IMPROVING CONCRETE PUMP ROAD SAFETY ASSESSMENTS METHODS AND STANDARDS




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Abstract

Current vehicle standards and operating conditions limit productivity of the concrete pumping industry and do not facilitate implementation of the latest vehicle technology. Inconsistencies in operating and access conditions applied across different Australian jurisdictions lead to costly delays, sub-standard safety outcomes, confusion and poor compliance. Research has been undertaken to review large concrete pump truck performance against the Australian heavy vehicle fleet, international standards and the status quo to formulate a better approach to performance standards and access for these vehicles in Australia.

There's a global trend to utilise longer and heavier concrete pump trucks, with booms greater than 50 m and GVM's exceeding 50 t for operational efficiency. These vehicles generally have 5 to 8 axles with sophisticated auxiliary steering and vehicle safety systems. They're preferred in certain operations for operational efficiency, but most oversize SPVs fail low speed turning requirements prescribed under the Performance Based Standards (PBS) scheme. This results in a complex and costly framework of individual road access permits and operating conditions often requiring pilot and escort vehicles.

Based on field testing and operating studies, a set of revised guidelines and low speed manoeuvring standards have been developed that better quantify the performance and risk associated with oversize Concrete Pumps on the road.

Keywords: Performance Based Standards (PBS), Low Speed Swept Path (LSSP), Tail Swing (TS), Frontal Swing (FS), Concrete Pump, Special Purpose Vehicle.

1 Introduction

This research aims to deliver new PBS performance requirements for LSSP and TS to improve oversize concrete pump access while maintaining safer drivers, safer vehicles and safer road use. The objectives of this research included:

1. Better understanding associated safety risks.
2. Reviewing existing PBS requirements applied to oversize concrete pump trucks and proposing more appropriate performance requirements.
3. Developing nationally consistent operating and access conditions.
4. Improving driver awareness and communicating appropriate driver behaviours.
5. Understanding the latest concrete pumping technology, industry trends with increasing size of pumps (> 50 m), international standards and opportunities to encourage the use of better technology to improve road safety.
6. Developing strong evidence to inform change by conducting field testing to validate computer models and development of better performance standards, guidelines for safe operation, appropriate operating conditions.

2 Methodology

A literature review was completed on assessing prescriptive and PBS standards which applied to large concrete pump trucks, their operating and access conditions in various jurisdictions. Then fleet performance was reviewed using 3D computer simulation of low and high-speed vehicle dynamic performance for 27 vehicles. The impact of different steering systems (passive & active) and drive axle configurations and articulated vs. rigid vehicles was included. Then a risk assessment of ten potentially hazardous scenarios based on various types of roads was completed.

Field tests/ operating studies was also completed with a large concrete pump vehicle to quantify and qualify performed on the road and during a PBS low speed manoeuvres using static/ dynamic LiDAR scans in comparison to traditional test methods. The vehicle's geometry and required road space were quantified during the prescribed PBS tests and various road intersections. The outcomes of the analysis drove guidelines and standards development including alternate PBS LSSP and TS requirements.

3 Literature Review

Larger pumps fall outside of prescriptive guidelines for Special Purpose Vehicle (SPV). Typical non-compliances include rear overhang, overall width, overall length, axle mass limits, bridge spacing and driver control position (left hand drive).

Risks are managed with operating conditions and restricted access applied by regulators and road managers along with ad-hoc assessment framework based on PBS which attempt to address mass, dimension, and vehicle standard non-compliances. LSSP, TS, pavement and bridge loading are chief areas of concern for road managers.

Regulators and road managers face challenges because of the diversity and complexity of the concrete pumping fleet. The variety of vehicle configurations means that each vehicle must be dealt with on a case-by-case basis which is time consuming and often leads to inconsistent outcomes and access conditions.

3.1 Frontal Swing, Low Speed Swept Path, and Tail Swing

FS, LSSP and TS are a suite of measures assessed during a low-speed 90 degree turn, refer to Figure 1. Large values of LSSP, FS and TS are undesirable since they may cause the bus or coach to encroach into adjacent or opposing lanes, collide with parked or stopped vehicles, damage roadside infrastructure or endanger pedestrians. Refer to Table 1 for current limits.

Table 1 Current PBS Performance Requirements

PBS Level	FS limits (m)	LSSP limit (m)	TS limit (m)
1	0.85	7.4	0.3
2		8.7	0.35

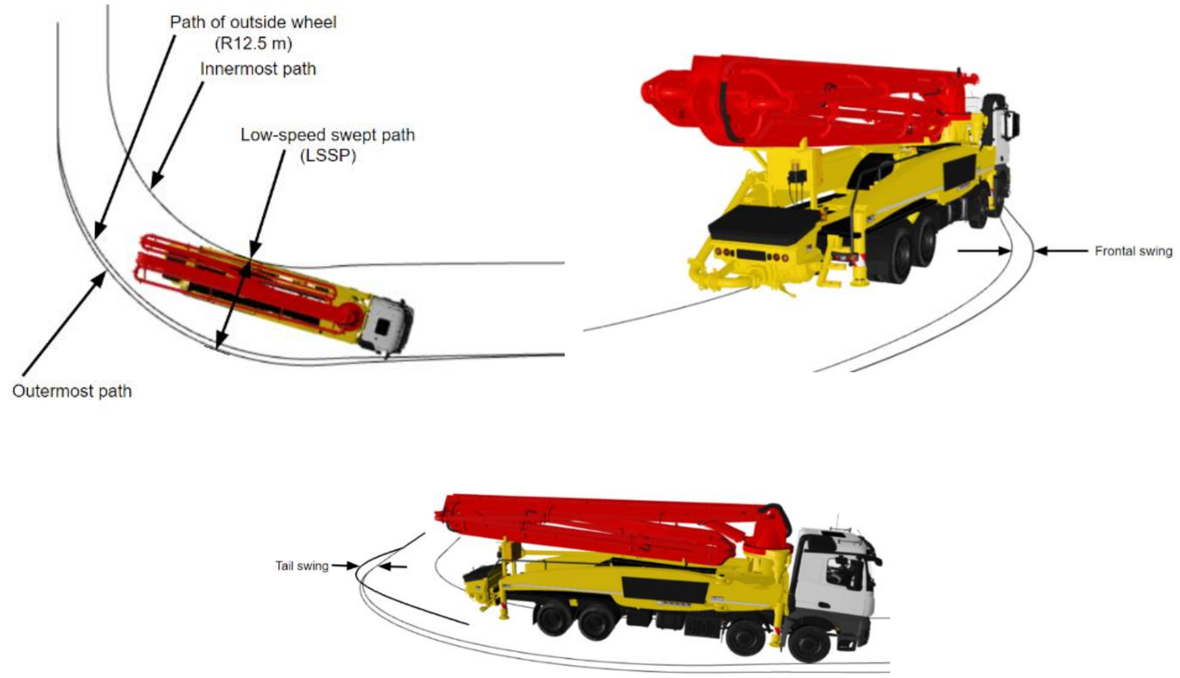

Figure 1 PBS Low Speed performance Measures

3.2 International Regulations

Most countries do not have vehicle design rules specific to boom mounted concrete pumps and other special purpose vehicles. These countries do not list specific regulation for boom mounted concrete pumps as they are widely included within the scope of single unit concrete pumps. Countries such as Japan, USA and Australia allow for extra weight limits and vehicles to have dimensions outside the prescribed ranges if a permit process is followed and the vehicles is approved by local government authorities.

3.3 The European Union

For single unit N2 and N3 category vehicles, the manoeuvrability requirements for a single unit combination is to fit within an outer circle of radius 12.5 m and an inner circle of radius 5.3 m while turning. The maximum permitted Rear Swing Out is 0.8m, EU Regulation 1230 (European Parliament, 2012).

3.4 China

Chinese Federal Regulation QC/T 718-2013 outlines mass and dimension requirements for truck mounted concrete pumps over 26 tonnes. The maximum dimensions are specified based on Boom Length and the chassis rear overhang shall be no more than 3.5 m, refer Table 2. According to QC/T 718-2013 4-axle concrete pumps may be up to 44 tonnes, and pumps with more than 6-axles are limited by the sum of axle mass limits which can be up to 12 tonnes for a non-driven axle, see Table 3. General mass and dimension limits in China allow 2.55 overall width, 12 m overall length and 4 m overall height to an allowable GCM of 31 t (Ministry of Transport of the People's republic of China, 2019).

Table 2 Chinese maximum outer dimension limits

Boom Length (m)	Overall Length (m)	Width (m)	Height (m)
H ≤ 37	≤ 12	≤ 2.5[1]	≤ 4
37 < H ≤ 48	≤ 14	≤ 2.5	≤ 4
48 < H ≤ 60	≤ 16	≤ 3	≤ 4
H > 60	≤ 22	≤ 3	≤ 4

Table 3 Chinese maximum Gross Vehicle Mass

No. of Axles	Maximum Load for Each Axle Type (kg)			Maximum GVM (kg)
	Lazy Axle	Drive Axle		
		Single Tyre	Dual Tyre	
3	≤ 8,000	-	≤ 13,000	≤ 33,000
4	≤ 9,000	-	≤ 13,000	≤ 44,000
5	≤ 9,000	≤ 10,000	≤ 13,000	≤ 54,000
6	≤ 9,000	≤ 10,000	≤ 13,000	≤ 64,000
> 6*	≤ 12,000	≤ 12,000	≤ 13,000	-

3.5 Road Safety Risks

To consider the implications of different PBS performance requirements, potentially hazardous scenarios were identified. Concrete pump trucks possess excellent directional stability whilst travelling at high speeds and rarely prove hazardous to other road users as they are equivalent to other trucks and buses travelling at comparable speeds. However, risks associated with TS may be present in certain conditions i.e., making tight turns on single lane roads with lane widths less than 3.5 m. A list of specific scenarios and on various types of roads and turns have been identified:

- Scenario 1 – Right turn from an Urban Median
- Scenario 2 – Protected Bicycle Lane
- Scenario 3 – Unprotected Bicycle Lane
- Scenario 4 – Left turn on single lane urban streets
- Scenario 5 – Left Turn on multilane urban streets

[1] China moved from 2.5 m to 2.55 m overall width in 2016 consequently the 2.5 m limit on the 2013 Truck Mounted Concrete Pump regulation is outdated and can be read as 2.55 m.

- Scenario 6 – Left turn on single lane roads without median
- Scenario 7 – Right turn with an adjacent straight path lane
- Scenario 8 – Two adjacent right turn lanes - no lane straddling
- Scenario 9 – Two adjacent right turn lanes - lane straddling
- Scenario 10 – Busy Urban Hook Turns

From a high-level review, the alterations of TS limits do not present any further increase in risk. However, field testing was required to quantify and qualify the change in risk.

4 Fleet performance and Risk Assessment

Assessment of 27 different SPV vehicle combinations were conducted to review key low speed performance measures, including those that fit within existing SPV Guidelines as well as oversize permit vehicles. This established a baseline assessment of the current SPV fleet operating in Australia. A qualitative review of the risks associated with the operation of various types of oversize concrete pump trucks has been conducted.

4.1 Fleet performance Assessment

The 27 vehicles were all assessed for: LSSP, FS, TS, Steer Tyre Friction Demand, Tracking Ability in a Straight Path (TASP), Load Transfer Ratio (LTR), and EU 1230/2012 Manoeuvrability requirements, refer to Table 4. Vehicles with a long wheelbase and lessor steer wheel angles did not meet the 12.5 m PBS turn radius, the EU 1230/2012 test and ADR 43/04 turning circle.

The results concluded that most of the vehicles meet PBS Level 1 LSSP requirements but failed PBS Level 1 TS requirements. However, the TS analysis is based on a square rear overhang profile which over-estimates the TS of most concrete pumps. In practice most vehicles operating under the Class 1 Notice and General access do meet PBS Level 1 TS.

The larger permit pumps generally do not meet PBS Level 1 TS requirements, and many cannot achieve a 12.5 m radius turning circle. For the Australian permitted pumps, this is large due to operators and suppliers specifying pumps to reduce rear overhang and TS to avoid access restrictions. The results show that the EU 1230/2012 test is significantly more challenging than the PBS LSSP manoeuvre. However, the EU test allows rear swing-out up to 1.0 m, whilst the PBS standards only allow 0.3 m.

Table 4 Fleet Performance Assessment Results

#	Chassis	Length (m)	Width (m)	ROH (m)	No. Axles	LSSP (m)	FS (m)	TS (m)	STFD	EU 1230/2012	PBS turn Radius	Access
1	4x2	11.3	2.5	3.7	2	4.64	0.65	0.32	8%	Yes	12.5	General
2	6x4	11.275	2.5	3.675	3	4.68	0.62	0.29	18%	Yes	12.5	General
3	8x4	11.275	2.5	3.675	4	4.68	0.62	0.29	13%	Yes	12.5	General
4	6x4	11.075	2.5	4.0	3	4.42	0.60	0.38	20%	Yes	12.5	Class 1 Notice
5	8x4	12.282	2.5	3.935	4	5.10	0.79	0.35	12%	No	12.5	Class 1 Notice
6	6x4	12.225	2.5	4.0	4	5.09	0.65	0.33	35%	No	12.5	Class 1 Notice

#	Chassis	Length (m)	Width (m)	ROH (m)	No. Axles	LSSP (m)	FS (m)	TS (m)	STFD	EU 1230/2012	PBS turn Radius	Access
7	6x4	11.78	2.5	4.0	4	4.80	0.63	0.33	17%	Yes	12.5	Class 1 Notice
8	6x4	12.295	2.5	3.995	4	5.00	0.64	0.38	19%	No	12.5	Class 1 Notice
9	10x4	12.22	2.5	4.0	5	5.04	0.64	0.34	25%	No	12.5	Class 1 Notice
10	10x4	13.78	2.5	5.26	5	5.13	0.63	0.66	26%	No	12.7	AU Permit
11	10x4	14.2	2.5	6.10	5	4.92	0.62	0.92	14%	No	12.5	AU Permit
12	10x4	14.2	2.5	4.7	5	5.47	0.64	0.48	13%	No	14.2	AU Permit
13	10x4	15.085	2.5	6.67	5	5.12	0.67	1.16	13%	No	12.5	South Korea
14	12x4	14.5	2.5	5.5	6	5.31	0.64	0.72	7%	No	13.5	AU Permit
15	12x4	14.5	2.5	4.908	6	5.59	0.65	0.48	15%	No	14.1	AU Permit
16	12x4	15.3	2.5	4.976	6	5.76	0.7	0.5	16%	No	14.9	EU
17	12x4	16.435	2.55	6.345	6	6.02	0.77	1.03	24%	No	14.9	EU
18	12x4	15.3	2.5	5.662	6	5.54	0.7	0.72	9%	No	14.3	AU Permit
19	14x4	15.41	2.5	5.055	7	5.18	0.57	0.36	5%	No	19	AU Permit
20	14x4	15.41	2.5	6.425	7	4.83	0.56	0.82	6%	No	16.4	AU Permit
21	14x4	15.41	2.5	4.37	7	5.47	0.58	0.22	10%	No	19.8	AU Permit
22	16x4	16.7	2.6	7.2	8	4.95	0.51	0.97	5%	No	17.6	USA
23	16x4	17.5	2.6	5.4	8	5.64	0.57	0.33	23%	No	22.5	USA
24	4x2	12.5	2.5	3.7	3	5.28	0.93	0.29	14%	Yes	12.5	General
25	6x2	13.5	2.5	4.0	3	5.65	1.08	0.32	12%	No	12.5	CAB
26	6x2	14.5	2.5	4.7	3	5.84	1.38	0.52	13%	No	12.5	CAB
27	6x2	14.5	2.5	4.9	3	5.73	1.37	0.59	13%	No	12.5	CAB

4.2 Road Space Assessment

Error! Reference source not found. presents the framework used to assess the road space performance of the following combinations and concrete pump trucks:

- PBS L1 19 m Truck & Dog,
- PBS L1 20 m Semi Trailer,
- Prescriptive 12.5 m Concrete Pump, and
- 14.5 m Concrete Pump which meets ADR and EU turning requirements.

The vehicles are assessed for their compliance with the following performance measures:

- EU turning and rear swing-out requirements,
- PBS LSSP, FS and TS requirements, and
- Austroads Local & Arterial Road envelope (ARTSA, 2003)

The turning requirements of the EU test and traditional Australian turn path envelopes are, unlike PBS road space “envelope” tests which limit the overall road space a vehicle can occupy, rather than prescribing a turn-path radius. Consequently, the technical assessment has multiple solutions for a given vehicle. Whilst this can add complexity to the assessment process and driving task, it does provide more flexibility for the assessment and better reflects the real-world physical implementation of a low-speed turn based on driver input.

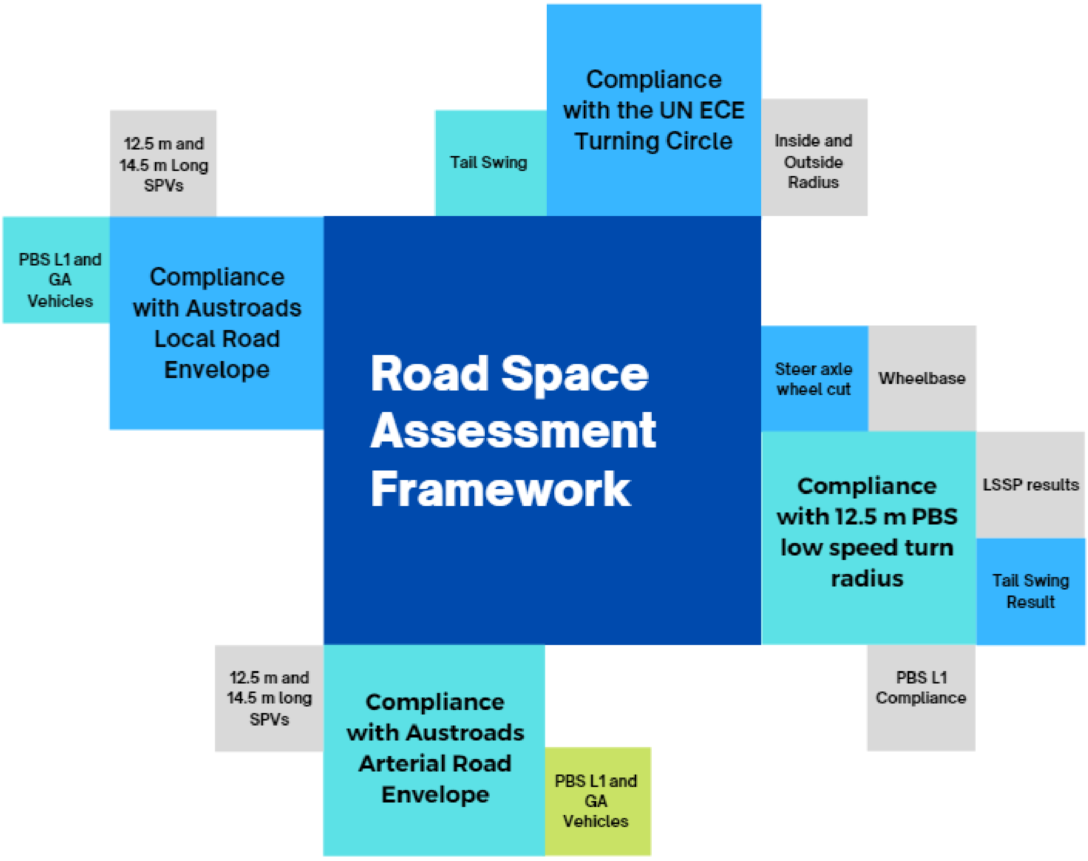

Figure 2 Road Space Assessment Framework

Figure 3 provides a comparison of the road space taken up by a 19 m Truck & dog, 20 m PBS Level 1 semi-trailer, both with general access, a 12.5 m prescriptive rigid concrete pump and a 14.5 m concrete pump maximised to meet EU turning requirements. The 19 m truck & dog combination meets the Local Road and Arterial Access turning envelopes, however, does not meet the EU turn by a small margin.

The 20 m PBS Level 1 Semi combination meets the Arterial Access turning envelopes, however, does not meet the Local Road or EU turn. Both the 19 m truck & dog and the 20 m semi combination meet PBS L1 prescribed 12.5 m radius PBS turning radius requirements with a LSSP of 5.9 m and 7.3 m, respectively.

Consequently, vehicles meeting PBS L1 turning standards do not necessarily meet the more realistic turning path envelopes developed by Austroads. Combinations that meet the PBS L1 standards are allowed access to a vast number of local roads including urban roads and tight intersections. The 12.5 m prescriptive rigid concrete pump meets ADR requirements and comfortably meets the turning circle requirements along with meeting the Australian local road envelope.

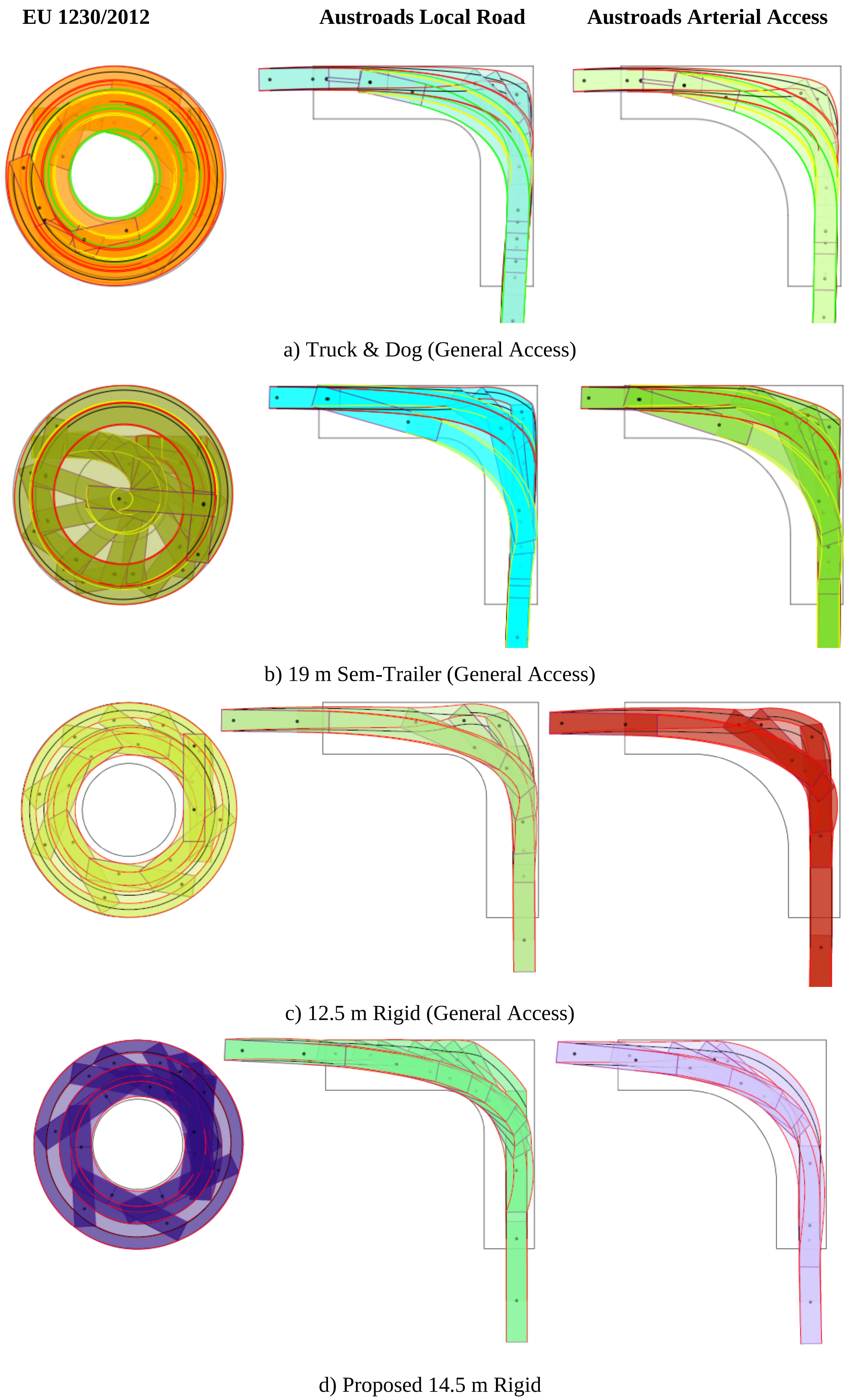

Figure 3 EU Manoeuvrability and Austroads Turning Path Comparison

5 Field Testing and Operating Studies

Field testing involved the prescribed PBS LSSP test and general navigation (free roam around tight intersections with usual traffic scenarios). LiDAR's, drones, and cameras was used to collect qualitative and quantitative data, refer to Figure 4.

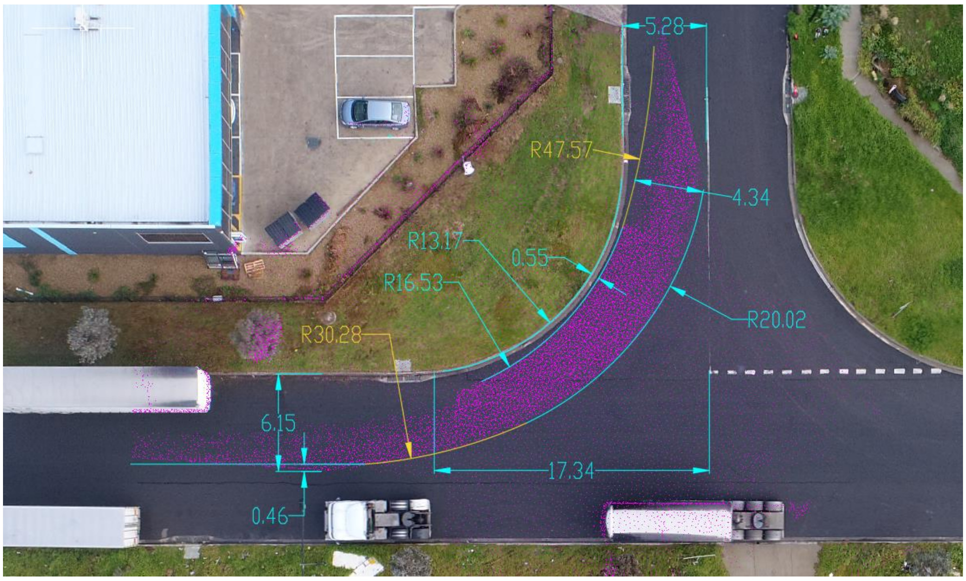

Figure 4 Dynamic LiDAR Scan of FS, LSSP and TS

5.1 On Road Operating Studies

Turning characteristics of the vehicle were observed while the vehicle travels through the test area near Daimler Laverton, VIC, Australia. Intersections of interest were encircled, and test data was collected using LiDAR, GoPro and Drone footage. Driver behaviour was accounted for while performing on road tests and the driver was not instructed on how to make the turn while driving the vehicle. The subject vehicle was also compared with other combination such as B-doubles and semi-trailers on certain intersections, refer to Figure 5.

Figure 5 Concrete Pump (left) vs Semi-Trailer (right) on roundabout

Each scenario described in Section 3.3 (Road Safety Risks) was tested (if possible) in the field. The risk assessment matrix (Government, 2018) was then with collected qualitative data to determine the risk index, refer to Table 5.

Table 5 Operating Studies Risk Assessment Summary

Scenario	Risk Index
Scenario 1 – Right turn from an Urban Median	Medium
Scenario 2 – Protected Bicycle Lane	Restricted Access
Scenario 3 – Unprotected Bicycle Lane	Restricted Access
Scenario 4 – Left turn on single lane urban streets	Low
Scenario 5 – Left Turn on multilane urban streets	Low
Scenario 6 – Left turn on single lane roads without median	Low
Scenario 7 – Right turn with an adjacent straight path lane	Low
Scenario 8 – Two adjacent right turn lanes - no lane straddling	Low
Scenario 9 – Two adjacent right turn lanes - lane straddling	Not required
Scenario 10 – Busy Urban Hook Turns	Restricted Access
Scenario 11 – Right turn on single lane roads without median	Low
Scenario 12 – Traversing through tight roundabouts	Low

From Table 4, most everyday scenarios have a low risk of an incident happening with median turning lanes showcasing medium risk depending on the width of the lane. Further, other observations which could decrease risks were:

- Even though there is slight encroachment required in certain scenarios to turn safely, the driver can account for other road users, patiently wait for a safe gap, and negotiate with other drivers to turn safely.
- Driver training and properly visible signage on the vehicle can be used to mitigate all risks. Training modules focusing on best practices in certain scenarios and coordinating with other drivers on will prove useful in reducing any incidents.
- Large vehicle may be required to be fitted with 360° cameras to aid in driver vision of all corners if travelling on very tight urban streets.

6 Proposed alternative turning performance standard

This research is proposing an alternative turning performance standard based on the EU doughnut test which will facilitate better vehicle manoeuvrability without increased road space requirements. Various alternatives standards have been considered which would preserve the purpose and intent of the PBS Level 1 standards, whilst offering more flexibility for rigid trucks, the possibility of better vehicle designs and optimised for low-speed manoeuvrability.

The preferred option allows alternative PBS Level 1 limits for LSSP and TS, refer to Table 6.

Error! Reference source not found.Table 6 Proposed new PBS Performance Requirements

Performance Standards Class	Option	Performance Level Required		
		Tail Swing	Low Speed Swept Path	Turn Radius
Level 1	(I)	No greater than 0.3 m	No greater than 7.4 m	12.5 m
	OR			
	(II)	No greater than 0.8 m	No greater than 5.4 m	12.5 m
Level 2	(I)	No greater than 0.35 m	No greater than 8.7 m	12.5 m
	OR			
	(II)	No greater than 1.0 m	No greater than 6.0 m	15 m

This strategy only works if the vehicle has significantly lower LSSP. Based on our analysis a reduction of the level 1 swept path requirement of 2 m is appropriate for an additional 0.5 m of TS. This corresponds to a proposed alternative LSSP Limit of 0.8 m provided that the vehicle has an ADR compliant turn radius of less than 12.5 m and a LSSP of no greater than 5.4 m. For very large vehicles which are not able to meet the PBS Level 1 performance requirements. We propose an alternatives PBS Level 2 performance standard which will correspond to PBS Level 2 network access. The main purpose of this is to allow a larger 15 m turn radius, the limits could perhaps be higher based on current PBS Level 2 limits. The proposed limits are based on the fleet assessment which showed that all vehicles which could meet the 15 m turn radius would have a LSSP of less than 6.0 m. The essence of this option retains the existing PBS test conditions but allow an increased PBS Level 1 TS provided LSSP is correspondingly reduced. This ensures the primary purpose and intent of limiting the required road space during a turn is preserved.

In addition, many larger concrete pumps do not meet the 25 m ADR turning circle requirement. Consequently, they cannot pass the PBS Level 1 swept path test as the turning radius is 12.5 m measured to the outermost edge of the outermost steer tyre. A vehicle that does not meet this requirement cannot pass this test condition – a larger turning radius is required. There needs to be an appropriate trade-off between TS and LSSP limits. Our Fleet analysis indicates that with the current standards only 11% of vehicles pass the current PBS Level 1 requirements. However, our operating analysis shows that even the worst-case concrete pump with excessive Rear Overhang and non-compliant turning circle, requires less road space compared to prescriptive semi-trailers. Further, our testing shows that despite not being able to meet ADR turning circle requirements a large concrete pump can safely negotiate a 90-degree turn. It does so by initiating the turn earlier and taking advantage of the fact that it has less swept path width, see **Error! Reference source not found.**. Where a semi-trailer of similar rigid body length requires the prime mover to turn late into the corner with a tighter turn radius, the concrete pump can “cut the corner” and negotiate the turn as efficiently.

By doing so the TS is reduced because the turn radius is larger, but it also means that the concrete pump can initiate the turn with a lateral position closer to the direction of the turn and thereby reducing the risks associated with TS.

7 References

- Americal Concrete Pumping Association. (2011). Cerified Operator Study Guide. Americal Concrete Pumping Association.
- ARTSA. (2003). PBS Explained Performance Based Standards for Road Transport Vehicles. Melbourne: ARTSA.
- Australian Government - Department of Infrastructure, Transport, Regional Development and Communications. (2021, June). Importing a Special Purpose Vehicle under the RVS legislation (interim arrangements). Canberra, ACT, Australia: Department of Infrastructure, Transport, Regional Development and Communications.
- Austroads. (2021). Guide to Road Design Part 3. Sydney: Austroads.
- Commonwealth of Australia. (2021). National Class 1 Special Purpose Vehicle Mass and Dimension Exemption Notice. Canberra: Commenwealth of Australia.
- European Parliament. (2012). Commission regulation (EU) No 1230/2012. European Parliament.
- European Parliament. (2012). Commission regulation (EU) No 1230/2012. European Parlieament.
- Government, N. (2018). WHS Risk Management - Roads and Maritime Services procedures governing the management of work health and safety risks.
- Health and Safety Authority. (2018). guidance on Safety in Concrete Pumping. Dublin: Health and Safety Authority.
- Ministry of Business, innovation and Employment. (2013). Concrete Pumping Health and Safety Guidelines. Wellington: Concrete Pumping Association of New Zealand.
- Ministry of Transport of the People's republic of China. (2019). Standards on Weights, dimensions and emissions of commercial vehicle in China. Tbilisi: Ministry of Transport of the People's republic of China.
- National Road Transport Commision. (2000). Specification of Performance Standards and Performance of the Heavy Vehicle Fleet. Melbourne: NRTC/Austroads.
- National Road Transport Commission. (2002, February). Perforamnce Characteristics of the Australian Heavy Vehicle Fleet (Performance Based Standards - NRTC/Austroads Project A3 and A4), Working Paper - February 2002. Melbourne, Victoria, Australia: National Road Transport Commission.
- National Transport Commission. (2008). Performance-Based Standards Scheme - Network Classification Guidelines. Brisbane: NTC.
- National Transport Commission. (2020, January). Performance-Based Standards Scheme – the Standards and Vehicle Assessment Rules. Melbourne, Victoria, Australia: NTC.
- Road Bureau Ministry of Land, Infrastructure, Transport and Tourism. (2018). Roads in Japan. Road Bureau Ministry of Land, Infrastructure, Transport and Tourism.
- U.S. Department of Transportation Federal Highway Administration. (2004). Federal Size regulations for Commercial Motor Vehicles. Washington: The Federal Highway Administration.
- Vehicle Safety Standards, D. o. (2016). Australian Design Rule 43/04 – Vehicle Configuration and Dimensions 2006 Compilation 3. Canberra: Commonwealth of Australia.
- Vehicle Safety Standards, Department of Infrastructure and Regional Development, Australian Design Rule 43/04 – Vehicle Configuration and Dimensions 2006, Compilation 3, 27/04/2016