SPRAY AND WIND BUFFETING FROM HEAVY VEHICLES: A LITERATURE REVIEW

Prepared by:

M. Ashton

P. Baas

Transport Engineering Research New Zealand Limited

(TERNZ)

Prepared for:

Road Safety Trust

Land Transport Safety Authority

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Executive Summary

Although regarded as minor contributors to road accident rates, splash, spray and turbulence from heavy vehicles (HVs) are considered by road users to be a major nuisance. A German opinion survey found that 88% of car drivers perceived truck spray as being a real danger followed by excessive speed and aerodynamic turbulence as the second and third most dangerous truck-related hazards (Infratest Burke, 1995).

Splash and spray reduce visibility of other road users, hazards, road signs and markings, and is a source of stress for the driver affected. Members of the European Union (EU) regard splash and spray as hazardous enough to warrant introducing mandatory legislation for spray suppression systems. The United Kingdom, Belgium, and France have already introduced compulsory regulations. Spain and Portugal are in the process of introducing legislation, and it is believed that all EU members will soon require the use of spray suppression systems. Israel has also introduced legislation and Australia, Japan, South Africa, and South America are showing increasing interest in following suit. However, less interest in law making has been shown in the US, primarily due to difficulties in identifying solutions without serious drawbacks.

For over thirty years, considerable effort has been put into studying HV-induced splash and spray. Although there have been difficulties such as those posed by the great variety of vehicle designs, vehicle combinations, and load configurations, the most success has been attained with the development of vehicle- and road-based countermeasures that redirect water and air away from critical areas. Efforts to alter vehicle aerodynamics have not yet been able to provide design solutions beneficial for both fuel efficiency and spray reduction, however, it has been found that a combination of measures can provide effective reduction of splash and spray. An effective vehicle-based suppression system would include textured flaps combined with either fenders or valances. Alternatively, the amount of water on the road surface can be reduced by providing sufficient cross slope, using rough textured chipseal, permeable pavement surfacing (e.g., porous friction course, also known as open-graded asphalt), or cutting grooves in the road surface.

Little information is available on the problem of aerodynamic disturbance from HVs as a hazard to other road users. Again it seems to be a significant nuisance rather than a major cause of crashes. Although not often studied, it seems to be another problem dependent on vehicle design and load configuration. It has been found that increasing the distance between vehicles travelling in the same direction, but in adjacent lanes, is an effective means of reducing disturbance.

As well as the purely safety-related costs, there is also a public nuisance component that needs to be considered by the road transport industry and the roading authorities. Already a number of truck operators fit spray suppression devices voluntarily and the roading authorities have been installing spray reducing pavement surfaces. A combination of vehicle and road-based measures may well result in an effective reduction in HV splash and spray in New Zealand. Further research is required to identify and promote the most appropriate measures.

Introduction

The splash, spray, and turbulence generated by heavy vehicles (HVs) are of considerable concern to other road users. Splash, spray, and the dirt they carry can result in a significant reduction in the visibility of other road users, while turbulence can result in sudden changes in the path of adjacent vehicles.

While both splash and spray are the result of water being ejected from a vehicle during wet weather, they describe different phenomena. Splash results from the mechanical action of a moving tyre forcing water out of its path and is generally defined as water drops larger than one millimetre in diameter that move away from the tyre in a ballistic fashion. In contrast, spray is defined as water droplets less than 0.5 millimetres in diameter that are suspended in the air. Spray is water that has been atomised after it collides with a smooth surface or enters a high-velocity airflow. Wind buffeting, or aerodynamic disturbance, involves both pressure and suction forces that are caused by a moving vehicle (Kirsch, 1972 cited in Pilkington, 1990).

Sandberg (1980) identifies seven negative consequences of splash and spray that can potentially increase accident risk directly by reducing visibility and indirectly by imposing additional stress on drivers. These consequences include reduced visibility of other road users, road signs, and road markings due to the presence of spray clouds and the dirt carried by splash and spray. Dirt on vehicle windows, external mirrors, headlights, and rear lights reduces visibility for the occupants and reduces vehicle conspicuity and sight distance at night. Road sign conspicuity is also reduced when signs are dirty. In addition, drivers may experience stress when they are subjected to a sudden, heavy shower of water on their windscreen that may cause panic if the driver is not prepared for such an event. This panic may lead to potential loss of vehicle control through sudden braking. Further, it may take several seconds for the windscreen wipers to be activated and the windscreen cleared. However, wipers are not effective against spray as the spray clouds are suspended in the air around the vehicles as opposed to covering only the windscreen.

The ability to detect hazards is very dependent on visual performance as well as ambient lighting and atmospheric conditions (Wright, 1992). Any factor that reduces the contrast of an object reduces object detection and recognition range (Ginsburg, 1983 cited in Wright, 1992). Wright tested visibility through simulated spray. He found that the loss of high spatial frequency sensitivity due to looking through simulated spray impaired participants’ ability to detect a target vehicle at longer distances. Another study by Evans and Ginsburg (1985 cited in Wright) found that older drivers in their study required much larger symbols on road signs to enable them to discriminate their meaning. Although all of their participants had the same visual acuity, the older participants had significantly lower contrast sensitivity. These results suggest that drivers with lower contrast sensitivity due to deficiencies within the eye may be at greater risk of having a crash when their visibility is impaired by spray. Standard static visual acuity tests, such as those used in drivers license tests, do not measure contrast sensitivity.

Motor cyclists are particularly at risk from splash, spray, and turbulence. They sit closer to the ground than heavy vehicle drivers and do not have windscreen wipers. Moreover, wiping their visor with their hand means that they must hold the handle bars with one hand while riding on a wet road (when there is a higher risk of hydroplaning) and possibly experiencing aerodynamic disturbance from the spray-producing vehicle (Tromp, 1985).

Many litres of water per second can be picked up and ejected by truck tyres travelling at speed on a wet road (Baughan & Hart, 1988). However, the clouds of spray cause the greatest reduction in visibility because of the relative height, dispersion qualities, and lingering nature of spray (Clarke, 1983). Further, problematic spray is typically generated only by heavy vehicles (Sheppard, 1989). Due to the strong influence of vehicle aerodynamic design on spray production, some light vehicles can also produce large clouds of vision obscuring spray (Subcommittee on Splash and Spray, 1973) but they pose less of a problem as they are fewer in number.

This literature review is part of a study concerned with identifying countermeasures for the alleviation of spray from heavy vehicles and determining whether the air turbulence generated by heavy vehicles is a significant problem that can be addressed effectively. Topics covered in the review include overseas experience with these phenomena, legislative requirements, principal factors involved in the occurrence of these phenomena, and countermeasures.

Overseas Experience with Splash, Spray, And Wind Buffeting

Internationally, splash and spray from heavy vehicles have been recognised as significant threats to road user safety. In particular, members of the European Union (EU) are quite actively involved in the mitigation of these phenomena. For example, they have established the European Safety Campaign Against Road Spray, or ESCARS (ESCARS, personal communication, 1997). The objective of this campaign is to reduce the danger and discomfort caused by vehicle-generated spray. The main initiatives of the campaign include raising drivers' awareness of technologies available to improve comfort and safety on wet roads; recommending effective, practical, and low cost solutions; and ensuring appropriate legislation is put in place.

However, complaints by motorists seem to provide the only indication that splash and spray are problems. It seems that the importance of these hazards in terms of accident rates is not clear. Initially, relevant data was not routinely collected at accident scenes, however, efforts have been made to estimate the size of the threat of splash and spray. Likewise, the importance of aerodynamic disturbance as a threat to road safety is also uncertain. Although numerous inquiries were made for this literature review, inadequate information was found on overseas experience with aerodynamic disturbance. However, an early study by Weir et al. (1971 cited in Pilkington, 1990) found that aerodynamic disturbance was far more hazardous than splash and spray.

The National Highway Traffic Safety Administration (NHTSA) of the US Department of Transportation and others have studied splash and spray for more than 30 years. Reviewing studies completed during this time, the NHTSA reports three major early studies that attempted to quantify the threat to road safety posed by splash and spray. The first was a British study that found splash and spray was involved in 0.41% of accidents (six of 1,469) in 1959. The second study on accidents in the US State of Michigan found that splash and spray were involved in 0.16% of accidents (four of 2,542) in 1957-1958 and 0.20% (five of 2,500) in 1960. The third study by the Connecticut Department of Transportation found that 0.15% of accidents (20 of 130,000) in 1965 to 1970 and 0.36% of fatal accidents (one of 275) in 1970 involved splash and spray. On the basis of these studies the NHTSA concluded that splash and spray were not a significant safety problem but rather a momentary nuisance for motorists (NHTSA, 1994).

Further research was conducted in the US in the late 1970's and early 1980's. Records of accidents that occurred between 1970-1975 and 1980-1982 were studied. Again, these studies failed to find evidence that splash and spray were serious safety problems. However, it was acknowledged that information concerning splash and spray as causal factors was not routinely collected at accident sites. Subsequently, the Fatal Accident Reporting System (FARS) was changed in 1982 to include a new data collection category called "Vision obscured by splash and spray of passing vehicle". However, FARS data collected between 1982 and 1987 also failed to suggest splash and spray were serious safety problems. Only 30 of 350,402 motor vehicle fatalities resulted from crashes that were attributed to splash and spray. Further, using the National Accident Sampling System (NASS), the number of tow-away crashes between 1988 and 1991 that were attributed to splash and spray has been so small that reliable estimates of national totals can not be made (NHTSA, 1994).

The most recent statistics from FARS also confirm that spray is not a common contributor to crashes. In 1996, a total of 35,579 occupant fatalities were recorded. The number of occupant fatalities in crashes involving a driver whose vision was obscured by splash/spray of a passing vehicle by vehicle type during this time were: one out of 22,416 passenger car occupant fatalities; two out of 9,901 light truck occupant fatalities; one out of 2,641 other vehicle occupant fatalities; and none out of 621 large truck occupant fatalities (NHTSA, personal communication, 1998).

In the early 1980's, spray suppression devices became compulsory on heavy vehicles in the UK. Subsequent to the introduction of legislation, the UK Automobile Association (AA) noted that although the problem of spray was not eliminated and no evidence of an improvement in the safety of roads has been seen, there has been a huge reduction in complaints about spray made by AA members. Thus suggesting that suppression regulation has resulted in 'nicer', if not considerably safer, roads. The UK AA has no information on a relationship between aerodynamic disturbance and accidents but suspects that their members would rather it did not happen (UK AA, personal communication, 1997).

An opinion survey on lorry nuisance was conducted in Germany in 1995. Over 400 car drivers and 100 truck/bus drivers were involved. Truck spray in wet weather was perceived as a real danger by 88% of the car drivers. Excessive truck speed and aerodynamic disturbance were the second and third most frequently mentioned truck-related hazards. Further, 92% of the truck/bus drivers regarded spray as a danger for car drivers. Of the car drivers, 64% wanted the government to impose more stringent regulations to avoid truck-related dangers. Regarding the problem of spray, 40% of the truck/bus drivers wanted an urgent solution (Infratest Burke, 1995).

Although little attention has been given to splash, spray, and aerodynamic disturbance in New Zealand, the Land Transport Safety Authority (LTSA) has attempted to analyse crash data to determine the number of crashes involving a truck and another vehicle in which spray may have been a possible contributing factor. A sample of 52 crashes that occurred in 1995 was searched for evidence of truck spray as a contributing factor. These crashes included those where visibility (particularly due to temporary obstruction from elements such as smoke or dust) was cited as a factor and any truck crash (except for single vehicle crashes) where the presence of heavy rain or a wet road was recorded. The result of the analysis was that water spray was a possible contributor to 3 crashes. However, of this sample, the Traffic Crash Reports of 23 crashes did not mention rain or a wet road.

Legislation

The UK was the first country to introduce mandatory legislation for spray suppression. It did so in 1985 and was followed by Belgium in 1990, France in 1993, and Israel in 1995. It is believed that Spain and Portugal are in the process of introducing legislation. Other countries including Australia, Japan, South Africa, and South America appear to be showing increasing interest in following suit. The EU introduced a Directive in 1991 (ref. 91/226/EEC) that is currently voluntary, although it is believed that it may be compulsory for all EU member states in the next few years (Solutia, personal communication, 1997).

The UK regulations, according to Regulation 64 of the Road Vehicles (Construction and use) Regulations 1986 (SI 1986/1078), require all heavy vehicles and trailers to be fitted with spray reducing devices that comply with the British Standard BS AU200. However, vehicles fitted with a spray suppression system that complies with the EU Directive are exempt if the suppression device is legibly and permanently marked with a designated approval mark (UK Department of the Environment, Transport, and the Regions, personal communication, 1997).

The EU Directive sets the technical requirements for spray suppression systems of large vehicles and their trailers. These systems variously consist of a mudguard (a rigid or semi-rigid component that traps water thrown up by moving tyres and directs it towards the ground), rain flaps (flexible components mounted vertically behind the wheel that also reduces the risk of small objects being thrown from the tyres towards other road users), and valances with a spray suppression device. Valances are a component located above the tyre in a vertical plane that is parallel to the longitudinal plane of the vehicle (Council of the European Communities, 1991).

The Directive focuses on two types of suppression device: energy-absorber and air/water separator devices. The energy-absorber type of device (a component that is part of the mudguard and/or valance and/or rain flap that absorbs the energy of water spray) must collect no less than 70% of the amount of water directed on to the device (averaged over five tests). Similarly, the air/water separator type of device (a component that is part of the valance and/or rain flap that allows air flow while reducing pulverised water emissions) must collect no less than 85% of the water directed onto its surface (also averaged over five tests). Requirements for the fitting of the spray suppression devices are also included in the Directive (Council of the European Communities, 1991).

Since 1970 in the US, the NHTSA have made numerous attempts to establish rules concerning the use of splash and spray devices on large commercial vehicles. However, they terminated rulemaking on splash and spray in 1988 due to difficulties with finding effective spray suppression devices. The 1970 proposal requiring the use of the DOT spray protector was withdrawn in 1973 due to a hazardous side effect of the protector. The DOT protector consisted of a combination fender, modified skirt, and a spray suppressant flap. It was found to be effective only at speeds of up to 50 miles per hour (~80 kilometres per hour). As it encased such a large portion of the wheel area, it prevented air from entering and keeping the tyres and brakes cool. Consequently, excessive heat build-up occurred resulting in tyre and brake damage (NHTSA, 1994).

Between 1973 and 1988 research and testing continued in the US and other countries. After analysing studies conducted during this period, the NHTSA found inadequate accident data and also concluded that "*no technology or combination of technologies has been demonstrated that will consistently and significantly reduce … splash and spray on tractors, semitrailers, and trailers to the extent that driver visibility will be significantly improved*" (p. 15). Further, between 1988 and the time of writing their 1994 report, NHTSA did not find any information that would cause them to come to a different conclusion. NHTSA concluded their report by explaining they did not intend to initiate a new rulemaking action (NHTSA, 1994).

However, according to the US Code of Federal Regulations (title 23, volume 1, part 658 "Truck size and weight, route designations- length, width, and weight limitations", revised 1 April, 1997) some States require double and/or triple trailer combination vehicles to be equipped with mud flaps and spray suppressant devices. The States concerned are Arizona, Indiana, Montana, Ohio, Oregon, and Oklahoma.

Moreover, it has been remarked that many fleet operators in the US and Canada specify the use of flaps because the operators and drivers evidently like them (Solutia, personal communication, 1997).

Principal Factors in Aerodynamic Disturbance

The Subcommittee on Splash and Spray (1973) has identified four principal airflow patterns that affect a moving vehicle. These patterns occur overhead, underneath, at the sides, and at the rear of the vehicle (see Figure 1). The rear turbulence results from the other three currents combined and the size and shape of the vehicle's rear surfaces. The Subcommittee explains that the magnitude of air turbulence patterns is related to the size of the vehicle and the area of any continuous surfaces. Under normal operating conditions, a longer truck combination may produce less critical turbulence than a shorter single unit vehicle.

Figure 1: Typical airflow patterns for a truck-semitrailer combination.

Pilkington (1990) reports on research completed by the FHWA in 1972 on the effect of truck-induced aerodynamic disturbance on the control and handling of cars. They found that the adverse effect of this disturbance increases as the speed of the vehicles increases, and decreases as the lateral distance between the vehicles increases. The maximum disturbance was found to occur when the relative speed of the two vehicles is between 5 and 35 km/h, the car is downwind of the truck, and travelling in the same direction as the truck. For traffic travelling in the same direction but in adjacent lanes, a reduction in the magnitude of the aerodynamic disturbance of approximately 50% can be achieved by increasing lane width from 3 metres to 3.5 metres.

It was also found that the areas of a heavy vehicle that produce objectionable turbulence are the front of the tractor; the gap between the cab, semitrailer, and driving wheels; the rear of the semitrailer wheels; the rear of the semitrailer; and with additional trailers, additional areas are the gaps between trailers and around the front trailer wheels. A further conclusion drawn was that a driver's guidance problems due to turbulence may be magnified as a result of physical and psychological stress felt when the car driver is in close proximity to a truck (FHWA, 1972 cited in Pilkington, 1990).

Efforts to identify recent information on aerodynamic disturbance were largely unsuccessful. Most of the literature found was from the early 1970's. No accident statistics, researchers, nor experts were found on aerodynamic disturbance from heavy vehicles as a threat to light vehicles, except the Netherlands organisation for Applied Research TNO which is currently undertaking some related research.. Improvements in fuel efficiency through reductions in aerodynamic drag are a more common focus of research than aerodynamic disturbance.

Principal Factors In Splash And Spray

The Western Highway Institute's Subcommittee on Splash and Spray lists water, air, the driver, the road, the vehicle, and vehicle speed as the principal factors contributing to the problem of splash and spray (Subcommittee on Splash and Spray, 1973).

Water

Water in various forms (i.e., rain, snow, slush, mud, etc.) results in splash and spray with road surface water providing the primary source. As a vehicle travels over this water, the water is splashed outward and inward from the tyres, with most thrown from the front tyres. As a result of wheel speed, water is thrown backward with great force often into the remainder of the vehicle (e.g., following tyres, the underside of the vehicle, the front of a towed trailer, flaps, etc.). This splashed water becomes spray when it collides with vehicle surfaces and is shattered into smaller droplets which are more easily affected by air and wind flow (Subcommittee on Splash and Spray, 1973). These small droplets sink very slowly and remain in the air wake behind the vehicle for a long time such that a 'tail' of up to 200 metres in length can be formed (Sandberg, 1980). Figure 2 shows splash and spray sources (from Pilkington, 1990).

Figure 2: Splash and spray sources

An experiment by the American Federal Highway Administration (FHWA) found that splash is primarily caused by water being thrown side-ways from a moving wheel and spray primarily originates from water that is picked up by the tyres (Weir et al., 1978 cited in Pilkington, 1990). In the latter case, water is picked up and adheres to tyre surfaces due to capillary adhesion before it spills off the top of the tyre as a result of centrifugal and other forces. This occurs at around 120 to 180 degrees of tyre rotation, measured from the tyre/road contact point (Subcommittee on Splash and Spray, 1973). This water then collides with vehicle surfaces and is atomised into spray (Weir et al.). Weir et al. explain that further spray is created from any remaining water on the tyre being stripped off the top of the tyre by the high-velocity air flow (however, this spray only constitutes 1% of the spray cloud).

The air blast and suction forces created by vehicles moving at speed provide another means of introducing water droplets into the air turbulence and wind patterns around the vehicle. These forces achieve this by blowing and vacuuming water off the road surface. In addition to road surface water, water (e.g., rain) that drips or is blown off vehicle surfaces also enters tyre and underbody air turbulence contributing to splash and spray. Finally, the hazard of splash and spray is increased by adverse weather conditions (e.g., falling rain or snow), poor lighting (e.g., at night or dusk or due to dirty or weak headlights), a dirty windscreen, and poor windscreen wipers (Subcommittee on Splash and Spray, 1973).

Airflow

Air becomes a factor in splash and spray when it is moving at a rapid rate. The two major types of airflow that influence splash and spray are the wind or ambient airflow and the turbulent flow caused by a moving vehicle (both the vehicle’s configuration and speed are important). When both the air and an object are moving the air effects (i.e., air resistance, air deflection, air compression, and air turbulence) are greatly magnified and more complicated than when either the ambient airflow or the object is stationary. A vehicle has many surfaces at angles that vary from the direction of the natural wind flow and the vehicle-induced airflow. These surfaces create additional air currents within these two major wind patterns (Subcommittee on Splash and Spray, 1973).

The air currents around the tyres and under the vehicle cause the majority of the problematic spray. In this area the airflow under the vehicle is complicated by the vertical bouncing movement of the vehicle on its suspension system in response to the unevenness of the road surface. This movement creates alternating air suction and air blast. Water spray is carried away on the outward blasts of air. In addition, high-speed wheel rotation creates air currents. These currents are deflected by surfaces including the underbody of the vehicle, tyre wells, flaps, and the road surface. When air and water strike any solid surface, water is atomised and carried on the air in the direction with the least resistance. Air patterns are also created by air drag due to surface friction (Subcommittee on Splash and Spray, 1973).

Different vehicle designs and configurations create different air patterns. Furthermore, the air turbulence created by a particular vehicle can increase in severity depending on features such as the load, wheel or tyre type, the smoothness of the sides of the trailer, and other apparently innocuous features. Consequently, the many causes of air flow and turbulence patterns prohibit the complete success of developing a single vehicle-based splash and spray countermeasure, either a device or system, that will be effective on all trucks and truck combinations. Total vehicle design must be considered in the search for a realistic solution to the problem (Subcommittee on Splash and Spray, 1973).

The Driver

The Subcommittee on Splash and Spray (1973) considers the driver as the most important factor in vehicle splash and spray as the driver has the capability of exercising judgement and compensating for the influence of the other principal factors involved. Although drivers are only able to control the speed of their vehicle, reducing speed (or pulling over to let following vehicles pass) is an effective means of reducing the adverse effect of the splash and spray caused by their vehicle.

The Road

Road design focuses strongly on providing safety and convenience for the road user. To achieve this, research on areas such as road profile, cross slope, surface material, and surface texture has focused on ways of providing better traction, enabling shorter stopping distances, and improving vehicle stability. However, some of these improvements have led to an increase in the severity of splash, spray and hydroplaning. For example, the macro- and microtexture of a road surface that has been designed to improve traction and braking ability can actually reduce the free movement of water from the road. Consequently, greater depths of water can remain on the road for longer periods. However, road designs that provide the greatest safety benefits, such as high skid resistance, have been preferentially chosen (Subcommittee on Splash and Spray, 1973).

The Vehicle

The size, configuration, and weight of a vehicle and the size, design, pressure, and condition of its tyres play a role in the problem of splash and spray. As vehicle size increases, so too does the air turbulence it creates. However, the shape and area of continuous surfaces influences the effects of vehicle width, length, and height. For example, under certain conditions a long truck combination with several units may produce less turbulence than a shorter, single unit vehicle (Subcommittee on Splash and Spray, 1973).

Configuration is considered as a very important variable. The extent and severity of splash and spray is determined by factors such as: the shape of the front, rear, side, top, and bottom surfaces; surface texture; the spacing between units; the distance between the underbody and the road; and the shape and location of equipment and accessories including wheels, axles, brake equipment, fuel tanks, grab bars, stirrups, and anything else attached outside the vehicle shell. However, a ‘good’ aerodynamic design is not necessarily associated with desirable levels of splash and spray (Subcommittee on Splash and Spray, 1973).

In their summary of research conducted in the early 1980's, Koppa and Pendleton (1987) report that short-nosed conventional tractors (particularly those with steering axles positioned directly behind the front bumper) produce the worst amounts of spray. Somewhat better are the cab-over-engine (COE) and long-nose conventional tractors which produce similar levels of spray. They also add that load shape on a flat bed trailer is important. An irregular load can increase spray production with little improvement provided by vehicle-based splash and spray countermeasures (fenders and flaps etc.).

However, Weir et al. (1978 cited in Pilkington, 1990) found that a COE tractor with a van semitrailer caused the largest aerodynamic disturbance effect and the largest spray cloud when compared with long nose conventional tractors with flat bed trailers, tanker semitrailers, and trailers in single, double, and triple configurations. Moreover, work conducted in the late 1980's found that articulated tanker vehicles produced more spray than box-bodied articulated goods vehicles. The aerodynamic forces generated by tankers and the flow field particularly between the tractor and the front of the trailer are significantly different to that of conventional box container vehicles (Garry, 1990).

The Subcommittee on Splash and Spray (1973) explain that vehicle weight primarily contributes to splash and spray by affecting the force with which the tyres strike water on the road. Consequently, a heavier weight results in a greater force and more splash. They also add that an increase in weight may also affect the underbody air blast and turbulence patterns. However, a study by Weir et al. (1978 cited in Pilkington, 1990) did not find any effect of vehicle weight on either aerodynamic disturbance or splash and spray.

The size and design of the tyres determine the amount of water displaced, picked up, and spilled from the tyres. Tyre design is primarily aimed at providing optimal traction for conditions of use. However, the designs that produce the most traction also tend to produce the most splash, spray, and noise. Although probably of more importance to hydroplaning than splash and spray, tyre pressure helps determine the ability of the tyre to pass through surface water and grip the road. Tyre condition, on the other hand, affects the amount of water picked up. When the tread is worn, the shallow grooves hold less water therefore greater splash results. Yet, tyre designs with deep longitudinal grooves result in greater spray as water is held in the grooves and thrown off in the upper wheel area with wheel rotation (Subcommittee on Splash and Spray, 1973).

Vehicle Speed And Following Distance

Vehicle speed is the only factor that controls all aspects of splash and spray production (Subcommittee on Splash and Spray, 1973). Maycock (1966 cited in Subcommittee on Splash and Spray) explained that at speeds over 30 mph (50 km/h), the intensity of splash and spray appears to increase at nearly three times the rate of the increase in vehicle speed. The equation is:

$$\text{spray density} = \text{a constant x speed}^{2.8}$$

It is valid for speeds of approximately 70 to 120 km/h (Maycock, 1966 cited in Tromp, 1985). In addition, Chapoux (1967 cited in Subcommittee on Splash and Spray) concluded that spray length seems to increase with speed squared and the square root of the depth of the water. Furthermore, Chatfield, Reynolds, and Foot (1979) explain that spray does not become measurable until heavy vehicle speeds exceed 48 km/h and is not significant until speeds exceed 64 km/h.

The Subcommittee on Splash and Spray (1973) report a number of studies that indicate that splash and spray are generally not a problem until heavy vehicles travel at speeds of at least 50 mph (80 km/h). Visibility problems for adjacent motorists have been noted at speeds of between 50 and 60 mph (80 and 97 km/h) in heavy standing water. Although splash and spray from trucks is objectionable at generally lower speeds than that of passenger cars, the design of certain car, utility, and car and trailer combinations can also produce problematic splash and spray at about the same speeds as for trucks. Vehicle speed is also associated with the height of splash and spray. Particularly on two-lane highways, it has been suggested that splash and spray pattern height may be more important to control than width (Subcommittee on Splash and Spray, 1973).

Splash And Spray Countermeasures

The most effective and global splash and spray countermeasures are those applied at the pavement surface to reduce the amount of water in the tyre path (Pilkington, 1990). However, no single solution has yet been found. Interest has been shown in driver and speed-related countermeasures but efforts have focused mainly on the road and the vehicle. Numerous vehicle-based devices have been developed and tested over the past 30 or more years (see Chatfield et al., 1979; Esser & Neill, 1984; Goetz & Schoch, 1995; Johnson, Stein, & Hogue, 1985; Kamm, Wray, & Kolb, 1970; Sagerer, 1992; Sandberg, 1980; Subcommittee on Splash and Spray, 1973). Although not all test results were consistent, many of these devices can produce a measurable reduction in splash and spray but often the difference was insignificant, as it was not noticeable to observers. However, greater success has been attained since the introduction of textured spray suppressant materials (Gorte, Joyner, Pedersen, & McConnell, 1985). By using a combination of partial solutions, significant improvements can be achieved.

Yamanaka and Nagaike (cited in Hucho, 1987) studied the effectiveness of a selection of fenders and chassis fairings by assessing the amount of HV-induced spray that hit the windscreen of a following car at various road speeds and following distances. They measured the amount of water collected on a 0.2 m^2 surface situated on the front of the car at driver eye height and the selection of windscreen wiper speed necessary for safe driving. Their results are presented in figures 3 and 4 below.

Figure 3: Effect of HV chassis fairings on spray striking a following car depending on vehicle speed.

The shading on each vehicle diagram shows the area of fairing treatment.

Figure 4: Effect of HV spray control devices on spray striking a following car depending on car following distance.

Testing of spray suppression devices has been conducted in laboratories as well as on the road. Although on-road testing with full-scale vehicles certainly provides more realistic conditions than a laboratory can, varying wind and light conditions have been found to adversely affect on-road test results. Consequently, analysing the effectiveness of devices has been difficult and unreliable (Mousley, Watkins, & Seyer, 1997). However, Mousley et al. from the Royal Melbourne Institute of Technology (RMIT) in Australia have developed a system for on-road testing that has been found to produce repeatable results under varying ambient light and wind conditions. During the past 10 years, considerable research on spray alleviation and measurement has been conducted by the RMIT. The Australian Federal Office of Road Safety (FORS) sponsored much of the work, but the work is, unfortunately, not yet publicly available.

The Driver

Although splash and spray can be eliminated quickly and effectively by the driver reducing vehicle speed and/or pulling over to allow following traffic to overtake, a number of factors limit the use of these strategies. Firstly, the threat caused by splash and spray may be lower than the accident risk posed by the heavy vehicle reducing its speed. This is because accident risk is believed to increase when vehicles on the roadway are not travelling at the same speed (leading to an increase of overtaking manoeuvres), especially in conditions where visibility is low and traction is poor. Secondly, due to differences in background scenery, direction of travel, and eye height, the heavy vehicle driver may not be able to determine the severity of splash and spray created by his/her vehicle as it affects following traffic. Moreover, the speed at which heavy vehicle drivers travel is influenced by the need to meet schedules (Subcommittee on Splash and Spray, 1973).

One Canadian trucking firm had considerable success with controlling splash and spray by training their drivers in public relations and highway courtesy. In doing so, they also reduced public criticism concerning splash and spray. The drivers were instructed to monitor other traffic and drive to please them. For example, by pulling over to let them pass (although inconvenient, good results were obtained) and on multi-lane roads drivers should drive in the down wind lanes. The company found that this type of driving behaviour was time consuming and it meant schedules were not always met but they found it cheaper and quicker in the long run (Subcommittee on Splash and Spray, 1973).

The Road

Road-based countermeasures can provide a long-term, but capital intensive, means of suppressing splash and spray by minimising the amount of water on the pavement. Although they will only provide a partial solution, road designs that improve drainage (minimising the layer of water on the road), and thereby reduce the intensity of splash and spray, also reduce the chance of hydroplaning for light vehicles and increase traction for all vehicles during wet weather conditions.

Means of improving drainage identified by the Subcommittee on Splash and Spray (1973) are: reducing the number and lengths of zero percent grades (by alternating slight plus and minus gradients); eliminating road shoulders that prevent or delay drainage (e.g., those with greater macrotexture than the pavement and those with inside edges higher than the adjoining edge); sloping multi-lane divided highways in both directions from the middle (as opposed to a continuous cross slope across several traffic lanes); avoiding excessively smooth surfaces (especially on flat cross slopes); and keeping shoulders and pavement edges free of obstructions to water flow from the pavement. In addition, they suggest that consistency and quality are required during pavement construction.

Three means of improving road drainage used today are: providing sufficient cross slope (typically at least 2%), using highly textured or permeable pavement surfacing, and cutting grooves in the road surface.

Open-Graded Asphalt

The Australian Asphalt Pavement Association, or AAPA, (1997) explain that Open-Graded Asphalt (OG) is a permeable pavement surfacing that has a high air void content (greater than 20%). It is generally used overseas in layers usually between 25 and 40 millimetres thick and is also known as porous friction mix, open-textured asphalt, friction course, drainage asphalt, whisper asphalt, porous asphalt, and pervious macadam.

As a result of improving drainage, the benefits of OG over traditional pavement surfaces include:

- reduced splash and spray;
- reduced hydroplaning (or aquaplaning) at normal speeds even when the drainage passages are cluttered with debris and dirt;
- improved skid resistance (although not equal to that of a dry road, resistance of a wet OG at high speeds is higher than that of a wet traditional asphalt, however, the

skid resistance of a wet OG is not higher than that of a wet traditional asphalt at low speeds);
- reduced dazzling from the reflection of lights (headlights, street lights, or sunlight) from water on the road surface that also leads to improved visibility of road surface markings;
- high resistance to permanent deformation (ruts in the road surface);
- reduced rolling noise from the passage of traffic (reduced noise internal and external to the vehicle);
- reduced drag resistance leading to considerable fuel savings (in certain conditions and in comparison with some road surfaces); and finally
- waste rubber from old car tyres can be disposed of by being incorporated in OG. Doing so also improves the noise reduction benefits and durability of OG (Lefebvre, 1993).

The disadvantages of OG include a shorter design life and possibly higher construction and maintenance costs. A limited life is the major concern when selecting an OG. The porous nature of the surface exposes the binding materials to the damaging effects of ultra-violet light, oxidation, and moisture. However, careful selection of binders and attention to the thickness of the binder-film can improve durability. Moreover, when design life is defined as retention of surface characteristics, as opposed to structural integrity, then the design life of OG exceeds most other surfacings. Pavement life can be prolonged by improving drainage through ensuring the underlying surface is impermeable, there is sufficient crossfall, and by providing side drainage (AAPA, 1997).

Construction costs depend on:
- the cost and quality of aggregates used (which can vary between countries);
- the skill of the designers and contractors;
- the need to adapt road markings (more marking material may be needed but as a result of the greater macrotexture it may last longer and so cheaper materials may be used);
- the need to have a watertight layer beneath the permeable surface, however, this depends on the nature of the existing surface on which the OG is to be applied (Lefebvre, 1993).

OG can also be more expensive to maintain. Repairs cost more as it is necessary to match the original mixture precisely to retain the drainage properties (Lefebvre, 1993). In addition, more maintenance is required in winter in regions where there is a risk of black ice as frost and black ice form more rapidly on OG than on traditional asphalt (ESCARS, personal communication, 1997). ESCARS add that authorities in Germany have now banned the use of OG in all regions with a risk of black ice. Clogging of the pores with road grime is another drawback of OG. However, the passage of high-speed traffic will clean the pores sufficiently to maintain a high porosity layer (AAPA, 1997). Moreover, a cost-benefit analysis completed by van der Zwan, Goeman, Gruis, Swart, and Oldenburger (1990) shows that the potential benefits of OG (i.e., improved road safety) justify the extra expenditure necessary.

Generally, OG is not recommended for use at higher elevations where there is freezing, in parking areas (due to the abrasive action of many tyres turning sharply), where mud can be tracked onto it from an unsurfaced side road, and in areas with exposure to tyre chains and studded tyres. OG is regularly used in California where hydroplaning is a concern and/or in areas where high rainfall intensities are common. They also use it on flat roads with a cross slope of less than 2% (a CALTRANS engineer, personal communication, 1997).

OG has been successfully used in a number of countries including Australia, the US, and several European countries. Extensive use has been made in Belgium, the Netherlands (van Heystraeten & Moreaux, 1990), Spain (Ruiz, Alberola, Perez, & Sanchez, 1990), and Italy (Camomilla, Malgarini, & Gervasio, 1990). First used in the 1950’s (AAPA, 1997), considerable improvements have been made to the types of mixtures used and methods of construction and many of the drawbacks of OG have been eliminated or reduced. For example, a French team of researchers has developed a mix with a higher than usual void content of close to 30% thus improving drainage (Goacolou & Le Bourlot, 1996). Another French team has developed an OG with a void content close to 30% that has greater permeability than conventional OG (Michaut, 1996).

In Spain OG is used on any type of road and for all traffic conditions (Ruiz et al., 1990). Recently, the Spanish have had success with the development of hot bituminous mixes that have very good surface drainage (Gordillo, Bardesi, & Ruiz, 1996). Moreover, one Dutch team has developed a new double-layered OG called Twinlay that has apparently largely eliminated the drawbacks of conventional OG mixes (Van Bochove, 1996). The Italians have also developed a double-layered OG that has been in use on a motorway since late 1995 (Battiato, Donada, & Grandesso, 1996) and in Denmark an OG called Combifalt® has been developed also with benefits for splash reduction (Pedersen & Ladehoff, 1996).

New Zealand open grade asphaltic concrete (better known here as porous friction course) is not as open and thickly applied as American and European OG. As a consequence NZ friction course tends to clog within 3-4 years even on high volume motorway sections (Cenek, personal communication 1998). The desirable water drainage and noise suppression characteristics of friction course are therefore negated, typically half way through the economic life of the pavement surface. The spray generated on clogged sections of the Wellington Motorway is equivalent to that of smooth asphaltic concrete and slurry seal surfaces and much worse than on smooth textured chipseals. Given that friction course surfaces are about 4 times more expensive than chipseals, but have half the useful life if spray is a major consideration for their use (4 years to typically 9 years) then promotion of friction course does not make much economic sense (Cenek, personal communication, 1998).

To minimise the likelihood of aquaplaning on the high speed sections of the national roading network, Transit New Zealand has specified a minimum chip seal pavement texture depth based on the sand circle method of 0.9 mm (Cenek, personal communication, 1998). However, modelling work being undertaken by Opus International Limited has shown that truck tyres when loaded to the legal limit can penetrate chipseal surfaces up to a depth of 1.5-1.6 mm. This suggests that at texture depths of below 1.5 mm, there is no drainage capability and so the water is squeezed out, resulting in spray. Heaton, Henry, and Wambold (1990) found that four surfaces with the same nominal texture depth had a factor of 4 difference in the drainage area, suggesting that texture depth is not a good predictor of the drainage potential of a road surface. A better form of continuous drainage characterisation than texture depth that can be applied at a network survey level is urgently required.

Grooving

Grooving in road pavements is similar in principle to grooving present in tyre tread patterns and is used primarily to reduce hydroplaning. The process involves cutting 2.41 millimetre slots in the road surface that are 3 to 7 millimetres deep and 19 millimetres apart. In California the grooves run in the same direction as the flow of traffic to reduce road noise. However, in Oregon the grooves are perpendicular to traffic flow. As rainfall intensities are higher and durations are longer in Oregon, the perpendicular grooves allow for faster drainage.

Although grooving is typically used on concrete pavement it has also been successfully used on asphalt concrete surfaces. Exposure to tyre chains and studs reduce the life of grooving yet it can remain effective for 10 years, even on California's busiest metropolitan freeways. On the older, flatter freeways in California with a cross slope between 1 and 1.5%, particularly those with 3 or more lanes, OG or grooving are considered the appropriate means of improving drainage (a CALTRANS engineer, personal communication, 1997).

The Vehicle

Koppa and Pendleton (1987) identified two fundamental and complimentary vehicle-based approaches to controlling and suppressing splash and spray. They are:

1. Utilising aerodynamic vehicle design or adding aerodynamic devices to reduce turbulent air flows in critical areas of the vehicle to
- reduce buffeting of airborne water,
- keep water on, or return it to, the pavement after it is picked up by the tyres, and
- minimise the formation of areas of low air pressure at critical points on the vehicle (that can suck spray outwards from the vehicle).
2. Containment and redirection of splash by
- enclosing the wheel assemblies, and
- replacing critical hard, smooth surfaces with textured surfaces.

Aerodynamics and Vehicle Design

As the air currents under the vehicle play the largest role in splash and spray production, vehicle designs that deflect air away from this area should reduce splash and spray. In particular, tractor designs that deflect air over the trailer (rather than under it) should reduce side spray (Subcommittee on Splash and Spray, 1973).

Improved aerodynamic vehicle design is considered a long-term solution. However, immediate improvements may be achieved by focusing on reducing, eliminating, or relocating accessories, equipment, or other external features that deflect air or water into critical splash and spray areas. Some success has been achieved by using air deflectors on the tractor cab that deflect air upward (thus reducing the amount of air that strikes the front of the trailer) to reduce air resistance and operating costs (Subcommittee on Splash and Spray, 1973).

Air deflectors may be placed in front and/or behind a wheel to break up air turbulence at the wheel area and direct air inwards to reduce the outward air forces. Devices placed behind the front wheels may also prevent water from landing on rearward surfaces (e.g., fuel tank) or being picked up by following tyres. A number of devices have been designed to divert and redirect air. Some have involved small air vanes fastened to the wheel, the use of a solid rubber flap the full width of the front bumper extending down close to the road, and an air scoop deflecting air into a hose or channel and directing it to critical areas. However, this last device was found to be neither effective nor practical (Subcommittee on Splash and Spray, 1973).

Moreover, a drawback of deflectors is that they will only change the shape of the spray pattern. They do not reduce the volume of spray produced. For example, directing the spray over the truck will result in spray entering the truck's wake, thus reducing visibility as far as 200 metres behind the truck (Allan & Lilley, 1983 cited in Pilkington, 1990).

Garry (1990) conducted wind tunnel tests on scale models of articulated tanker vehicles to determine the effect of various vehicle modifications on aerodynamic drag and water spray dispersion. Paraffin smoke was used to simulate water spray and devices tested included a selection of tractor-trailer gap seals, tractor side skirts, and cab roof-mounted fairings. The tests showed that devices designed specifically for box containers are not so effective on tanker vehicles. Unlike the box-bodied articulated vehicles, the aerodynamic devices that reduced drag did not appear to significantly affect spray dispersal beside and behind the articulated tanker.

The design of additional equipment on the perimeter of the vehicle is constrained by height restrictions on heavy vehicles and practical limitations such as the proximity of the road (Subcommittee on Splash and Spray, 1973). However in the US, splash and spray suppressant devices are excluded from width restrictions. They are also excluded from length restrictions if their function is related to the safe and efficient operation of the semitrailer or trailer (Code of Federal Regulations, 23cfr658, 1997).

The PACCAR Technical Center has made splash and spray measurements on their American products, Kenworth and Peterbilt tractors. Their tests focused on van-type trailers which, they explain, produce less splash and spray than other types (e.g., tanker and flatbed). Although they did not focus on individual spray suppression devices, they did find that in low wind conditions aerodynamic tractor-trailer combinations produce significantly less spray. Moreover, the best results were achieved with an inherently aerodynamic tractor, front air dam, treated fenders, side fairings, cab extenders, rear quarter fenders, and a minimal tractor-trailer gap. Further, as their focus has been on the spray cloud, their impression is that the size and intensity of the cloud are inversely proportional to how aerodynamic the tractor-trailer is (PACCAR Technical Center, personal communication, 1997).

NHTSA (1994) reviewed research conducted by PACCAR and another truck tractor manufacturer, Freightliner. Both companies claimed that they had made more aerodynamic vehicles that resulted in a near 90% reduction in splash and spray production. NHTSA discounted their claims as neither manufacturer had addressed two stumbling blocks (as identified by NHTSA) to using improved aerodynamics as the universal solution. First, aerodynamic improvements are adversely affected by the presence of even moderate crosswinds and second, the success of aerodynamic improvements was dependent on the tractor towing a van semitrailer only (as opposed to any other type of semitrailer).

Spray Suppression Equipment

Sandberg (1980) regards a good spray protector design as one using the following principles:

- vehicle surfaces hit by water droplets should be made of a material that prevents the droplets flowing into the air stream;
- the same material should also be used between tandem wheels;
- side valances should extend down to at least the periphery of the tyre or, on the front tyres, as low as practical;
- flaps should extend down to about 150 millimetres above the road;
- the protectors should extend down in front of the tyres, below tyre height;
- protector material should be able to withstand great amounts of water without becoming saturated at high road water depths (to achieve this, changes to the front wheel protectors and flaps may be required); and
- the protector material should be self-cleaning to maintain effectiveness.

Flaps, fenders, and valances seem to be the most common and effective spray suppressant equipment in use today.

Flaps

Rubber or plastic flaps (or mud flaps) are the most common type of vehicle-based countermeasure representing 99% of the market with air/water separators representing less than 1%. It has been argued that flaps are preferable because they are simple, low-cost, and can fit all vehicles. Further, flaps typically last the lifetime of the truck (5 to 7 years) yet have performed well in all climates for more than 12 years. An additional benefit is that many are recyclable (Solutia, personal communication, 1997).

The purpose of flaps is to absorb the impact energy of, and capture water thrown from the tyre tread and the top of the tyre, and deposit the water back on the road (Clarke, 1983). Factors mentioned by Clarke as being important for flap effectiveness include:

- surface texture;
- location and manner of installation (close to the tyre but not so close as to result in damage to the flap);
- length (as close to the ground as possible);
- width (at least as wide as the tyre or tyres it is behind);
- upper height (as high as practical but at least as high as the top of the tyre); and
- flexibility or ‘anti-sail’ characteristics (it should remain as vertical as possible).

As an example of a textured flap, Solutia (formerly the chemical businesses of Monsanto Company) has produced a textured flap called ‘Clear Pass®’ in the UK and Europe and ‘Spray Guard®’ in the US that was previously known as the ‘Reddaway System’. This product meets the EU Directive criteria and is widely used in EU member states. Appendix 1 is a brochure advertising the Clear Pass flaps illustrating the location of the flaps on a HV and the nature of the textured surface of the flaps. No endorsement of this product is intended. It is included purely as an example. There is a large range of rubber and plastic flaps available for heavy vehicles in New Zealand.

Fenders

The principal advantage of fenders (guards, mudguards, wings) is to catch water thrown rearward from the tyre tread and peripherally from around the tyre circumference. Secondarily, the fender must prevent turbulent air mixing with the water collected. To achieve this, the fender, or a back flap, must extend down close to the road pavement, consist of an impact attenuating surface, prevent turbulent air reaching the tyre periphery, and utilise a means of depositing the water back on the road away from turbulent air. To be successful a fender must also block the main source of air entering from the area directly in front of the tyre. This may involve adding valances to the fender. However, it is only necessary to partially enclose the tyre. By allowing some airflow around the tyres and wheels, excessive tyre and brake temperatures are avoided. Total enclosures are not necessary as they only provide a modest improvement in the control of spray (Clarke, 1983).

One fender device described by Hucho (1987) incorporates a flexible, large-pored flap at the rear of the wheel housing. The flap is permeable to air yet captures spray flung from directly behind the tyre contact patch or ‘tread throw’ area which the fender cannot catch. This device is claimed to largely eliminate the influence of vehicle shape, road speed, tyres, and road surface on the degree of soiling.

There seems to be a large range of aluminium and plastic fenders in New Zealand. Fenders with brushes inside them are also available. Early models, at least, of this brush type had one major drawback. The Subcommittee on Splash and Spray (1973) explain that they had poor durability as the brush material is subjected to severe pounding and abrasive effects of road debris, and it also clogged up quickly.

Valances

Also known as skirts, side flaps, wheel protectors, and wheel aprons, valances are an extension of the fender lip. On trucks, valances reduce the amount of spray (thrown from the top of the tyre) being blasted outward at car windshield height. But they do not suppress splash and spray produced from lower tyre and vehicle body surfaces (Subcommittee on Splash and Spray, 1973).

The benefits of combining suppression system components have been demonstrated by ESCARS. ESCARS have produced video footage showing that a clear reduction in spray has been achieved on British motorways since spray suppressant systems became a legal requirement in the mid 1980’s. While travelling at approximately 90 km/h in wet conditions, obvious improvements in visibility can be seen with HVs fitted with flaps and fenders or flaps and valances. A comparison is made with HVs without any suppressant device and those fitted only with plain flaps or only fenders.

Tyre Design

The Subcommittee on Splash and Spray (1973) explain that tyre designs are limited by the greater importance of traction to road safety than the need to reduce the nuisance caused by splash and spray. They add that designs which improve traction (and also reduce noise) are counterproductive to reducing splash and spray. However, they suggest that the chinned tyre, as successfully used on aircraft, may provide an answer. The chinned tyre has a built-up lip or protuberance on the outer side wall. It projects 25mm or more from the side-wall of the tyre and is about 12mm from the pavement. The lip deflects water and debris thrown upwards and outwards from the tyre tread as it strikes the road pavement. It does not suppress water picked up and thrown from the tyre tread.

However, disadvantages of a chinned tyre on road vehicles may include poor durability (due to curb parking and wear and tear from running over raised objects), heat build-up due to the thickened cross section, or steering or wheel balance problems. Chined tyres may be most successful when used on the front wheels where they would provide a cleaner wheel path for following tyres by removing some water from the pavement (Subcommittee on Splash and Spray, 1973).

It seems that little progress has been made on tyre designs since the 1970's. Leading international truck tyre manufacturers (Bridgestone/Firestone, Michelin, Dunlop, and Goodyear) do not currently have any information available on tyre designs nor products on the market that are beneficial to the HV splash and spray problem.

Other Countermeasures

Numerous other concepts have been considered over the years. One idea involved attaching a false bottom to the vehicle or revising vehicle design to reduce the air space below it. Some reduction in splash and spray has been noted with this idea in use. Thought has also been given to the use of advisory signs indicating the maximum safe speeds for wet weather driving (Subcommittee on Splash and Spray, 1973).

Discussion

The proportion of crashes due to spray and wind turbulence is difficult to quantify, but from the available NZ and overseas data, it is probably a factor in less than 0.4% of HV crashes. This may well be because motorists on the whole allow for the increased risk caused by the reduced visibility. The increased level of risk is reflected in the high level of public concern about spray and turbulence. Further, the risk of splash and spray-related crashes may increase as traffic speeds increase (i.e., as speed increases spray production increases and reaction time and stopping distances decrease), traffic volume increases, and where there are insufficient overtaking opportunities.

In order to obtain an order of magnitude of the social costs involved, it is assumed that 0.4% of HV crashes are spray and turbulence related. There are approximately 100 fatal truck-related crashes per year in New Zealand. The proportion of fatal: serious injury: minor injury: property damage only crashes is 1:2.25:6.75:243 for truck combinations, and the cost per reported crash is $2,603,000 for a fatality, $230,000 serious injury, $16,000 minor injury, and $1600 property damage only according to data supplied by LTSA. From these assumptions spray and turbulence-related crashes cost approximately $1.5 million per year. Assuming a fleet size of 60,000 HVs then the cost per rig is approximately $25 per year. If it is assumed that HVs have an average remaining life of 5 years, then the present value of the social costs is $94.77. That is, it is worth spending up to $95 on each and every HV if that would eliminate all spray and turbulence-related crashes.

However spray is not a problem in 50km/h areas, so HVs that are primarily operating in the urban environment do not need spray suppression devices. While the numbers are not known at this stage, spray suppression treatment for the open road, high mileage vehicles will result in the largest improvements. This issue needs to be investigated further through an analysis of vehicle usage. The base data for this analysis is being collected as part of the Heavy Vehicle Performance Measures project being conducted by TERNZ.

Roading-based solutions are recognised internationally as being of primary importance in reducing splash and spray. Only the high-speed at-risk road sections need to be treated. Road-based options include texture improvements to chip seals, porous asphalt surfaces and the elimination of standing water through improved road geometry and drainage.

As mentioned above, HV spray and turbulence are of considerable concern to the motoring public. As well as the purely safety-related costs, there is also a public nuisance/acceptance component that needs to be considered by the road transport industry, LTSA, and the roading authorities. Overseas experience suggests that cost-effective steps can be taken to significantly reduce spray and turbulence. Already a number of truck operators in New Zealand fit spray suppression devices voluntarily and the roading authorities have been installing porous pavement surfaces and controlling chipseal texture

It is recommended that the various road and vehicle based options be investigated further and their benefit-costs determined in order to identify the most appropriate range of measures for the New Zealand environment. No single measure is likely to be effective on its own. Options include the identification and treatment of road sections that pose a risk through retained water, appropriate use of chip seal and porous pavement surfaces, and the promotion of spray suppression devices on the HVs that spend considerable periods of time on the heavily trafficked, high speed sections of the roading system.

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Appendix 1 Example of Flap

Appendix 1 is a brochure advertising the Clear Pass flaps illustrating the location of the flaps on a HV and the nature of the textured surface of the flaps. No endorsement of this product is intended. It is included purely as an example.