Evaluating Electronic Stability Control Technologies in PBS Vehicles





A. Germanchev

National Transport Research Board, Melbourne Australia.

Graduate of Swinburne University of Technology, 2003.

Principal Professional Leader – Transport Futures vehicles at NTRO.

L. Bruzsa

National Heavy Vehicle Regulator, Brisbane, Australia.

MSc. Mechanical Engineering (Major in Automotive Engineering) from Budapest University of Technology and Economics.

Chief Engineer at NHVR.

J. Diyn

National Heavy Vehicle Regulator, Brisbane, Australia.

Obtained BE(Mech) from the Queensland University of Technology, an MDiv and MA(Th) from Malyon College.

Assistant Chief Engineer – Office of the Chief Engineer at NHVR.

S. Varghese

National Heavy Vehicle Regulator, Brisbane, Australia.

Obtained Master of Engineering Practice from University of Southern Queensland.

Mechanical Engineer Office of The Chief Engineer at NHVR.

M. Fletcher

National Heavy Vehicle Regulator, Brisbane, Australia.

Obtained BEng (Mech) from Queensland University of Technology.

Senior Mechanical Engineer – Office of the Chief Engineer at NHVR.

Abstract

The Performance-Based Standards (PBS) scheme in Australia enables the operation of high-productivity vehicles on the road network provided they meet stringent safety and infrastructure standards. Among these, rearward amplification, a measure of how lateral forces amplify through the vehicle, is a safety parameter that often limits the payload capacity of combinations like A-doubles. Emerging technologies, such as Trailer Electronic Braking Systems (TEBS) with integrated Roll Stability Control (RSC), offer the potential to mitigate the risks associated with elevated rearward amplification or enable vehicles to meet safety standards more effectively. The PBS scheme does not require the fitment of these systems other than to the extent required under the Australian Design Rules (ADRs). The motivation for this project was that it would provide evidence to support the adoption of a requirement for stability systems on PBS vehicles as an addition to the scheme rules.

This study investigates the impact of TEBS on rearward amplification through both physical testing and simulation. Lane-change testing of an A-double equipped with TEBS demonstrated significant reductions in rearward amplification, enhancing vehicle stability. To extend these findings, a TEBS model replicating the RSC function was developed and validated using physical test data. This modelling exercise enabled the evaluation of TEBS effectiveness within multibody dynamic simulations, which are widely used in PBS assessments. By quantifying the impact of TEBS on vehicle performance, this paper provides a foundation for integrating advanced braking technologies into PBS standards, ultimately supporting safer and more efficient road freight operations.

Keywords: A-double, Rearward amplification, Performance Based Standards, Trailer Electronic Braking Systems, TEBS, Roll Stability Control, RSC

1 Introduction

Heavy vehicle safety remains a critical focus for Australia's freight industry, particularly with the increasing adoption of PBS vehicles that push the boundaries of vehicle design and performance. These combinations offer enhanced productivity but particularly in the case of long multi-combination vehicles present unique challenges in high-speed dynamic stability.

Electronic Stability Control (ESC) and Roll Stability Control (RSC) technologies have demonstrated their ability to mitigate rollover risk, and the benefits are well accepted in steady state conditions when negotiating tight radius curves. However, the functionality of these systems during high-speed dynamic manoeuvre such as the PBS lane change are less well known and have not been thoroughly evaluated in the context of PBS. While these systems are mandated for prime movers under ADR 35/06, they are not specifically required for PBS combinations, creating a critical safety gap. This project aims to address this gap by characterizing the performance of EBS with RSC technologies and supporting their inclusion as requirements within the PBS scheme.

2 Methodology

This project employed a two-phase approach to evaluate the performance of RSC systems:

1. In-service data monitoring
2. Field testing program.

The aim of in-service data monitoring was to gain a better understanding the performance of the vehicles fitted with RSC, with a focus on the frequency and location of the RSC interventions. In this phase, the operational performance of RSC systems was analysed using telematics data from a fleet of PBS A-double vehicles. Metrics included:

- The number and type of RSC interventions (e.g. high-speed manoeuvres, low-speed curves).
- System faults affecting stability control functionality.

The data were anonymised and aggregated to assess system reliability and the prevalence of interventions during real-world operations.

In-service data revealed critical insights into the operational effectiveness of ESC and RSC:

- RSC interventions occurred in both high-speed scenarios and during tight-radius curves, highlighting their importance in preventing rollovers.
- A significant number of system faults were detected which underscored the need for robust in-service compliance standards to maintain safety performance.

The in-service data provided valuable insights into the operational effectiveness of ESC and RSC which informed the second phase of the project, the field testing program. Its objective was to validate the functionality of Electronic Braking Systems (EBS) with RSC during a high-speed dynamic lane change manoeuvre and collect data to characterise the system's performance. This data was intended to support the development of a model for inclusion in the PBS assessment process.

These findings support the inclusion of ESC and RSC systems in PBS standards, not only during vehicle design and approval but also throughout their operational lifecycle. The in-service compliance monitoring of EBS and RSC systems is an important consideration for the future proofing of PBS and was an important part of the research project undertaken, however this paper focuses on field testing program which is described in detail in the following section.

3 Field Testing Program

Controlled field testing was conducted to quantify the performance of ESC and RSC during high-speed maneuvers. The PBS Lane Change manoeuvre was used to evaluate functionality of the EBS system with RSC by measuring the key metrics such as:

- Lateral acceleration
- Yaw rate
- Rearward amplification (RA)
- System activation thresholds.

The PBS lane-change manoeuvre is the method used to measure the rearward amplification (RA). The intention of the lane-change manoeuvre is to produce a known lateral acceleration at the steer axle, at a given frequency, and to record the lateral acceleration experienced at the rear unit. The ratio of peak lateral acceleration at the rear unit to that at the steer axle is the RA of the vehicle. This phase of the project comprised the following tasks which are described in the sections below:

- 3.1 Test Design, Venue and Vehicle Configuration
- 3.2 Measurement equipment and vehicle sensors
- 3.3 High-speed tests
- 3.4 Data analysis

3.1 Test Design, Venue and Vehicle Configuration

Test design

Key requirements influencing the design, vehicle, and venue selection included:

- Conducting tests at speeds up to 88 km/h.
- Use of a closed road or controlled environment to minimize traffic interaction.
- Ensuring vehicles were equipped with outriggers for safety (see Figure 7)
- Selecting roads with sufficient width for lane changes with outriggers.
- Evaluating RSC functionality under various operational states.
- Conducting tests with fully loaded trailers across multiple center-of-gravity (CoG) heights, reflecting typical PBS A-double combinations.

Test manoeuvre

The PBS lane change manoeuvre was used to evaluate the performance of the EBS with RSC. This manoeuvre measures two critical metrics:

The driver followed a prescribed path marked on a flat, even road section with minimal cross-slope, as per ISO14791:2000 standards. Given the technical difficulty of maintaining precise path alignment without automated steering, the manoeuvre aimed to approximate PBS requirements while inducing RSC intervention for vehicle stability. A camera mounted to the front of the vehicle recorded the position of the steer tire relative to the markers, ensuring adherence to acceptable tolerances.

The road surface was sealed and within the road geometry (alignment, roughness, crossfall and grade) tolerances of the test standard.

The tests were conducted at the Australian Automotive Research Centre (AARC), on a controlled section of their test facility.

Vehicle configuration

Testing was conducted using a PBS A-double fitted with:

- Adjustable CoG heights for lead and rear trailers.
- Instrumentation including IMUs, GPS, and synchronized cameras.
- ESC and RSC systems configurable to "on," "off," and partial activation states.

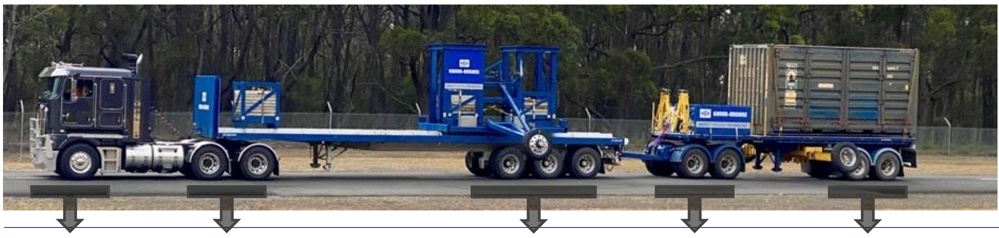
The subject vehicle selected for testing is shown in Figure 1. The combination comprised a Kenworth prime mover hauling a specialist A-double trailer set from Knorr-Bremse. The lead trailer was fitted with hydraulically controlled outriggers and weights allowing for CoG height adjustment. The rear trailer was fitted with a container with a mezzanine floor that allowed for test weights to be positioned on the upper or lower decks.

Figure 1 - Subject vehicle during preparation.

Source: A.Germanchev (NTRO)

The subject vehicle was tested at axle weights shown in Table 1.

Table 1 - Test vehicle axle weights.



Steer	Drive	Lead Trailer	Dolly	Rear Trailer	Total
6,348 kg	15,904 kg	19,426 kg	16,141 kg	16,171 kg	73,990 kg

The subject vehicle was tested at two centre of gravity (CoG) heights. The two CoG heights were selected based on a review of PBS assessments, with the aim of representing a PBS A-double with a low CoG (front trailer 1.86 m, rear trailer 1.93 m) and one with a high CoG (front trailer 2.25 m, rear trailer 2.25 m).

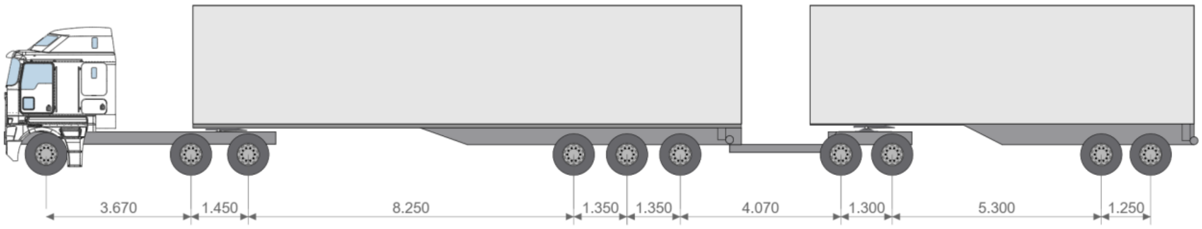


Figure 2 – Inter-axle spacing of 30m overall length subject vehicle.

A vehicle model of the subject was developed assessed using computer simulation in accordance with the PBS assessment rules. The results of this assessment are shown in Table 2 with the associated PBS Level 2 requirements and the resultant pass or failure to meet these requirements.

Table 2 - PBS results for subject vehicles.

PBS	Low CoG	Level 2	Result		High CoG	Level 2	Result
SRT1 (Static Rollover Threshold of Roll-Coupled Unit 1)	0.47 g	0.35 g	PASS		0.36 g	0.35 g	PASS
SRT2 (Static Rollover Threshold of Roll-Coupled Unit 2)	0.45 g	0.35 g	PASS		0.35 g	0.35 g	PASS
HSTO (High Speed Transient Offtracking)	0.44 m	0.8 m	PASS		0.56 m	0.8 m	PASS
RA (Rearward Amplification)	1.87	2.57	PASS		2.00	1.99	FAIL

3.2 Measurement equipment and vehicle sensors

The following sensors and equipment were fitted to the test vehicle:

- a high-speed global positioning system (GPS) measuring vehicle position and speed.
- 3 x inertial measurement units (IMU) fitted to the prime mover, and first and second trailer bodies, each IMU contained the following sensors:
- tri-directional accelerometers measuring the acceleration in the X, Y and Z directions.
- yaw sensors, measuring the yaw rate of the prime mover body, and two trailer bodies.
- two camera units, both synchronised to the data.

3.3 High-speed tests

The tests were conducted on the highway circuit of the AARC vehicle proving grounds. This circuit provided sufficient distance for the vehicle to accelerate to the required test speeds in the lead-in section, then execute the manoeuvre. The path the driver was required to follow was marked on the test section, as shown in Figure 3.

Figure 3 - Lane change path as marked for testing on AARC highway circuit.

Source: A. Germanchev (NTRO)

The test schedule presented in Table 3.1 lists the tests in a sequential order determined through a risk assessment. The tests with the lowest risk were prioritised and conducted first, starting with the low centre of gravity (CoG) height configuration at low speed. For each CoG height configuration, tests were conducted with the following three RSC (Roll Stability Control) configurations:

- ALL ON: RSC was active on all vehicle units.
- ALL OFF: RSC was inactive on all vehicle units.
- ON/OFF/ON: RSC was active on the lead and rear trailer units, but inactive on the dolly.

Additional double-lane change testing was conducted to replicate a more severe manoeuvre to engage the outriggers and fully demonstrate the performance of RSC system to prevent rollover in a high-speed dynamic manoeuvre. Figure 4 shows the test vehicle performing the lane change manoeuvre at 88 km/h at AARC test facility.

Figure 4 - Test vehicle during testing on the highway circuit at AARC.

Source: A. Germanchev (NTRO)

3.4 Data analysis

A total of 64 tests were performed to quantify the performance of the RSS during high-speed manoeuvres. All test data was processed and analysed. The tests were reviewed for compliance with the lane change requirements including the entry and exit speeds and steering path. A selection of tests that were within the acceptable tolerances were selected for further analysis.

For each valid test, the test section was identified, and data over a 10-second period was analyzed in detail. During this period, the peak values for lateral acceleration were determined for both the prime mover (AY1) and the rear trailer (AY3). Using these peak values, the Rearward Amplification (RA) was calculated for each test to assess the relative lateral dynamics of the vehicle.

The entry and exit speeds of the vehicle were also recorded as part of the analysis. These speeds provide critical context for understanding the vehicle's dynamics during the test section. Entry speed reflects the conditions under which the vehicle initiates the maneuver, while exit speed indicates the test remained compliant with the PBS test requirements.

An example of raw data collected, and the analysis method applied to Test No.1 (Test ID 019) is shown in Figure 5. This example shows a peak value of 0.31 g for AY1 0.43 g and AY4. A moving average window = 2 filter was applied to all data. That is, each new data point is combined with the previous one, creating a simple average that helps smooth out sudden changes.

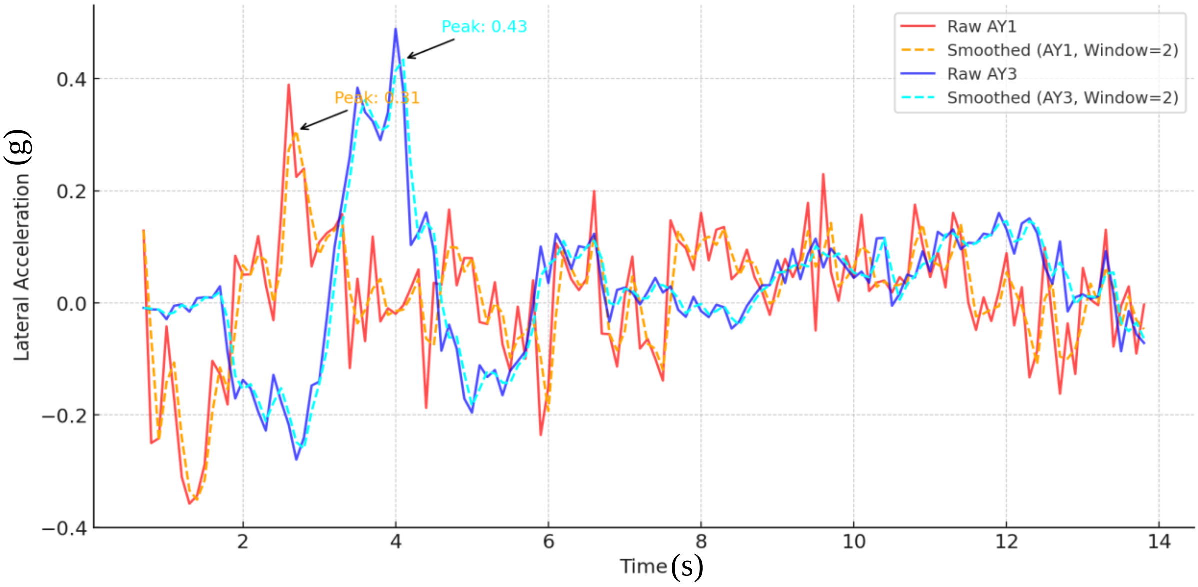


Figure 5 - Test vehicle during testing on the highway circuit at AARC.

An example of rearmost trailer onboard data collected is shown in Figure 6. The activation of the RSC unit in response to the lateral acceleration experienced by the trailer can be seen to apply brake pressure at proportionally to either side of the trailer accordingly.

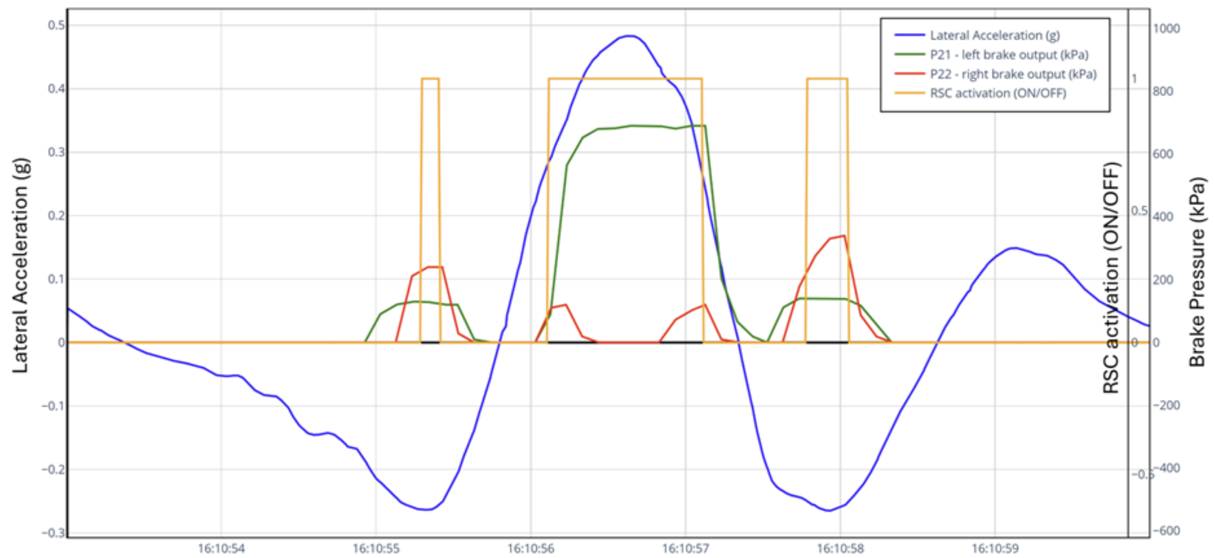


Figure 6 - RSC outputs from the test vehicle on the highway circuit at AARC.

The test results are listed in Table 3 for low CoG and Table 4 for high CoG.

Table 3 - Summary of tests for low CoG configuration.

No.	Test ID	Entry speed (km/h)	Exit speed (km/h)	Speed Diff. (km/h)	Lat. Acc AY1 (g)	Lat. Acc AY3 (g)	RA	EBS
1	019	88.4	85.4	-3.0	0.307	0.434	1.45	ALL ON
2	020	88.8	84.9	-3.9	0.297	0.431	1.45	ALL ON
3	021	88.4	84.5	-3.9	0.298	0.439	1.47	ALL ON
4	032	88.7	85.8	-2.9	0.245	0.371	1.51	ON/OFF/ON
5	033	88.0	84.9	-3.1	0.300	0.363	1.21	ON/OFF/ON
6	034	88.2	84.7	-3.5	0.258	0.410	1.59	ON/OFF/ON
7	041	88.5	88.5	-0	0.192	0.304	1.58	ALL OFF
8	042	88.8	88.6	-0.2	0.217	0.477	2.20	ALL OFF
9	043	88.8	88.6	-0.2	0.232	0.405	1.75	ALL OFF

Table 4 - Summary of tests for high CoG configuration.

No.	Test ID	Entry speed (km/h)	Exit speed (km/h)	Speed Diff. (km/h)	Lat. Acc AY1 (g)	Lat. Acc AY3 (g)	RA	EBS
10	049	88.4	85.5	-3.0	0.220	0.377	1.71	ALL ON
11	050	88.6	86.0	-2.6	0.221	0.418	1.89	ALL ON
12	051	88.6	85.6	-3.0	0.248	0.402	1.62	ALL ON
13	062	89.2	86.7	-2.5	0.327	0.419	1.28	ON/OFF/ON
14	063	88.8	86.5	-2.3	0.327	0.394	1.21	ON/OFF/ON
15	064	88.8	86.9	-1.9	0.267	0.437	1.64	ON/OFF/ON
16	075	88.4	88.2	-0.2	0.317	0.429	1.35	ALL OFF
17	076	88.5	88.2	-0.3	0.194	0.416	2.14	ALL OFF
18	078	88.5	88.3	-0.2	0.324	0.471	1.45	ALL OFF

Further testing was conducted in the form of a double lane change test, both with and without RSC enabled. The stark difference between RSC enabled and disabled is evident in Figure 7.

Figure 7 - Test vehicle performing double lane change with RSC off (A) and on (B)

The purpose of the double lane change test was to demonstrate the significant lateral acceleration experienced by the rear trailer under non-intervention conditions, which exceeded the trailer's rollover threshold. This extreme lateral force caused the rear trailer to rely on its outriggers to prevent rollover. In contrast, testing with the Rollover Stability Control (RSC) system activated demonstrated the system's effectiveness in mitigating rollover during a high-speed dynamic manoeuvre.

This test was a world-first involving a PBS road train performing a PBS-compliant lane change to quantify the performance of Rollover Stability Control (RSC) during a high-speed dynamic maneuver. The test successfully demonstrating the system's ability to prevent the rear trailer of a long multi-combination vehicle from rolling over.

4 Results

The key findings from the results are:

Entry and Exit Speeds:

- Tests with "ALL ON" or "ON/OFF/ON" EBS configurations experienced a deviation from the average speed ranging from 1.95 km/h to 0.95 km/h, less than the permitted maximum of 3 km/h proving that all tests were compliment with the PBS requirements.
- "ALL OFF" EBS configurations had minimal speed differences (close to zero) as EBS was in-active and no braking occurred during these tests.

AY1 (Lateral Acceleration at the prime mover):

- The lateral acceleration generated at the prime mover ranged between 0.220–0.327, this suggests the lane change manoeuvre was more severe with a higher input than the 0.15 g required for PBS assessment. It should be noted that the location of the accelerometer was on the prime mover body not the steer axle.

- The AY1 values for the ON/OFF/ON and ALL OFF configurations were higher in the high CoG tests (0.31g and 0.28g, respectively) compared to the low CoG tests (0.27g and 0.21g). However, this does not necessarily result in higher RA values, as the RA calculation incorporates a high denominator, offsetting the potentially greater lateral acceleration experienced by the rear trailer due to the increased input.

AY3 (Lateral Acceleration at the rear trailer):

- ALL ON: On average AY3 was less in the high CoG test for the "ALL ON" configuration (0.40 to 0.46g), suggesting that stability control effectively mitigated the peak lateral acceleration experienced by the rear trailer, even with a higher centre of gravity. This counterintuitive result is influenced by the fact that the high CoG tests had significantly lower input lateral accelerations, reducing the magnitude of forces acting on the rear axle.
- ON/OFF/ON: On average AY3 was higher in the high CoG tests (0.42g to 0.38g), showing that intermittent braking configurations result in greater lateral forces under high CoG conditions.
- ALL OFF: The high CoG test in the ALL OFF configuration experienced the highest peaks on average (0.39g), indicating higher lateral forces at the rear trailer, due to the higher centre of gravity.

RA (Rearward Amplification):

When comparing the RA results from the Low CoG tests, the findings are straightforward. Both the ALL ON and ON/OFF/ON configurations produced similar RA values (1.46 and 1.44, respectively), which were significantly lower than the RA value of 1.84 observed for the ALL OFF configuration. Proving that RSC effectively reduced the RA during the lane change manoeuvre.

For the High CoG tests, the RA results for the ALL ON configuration were inconsistent with the ON/OFF/ON and ALL OFF configurations. This discrepancy was primarily due to the ALL ON tests having a lower AY1 input. However, when focusing on the ON/OFF/ON configuration—which was not influenced by a low AY1 input—the trend remained consistent. The RA value for ON/OFF/ON (1.38) was lower than the RA for ALL OFF (1.65), further highlighting the stability benefits of active EBS.

The testing demonstrated the critical role of EBS with RSC in maintaining vehicle stability and how this equates to an improved RA result during a PBS lane change manoeuvre.

The test results provided compelling evidence that the vehicle, which had previously failed PBS assessments when evaluated using computer simulations that did not account for the functionality of RSC, was able to achieve a PASS during physical testing with the RSC system active. This highlights the limitations of traditional simulation models in accurately reflecting the impact of advanced safety technologies and underscores the importance of incorporating such functionalities into future PBS assessment frameworks. By demonstrating the RSC's ability to enhance stability and mitigate rollover risk, this test showcases the potential for these systems to enable vehicles to meet stringent safety standards while maintaining high productivity.

5 Key Findings and Discussion

The project identified several key findings:

- Effectiveness of EBS with RSC: These systems significantly reduced RA and maintained stability, preventing rollovers even in high-severity manoeuvres at high speeds.
- Operational Reliability: Fault rates were detected during in-service monitoring highlighting the importance of ensuring compliance during operation.
- Policy Implications: The field testing underscored the importance of integrating EBS with RSC in PBS assessments to improve vehicle stability, whereas the operational data highlighted the need for in-service compliance standard that includes data monitoring.
- Model development: The testing was sufficient to develop a method for integrating the impact of RSC into the PBS assessment of the lane change manoeuvre.

6 Recommendations and next steps

To enhance road safety and vehicle stability, the following recommendations are proposed:

- Integration of EBS with RSC for PBS vehicles as part of the NHVR's PBS 2.0 review.
- In-Service Compliance Standards: Develop a framework to ensure operational reliability of these systems throughout the vehicle's lifecycle.
- The next critical step is the development of a model or method that incorporates the demonstrated safety and productivity benefits of this technology, as evidenced by the field testing. This model will serve as a vital step in shaping informed policy that supports the adoption of advanced safety systems across the industry.

7 Conclusion

This project successfully demonstrated the safety benefits of EBS with RSC technologies in PBS vehicles through a rigorous evaluation process. By closing the knowledge gap on their performance, the study provides a robust foundation for policy changes that will ensure PBS vehicles remain at the forefront of road safety.

The test results conclusively demonstrated that a vehicle, which had previously failed PBS assessments when evaluated using computer simulations excluding the functionality of Rollover Stability Control (RSC), successfully achieved a PASS during physical testing with the RSC system active.

8 Acknowledgments

The authors thank the National Heavy Vehicle Regulator, Australian Automotive Research Centre and technical partners Knorr-Bremse for their support in data collection and testing.

9 References

International Organization for Standardization, *ISO 14791:2000 - Standard for Dynamic Testing Procedures*, Geneva, Switzerland, 2000.

National Transport Research Organisation, *HVSI 557-01: Testing of Electronic Stability Control Technologies on Long Combination Vehicles*, HVSI Project 557 Research Report, unpublished draft, Port Melbourne, Australia, 2024.

National Heavy Vehicle Regulator, *PBS Standards and Vehicle Assessment Rules*, Nov. 2022. [Online]. Available: https://www.nhvr.gov.au/files/media/document/123/202211-0020-pbs-standards-and-vehicle-assessment-rules.pdf. [Accessed: Nov. 21, 2024].