was illustrated in Figure 2 earlier in this report. The intention of the sideguard Regulations was always to provide structure that prevented vulnerable road users falling against the side of an HGV and being run-over by the rear wheels. At the time of writing the regulation, centre axle trailers towed by rigid vehicles were very rare in the UK and it is perhaps not surprising that the wording of the regulation did not consider such a situation. However, now that they have become slightly more common (particularly in continental Europe) it would be logical to amend the regulation to require a sideguard ahead of the first trailer axle on such centre axle trailers in order that these vehicles meet the original spirit of the regulation. In addition to this, where a rigid vehicle is designed and constructed to be capable of towing a centre axle trailer a sideguard should be required behind the rear wheels.

It is not possible to quantify the benefits of this change directly because only a small number of vehicles will be affected so both the costs and benefits will be very low.

13.2.3 Amending the wording of the sideguard ground clearance requirements

Research supporting the original sideguard regulation (Riley et al, 1985) showed that the ground clearance of a sideguard was an important factor influencing its effectiveness. It showed that in general lower ground clearances improved performance with cyclists being run-over in tests six out of ten times when the ground clearance was 550 mm reducing to none as the ground clearance was lowered to 300 mm. Both the UK and EC sideguard Regulations are intended to ensure that the
ground clearance is never more than 550 mm. However, the Regulations are worded such that when a semi-trailer is approved the ground clearance is measured when the vehicle is positioned on flat level ground and the load bed of the trailer is also flat and level.

The heights of the fifth wheel/king pin coupling of articulated vehicles are standardised in an ISO standard but the standard permits a significant tolerance that can mean that when some vehicles and trailers are coupled together the load bed of the trailer slopes significantly downward toward the rear of the vehicle. This can mean that if the ground clearance of the sideguard is 550 mm when the load bed is level that it is significantly higher in service. This is perceived to be more likely to be a problem in the UK where tractor unit 5th wheels are perceived to be positioned at the higher end of the scale to allow more room for the spray suppression equipment. Research has shown that 15% of articulated vehicles were found in service, to have sideguards exceeding the maximum 550 mm permitted by regulation, although it was not known whether this was as a result of compatibility problems with the coupling height or simple non-compliance in the design.

The existence of vehicle combinations with sideguard ground clearances in excess of 550 mm does present an increased risk to vulnerable road users. In addition to this it also creates problems for periodic inspection and roadside enforcement agencies. The enforcement authorities have found incidences where they have failed vehicle annual inspection because of non-conformance with the sideguard regulations but the vehicles are only one year old and have not been modified by the owner who purchased the vehicle in good faith from a reputable manufacturer.

Consultation with industry during this project suggested that several manufacturers did not recognise this as a significant problem but that most would not object to re-wording the Regulation such that the ground clearance must be no more than 550 mm when the king-pin was at the upper height permitted by the ISO standard for the 5th wheel or even to be no more than 550 mm in all legal travelling conditions. The front underrun Directive is already worded in a similar way such that in practice most guards are substantially lower than the maximum in order to ensure that they always meet the requirements on all vehicle variants and in all conditions.

Again, both the costs and benefits of this change are likely to be low because only a relatively small number of vehicles will be affected and the technical change is also relatively small.

13.3 Further work required to achieve the benefits

The main barrier preventing the introduction of integrated safety guard and spray suppression systems remains the method used to assess the effectiveness of the spray suppression system. Current methods are design prescriptive and do not allow the use of aerodynamics to control spray. A whole vehicle test is likely to be required. This project has made significant progress in developing a camera-based method for the measurement of spray but has encountered some notable difficulties.

The method was found to be sufficiently repeatable to reliably discriminate between the spray generated by two different vehicles. However, the results were found to be strongly affected by the ambient light level meaning that valid tests could only be carried out in a small range of weather conditions. This is likely to be impractical for a type approval test. It was recommended that the use of modern laser techniques should be further investigated in order to eliminate the variation due to ambient light and enable testing in a much wider range of conditions.

This project only examined the repeatability of the test on one test track. The research showed that the quantity of water sprayed onto the road surface and the texture depth of the surface itself could also affect the results and hence the reproducibility of the results at different test venues. This aspect will need further investigation before a type approval test can be implemented. The work is likely to involve testing on a range of surfaces with a range of water depths and is likely to recommend strict tolerances on test facilities or possibly the use of a relative method where a standardised wheel assembly is used as a reference spray generator and the spray results from the candidate vehicle are expressed as a percentage of the reference spray measurement. The latter method has the potential to eliminate much of the track to track variation and a precedent for such relative approval methods has
been set by the draft proposal for a tyre grip regulation, where track surface and water depth can also substantially affect results at different tracks.

The procedures developed in this project used experimental equipment that was costly and time consuming to set up and the resulting data was processed run by run. Any type approval procedure should be as quick and cheap as possible to carry out in order to minimise the burden on industry and the approval authorities. It is technically feasible to construct permanent facilities and automate much of the process developed in this project but such development was beyond the scope of this contract. This development should form part of the final implementation phase of work, if a suitable method is to be developed and incorporated into regulations.

Certain aspects of the proposals made in this report are likely to be welcomed by industry. For example all operators are likely to be interested in changes that could save fuel bills and removing the restrictions on innovative alternative methods of spray control would increase competition as well as potentially reducing spray, which may be beneficial for both operators and drivers. However, other aspects are likely to encounter some resistance from industry. Most examples of integrated designs that are voluntarily fitted to some vehicles have a ground clearance much lower than the maximum permitted because this is beneficial for the aerodynamics. If a low ground clearance was required for all vehicles as part of regulation a number of vehicle operators could potentially perceive there to be problems with ground clearance. The operation where there is most evidence to support this is with vehicles that use roll-on roll-off ferries. Similar arguments will apply if amendments to reduce the number of vehicles exempt from the safety guards regulations, possibly even more vehemently. TRL would expect most resistance to come from the tipper industry where use on construction sites, quarries and tips is frequent.

In order to implement more restrictive policies on exemptions the most effective solution may be to conduct some full scale vehicle trials. These could be relatively straightforward demonstration-type trials with little instrumentation. For example, a number of different types of currently exempt vehicles could be driven around an off-road test track to identify what types of terrain they were capable of negotiating in standard form. The same vehicles could then be fitted with mock-up safety guards and driven on the same routes to identify whether the safety guards restricted their mobility in any way. Industry representatives could be invited to be involved from the start and/or to attend a demonstration day in their own vehicles. Trials could be repeated at a live site of industry’s choice. If carried out in collaboration with industry in this way, such a programme has the potential to provide a definitive answer to the question of exemptions for the first time since the introduction of safety guards.

The use of vehicles equipped with lower safety guards on roll-on roll-off ferries is a very specific problem that is applicable to only a small proportion of the fleet. It is highly likely that the problem can be overcome with innovative design. In order to convince industry that improved safety requirements are achievable it may be necessary to develop a prototype set of safety guards that meet all of the improved criteria (including any recommendations on rear underrun from the VC-COMPAT project) whilst retaining the capability of negotiating the ferry ramps without undue difficulty, effort, or weight penalty.
14 Conclusions

1. The safety guard regulations have been reviewed in detail to assess inconsistencies between individual regulations and any factors that prevented an integrated design. A number of inconsistencies or anomalies were found that might affect the performance of underrun devices. For example, there were substantial differences in strength requirements for front and rear underrun protection and the test methods differed slightly. Few, if any, features that would prevent an integrated design were identified but there were was little to encourage a manufacturer to do so.

2. A review of the exemptions to safety guard regulations was carried out. There was strong evidence to suggest that the exemptions granted to many vehicles were not justified. However, there was also evidence to show that the exemption system could not simply be ended because some vehicles or operations were likely to require their exemption. A range of potential alternative ways to assess whether vehicles should be exempt was proposed based upon three main considerations of off-road use, the operation of complex ancillary equipment and the presence of vehicle body structure in the controlled areas.

3. Computer simulation showed that smooth flat panelled sideguards did offer potential for improved protection for vulnerable road users and analysis of accident data did suggest that these would translate to real world casualty reductions.

4. Methods of measuring the road spray produced by whole vehicles were developed, using laser and camera-based technology. These methods need further development to become suitable for use in a regulatory framework. The video method of spray measurement was adversely affected by ambient lighting conditions, and in its current state is suitable only for use as a research tool to assist in the development of a laser based method. The laser method was developed based on a single point measurement. Further research should develop a laser line measurement method, which would offer the advantages of covering a larger area of the measured spray cloud and not being affected by ambient lighting conditions.

5. Due to the problems with ambient light conditions, comparisons between the SafeLiner and Baseline trailers can only be made at test speeds of 50 km/h. The spray generated by the baseline vehicle at this speed was seen to be greater than the spray generated by the SafeLiner trailer at the same speed, and was statistically indistinguishable from the spray generated by the SafeLiner vehicle at 70 km/h. There is, therefore, evidence to suggest that using aerodynamics to control spray could result in a substantial improvement in spray suppression.

6. In fuel economy tests, the mean volume of fuel consumed by the tractor unit when drawing the SafeLiner semi-trailer was 2.4% less than that consumed when drawing the York semi-trailer. However, the results were not statistically different at the 95% confidence level.

7. A full cost benefit analysis is included in the Regulatory Impact Assessment carried out for this project but the research has suggested that applying an integrated safety guard and spray suppression design to all HGVs currently subject to the individual regulations (i.e. excluding exempt vehicles) would save up to 5.6m GBP from safety guard improvements, up to 338m GBP from elimination of spray accidents and approximately 77m GBP from reduced fuel consumption.

8. The main barrier to the introduction of such requirements was considered to be the test method for the measurement of whole vehicle spray. Although a method that was sufficiently accurate and repeatable to discriminate between vehicles was developed it was adversely affected by weather conditions and not sufficiently robust for type approval tests. Further development of the methods could solve these problems.

9. The research predicted that requiring all vehicles currently exempt from safety guards regulations to be equipped with guards meeting current requirements would save up to 14.4m GBP from casualty reductions.
10. The main barrier to this measure was considered likely to be industry opposition and it was suggested that physical off-road testing may be required to prove the capability of vehicles equipped with safety guards.

11. Two smaller issues were identified that could improve the performance of sideguards. These were that some drawbar trailers were not adequately covered by current regulations and that height compatibility issues between tractor and trailer of articulated vehicles could potentially result in excessive ground clearances. Re-wording of the appropriate parts of the regulation was recommended.

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