Report to

Queensland Department of Transport and Main Roads

Project RSSM 07-11

Benefits of Heavy Vehicle Stability Safety Technologies

FINAL REPORT

JUNE 2011

Prepared by

Bob Pearson and Bob Gardner

Pearsons Transport Resource Centre Pty Ltd

Pearsons Transport Resource Centre Pty Ltd
ABN 54 075 922 566
8 Meaka Court Warrandyte Vic 3113
tel: (03) 9844 2555 fax: (03) 9844 2209
e-mail: bobp@ptrc.com.au

EXECUTIVE SUMMARY

This project was primarily aimed at conducting research into the heavy vehicle stability safety technologies (HVSST) available and analysing crash data to determine the safety benefits of HVSST to reduce the road toll and improve safety outcomes.

Heavy Vehicle Stability Safety Technologies

Heavy vehicle stability safety systems are currently available from a number of manufacturers of heavy road transport equipment. Advisory systems to warn the driver of impending rollover were developed over a decade ago and have been superseded by technology development. Advisory systems were not considered in this project, nor were systems in the experimental stages such as those that pump up air bags. The technologies that were used in the crash analysis part of the project were:

- ESC/ESP[1] for rigid trucks and prime movers; and
- RSS/RSC[2] for trailers and semi-trailers.

Stability safety technology is claimed to be highly effective in potentially dangerous situations like:

- overestimating curve speed limit (e.g. narrowing curves, highway exits);
- obstacle avoidance manoeuvres with sudden steering input (e.g. steering from the shoulder back onto the road and skidding); and
- laden semi-trailer in narrow curves on slippery surface (jackknifing on turns).

Analysis of Crashes

In total, 440 crashes were examined in detail, half of which occurred in Queensland and the other half in Victoria. Each crash was a stability related crash to ensure that adequate numbers of crashes of that type were analysed.

Not all stability related crashes can be eliminated or reduced by HVSST. In particular, the following crash types would still occur:

- rollover crashes when the vehicle enters a curve so fast that it cannot be slowed sufficiently to prevent rollover;
- fatigue related crashes or similar where the driver simply does not perceive a curve and drives straight ahead; and
- crashes where the vehicle is tripped causing a rollover.

The tables below outlines the configurations that were involved in the crashes assessed together with the safety benefits of the assessed crashes. The average benefit (per crash) resulted from an assessment as to what proportion of the crash might have been reduced in severity while the overall benefit is the assessed reduction in crashes for the group of stability related crashes.

Configurations in assessed crashes	**Queensland**	**Victoria**	**Combined**
Rigid truck > 4.5 tonnes GVM	36.4%	44.5%	40.5%
Articulated vehicle	42.7%	49.1%	45.9%
B-double	15.9%	6.4%	11.1%
Type 1 road train	5.0%	0	2.5%
Safety benefits in assessed crashes	**Queensland**	**Victoria**	**Combined**
Crashes considered to benefit	41.8%	50.0%	45.9%
Average benefit	54.6%	68.7%	62.4%
Overall benefit	22.8%	34.4%	28.6%

[1] ESC: Electronic Stability Control, ESP: Electronic Stability Program.
[2] RSC: Roll Stability Control, RSS: Roll Stability Support.

Economic Analysis

Any economic analysis relies on a range of assumptions, and this project was typical in that regard. The most important assumptions were:

- Technology costs decreased by 3% per annum;
- New trucks above 4.5 tonnes GVM that would be fitted with the technologies each year totalled 18,000 and of that 18,000, 80% were rigid trucks, 16% were prime movers for single articulated vehicles and 4% were prime movers for B-doubles;
- It would take 15 years for the technology to fully penetrate the fleet;
- Costs for fatal and serious injury crashes were increased by 44% to provide for savings in all crashes including property damage only; and
- Truck numbers were assumed to increase 2% per annum.

Results of the economic analysis (over 15 years at 7% discount rate)

	Articulated vehicles	Rigid vehicles	Trailers only
Benefits	$328.3 million	$205.2 million	$229.8 million
Costs	$229.9 million	$534.0 million	$96.4 million
Benefit cost ratio	1.43	0.38	2.38

The technology costs used in the assessment are likely to be conservative and future costs are likely to be lower than presently available. In addition, given industry practices that newer trucks travel the greatest distances, it is most likely that a very large proportion of the benefits would be achieved well within the 15 years. Given these issue, the benefit cost ratios given in the table above could well be significantly higher.

Conclusions

It is concluded that the HVSST would be valuable for articulated vehicles but less so for heavy rigid vehicles, although the analysis was not sufficiently detailed to determine if a sub-set of heavy rigid vehicles might benefit more than the whole group. The highest benefit cost arose from use of trailer only systems due to the high prevalence of the rollover of articulated vehicles.

The majority of major stakeholders favour use of the technology and therefore there is likely to be strong support for a publicity campaign encouraging transport operators to fit the technologies to any new equipment purchased by their companies. A number of operators such as the Noske Group have valuable positive experience with using the technologies which could be used to support the campaign by using case studies. At lest two different demonstrations have been put on recently and it is likely that a video of one of these recent or similar demonstrations could be obtained and used with a publicity campaign at a fraction of the cost of putting on an additional demonstration.

To verify manufacturer's claims by means of a full scale testing program would most likely be both extremely difficult and very expensive. Tests would have to be conducted on both rigid vehicles and combination vehicles, and with a combination at least the trailer must be fitted with outriggers. Even with the support from equipment manufacturers the cost of such a test program is likely to be in the region of $400,000.

Recommendations

It is recommended that:

1. A publicity campaign be developed to demonstrate the value of heavy vehicle stability safety technologies to the transport industry;
2. That the campaign utilise case studies and video of physical demonstrations but not undertake it's own physical demonstrations or testing program;

3. That the campaign:
   - concentrate on the benefit of the technologies for articulated vehicles (including road trains); and
   - highlight the fact that fitment on the trailer alone has a significant benefit; but
   - not ignore the fact that fitting ESC to rigid vehicles is beneficial.
4. The situation with mandatory use of the technologies in the United States and Europe be monitored and further consideration be given to mandatory introduction in Australia when the appropriate technical standards have been identified in those jurisdictions.

CONTENTS

1 BACKGROUND

1.1 Introduction

The Queensland Department of Transport and Main Roads (TMR) is undertaking a project investigating safety benefits of Heavy Vehicle Stability Safety Technologies (HVSST). The primary objective of the project was:

> to conduct research by reviewing HVSST available and to analyse crash data to determine the safety benefits of HVSST to reduce the road toll and improve safety outcomes.

The project was undertaken by Pearsons Transport Resource Centre Pty Ltd (PTRC). This report details the outcome of the investigation.

An explanation of types of vehicle instability crashes, which are the crashes that the Stability Safety Technologies may eliminate or reduce, is given in Section 1.3.

1.2 Terminology

A wide range of terminology, much of it confusing, is being applied to the various electronic equipment and programs presently in use. Attachment A has a listing of the common acronyms and their meaning, but a few of the more important are listed below:

EBS – Electronic Braking System: A system for applying the brakes via an (instantaneous) electrical signal. This results in the simultaneous application of all the vehicle brakes.

ESC - Electronic Stability Control: ESC continuously monitors a number of vehicle parameters using on-board sensors to predict if a vehicle is approaching its rollover threshold or loss of directional control is likely and then takes action to reduce the risk without intervention from the driver.

ESP – Electronic Stability Program: The same as ESC.

RSC - Roll Stability Control: RSC continuously monitors a number of vehicle parameters using on-board sensors to predict if a vehicle is approaching its rollover threshold and then takes action to reduce the risk without intervention from the driver.

RSS - Roll Stability Support: The same as RSC but is the term sometimes used for RSC on trailers.

1.3 Vehicle Instability Crashes

Heavy vehicle crashes where vehicle instability is an issue can be divided into two broad types – rollover crashes and loss of directional control crashes. This latter type can also result in vehicle rollover particularly where the vehicle leaves the pavement. The vehicle might slide sideways and strike a low object such as a kerb or roll over because it moves onto soft ground or runs onto a steep embankment.

1.3.1 Rollover Crashes

Rollover crashes occur when the resultant force on the centre of gravity of the vehicle falls outside the vehicle track. This resultant force is the combination of the lateral force, usually from a turning manoeuvre, and the vertical force as a result of gravity. This assumes that the sideways friction between the tyres and the road surface is sufficient to equal the lateral force. If it is not, sliding and loss of directional control rather than rollover will occur.

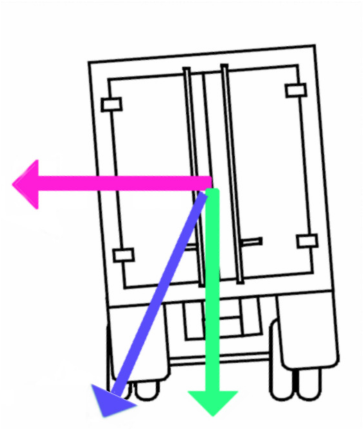
Figure 1 shows the rear view of a vehicle turning to the right. There is a lateral force acting to the left (shown red) and a constant downward vertical force due to gravity (shown green). The resultant of these two forces on the centre of gravity of the vehicle is the force shown as blue. In a gentle turn the lateral force is small and the resultant force falls within the vehicle track. However, as the sharpness of the turn increases the lateral force increases until the resultant falls outside the vehicle track and rollover occurs.

In addition, for the same sharpness of turn:

- the higher the speed then the higher will be the lateral force; and
- the greater the load mass then the higher will be the lateral force also.

It has been claimed that a 16 km/h increase in speed increases the odds of a rollover by 49% and a 10% increase in cargo mass increases the odds of a rollover by 23% for combination vehicle configurations.[3]

Figure 1: Forces acting on a turning vehicle



Consequently, if a vehicle is approaching the rollover threshold the risk of overturning can be reduced by reducing the speed or the sharpness of the turn or both. Nothing can be done about the cargo mass.

A soft vehicle suspension which allows the vehicle to roll or tilt will reduce the speed at which the vehicle can safely negotiate a given curve as it moves the vertical force acting through the centre of gravity of the vehicle towards the outside and hence closer to the outside of the track. The lateral force can then be less for the resultant to still fall outside the track. The higher the centre of gravity the further it moves sideways as the vehicle tilts. Also, the softer the suspension the more readily the vehicle will tilt. Conversely, superelevation of the roadway on a curve increases the speed at which that curve can be negotiated because it tilts the vehicle towards the inside of the curve thus moving the vertical force acting through the centre of gravity of the vehicle away from the outside and hence further from the outside of the track. Superelevation of the roadway also reduces the likelihood of the vehicle sliding out sideways in a curve as the vertical force acting through the centre of gravity of the vehicle tends to make the vehicle slide towards the inside of the curve.

1.3.2 Loss of Directional Control Crashes

Loss of directional control crashes occur because one or more axle groups loose directional control. This usually occurs under braking and/or turning where the road surface friction is low.

Loss of directional control under braking when travelling in a straight line is usually caused by a brake imbalance across an axle group which imparts a yaw motion to the vehicle or by a brake imbalance between axle groups which cases one or more axle groups to lock up. Once an axle group has locked up there is no directional control provided by that axle group as the tyres can just as easily slide sideways as forward.

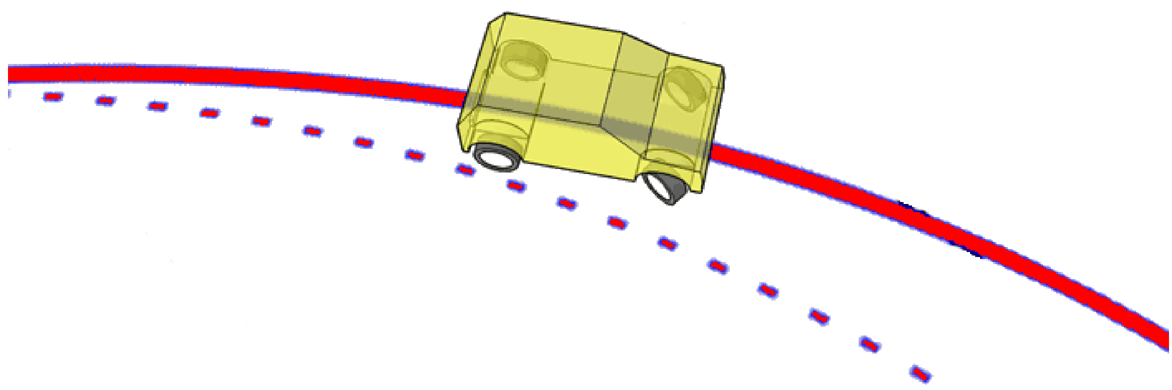
In this locked up condition any small variation in surface friction can impart a yaw motion and in the case of a combination vehicle create a jack knife or trailer swing situation.

In a turning situation (without braking) there needs to be enough road surface friction to provide the sideways forces needed by the tyres to allow the vehicle to turn. If the sideways force on the steer axle exceeds that available from the road/tyre interface the actual path of the steer axle tyres will be less sharp

[3] Haldex TRS-L20578W TRS Brochure 6-10

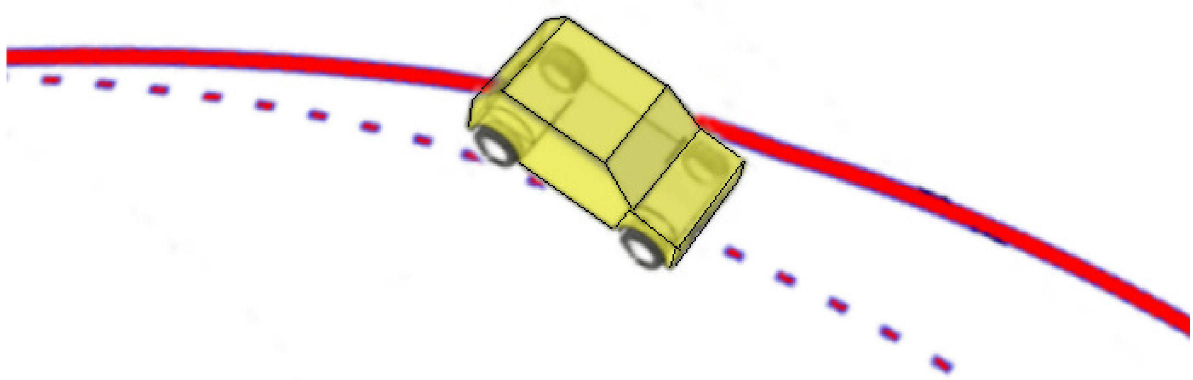
than the steering angle and the vehicle will understeer. That is, the front of the vehicle will run wide on the curve with the likelihood of the vehicle leaving the road.

Figure 2: Understeer – vehicle front should have followed the dotted line



If the sideways force on the drive axle(s) exceeds that available from the road/tyre interface the actual path of the drive axle(s) tyres will be sharper than the steering input and the vehicle will oversteer. That is, the rear of the vehicle will run wide on the curve with the likelihood of the vehicle spinning out.

Figure 3: Oversteer – vehicle rear should have followed the dotted line



With a combination vehicle in a turning situation (without braking), if the sideways force on the trailer axle(s) exceeds that available from the road/tyre interface the trailer axle(s) tyres will slide outwards (in effect – oversteer) with the likelihood of the trailer leaving the road and in an extreme case come right around and jack knife with the prime mover or another trailer in the case of a B-Double or road train.

For a rigid vehicle, when both braking and turning are involved, the understeer or oversteer will be exacerbated by the application of the foundation brakes. If the vehicle is already understeering the application of the brakes will make the understeer worse as an even greater load is placed on the steer axle and there is a likelihood that the vehicle will run off the road. However, reducing the throttle will apply some engine braking to just the rear wheels slowing the vehicle and this may reduce the understeer of the front axle. If it is oversteering, the application of the brakes will place a greater load on the drive axle(s) and a spin is likely. In this case, reducing the throttle will also apply some engine braking to just the rear wheels which is likely to exacerbate the situation. The only way the driver can reduce the oversteer is to reduce the steering lock or apply opposite steering lock but this introduces the potential that the vehicle will not make the turn.

For vehicle combinations, when both braking and turning are involved, some axles may understeer while others may oversteer and very complex movements might occur.

The above situations apply where simple or basic manoeuvres are being executed. However, where a vehicle has to swerve sharply perhaps to avoid another vehicle or an object on the road it may then have to swerve sharply the opposite way to get back onto the correct side of the road and then straighten up again. These swerve and correction motions may result in a straight forward rollover one way or the other where the directional change was too sudden for the travel speed. Alternatively, loss of directional stability may occur with the vehicle either running wide or spinning or in the case of a combination vehicle, with jack knifing or trailer swing occurring (note that jack knifing and trailer swing are really just the result of one or more vehicles in the combination spinning). In these situations a series of corrections or adjustments are needed if the vehicle is to avoid a crash and the driver only has the very limited capabilities of the front axle steering and all wheel braking to utilise.

2 VEHICLE STABILITY SYSTEMS

2.1 Introduction

Vehicle Stability Systems (VSS) continuously monitor a number of vehicle parameters using on-board sensors to predict if a rollover is imminent due to excessive speed in a curve or as a result of sudden lateral manoeuvres. They can also predict if loss of directional control is likely to occur by monitoring the rotational movement of the vehicle (yaw) and comparing it with the steering input.

Currently available Vehicle Stability Systems for motor vehicles use a wide range of names and acronyms. They include Roll Stability Advisors (RSA), Roll Stability Control (RSC) systems, and Electronic Stability Control (ESC) systems, also known as Electronic Stability Programs (ESP) and Roll Stability Support (RSS) also called Roll Stability Control (RSC) available for trailers. A summary of the various names and acronyms is provided at Attachment A.

Two basic vehicle stability concepts are currently available for motor vehicles. One concept targets rollover only while the other addresses overall instability. Both systems help mitigate the potential for rollovers but only the one which targets overall instability, also sometimes termed a full stability system, can help mitigate the loss-of-control events that also often lead to rollover.

Only roll stability systems are available for trailers as a full stability system is not feasible. Directional or steering control of trailers is dictated by the vehicle to which the trailer is attached so brake applications on selected wheels of a trailer has little effect on its yaw.

2.2 Rollover Only Systems

Systems which address only rollover can be divided into two groups. One group simply monitors the vehicle parameters that influence rollover and provides a warning to the driver. These systems are referred to as Roll Stability Advisors for the purpose of this report. These systems were developed about a decade ago and have now been overtaken by developments in technology. The other group also monitors vehicle parameters that influence rollover but when a potential for a rollover is detected the system takes action without input from the driver. For this report these systems are referred to as Roll Stability Control.

2.2.1 Roll Stability Advisors

Roll Stability Advisors are passive systems that warn the driver when the risk of a rollover is significant. The RSA monitors lateral force information received from on-board sensors and determines when a warning is warranted. The warning is usually an audible signal and visual message to the driver. The wording of the message, the length of display time, and the duration of the audible signal can be associated with increasing levels of rollover risk severity. For some systems, the visual message displays the presence of a risk and a recommended reduction in speed. The recommended reduction in speed is variable and calculated based on the vehicle’s speed and lateral acceleration detected.

In many applications, RSAs are really training tools that can advise the driver within seconds that the recent operation of the vehicle was susceptible to a rollover. One of the problems with RSAs is that to be effective they need to provide the warning well before the rollover commences to give the driver time to observe the warning and respond appropriately. Therefore the warning threshold has to be set below the actual rollover threshold. This can result in spurious or false warnings if set too low and lead to drivers ignoring the warning, or be ineffective if set too close to the actual rollover threshold as there is insufficient time for the driver to take corrective action.

RSAs were the result of early attempts to reduce or prevent rollovers but in almost all applications they have been overtaken by advances in technology and reducing costs of complex but highly sensitive electronic sensors and control systems.

2.2.2 Motor Vehicle Roll Stability Control

Motor Vehicle Roll Stability Control systems are active systems that automatically intervene if a high risk of rollover is detected. The system intervenes by automatically reducing the throttle and applying the brakes without action by the driver. The RSC system is typically integrated with antilock braking systems, but some systems are integrated with electronically controlled braking systems.

RSC systems are suitable for rigid vehicles but are less effective when fitted to the towing vehicle of a combination as the coupling(s) provide a substantial amount of insulation and the trailer(s) may reach their rollover threshold before it can be detected by sensors on the prime mover.

Again, to be effective they also need to intervene before the rollover actually commences. Therefore the intervention threshold has to be set below the actual rollover threshold. However, in this case, while spurious or false interventions may occur the driver is less likely to be aware that the intervention was unnecessary.

A RSC system that attempts to prevent a rollover by changing the air pressure in an airbag suspension was noted in literature but this does not appear to be available from any OEM. No performance details were found but given the relatively small effect of a small lateral movement in the centre of gravity of a vehicle its effectiveness is questionable and it has not been pursued further.

2.2.3 Trailer Roll Stability Control

Trailer Roll Stability Control systems are active systems that automatically intervene if a high risk of rollover is detected. The system intervenes by applying the trailer brakes without action by the driver. There is no interaction with the towing vehicle. RSC systems can be integrated with antilock braking systems or with electronically controlled braking systems and can also be used in conjunction with standard trailer foundation brakes albeit less effectively as in this latter case there is no means of limiting or controlling wheel lockup as usually the brakes are applied with great force to reduce vehicle speed.

These systems typically only need a power supply from the towing vehicle as all sensors and controls are mounted on the trailer. The whole system is usually incorporated into one single unit similar to the BPW ECO Tronic Control Module shown in Figure 4 below.

Figure 4: Typical Trailer self contained RSC module

The unit is remotely mounted on the trailer and consists of a multiple port relay valve with internal pressure transducers to measure air tank, airbag and control line pressures. It also contains an internal accelerometer so that it can measure lateral acceleration and the valve is controlled by an internal electronic control unit (ECU) that is programmed to give appropriate braking performance.

It should be noted that a trailer fitted with a RSC system cannot negotiate a curve at a higher speed than a trailer without RSC. The rollover threshold is the same for both trailers. RSC simply attempts to slow the combination to a speed at which the corner can be safely negotiated by the application of the trailer brakes.

2.3 Full Stability Systems

Systems which address the full stability of the vehicle monitor vehicle parameters from a range of sensors and utilise various control devices to influence the stability of the vehicle. As a general rule, the more parameters that are monitored and the number and sensitivity of the sensors used, the more effective the system is likely to be. The ability to gain insight regarding the vehicle dynamics and the driver's intention is critical to the operation of a stability system. The availability of more information means more data to enable the system to determine what's happening and, as a result, deliver an earlier, proactive response.

When full stability systems on prime movers and trucks intercede, they typically utilise reduction in throttle (either by directly reducing the throttle, engaging the engine retarder, or a combination of both) and application of the brakes on various wheels or axles of the combination or truck. Systems differ, however, in which axles are braked, what wheels are controlled, and how much brake pressure individual wheels receive. The quality of the information delivered via the sensors, the intelligence of the electronic control unit (ECU), and its intervention speed and capabilities, have a significant impact on the effectiveness of the stability system.

While there are differing degrees of complexity between systems offered by various manufacturers and thus potential differences in effectiveness, for the purpose of this section of the report, these full stability systems are all referred to as Electronic Stability Control.

Electronic Stability Control (ESC) systems, also known as Electronic Stability Programs (ESP), are active systems that automatically intervene when there is either a high risk of rollover or yaw instability. They are usually integrated with electronically controlled braking systems or anti-lock braking systems. The ESC system's electronic control unit continuously compares the vehicle's actual movement to stored performance models using input from the wheel speed sensors, as well as lateral, yaw, and steering angle sensors. If the vehicle appears to be leaving an appropriate travel path, or if critical threshold values are approached, the system will intervene.

When a potential rollover risk is detected, the ESC system reduces the throttle and applies the proper brake pressure to slow the vehicle below the rollover risk threshold.

When a potential loss of directional control (i.e. vehicle slide with either over-steer or under-steer) is detected, the ESC system reduces the throttle and then selectively applies the appropriate individual brakes to produce a counter force to better align the vehicle with the appropriate path of travel. In an over-steer situation i.e. where sideways sliding of the rear tyres is occurring, the system applies the outside front brake; while in an under-steer condition i.e. where sideways sliding of the front tyres is occurring, the inside rear brake is applied. Note that any application of the brakes on the sliding tyres will only aggravate the problem. Further, in some implementations of ESC systems the engine throttle may actually be opened rather than closed in certain circumstances as the engine braking provided by a large capacity diesel engine may be detrimental to stability. This is particularly the case where oversteering (sideways sliding of the rear tyres) is occurring.

It should be noted that ESC systems cannot increase the available grip between the tyres and the road surface, but they maximise the possibility of keeping the vehicle under control and on the road during extreme manoeuvres. However, no matter how effective a system is, there will always be situations where the laws of dynamics will rule but the sooner the ESC system can detect a problem and take action the more likely a positive outcome.

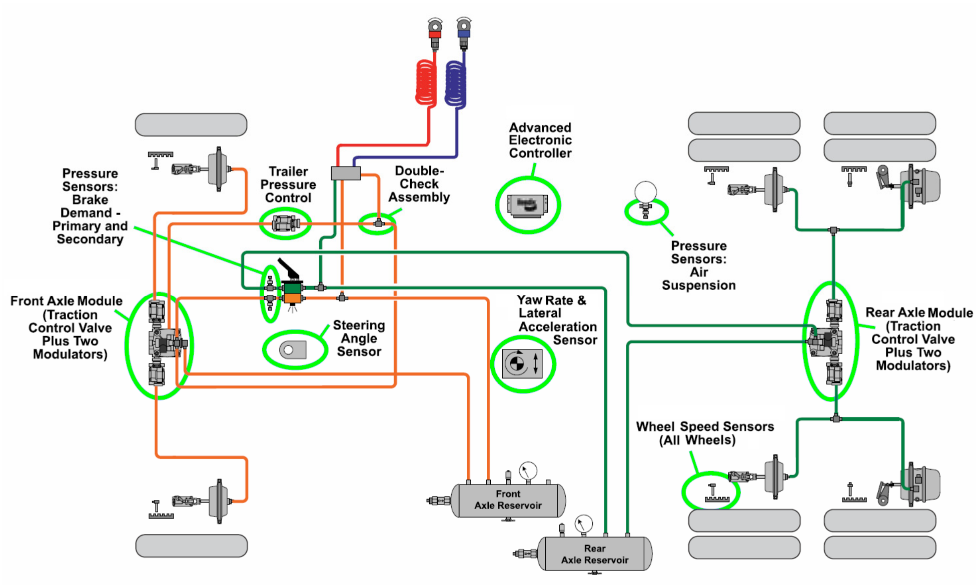
2.4 Comparison Between Heavy Vehicle and Light Vehicle Full Stability Systems

As noted in the preamble of Federal Motor Vehicle Safety Standard (FMVSS) 126, passenger car instability events are often loss of directional control events (directional instabilities) that result in a rollover. Heavy vehicle instability events are a combination of loss of directional control and tripping events as well as straight rollover. Passenger cars do not have the load variation and CG height that heavy vehicles do, so tripping events and straight rollover are less common. Heavy vehicles have a varied CG height and load profile, making tripping events a portion of the causal factors for rollovers. However, the major rollover causal factor for heavy vehicles (according to the FMVSS 126 preamble), as with passenger cars, is still loss of directional control. Therefore, a full-stability system (ESP/ESC) for heavy vehicles includes both rollover and yaw (directional) control. The vehicle configuration variation (number of axles, wheelbase, combination and function, weight, height, etc.) are also significant factors making a full-stability system the best choice for heavy vehicles.

2.5 Key Components of a Heavy Vehicle Stability System

Figure 5 outlines the key components of a full stability system on a heavy motor vehicle. Both roll-only and full-stability systems use a lateral acceleration sensor, but only a full stability system (ESP/ESC) uses the yaw sensor, which measures the directional stability of the vehicle, plus the steering-angle sensor, which measures the driver's steering intent for the vehicle.

Figure 5: Key Components of a full Stability System



2.6 Some Additional Operational Issues With Vehicle Stability Systems

Sufficient sensors and control devices can be mounted on rigid vehicles so that an Electronic Stability System can take full and appropriate control in a vehicle instability situation and within physical limits prevent a crash. This applies to both potential rollover events and loss of directional control. However, when fitted to a prime mover the system cannot effectively sense the operational performance of the trailer(s). This also applies to the driver of the prime mover as in many rollover instances the trailer has passed beyond the rollover threshold well before the driver is aware of any problem. This lack of timely warning is because couplings between the vehicles are sufficiently flexible that trailer roll movements are not transmitted to the prime mover until it is much too late.

The situation is even more so for large combination vehicles such as road trains where the rear trailer, the one most susceptible to rollover, is separated from the towing vehicle by other trailers and dollies. There have been instances where the driver of such a combination only becomes aware of the rollover because of the added drag caused by the toppled trailer.

For combination vehicles it is therefore essential that a rollover stability control system that has sensors mounted on the trailer be used in conjunction with, but not necessarily communicating with, the system on the prime mover. However, even here, for large combination vehicles negotiating a curve, the system might not be particularly effective. Rollover stability control systems can only reduce the risk of rollover by slowing the whole combination and just the application of the brakes on the last trailer may not overcome the momentum quickly enough particularly on low grip surfaces such as gravel roads. They may be of some benefit in situations where a road train trailer is fishtailing because of rearward amplification of a small directional change even though the combination is nominally travelling in a straight line. Here, the application of the rear brakes on the trailer will tend to pull the combination straight. The tractive effort of the preceding vehicles one way and the braking effect of the rear axles the other way is like pulling tight both ends of a loose piece of chain.

The other concern with ESC on combination vehicles is that the first action of most ESC implementations when vehicle instability is detected is to apply the trailer brakes. This has the effect of both slowing the combination and pulling the vehicles back closer to a straight line. The ESC then proceeds to apply selected brakes on the prime mover to further reduce the instability. However, if the trailer does not have either a load sensing brake system or electronic brake system (these systems can adjust the brake application pressure to suit the axle load) trailer wheel lockup can occur. This will result in reduced stability and a possible crash. Because of this, some manufacturers will not supply a prime mover with ESC unless the trailer(s) are so equipped. In other cases, the manufacturer has modified the ESC program to remove this feature for vehicles sold in Australia where the majority of trailers do not have a load sensing brake system or electronic brake system.

2.7 Aggressiveness of Stability Systems

Both roll stability control and full stability control systems must detect a potential rollover or loss of directional control before it occurs or becomes un-recoverable and in general, the sooner it does so the better the likely outcome. However, if the system is too cautious it may frequently intervene when it is not needed. These frequent unnecessary interventions can increase brake wear and reduce driver acceptance. Therefore, the manufacturers of the systems must carry out extensive testing to find the best compromise. For dedicated function vehicles where the vehicle mass and the centre of gravity height can be predicted such as prime movers, the system may allow more roll to occur before it intervenes but in many other cases, and particularly general purpose trailers, the system will need to be set for the worst case scenario and will thus be over-cautious in many instances.

In a recent development in trailer roll stability control systems, at least one supplier (Haldex) now uses adaptive learning loop technology which allows the system's ECU to learn by calculating the trailer's lateral acceleration, vehicle speed, air suspension[4] pressure and air system[5] pressure many times per second and thus adapting to the particular trailer's dynamics and load conditions.

2.8 Availability of Vehicle Stability Systems

VSS are generally installed by Original Equipment Manufacturers (OEMs) when the vehicles are manufactured, either as a standard feature or as an optional installation. The systems installed on trucks and prime movers are usually proprietary systems developed and tuned by the individual OEM although many of the components may be generic across OEMs.

Some trailer manufacturers offer a Roll Stability Control system as an option. This system is usually a generic system manufactured by another supplier but can be tuned and adjusted to suit the particular application.

The offerings of most of the truck suppliers in Australia were examined along with discussions with a number of truck and trailer suppliers and one equipment supplier. Many manufacturers now offer antilock brake systems (ABS) and/or electronic brake application systems (EBS) but only a few currently offer full vehicle stability systems. Note that a full stability system (i.e. ESC) requires both EBS and ABS fitted as the ESC must be able to quickly and accurately control the braking forces at each wheel. No instances of an OEM offering just a roll-only system for motor vehicles were found.

Of the OEMs that do offer a full stability system this is often only available on prime movers. This may be largely because an ESC system must be tuned for the particular vehicle and this is usually done when the vehicle is being manufactured by the OEM and in many cases overseas. As rigid trucks are usually sold as a cab/chassis, the final configuration is unknown to the OEM. Changes to centre of gravity height, wheelbase and braking performance, etc will radically alter the performance of the ESC. However, prime movers are usually sold as virtually completed vehicles and the performance characteristics can more readily be predicted and the ESC system tuned accordingly.

[4] Enables mass being carried by the axles to be determined
[5] Enables the brakes to be effectively modulated

The following is a listing of those manufacturers identified as offering a full stability control system and a brief description of what they offer.

DAF (PACCAR)

All DAF trucks have EBS as standard and ESC is offered as an option on their prime movers only. The cost for factory fitment of the ESC is between $4000 and $5000. DAF state that they will not supply ESC unless the trailers to be towed are load sensing or are fitted with EBS. The ESC has a roll stability component but as trailer mass and centre of gravity height are unknown (to the prime mover unit) it is quite conservative and set for the worst case scenario.

Kenworth

Kenworth offer what they call a Electronic Brake Safety System (EBSS) which is available as an option on all prime movers and rigid trucks. EBSS has three levels:

Level One – includes antilock braking (ABS) and automatic traction control (ATC). As well, as part of the installed software that controls the truck's Bendix ABS-6 Advanced braking system, drag torque control (DTC) is included. This adds about $5000 to the base vehicle.

Level Two – includes all the features of level one, but adds an Electronic Stability Program (ESP) which is *"calibrated specifically for Australian models, road conditions and applications*". This adds about a further $2000 over the level 1 cost.

Level Three– includes the same features as levels one and two, adding the trailer response management (TRM) for customers with trailers fitted with EBS.

MAN

MAN offer what they term an Electronic Stability Program (ESP) on prime movers only. This comprises two main functions: DSP (dynamic stability program) and ROP (rollover prevention). This is essentially a full stability control system.

Mercedes Benz

Mercedes Benz have what they term a Telligent® stability control function which is the equivalent of the Electronic Stability Program (ESP) installed in their passenger cars. Within physical limits, it prevents a semitrailer combination from developing a skid. A sensor detects any tendency to oversteer, whereupon the stability control system first reduces the engine power and then applies brake pressure to specific wheels to keep the vehicle on course. It also intervenes in the braking system of the semitrailer.

The Telligent® stability control is available on prime movers but is not available on the range of rigid trucks.

Scania

Scania offer an Electronic Stability Program on all prime movers equipped with electronically controlled disc brakes. This is essentially a full stability control system.

Volvo

All Volvo trucks have EBS & ABS as standard as part of their Electronic Brake System which is available in two different program packages - Medium and High. In addition to a wide range of warnings and sensors relating to traction control, lane change support and the brake maintenance and operation, the high package includes an Electronic Stability Program (ESP). This is available for both prime movers and rigid trucks. The high package adds about $5000 to the cost of the vehicle.

Volvo's ESP has been modified for Australian conditions to cater for trailers which do not have a load sensing brake system or electronic brake system. In effect, unlike many other OEM's implementations of a full stability control system, the Volvo ESP does not apply the trailer brakes as its initial action.

Trailer Manufacturers

Trailer manufacturers that offer a trailer RSC have not been included in the above as, of those that do, all utilise an external provider such as BPW Transpec, etc. to supply the equipment.

Some trailer manufacturers say that the prime mover requires ABS/EBS but this is only because the electrical coupling between the towing vehicle/prime mover and the trailer needs the extra terminals provided on a ABS/EBS equipped vehicle. The basic ISO electrical connection has 5 terminals while an ABS/EBS equipped tow vehicle has a 7 terminal ISO connector which can cater for the power supply needed for the trailer RSC module. However, components are available to provide the necessary connections for non ABS/EBS prime movers.

A trailer RSC will function the same irrespective of the towing vehicle's brake system as the trailer RSC operates on just the trailer brakes.

2.9 Costs

The cost of VSS varies greatly depending on a particular system's capability and the nature of standard equipment already fitted. Also, VSS are often part of a larger package which includes a range of other safety features further varying the cost between OEMs many of whom could not indicate a price for just the VSS itself.

A full stability control system for a truck or prime mover requires ABS/EBS so that if they are standard the additional cost of ESC might only be in the order of $2000 per vehicle for OEM installation as only a lateral accelerometer and a yaw sensor needs to be added plus the enhanced logic to control the brakes appropriately. If ABS/EBS is not standard then the cost of ESC might be more in the order of $7000 to $8000. The costs can be even higher if ESC only comes as part of a package. Aftermarket or retrofitting will cost more as some other existing components may need to be changed.

No instances of rollover only systems for trucks or prime movers were identified. This is most likely because the added benefits provided by a full stability control system far outweigh the increase in costs over a rollover only system.

Prices for supply and installation of a RSC on a new tri-axle trailer is between $2000 and $3000 (this includes ABS/EBS because it is all part of the RSC module). An "A" trailer of a B-Double costs a bit more because of the need for extra wiring and connectors to cater for the rear trailer and has been quoted at between $3000 and $3500. Retrofitting to an existing trailer could be much higher depending on the equipment already fitted and is likely to be over $5000. Generally retrofitting is not a viable option except for special long life trailers.

2.10 Trials and Effectiveness of Vehicle Stability Systems

All suppliers of VSS have carried out in-house testing and trials to evaluate their systems, components, sensors, etc and to develop and tune the software that controls the operation of the systems. Much of this is to tune sensors and adjust the performance and responses to the various vehicles on which the system will or might be used. For example, the braking effort needed on one front wheel of a vehicle to correct oversteer yaw will be different depending on the wheelbase. If the force that is applied on a long wheelbase rigid truck with a particular rate of yaw to correct that yaw, is applied to a short wheelbase prime-mover running without a trailer, over-correction may occur so quickly that the stability system cannot respond in time. Alternatively, a particular yaw rate on a short wheelbase prime mover might be well within the acceptable parameters but the same yaw rate on a long wheelbase rigid truck might indicate a serious loss of directional control. One does not require intervention while the other does.

The detailed results of VSS suppliers' testing is confidential for business reasons but there are numerous reports, videos, etc available demonstrating the effectiveness of these systems. These usually show the same vehicle with and without the VSS. They also often show the performance in extreme conditions such as icy roads rather than more normal conditions as instability is more easily re-created at relatively low (and hence safer) speeds. There have also been numerous demonstration and promotional trials again usually using the same vehicle with and without VSS and in artificially created situations. These latter trials also clearly demonstrate the effectiveness of VSS.

In addition, there have been a number of tests carried out on vehicles fitted with VSS but these have generally been on instrumented vehicles to document the typical performance characteristics and parameters of vehicles fitted with VSS. This is to enable validation and refinement of the mathematical models developed to assess the performance of vehicles fitted with commercial systems. A typical example is the 2007 thesis by Santhosh Chandrasekharan, B.E.[6]

Comprehensive trials of stability systems on heavy vehicles is prohibitive due to inherent reasons such as safety and the incurred costs and no examples of such trials have been found. Also, no large scale real world assessment of the benefits of VSS appear to have been carried out probably because of the limited penetration to date of VSS and the variety and perhaps differing performance of the systems offered.

There have been a number of studies based on the mathematical models developed for VSS, notably the US Department of Transportation's February 2009 document[7] which concluded that overall, the crash reduction benefits of a full stability system on combination vehicles are estimated to be between 37% and 53%.

A 2009 University of Michigan Transportation Research Institute study in conjunction with Meritor WABCO and sponsored by NHTSA estimated that RSC would reduce rollovers by 0 to 71 percent and ESC would reduce rollovers by 0 to 75 percent. The magnitude of the effect varies depending on roadway alignment (straight, curved) and roadway surface conditions (dry, wet). In parallel, for loss of control crashes, RSC would reduce these types by 2 to 14 percent and ESC would reduce these crashes by 18 to 39 percent.

According to a Bendix[8] analysis, "*full-stability systems are a viable factor in abating up to 68 percent of the crashes labelled as rollover events, while roll-only systems can mitigate less than half that number – only 29 percent. A full-stability system offers 2.3 times the level of mitigation than that of a roll-only system. Taken in context, the incremental cost to the fleet for choosing full stability is less than 1 percent of the price of a new vehicle*".

In addition to rollover crashes covered in the Bendix analysis, full stability systems can address a significant proportion of other stability related crashes where the vehicle leaves the road or moves into oncoming traffic.

Another example of the effectiveness of VSS is a University of Michigan mathematical model study[9] which concluded that for a typical curve with a safe entry speed of 55km/h, a RSC system was able to manage a curve entry over-speed of 8km/h and ESC could manage a curve entry over-speed of 17km/h. It should be noted that the vehicle did not negotiate the curve at these higher speeds. The RSC & ESC systems quickly reduced the vehicle speed early in the corner entry to a speed at which the curve could be negotiated without rolling over.

2.11 Summary

Heavy Vehicle Stability Systems are currently available from a number of manufacturers and all active systems i.e. those that automatically intervene without any action on the part of the driver, have the capability of significantly reducing the overall number of vehicle stability related crashes.

Advisory systems i.e. those that just provide a warning to the driver, were initially developed over a decade ago primarily as a training aid and have been superseded by technology development and are no longer a viable consideration.

For motor vehicles there is therefore the possibility of providing either a full stability control system or a system that addresses roll-over only, although no manufacturer offers this latter system in Australia. This

[6] Development of a Tractor – Semitrailer Roll Stability Control Model - Ohio State University
[7] Analysis of Benefits and Costs of Roll Stability Control Systems for the Trucking Industry - US Department of Transportation February 2009
[8] Road Map For The Future - Making The Case For Full Stability - Bendix Commercial Vehicle Systems LLC
[9] Analysis of Stability Control Systems for Tractor-Semitrailers - J Woodrooffe, D Blower & P Green

is probably because of the much greater benefits of the full stability system at a small additional cost particularly when piggy backing on existing EBS/ABS implementations.

For trailers, a full stability control system is not feasible as the directional control of a trailer (whether it be a semi trailer, a dog trailer or a pig trailer) is dictated by the vehicle to which it is attached. Very little, if any, directional control of a trailer can be achieved by braking selected wheels on the trailer itself.

Roll stability control is available and effective for trailers.

While technically there is an option for motor vehicles, circumstances and current offerings suggest that the logical option is a full stability control system (i.e. ESC) on the towing vehicle and roll stability control (i.e. RSC) for dog, pig and semi trailers.

2.12 Discussion and Conclusions

Given the findings reported above, it appears that advisory systems should not be considered further in this project. In addition, systems in the experimental stages such as those that pump up air bags should also not be considered as their potential is unproven at this time.

While ESC is not generally available on rigid trucks at this time due to manufacturing practices, there is no reason to exclude rigid trucks from the analysis of benefits.

Therefore, the technologies that will be used in the crash analysis part of the project are:

- ESC/ESP for rigid trucks and prime movers; and
- RSS/RSC for trailers and semi-trailers.

It is also important to note that not all stability related crashes can be eliminated or reduced by VSS. In particular, the following crash types would still occur:

- Rollover crashes when the vehicle enters a curve so fast that it cannot be slowed sufficiently to prevent rollover;
- Fatigue related crashes or similar where the driver simply does not perceive a curve and drives straight ahead; and
- Crashes where the vehicle is tripped causing a rollover.

3 ANALYSIS OF CRASH DATA

3.1 Introduction

Road crash data used in this project was obtained:

- in Queensland, from CrashStats;
- in Victoria, from Restricted CrashStats; and
- in New South Wales, from CrashLink.

In the case of Queensland and New South Wales, data was provided by the authority following data requests. In Victoria, data was accessed via the Restricted CrashStats website.

It was specified in data requests that crashes were to involve a truck with a GVM of at least 4.5 tonnes.

The most common means of assigning circumstances to a crash is the use of the *Definition for Classifying Accidents* (DCA) system (called in some jurisdictions *Definition for Coding Accidents*). This system assigns over 80 circumstances that result in a crash, grouped into the 10 different series. Victoria, NSW and Queensland all have different numbering systems but all other details are very similar although not identical. Table 1 below shows the different series numbers.

Table 1: Main groups in the DCA system

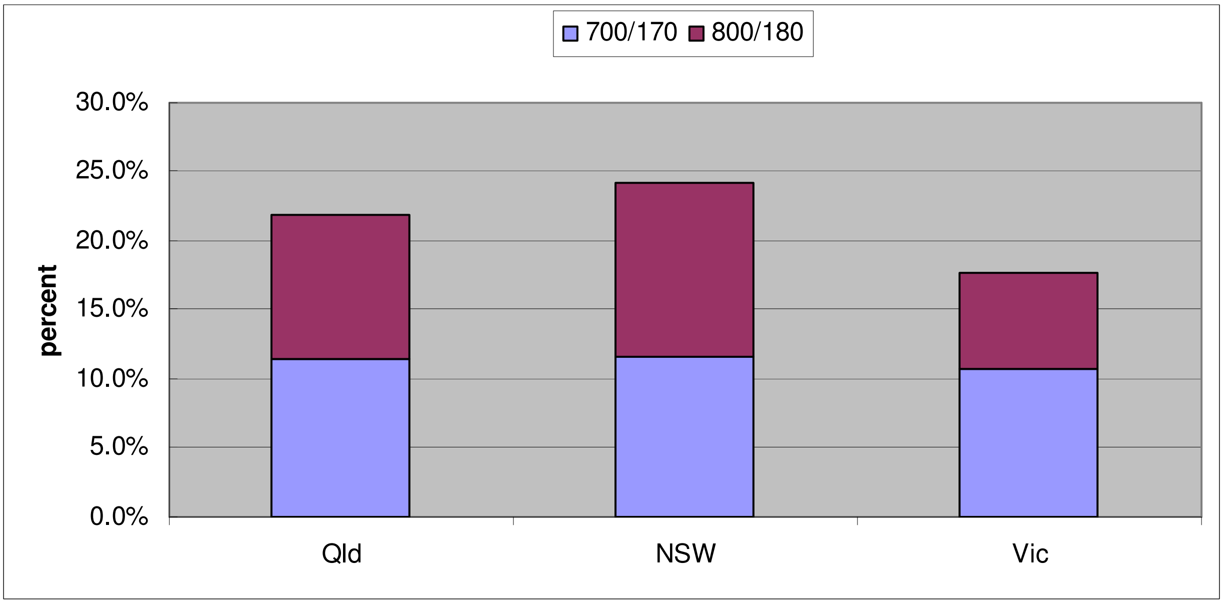
Series numbering			Series Description
Qld	**NSW**	**Victoria**	
000	00	100	Pedestrian on foot
100	10	110	Vehicles from adjacent directions (intersection only)
200	20	120	Vehicles from opposite directions
300	30	130	Vehicles from same direction
400	40	140	Manoeuvring
500	50	150	Overtaking
600	60	160	On Path
700	70	170	Off path on straight
800	80	180	Off path on curve (or turning in Qld NSW)
900	90	190	Passenger and miscellaneous

Lack of heavy vehicle stability would most likely result in “off path” crashes, although there are some crashes in other crash groups that might result from vehicle instability. Therefore, all crashes that were examined in detail in the project were in the 7 and 8 series crashes (700/70/170 and 800/80/180). In this way, a more accurate analysis of the possible influence of stability technologies was obtainable.

Figure 6 is the percentage of truck casualty crashes for these series compared to all truck casualty crashes. The percentage of 700/70/170 crashes are remarkably consistent. Victoria has the lowest proportion of 800/80/180 crashes but that is probably explained because they have the greatest proportion of travel in a capital city, where these type of crashes are least prevalent.

There appears to be little real difference between the prevalence of instability crashes in the three Eastern States.

Figure 6: Instability casualty truck crashes compared to all casualty truck crashes



Data obtained from Queensland consisted of the description of the crash as provided by attending police officers together with the vehicle type involved in the crash and a diagram of the crash scene. Data from Victoria included the description, crash diagram and vehicle type together with other information such as weather conditions and time of crash. New South Wales data was statistical data only.

In total, 440 crashes were examined in detail, half in Queensland and the other half in Victoria. The crash description and crash diagrams were assessed as to the cause of the crash and the possible benefits that would have arisen if vehicle safety technology had been fitted were identified.

3.2 Assumptions and Limitations

Information about the crash included the number and types of vehicle involved in the crash, for example, car, motorcycle, semitrailer (single articulated vehicle), B-double or rigid truck. However, the data set did not include whether a rigid truck had a trailer attached. In some circumstances, the description of the crash identified that a trailer was attached but it could not be determined with any certainty whether the vehicle involved was a truck and trailer combination. Therefore, no attempt was made to separately identify the vehicle configuration of truck and trailer combination. The main issue arising is that the contribution of truck and trailer combinations cannot be separately reported.

Safety stability technology is claimed to be highly effective in potentially dangerous situations like:

- overestimating curve speed limit (e.g. narrowing curves, highway exits);
- obstacle avoidance manoeuvres with sudden steering input (e.g. steering from the shoulder back onto the road and skidding); and
- laden semi-trailer in narrow curves on slippery surface (jackknifing on turns).

However, the technology will not be able to prevent a crash in *all* of these situations. For example, technology will not always compensate sufficiently for excessive speed into the curve, nor will steering from the shoulder back onto the road always be possible where there is a significant height difference between the shoulder and the road.

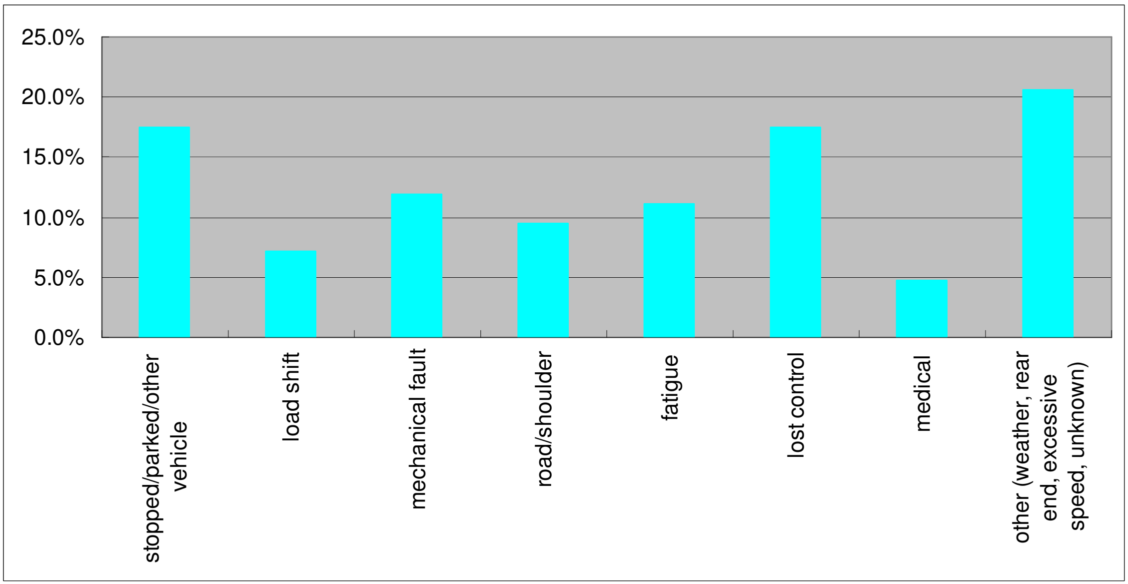
The descriptions and crash diagrams are not always a reliable indicator of the causes of a crash. In some cases, the cause of the crash was reported by the reporting officer, such as where there was considered to be a clear cause such as a blown steer axle tyre, a medical condition or swerving to avoid another vehicle. In some other cases, it appears the reporting officer speculated as to the crash cause.

In a number of cases, a judgement had to be made as to whether the stability technologies would have prevented the crash or reduced the severity of the crash. To reduce the possibility of significant errors, a grading system was introduced such that if it was considered that a crash would have been assisted by stability technology, the benefit was assessed as either 25%, 50%, 75% or 100% effective in preventing the crash. A weighted benefit was calculated at the end of the assessment.

There was no indication from the crash descriptions as to whether stability technologies were in fact fitted to the heavy vehicle involved in the crash but it was assumed that no vehicle was fitted with the relevant technology.

Where the technology was not assessed as being beneficial to the crash, the likely cause of the crash was also assessed. Figure 7 shows the assessed causes of these other crashes.

Figure 7: Assessed cause of other crashes (non beneficial)



About 17% of the crashes did not involve the active participation of a heavy vehicle, while about 12% were assessed by reporting officers as being due to mechanical condition such as faulty brakes or a blown tyre. Load shift was assessed by officers in about 7% of non-beneficial cases but there is doubt as to whether this is an accurate reflection of this cause as drivers may have used load shift as an excuse to avoid blame. For example, in one case the vehicle had travelled a long distance prior to the crash so a load shift is unlikely while on other occasions load shift was blamed for rollover of tanker vehicles.

The lost control crashes in this group were often the result of evasive action, such as:

> the driver stated that the cause of the accident was from another vehicle coming towards him on the wrong side of the road, which caused him to take evasive action.

While some of these crashes might have benefited from the stability technology, rarely was a crash of this type assigned as being beneficial due to the likely severity of the evasive action described and the path taken by the vehicle.

The road shoulder group of crashes (about 10%) were assessed as being too severe in circumstances to have benefited from the stability technology. An example of this situation arose when the report stated:

> The driver of the vehicle moved to the left side of the road to avoid an accident with a sedan who was overtaking the truck. The left front wheel of the truck ran off the edge of the road on to soft ground. The driver felt the weight of the cattle shift. The weight of the cattle and wheel dug into the soft ground caused the truck to roll onto its left hand side

Advice was received that use of the technologies with suspensions other than air suspension is not possible due to the limited spring deflections with Australian suspensions. However, as the vast majority of vehicles in Australia are fitted with air suspension, this issue was not considered major.

Overall, it is considered that the assessments were conservative and that the benefits assessed are at the low end of likely beneficial outcomes.

3.3 Results

The results below are given wherever possible for both Queensland and Victorian crashes but some details were only available for Victorian crashes.

Firstly, it is of note that the majority of stability related crashes are single vehicle crashes as illustrated by Table 2

Table 2: Numbers of vehicles involved in the crashes analysed

	Queensland	Victoria
Single vehicle	87.3%	77.7%
Multiple vehicle	12.7%	22.3%

Single vehicles crashes, with the notable exception of crashes due to external causes such as medical condition, fatigue or mechanical failure, are often the result of judgement failures and likely to be assisted by the safety stability technologies.

The vehicles involved in the crashes that were examined are shown in Table 3. More than twice as many B-doubles were involved in Queensland, but more rigid trucks and articulated vehicles were involved in Victoria. Involvement of course does not necessarily mean fault as there were a number of rigid vehicle crashes that were the result of a car colliding with a parked truck, more likely in urban areas.

Table 3: Vehicle configuration in crashes analysed

Configuration	Queensland	Victoria	Combined
Rigid truck > 4.5 tonnes GVM	36.4%	44.5%	40.5%
Articulated vehicle	42.7%	49.1%	45.9%
B-double	15.9%	6.4%	11.1%
Type 1 road train	5.0%	0	2.5%

Due to data availability, the next two sets of data relate only to Victoria, being road surface and speed zone information. Table 4 shows that dry road surface predominates for stability crashes while more than half the Victorian crashes were in 100 km/h speed zones (Table 5) and only a small percentage were in low speed zones.

Table 4: Road surface in Victorian crashes

dry	81.4%
wet	17.3%
unknown	1.4%

Table 5: Speed zone (km/h) in Victorian crashes

100/110	56.4%
90	1.4%
80	14.1%
70/75	9.1%
60	13.6%
50	5.5%

The main outcomes of the assessment are given in Tables 6 and 7. In Table 6, the likely benefits of safety stability technologies are given for the individual States of Queensland and Victoria and then the combined assessment. In Victoria, it was assessed that 50% of the stability-type crashes would have benefited from the use of stability technology, whereas in Queensland the equivalent figure is 41.8%. In Victoria, the likelihood was 68.7% that the technology would have been of benefit in the crash compared to a likelihood of 54.6% in Queensland.

Overall, it was assessed that nearly 46% of all stability related crashes would have benefited from the technology and the overall effectiveness in crash reduction was close to 30%.

Given that the assessment and the methodology was considered conservative, the contribution of the technologies would certainly be higher, probably as high as a 40% and perhaps a 50% increase in overall effectiveness for stability related crashes.

Table 6: Assessed Benefits of Stability Technology

	Queensland	Victoria	Combined
Crashes considered to benefit	41.8%	50.0%	45.9%
Average benefit	54.6%	68.7%	62.4%
Overall benefit	22.8%	34.4%	28.6% (1)

Note 1: 28.6% of stability crashes or 6% of all crashes as stability crashes account for about 20% of all crashes (see Figure 6)

Table 7 shows that some vehicle configurations are likely to benefit more than other configurations from the fitting of the stability technologies. For example, it was found that in more than three-quarters of crashes involving a B-double, the technology would have been of benefit in preventing the crash compared to 55% of crashes involving a single articulated vehicle. These overall results are consistent with the fact that a B-double is a more stable vehicle in many manoeuvres than a single articulated vehicle but that in a potential rollover on a curve there is little difference in crash risk. While advice was received that only moderate results are presently obtained with the multiple trailers used in road trains, it was assumed that this problem would be rectified by the time any significant number of systems were working in that environment.

The lower numbers in Queensland resulted from greater uncertainty about the possible benefits due to greater doubt about road/shoulder crashes in that the crash description in Queensland often referred to a soft shoulder after rain and the consequent doubt about whether the technologies would be of benefit in these circumstances.

Table 7: Number and percentage of that configuration that would have had a beneficial outcome

	Victoria		Queensland		Combined	
	Number	Percent	Number	Percent	Number	Percent
Rigid	29	29.6%	15	18.8%	44	24.7%
Articulated	69	63.9%	43	45.7%	112	55.4%
B-double	12	85.7%	26	74.3%	38	77.6%
Type 1 RT	0	0	8	72.7%	8	72.7%
Total	110	na	92	na	202	na

The relatively low percentage of crashes involving rigid trucks that would have benefited from the technology (about 25%) is consistent with the greater use of rigid trucks in urban areas with lower speed zones and less stability related crashes. In most cases of another vehicle hitting a parked truck, the truck was a rigid truck.

4 ECONOMIC ANALYSIS

4.1 Introduction

The economic analysis assesses the cost and benefits of the introduction of safety stability technology on heavy vehicles. Costs arise from the fitting of the technologies to vehicles and the benefits arise from the reduction of crashes arising from the technologies.

In undertaking the analysis, a number of assumptions were needed as outlined in this section.

4.2 Assessment of Costs

It has been assumed that all equipment technology costs are incurred for new vehicles and that retrofitting is not widely adopted. The costs assumed for new fitment are:

- Motor vehicles (rigid trucks and prime movers) - $5,000
- Trailers and semi-trailers - $3,000

Therefore, the establishment costs for the different configurations were

Single articulated vehicle	$8,000
B-double	$11,000
Rigid truck	$5000

The technology therefore would increase capital cost by between 1.5% and 3% depending on the body type of the trailers in the combination, with tankers being much more expensive than curtain side trailers.

The analysis is based on annual sales of 18,000 truck units with a gross mass exceeding 4.5 tonnes. This figure was based on advice from the Truck Industry Council (TIC) of total numbers sold in 2010, less an allowance for off-road vehicles. The TIC data did not identify which units sold ended as prime movers or rigid trucks. Therefore, it was assumed that prime movers accounted for 20% of the sales of trucks, based on the proportion of rigid and articulated vehicles as provided in the ABS Motor Vehicle Census. Because the crashes involving truck and trailers could not be separately identified, this configuration has not been included in the calculations. In addition, the ratio of new prime movers used for single articulated vehicle and for B-doubles is not available so it was assumed that B-doubles accounted for 20% of all prime movers sold, based on the numbers given by NTC for the 2007 Charges Determinations increased to allow for a greater increase in B-doubles rather than other articulated vehicle types since 2007.

Costs in year one for annual sales of 18,000 motor vehicles are given in Table 8.

Table 8: Estimated equipment costs in year 1

	Single articulated	B-double	Rigid truck	Trailers only
Number in year one	2,880	720	14,400	4,320
Cost each	$8,000	$11,000	$5,000	$3,000
Cost in year one	Total $31 million		$72 million	$13 million

For the analysis, an increase of 2% was assumed for vehicle sales for each succeeding year. A 3% per year reduction in costs is assumed from advances in technology. Calculated over 15 years (the estimated period for full fleet penetration) at a discount rate of 7%, the costs are given in Table 9.

Table 9: Estimated equipment costs over 15 years (7% discount rate)

	Articulated vehicles	Rigid vehicles	Trailers only
Cost over 15 years	$229.9 million	$534.0 million	$96.4 million

4.3 Assessment of Benefits

Benefits arise from the stability technology due to the reduction of the number of crashes involving heavy vehicles. The benefit is the reduction in the number of crashes times the crash cost.

In relation to crash costs, BITRE (2009) provides estimates of the cost of various types of road crash including fatal and hospitalised injury crash for the base year of 2006. The costs estimated by BITRE were:

- a fatal crash was $2.67 million; and
- a hospitalised injury crash was approximately $266 000.

As costs were 2006 costs, these costs were increased by 16% to allow for inflation to $3.1 million for a fatal crash and $310,000 for a hospitalised crash.

The benefits have been calculated for fatal and hospital injury crashes only. To allow for the savings from minor injury and property only crashes, a factor of 1.44 has been applied to the benefits as was used by Anderson et al (2010).

Australia wide in 2009, there were 117 fatal crashes involving articulated vehicles and 74 fatal crashes involving rigid vehicles. Allowing that fatal crashes are 12% of the total of fatal and hospital injury crashes, there would have been about 975 and 617 hospitalisation (serious injury crashes) arising from articulated vehicle crashes and rigid truck crashes respectively.

Assumptions important to the analysis are that:

- using the technology on trailers only would provide 70% of the benefit of articulated vehicles:
- full benefits are achieved 15 years after the technology introduction; and
- the effectiveness of the technology is that it will prevent 40% of the stability related crashes.

Other factors used in the analysis are given in Table 10.

Table 10: Calculation of full benefits from the introduction of the stability technology

	Articulated trucks	Rigid trucks	Trailers only
Fatal crashes 2009	117	74	82
Ratio fatal crashes to serious injury crashes		12%	
Therefore, number of serious injury crashes 2009	975	617	683
Percent of stability crashes to all crashes (Figure 6)		21.0%	
Therefore, fatal stability crashes	25	16	17
and serious injury stability crashes	205	130	143
Savings from technology use		40.0%	
Therefore fatal crashes saved	10	6	7
And serious injury crashes saved	82	52	57
Cost per fatal crash		$3.1 million	
Cost per serious injury crash		$310,000	
Increase for other injury and PDO		1.44	
Savings			
Savings in fatal crashes	$30,470,000	$19,270,000	$21,327,000
Savings from serious injury crashes	$25,390,000	$16,060,000	$17,772,000
Total savings in year 15 (all crashes)	$80,430,000	$50,870,000	$56,302,000

If it is assumed that each year provides for an additional one-fifteenth of the benefits, the savings over 15 years at a 7% discount rate would be as shown in Table 11.

Table 11: Estimated crash savings over 15 years (7% discount rate)

	Articulated vehicles	Rigid vehicles	Trailers only
Benefits over 15 years	$328.3 million	$205.2 million	$229.8 million

The assessment in this section is likely to be a conservative result. The costs that have been used do not take account of the likelihood that overseas jurisdictions will mandate the use of the technologies over the next few years, leading to a lower cost for fitting the technologies on prime movers and rigid trucks destined for the Australian market. For example, if the cost of technology for prime movers was half what was assumed above, the benefit cost ratio would exceed 2 for articulated vehicles. If the cost for trailers was similarly to be half that assumed, the benefit cost would exceed 3.

In addition, it is usual for newer vehicles to travel longer distances and then be repatriated to tasks with less travel demand. In these circumstances, it is likely that the majority of benefits will be achieved within the first 10 years rather than the 15 years used in the assessment.

4.4 Summary

Table 12 summarises the outcome of the economic analysis.

Table 12: Estimated benefits and costs over 15 years (7% discount rate)

	Articulated vehicles	Rigid vehicles	Trailers only
Benefits over 15 years	$328.3 million	$205.2 million	$229.8 million
Cost over 15 years	$229.9 million	$534.0 million	$96.4 million
Benefit cost ratio	1.43	0.38	2.38

Therefore, the greatest value would be gained by utilising the technology on trailers but there would still be benefits from providing the technology on all articulated vehicles.

The technology costs used in the assessment are likely to be conservative and future costs are likely to be lower than presently available. In addition, given industry practices that newer trucks travel the greatest distances, it is most likely that a very large proportion of the benefits would be achieved well within the 15 years. Given these issue, the benefit cost ratios given in Table 12 could well be significantly higher.

5 HVSST IMPLEMENTATION

Options for HVSST implementation include:

- Publicity based arrangements;
- Compulsory (legislative) requirements; and
- Incentive based schemes.

Each of these options is discussed in turn below.

5.1 Publicity Based Arrangements

Publicity based arrangements can range from extensive media campaigns to simple industry campaigns featuring brochures. With a very focussed and relatively tight-knit industry, extensive media campaigns do not seem warranted and are likely to be a waste of money. There are likely to be examples of operators with excellent returns from use of the technology, such as the Noske Group, a Victorian based company who effectively paid for the fleet installation by avoiding one crash with a B-double.

A publicity campaign does not need to decide on full equipment or trailer only fitment as these decisions are made by the operator. Similarly, publicity campaigns do not need to decide if a retro-fit program should be pursued as again that decision will be made by the individual operators, although the retro-fit costs are likely to be a factor in most cases.

A publicity campaign can be aided by physical demonstrations of the value of the technology. A couple of different demonstrations have been put on for operators, most recently in conjunction with the 2011 Brisbane Truck Show. At that demonstration at the Mount Cotton training complex, Knorr-Bremse showed off a range of advanced braking and stability systems on offer in Australia. Another demonstration put on a few years earlier at DECA in Shepparton by Transpec also demonstrated the technologies. At both events, the value of the technologies was shown using a prime mover equipped with outriggers, whereby the same speed through a variety of common manoeuvres resulted in a potential rollover when the stability equipment was not operating.

Cost is likely to be relatively low and obviously will depend on the extent of the campaign. For example, the relatively low key VicRoads promotion on rollover prevention cost in the region of $200,000 and is considered a success.

5.2 Compulsory (legislative) Requirements

The usual legislative instrument used to introduce technologies such as the HVSST is the Australian Design Rule (ADR) system under the Motor Vehicle Standards Act 1989 (Cwlth). The ADR system applies to new vehicles in nominated categories from a particular date.

The US National Highway Traffic Safety Administration's Vehicle Safety and Fuel Economy Rulemaking and Research Priority Plan proposes that the United States will develop test procedures for a standard on stability control systems for prime movers and buses with a view to proposed Rule making later this year. In addition, it is understood that a European standard will be developed in the near future.

New legislative requirements could be introduced under State and Territory legislation, which could apply to new vehicles or to existing vehicles. Such arrangements are less cost effective than the ADR system as new compliance/certification arrangements would need to be developed and implemented. In addition, if the requirement was imposed as a condition of registration, the requirement could not be imposed on visiting vehicles and would likely be an encouragement to operators to transfer registration to another State or Territory where the requirement did not exist. It would also complicate national interstate registration arrangements. If the requirement was introduced under State or Territory Vehicle Standards legislation and apply to all vehicles used within a State or Territory, compliance arrangements would be difficult due to the nature of assessing the presence of the stability technologies.

Government costs for ADR introduction would be in the order of $50,000 to $200,000 depending on the amount of research necessary, while the cost for introduction under State or Territory legislation would most likely be of a similar order of magnitude. Industry costs would depend on which vehicle manufacturers did not have adequate systems in place but the likelihood is that all European and US sourced trucks would have HVSST available within a few years, leaving only the Japanese manufacturers with significant costs.

5.3 Incentive Based Schemes

Incentives for fitting of HVSST would logically be undertaken by insurance companies who would benefit from safer trucks but such decisions would be outside the control of government.

If a government incentive scheme was to be introduced, reductions in registration charges are virtually the only avenue available. No precedents are known for government incentive schemes but it is expected that the incentive would need to be in the region of 25% to 50% of the actual cost of the technology to be an adequate encouragement to operators. The difficulties outlined in Section 5.2 above relating to State and Territory based schemes would again apply to incentive schemes.

For each 10% take-up with new articulated vehicles, the annual cost would be in the region of $750,000 if the incentive is 25% and restricted to articulated vehicles, excluding the cost of administration. If heavy rigid vehicles are included, an additional cost of more than $2 million per annum would be expected for each 10% take-up.

5.4 Discussion

The high cost of incentive schemes suggest that such schemes would not be cost effective in the short term, while implementation of State or Territory based legislative schemes are most unlikely to be cost effective and would cause conflicts with the established ADR system.

By elimination, publicity based arrangements or imposition of legislative arrangements by means of the ADR system would be the two most logical schemes, and these two options are not mutually exclusive. There is broad support for the use of stability technology among stakeholders and early implementation of some publicity schemes is encouraged and recommended. While such publicity is taking place, developments in the United States and Europe could be monitored with a view to possible implementation by means of an ADR. Careful consideration of vehicle categories, however, would be required as it is likely that there are differences in benefits between rigid trucks and prime movers, and the ADR system has difficulty differentiating between these end uses.

6 CONSULTATION

Consultation took place with a range of stakeholders such as Eastern States industry associations and government departments including Police. The main aim of the consultation was to determine:

- views on the value of the stability technologies; and
- attitudes to different means of implementation of the technologies;

Because the technologies are relatively new and few organisations have official views on their introduction, representatives of the organisations consulted were reluctant to be quoted as providing the views of their respective organisations. However, the most common views were that:

- any reasonable means of providing a safer road environment would be supported;
- it is perhaps a little early to consider an ADR as the technology needs to be developed further for Australian conditions and multiple vehicle configurations, particularly road trains;
- there was no support for State and Territory based schemes, either compulsory or incentive based; and
- most organisations would support a voluntary take-up of the technology.

The Australian Trucking Association (ATA) will be releasing shortly a Technical Advisory Procedure which will include advice on ESC and roll stability. It is clear from the draft procedure that the thrust is support for roll stability systems including trailer only systems.

7 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Heavy Vehicle Stability Technologies

Heavy Vehicle Stability Systems are currently available from a number of manufacturers and all active systems have the capability of significantly reducing the overall number of vehicle stability related crashes. Advisory systems were initially developed over a decade ago and have been superseded by technology development.

With powered vehicles, a full stability control system is provided rather than a system that addresses roll-over only, probably due to the much greater benefits of the full stability system at a small additional cost.

For trailers, a full stability control system is not feasible as the directional control of a trailer (whether it be a semi trailer, a dog trailer or a pig trailer) is dictated by the vehicle to which it is attached. Very little, if any, directional control of a trailer can be achieved by braking selected wheels on the trailer itself. However, roll stability control is available and effective for trailers.

Given theses conclusions, advisory systems were not considered in this project, nor were systems in the experimental stages such as those that pump up air bags. The technologies that were used in the crash analysis part of the project were:

- ESC/ESP for rigid trucks and prime movers; and
- RSS/RSC for trailers and semi-trailers.

7.2 Analysis of Crashes

In total, 440 crashes were examined in detail, half of which occurred in Queensland and the half in Victoria. Each crash had the following characteristics:

- it involved a heavy vehicle with a GVM of at least 4.5 tonnes;
- it was a stability related crash where the vehicle was off its intended path;
- the crash resulted in a fatality or a serious injury; and
- the crash occurred in the two years prior to the end of 2009.

Safety stability technology is claimed to be highly effective in potentially dangerous situations like:

- overestimating curve speed limit (e.g. narrowing curves, highway exits);
- obstacle avoidance manoeuvres with sudden steering input (e.g. steering from the shoulder back onto the road and skidding); and
- laden semi-trailer in narrow curves on slippery surface (jackknifing on turns).

However, not all stability related crashes can be eliminated or reduced by VSS. In particular, the following crash types would still occur:

- rollover crashes when the vehicle enters a curve so fast that it cannot be slowed sufficiently to prevent rollover;
- fatigue related crashes or similar where the driver simply does not perceive a curve and drives straight ahead; and
- crashes where the vehicle is tripped causing a rollover.

Table 13 outlines the configurations that were involved in the crashes assessed together with the safety benefits of the assessed crashes. The average benefit (per crash) resulted from an assessment as to what proportion of the crash might have been reduced in severity while the overall benefit is the assessed reduction in crashes for the group of stability related crashes.

Table 13: Vehicle configuration in crashes analysed

	Queensland	Victoria	Combined
Configurations in assessed crashes			
Rigid truck > 4.5 tonnes GVM	36.4%	44.5%	40.5%
Articulated vehicle	42.7%	49.1%	45.9%
B-double	15.9%	6.4%	11.1%
Type 1 road train	5.0%	0	2.5%
Safety benefits in assessed crashes			
Crashes considered to benefit	41.8%	50.0%	45.9%
Average benefit	54.6%	68.7%	62.4%
Overall benefit	22.8%	34.4%	28.6%

7.3 Economic Analysis

Any economic analysis relies on a range of assumptions, and this project was typical in that regard. The assumptions are outlined earlier in the report.

The establishment costs for the different configurations were based on $5,000 for a rigid truck or prime mover and $3,000 for a trailer, giving costs for vehicle configurations as follows:

Single articulated vehicle	$8,000
B-double	$11,000
Rigid truck	$5,000

Costs were assumed to decrease by 3% per annum.

New trucks above 4.5 tonnes GVM that would be fitted with the technologies were a total of 18,000 each year, and of that 18,000, 80% were for rigid trucks, 16% were prime movers for single articulated vehicles and 4% were prime movers for B-doubles. Truck numbers were assumed to increase 2% per annum.

Table 14: Results of the economic analysis (over 15 years at 7% discount rate)

	Articulated vehicles	Rigid vehicles	Trailers only
Benefits	$328.3 million	$205.2 million	$229.8 million
Costs	$229.9 million	$534.0 million	$96.4 million
Benefit cost ratio	1.43	0.38	2.38

7.4 Conclusions

It is concluded that the HVSST would be valuable for articulated vehicles but less so for heavy rigid vehicles, although the analysis was not sufficiently detailed to determine if a sub-set of heavy rigid vehicles might benefit more than the whole group. The highest benefit cost arose from use of trailer only systems due to the high prevalence of the rollover of articulated vehicles. Trailers are equipped only with Roll Stability Control (RSC) as yaw correction is not possible due to the coupling to the prime mover.

The majority of major stakeholders favour use of the technology and therefore there is likely to be strong support for a publicity campaign encouraging transport operators to fit the technologies to any new equipment purchases by their companies. Operators such as the Noske Group have valuable positive experience with using the technologies which could be used to support the campaign by using case studies.

To verify manufacturer's claims by means of a full scale testing program would most likely be both extremely difficult and very expensive, as outlined in Section 2.10. Tests would have to be conducted on both rigid vehicles and combination vehicles. Even with the support from equipment manufacturers the cost of such a test program is likely to be in excess of $400,000.

Demonstrations require the use of outriggers to protect the equipment from rollover. The two recent demonstrations described in Section 6.1 were held at driver training facilities. It is likely that a video of one of these recent or similar demonstrations could be obtained and used with a publicity campaign at a fraction of the cost of putting on an additional demonstration.

7.5 Recommendations

It is recommended that:

1. A publicity campaign be developed to demonstrate the value of heavy vehicle stability safety technologies to the transport industry;
2. That the campaign utilise case studies and video of physical demonstrations but not undertake it's own physical demonstrations or testing program;
3. That the campaign:
   - concentrate on the benefit of the technologies for articulated vehicles (including road trains); and
   - highlight the fact that fitment on the trailer alone has a significant benefit; but
   - not ignore the fact that fitting ESC to rigid vehicles is generally beneficial.
4. The situation with mandatory use of the technologies in the United States and Europe be monitored and further consideration be given to mandatory introduction in Australia when the appropriate technical standards have been identified in those jurisdictions.

8 BIBLIOGRAPHY

ABS (2010). *Motor Vehicle Census, Australia, year ending 30 March 2010.* Catalogue 9309.0. Australian Bureau of Statistics, Canberra.

Anderson, RWG., Hutchinson TP, Linke, B., and Ponte, G (2010). *Analysis of crash data to estimate the benefits of emerging vehicle technology*. Centre for Automotive Safety Research, The University of Adelaide.

BITRE, (2009). *Road crash costs in Australia 2006, Report 118*. Bureau of Infrastructure, Transport and Regional Economics, Canberra.

NTC (2007). *2007 Heavy Vehicle Charges Determination: Draft Regulatory Impact Statement*. National Transport Commission, Melbourne.

Sampson, D., Jeppesen, B., and Cebon, D (2000). *The Development of an Active Roll Control System for Heavy Vehicles*. 6th International Symposium on Heavy Vehicle Weights and Dimensions, Canada 2000.

9 CONSULTATION

Truck and equipment suppliers

Using Section 12 of Glass's Black & White Data Book as a base, phone contact was made with representatives of the truck makes as listed below. However, the position of the representative in the manufacturer/importer/distributor organisation was extremely variable because of availability and the structure/nature of the organisation in Australia. Sometimes it was an engineering supply manager, sometimes a design engineer, sometimes a marketing manager or salesperson and sometimes the only person available was a service department manager. As a result the technical information obtainable was also highly variable.

DAF
Freightliner
International
Kenworth
Mack
MAN
Mercedes Benz
Mitsubishi-Fuso
Scania
Sterling
UD
Volvo
Western Star

Note that sometimes different areas of the one organisation had to be contacted (e.g. separate areas of PACCAR at different locations had to be contacted to get information on DAF and Kenworth trucks) while sometimes the only source of information was a sales office or outlet (e.g. Hallam Truck Centre, a division of the CMV Group, as well as CMV Laverton & CMV Dandenong were all contacted to get information about Mack trucks).

Phone contact was made with a representative of Transpec - a supplier of trailer braking and roll stability control systems.

Other organisations

Phone contact was made with representatives of government organisations as follows:

Queensland Police
Victoria Police
VicRoads
Road and Traffic Authority NSW
Department of Infrastructure and Transport.

Because no official policy position has been announced from any of these organisations, the officers consulted in these organisations are not identified.

ATTACHMENT A

SOME COMMON ACRONYMS

ABS – Antilock Braking System. Prevents wheel lockup when the vehicle is over braked. The ABS works by sensing wheel rotation and comparing it to vehicle speed and what is happening on the other wheels and momentarily reduces the brake pressure to any wheel that is starting to lock-up i.e. skid.

ACB – Active Cruise Braking (Kenworth). ACB is activated when cruise control is engaged and uses onboard computers and radar to continually assess surrounding traffic conditions. The Kenworth ACB system will warn and provide active interventions – reducing throttle, engaging the engine retarder, and, if necessary, automatically applying the brakes to help the driver maintain the intended following distance.

ATC – Automatic Traction Control. ATC prevents wheel spin under acceleration. Works similarly to ABS but in reverse. When a wheel is detected as spinning it firstly applies the brake on that wheel and then reduces engine torque usually by cutting off fuel injectors.

DSP – Dynamic Stability Program (MAN). This is that part of the ESC package offered by MAN that addresses the loss of directional control component of ESC. The other part of the package is termed ROP for roll-over protection – see ROP below.

DTC – Drag Torque Control (Kenworth). Prevents the driving wheels from locking on slippery surfaces because of engine braking by raising engine revs to assist with vehicle stability.

EBS – Electronic Braking System. A system for applying the brakes via an (instantaneous) electrical signal. This results in the simultaneous application of all the vehicle brakes.

EBSS – Electronic Braking Safety System (Kenworth). A three level package of systems to improve the brake performance and stability of vehicles.

ESC - Electronic Stability Control. ESC continuously monitors a number of vehicle parameters using on-board sensors to predict if a vehicle is approaching its rollover threshold or loss of directional control is likely and then takes action to reduce the risk without intervention from the driver.

ESP – Electronic Stability Program. The same as ESC.

VSS - Vehicle Stability Systems. VSS continuously monitor a number of vehicle parameters using on-board sensors to predict if a rollover or loss of directional control is imminent.

ROP – Rollover Protection (MAN). This is that part of the ESC package offered by MAN that addresses the roll-over component of ESC. The other part of the package is termed DSP and addresses loss of directional control – see DSP above.

RSA - Roll Stability Advisors. RSA continuously monitors a number of vehicle parameters using on-board sensors to predict if a vehicle is approaching its rollover threshold and provide a visual and audible warning to the driver.

RSC - Roll Stability Control. RSC continuously monitors a number of vehicle parameters using on-board sensors to predict if a vehicle is approaching its rollover threshold systems and then takes action to reduce the risk without intervention from the driver.

RSS - Roll Stability Support. The same as RSC but is the term sometimes used for RSC on trailers.

TRM – Trailer Response Management (Kenworth). Electronic trailer brake actuation improves trailer braking response to help reduce stopping distances (for EBS compatible trailers only)