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A REVIEW OF THE EFFECT OF INCREASES IN VEHICLE SIZE ON AUSTRALIAN GEOMETRIC ROAD DESIGN STANDARDS

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ABSTRACT

This paper presents a review by the Queensland Department of Main Roads of the suitability of current Geometric Road Design standards for the vehicles which are currently in use on Australian roads. It reviews standards which relate both directly and indirectly to vehicle swept path and presents, for the record, any underlying principles and assumptions associated with the standards.

Swept paths for a range of turning conditions and a range of heavy vehicles (8.8m Service Vehicle, 12.5m Rigid truck/bus, 19m articulated vehicle/semi-trailer, 25m B-double, Type 1 Road Train, Type 2 Road Train) were generated by the Main Roads VPATH program. These were used to check current standards for deficiencies in terms of the class of vehicle on which they were originally based and in terms of other (larger) vehicles. In some cases, there may now be a need to use a larger class of vehicle (e.g. an articulated vehicle instead of a rigid truck for curve widening standards) or different standards (based on relevant vehicles) will be needed for different roads. Traffic data collected by Main Roads has been used to verify this approach.

Standards relating to curve widening and turning roadway widths were found to be deficient because of the increases in size of the vehicles upon which they were based. Furthermore, the scope for accommodating larger classes of vehicle has been reduced to the extent that larger vehicles unduly compromise traffic flow.

INTRODUCTION

Geometric road design standards cover a wide range of issues such as choice of horizontal and vertical curve size, traffic lane width, angles of intersection of roadways, overtaking provision, etc. However, all geometric road design standards have some underlying basis of vehicle dynamics, vehicle size, driver characteristics or some combination of these.

Vehicle size has an obvious impact on traffic lane width and clearance to vertical obstructions. As far as maximum vehicle width and maximum vehicle height is concerned, these have been static in Australia for more than 25 years although recognition has been given to the need for some roads to cater for special vehicles with increased width and/or height. Increases in vehicle length lead to increases in the time needed for a heavy vehicle to clear an intersection and have an impact on the time needed to overtake a heavy vehicle. Less obvious is the link between vehicle length and vehicle swept path.

The swept path of a vehicle is the area of ground swept by all parts of the vehicle as it moves along the road. More importantly, swept path width increases when a vehicle is on a horizontal curve because the rear wheels offtrack with respect to the front wheels of the vehicle. At low speeds or when there is a low side friction demand by the vehicle in making the turn, the offtracking will be towards the centre of the curve (AASHO 1965). This is commonly called low speed offtracking. At high speeds and when there is a high side friction demand by the vehicle in making the turn, the offtracking will be outwards from the centre of the curve. This is commonly called high speed offtracking (Sweatman 1993). Low speed offtracking increases exponentially with increases in horizontal curvature (curvature = 1/R) and an increase in the wheelbase of a vehicle unit leads to an increase in swept path width for a given curve radius.

Standards which are directly related to swept path are:

- Lane Width.
- Curve widening.
- Method of applying curve widening.
- Turning roadway (left turn slip lane) widths.
- Turning roadway geometry, in particular the ratios used for the curves which make up the 3 centred curves on the inside of the turning roadway.
- Roundabout geometry.
- Median Openings.
- Driveway entrances to properties.
- Vehicle turning templates.

Standards which are indirectly related to swept path are:

- Application of superelevation because traditionally, the application of curve widening has been tied to this.
- Aspects of roundabout geometry which control the path steered by the drivers of heavy vehicles.

It is these standards which are based either directly or indirectly on vehicle swept path which are the main focus of this paper. The primary geometric road design standards that are used in Australia are documented in the following manuals:

- Rural Road Design - Guide to the Geometric Design of Rural Roads (Austroads 1989).

- Part 5, Intersections at Grade, of the Austroads Guide to Traffic Engineering Practice (Austroads 1988).
- Part 6, Roundabouts, of the Austroads Guide to Traffic Engineering Practice (Austroads 1993).

In turn, many of the Austroads standards which relate to swept path are based on principles that are documented in the AASHTO Policy on Geometric Design of Highways and Streets (AASHTO 1994) and which were documented in the 1954 version of the publication (AASHO 1954). In addition to the Austroads manuals, some Australian State road authorities have maintained at times their own manuals in order to address certain local requirements, provide additional detail, or provide more specific guidelines or directions with respect to options in the Austroads manuals. A current example is the Victorian suite of guidelines (VicRoads 1996).

DESIGN VEHICLES

Austroads (formerly NAASRA) has had design vehicles and associated turning templates since 1965 (NAASRA 1965). Initially, the design vehicles were:

- Design Car (5.18m)
- Design Single Unit Truck (10.06m)
- Design Semi-Trailer (13.72m)

Throughout this paper, the term semi-trailer is used to refer to the combination of the prime mover and semi-trailer for compatibility with the terminology used by Austroads and AASHTO.

In 1974 the semi-trailer was increased to 14.4m and the single unit truck was increased to 10.97m.

In 1984 the semi-trailer was increased to 17m.

In 1986 the semi-trailer was increased to 17.5m, the single unit truck became an 11m single unit truck / bus with revised component dimensions and a 12.2m Inter City Bus was added. Useful guidelines on the choice of design vehicle and in the use of turning templates were introduced (NAASRA 1986).

In 1993, the design car was reduced in size to 5.0m to reflect the increasing proportion of smaller vehicles in Australia, the semi-trailer was increased to 19.0m and the single unit truck / bus was increased to 12.5m.

Also in 1993, Austroads/SAA introduced additional design vehicles to cover special applications, namely:

- Service Vehicle (8.8m)
- Long Rigid Bus (14.5m)
- Articulated Bus (19.0m)
- Long Semi-Trailer (25m)
- Type 1 (Double) Road Train (36.0m)
- Type 2 (Triple) Road Train (53.0m)
- B-Double (25.0m)

From the outset, each design vehicle was intended to be an 85th percentile vehicle by being equal to or larger than 85% of the vehicles of that type in use on Australian roads. In 1986, the single unit truck / bus and semi-trailer were changed to match the legal maximum size permitted in most states. This was done to reflect the rapid uptake of increases in vehicle size when dimensional limits were increased – in particular, with semi-trailers.

With the exception of the design car and the service vehicle, the 1993 design vehicles reflect the maximum sizes permitted by national vehicle regulations which were introduced at that time.

TURNING TEMPLATES

Turning templates for the respective design vehicles have been provided by Austroads for the purpose of checking turns at intersections, driveway crossings and even off-street manoeuvres. Originally these templates were produced by conducting field tests on actual vehicles but since 1974, were generated by computer modeling. The Austroads templates have always been for circular turns in the forward direction, with the vehicle lined up initially on the entrance tangent to the curve. Such turns are characteristic of the turns made by vehicles at intersections but are not characteristic of the turns made by vehicles pulling out of a parking space (or bus stop) where initial lock is applied while the vehicle is stopped.

For each design vehicle, the templates have been produced for a limited range of steering path radii and scales. The minimum steering path radius used for each design vehicle is representative of the minimum radius likely to be used by that type of vehicle when operating on the road network. For the design truck/bus, the minimum steering path radius of 12.5m is very close to the minimum possible for that vehicle.

In 1989, a limited range of templates for the reversing of vehicles into loading docks was included in AS2890.2, Off-street parking, Commercial vehicle facilities. This includes a template for a semi-trailer (articulated vehicle). The vehicles in AS2890.2 are different to the Austroads design vehicles of the time but the standard is currently being revised and will use the current Austroads/SAA design vehicles.

With both the Austroads/SAA templates and the AS2890.2 reversing templates it is necessary to provide clearances outside of the swept path lines when using the templates. Besides providing operational clearances to obstructions and other vehicles, the clearances give some provision for steering variations by drivers, especially for large commercial vehicles, and they give some scope for future increases in vehicle size. Austroads recommends clearances should not be less than 0.6m each side.

LANE WIDTH

Traffic lanes have to accommodate the operation of 2.5m wide vehicles. The main factors governing the choice of lane width are traffic volume, traffic composition and operating speeds. For two-lane two-way roads, lane widths as narrow as 3.0m may be used on low volume roads (Austroads 1989). The desirable lane width on rural roads however, is 3.5m which allows large vehicles to pass or overtake without having to move sideways towards the outer edge of the road. The notes in Table 4.1 in Austroads 1989 further promote the use of 3.5m lanes when design traffic volumes indicate that 3.0m lanes are acceptable.

Given that road train operation is usually restricted to roads with low traffic volumes where only a single 3.5m lane or two 3.0m lanes would normally be justified, the question arises as to whether a 3.0m lane width is suitable for road train operation.
Studies in Western Australia during the 1970’s found that Type 1 road trains were capable of tracking wholly within a 3.0m lane (Widdup 197?) but had an effective increase in width of 0.2m even when travelling on a straight. This is due to a combination of vehicle misalignment, crossfall and a natural tendency to “snake”, even when the vehicle is in good mechanical condition. More recent studies have shown that the effect of high speed offtracking due to a 3% crossfall can be 0.2m (Sweatman 1993) and potholes and pavement deformation can cause even greater deviations in tracking. It is these tracking characteristics that have led to the use of 3.4m as a minimum lane width for road train operation in Queensland.

CURVE WIDENING

On smaller radius horizontal curves, traffic lanes may need to be widened in order to maintain the lateral clearances that apply to vehicles on straight sections of road. This is due to the following vehicle and driver characteristics:

- The rear wheels of a vehicle offtrack with respect to the front wheels on a curve and this also causes the front overhang of a vehicle to have a lateral component. The low speed offtracking (or offtracking when vehicles have a low side friction demand) together with the lateral front overhang component is shown in both tabular and graphical forms for each of the current design vehicles in **Appendix 1**.
- Vehicles deviate more from the centreline of a lane when on a curve.

The amount of widening per lane depends on:

- The radius of the curve
- Type (size) of vehicle operating on the road.
- Some allowance for steering variation by different drivers.

However, there is a lower practical limit to widening and for a two-lane road, curve widening would be omitted when the total widening is less than 0.5m. The current Austroads standard for curve widening is based on the requirements for a single unit truck. This can be traced back through earlier editions of Austroads 1989 and to AASHO 1954. The use of the single unit truck instead of the semi-trailer combination was based on the much higher incidence of the former at the time, ease of calculating offtracking, and the fact that for curve radii above 120m, the difference in offtracking was insignificant. These days, the incidence of semi-trailer (and other articulated vehicle) combinations is much higher. Table 1 shows the current level of operation on a range of roads in Queensland. Given that the percentage of semi-trailer combinations exceeds the percentage of single unit trucks on most highways, curve widening based on the design semi-trailer is now more appropriate for highways which are not B-Double or road train routes. AASHTO (1994) recognises that extra curve widening is necessary when "semi-trailer volumes are significant". Victorian practice is to base curve widening on the Austroads 19m semi-trailer or in special cases, the Austroads 25m semi-trailer. Since 1972, it has been Queensland practice to provide curve widening based on the appropriate type of road train on road train routes. It should also be noted that Austroads does not preclude the provision of curve widening based on the type of heavy vehicle that is allowed to operate on a given section of road.

Table 1. Level of Articulated Vehicle versus Single Unit Truck Operation in Queensland

	State Highways	Other Roads
No of sites	105	189
No sites where Artic > SU	60	30
Max. Artic : SU	6.9:1	5.6:1
Min. Artic : SU	0.32:1	0.05:1
Overall % SU	5.9	5.2
Overall % Artic	5.9	2.1
Max % SU	28.7	33.5
Max % Artic	42	38.4
No sites where SU > 10%	25	36
No sites where Artic > 10%	42	23
No sites where SU > 8%	55	54
No sites where Artic > 8%	61	31
No sites where SU > 6%	75	105
No sites where Artic > 6%	79	38
No sites where SU > 4%	94	151
No sites where Artic > 4%	95	58

Source: Compiled from 1995 Traffic Data collected by Main Roads classified counters.

Figure 1 shows the road width components when two vehicles are passing on a horizontal curve (AASHTO 1994). These components are:

- Horizontal clearances. For lane widths (on straight) less than 3.5m, these are the same as on straights.
- Track width, being greater on the curve due to offtracking of the rear wheels.
- Horizontal component of the front overhang of the vehicle; inside lane only.
- A steering allowance for difficulty of driving on curves.

Of the four components, it is the steering allowance which is most contentious. AASHTO and prior to 1979, NAASRA, used this component when determining curve widening requirements and also the width of turning roadways at intersections. The steering allowance is determined by an empirical formula ($Z_m = V_{km/h}/10/\sqrt{R_m}$) and the basis of the formula is not known. There is no allowance for different vehicle types. For road applications, the formula yields a practical maximum value of 0.6m for curves with a combined side friction plus superelevation value of 0.3. Such cases only occur with turning roadways at intersections. However, the formula still yields a value of 0.41m for curves with a combined side friction plus superelevation value of 0.13, but in practice, many such curves are built without widening. For 7.4m wide roads (2 x 3.6m lanes) AASHTO adopts a horizontal clearance value of 0.9m per lane on curves versus a value of 1.1m on straights to help cancel out the steering allowance on "larger" curves for a given speed. Similarly, Victorian practice adopts the AASHTO steering allowance component and adopts a horizontal clearance value of 0.6m per lane (VicRoads 1996). Given the questionable soundness of the formula for the steering allowance component and the fact that Austroads has not used it for determining curve widening since 1979 and for determining turning roadway widths since 1986, the curve widening values in Table 2 do not include a steering allowance component. The front overhang component is however, incorporated into the widening for both lanes on a two-lane, two way road rather than just the inner lane.

It is also now reasonable to argue that the use of partially sealed shoulders (and more recently, fully sealed shoulders) is a viable compensation for dropping the steering allowance component. Indeed, current Victorian practice is to limit curve widening to 0.5m per lane and achieve the necessary sealed width for smaller radius curves via full depth paved and sealed shoulders. This is because cars start to form two lanes within a wide single lane. In contrast, Austroads (1988, 1993) considers that unwanted two lane operation only starts to occur with lanes greater than 4.6m width when traffic flows are greater than 1000 vehicles/hour and this width approaches 10m in the case of a circulating roadway of a roundabout.

Table 2 lists the curve widening requirements for semi-trailer, B-double and road train operation. The table lists the widening per lane with the need for widening ceasing when the widening is less than 0.25m (to fit the minimum practical widening for a two lane road of 0.5m).

Table 2. Curve Widening per Lane for Current Design Vehicles, m

Radius m	SU Truck/Bus	Semi-trailer	B-double	Type 1 Road Train	Type 2 Road Train
30	Use				
40	1.03				
50	0.82		Turning		
60	0.71	1.27			
70	0.59	1.03	1.31		
80	0.52	0.91	1.16	1.62	Templates
90	0.46	0.81	1.03	1.44	
100	0.41	0.71	0.90	1.26	1.80
120	0.36	0.63	0.80	1.13	1.61
140	0.32	0.56	0.71	1.00	1.43
160	0.28	0.49	0.62	0.87	1.25
180	0.24	0.42	0.53	0.74	1.07
200		0.35	0.45	0.62	0.89
250		0.29	0.37	0.51	0.74
300		0.23	0.30	0.41	0.59
350			0.26	0.35	0.51
400			0.22	0.30	0.44
450				0.27	0.39
500				0.25	0.35
600				0.21	0.30
700					0.25
800					0.22

Need for using Turning Templates determined by variation in widening due to angle of turn.
Need for curve widening ceases when widening per lane < 0.25m

APPLICATION OF CURVE WIDENING

It has always been AASHTO and Austroads practice to apply curve widening by tapering over the length of the roadway used for the development of superelevation. This is actually the length where the outer lane goes from level to full superelevation. In the case of a transitioned curve, the superelevation development corresponds with the plan transition. In the case of an untransitioned curve, it is applied equidistant about the tangent point of the horizontal curve and approximates the length that drivers use to make their own transition when entering or leaving an untransitioned horizontal curve. The theoretical basis for the uniform application of the superelevation along the length of the transition is that when combined with the uniform increase in curvature provided by the clothoid spiral transition, there will be a uniform attainment of the side friction demand that will be used on the horizontal curve.

The basis for tieing the application of curve widening to the development of superelevation is largely one of convenience and that the changing curvature over the transitioned path has some correspondence to the change in swept path width, and hence the change in lane width. Most importantly, this had been found to work in practice.

For transitioned curves, it is normal practice to apply half of the curve widening to each side of the road. However this means that the shift associated with the transition (shift = $L^2/24/R$ approx.) must be greater than the curve widening that is applied to the outer side of the curve so that design vehicle will make use of the widening and for appearance. This will usually only be a problem when the curve widening has to suit a road train and a greater proportion of the total widening will have to be applied on the inside of the curve. The painted centreline will then be offset from the control line in order to provide equal lane widths.

For untransitioned curves, it is normal practice to apply all of the curve widening to the inside of the curve with the painted centreline then being offset from the control line in order to provide equal lane widths. This practice aids drivers in making their own transition.

Given the significant increase in length of vehicles since these practices for applying curve widening were established, a range of cases were checked to see if the vehicle swept paths could be accommodated satisfactorily; in particular for B-double and road train operation. These swept paths were generated by the Main Roads VPATH program. The cases which were checked are listed in Table 3. All cases confirmed that the current practices for applying curve widening are still suitable, both for entering and leaving the curve and for both directions of travel.

Table 3. Cases Checked for Application of Curve Widening

Radius, m	Transition Length, m	Application Length, m	Vehicle
150	20	20	Semi-trailer
150	0	20	Semi-trailer
150	40	40	Semi-trailer
150	0	40	Semi-trailer
200	30	30	Semi-trailer
200	30	30	Type 2 Rd Train
200	0	30	Semi-trailer
200	0	30	Type 2 Rd Train
300	50	50	Semi-trailer
300	50	50	Type 2 Rd Train
300	0	50	Semi-trailer
300	0	50	Type 2 Rd Train
400	50	50	Semi-trailer
400	50	50	Type 2 Rd Train
400	0	50	Semi-trailer
400	0	50	Type 2 Rd Train

LEFT TURN SLIP LANES

Left turn treatments at intersections can take the form of simple left turns, (with or without tapers), auxiliary left turn lanes and left turn slip lanes. With the first two forms, larger vehicles may have to encroach into adjoining lanes on the approach and/or departure side when only a small corner radius is provided. Left turn slip lanes are separated from the through lanes at an intersection by a corner island. Left turn slip lanes are provide in order to minimise delays to left turning vehicles, to provide better turn geometry and to separate turning vehicles from through vehicles so that delays to through vehicles are reduced (Austroads 1988). Left turn slip lanes can take two forms:

- The free flow left turn slip lane which has been in use for more than 40 years and can be traced back to NAASRA 1965 and AASHO 1954. Prior to 1988, these were called turning roadways in Australia. The main features of the free flow left turn slip lane is that their geometry is based on the tracking characteristics of large turning vehicles and that they aim to reduce relative speeds for the diverging and merging operations.

- The high entry angle left turn slip lane which is a more recent development for improving safety when there are high traffic flows. In cases of high traffic flow, turning vehicles will usually be forced to stop because there is not a sufficient gap for merging into the traffic stream and there will be loss of relative speed advantage for the merge. The high entry angle provides improved visibility for gap acceptance.

With respect to heavy vehicle operation, the high entry angle left turn will force semi-trailers and even large single unit trucks and buses to turn into the traffic lane adjoining the left hand traffic lane unless they can make use of a sealed shoulder on the road being turned into (see **Figure 2**). However, the sealed shoulder can lead to cars cutting the corner and losing the advantage of improved visibility for gap acceptance. High entry angle turns will always have to be designed with the aid of vehicle swept path plots unless heavy vehicle operation is to be excluded.

The free flow left turn is characterised by the use of a three centred curve for the inside edge of the turning roadway. The shift associated with the middle curve and the ratios of the other two curve radii to the middle curve radius are intended to make the inside edge of the turning roadway match the tracking characteristics of the turning vehicles.

With respect to heavy vehicle operation, the free flow left turn slip lane was originally intended to allow semi-trailer operation by virtue of the turning roadway widths and the three centre curve geometry (NAASRA 1965). This was confirmed by checking several cases after generating swept paths for the design vehicles of that time. The design principles used by NAASRA were the same as those used by AASHO (1954), including the steering allowance component; although AASHO did also show cases where the steering allowance was omitted when the volume and speed of heavy vehicles was low. The lane widths shown in AUSTROADS 1988 are simply metric equivalents of the 1965 widths with no allowance for the change in design vehicles. The shift values associated with the three centred curves have also been omitted. However AUSTROADS 1988 also recommends that turning templates be used to design any turn with a radius of 30m or less and most Australian road authorities have made use of swept path programs such as VPATH for at least the last 10 years to design left turn slip lanes to suit current vehicle sizes. This even includes cases where certain heavy vehicle operation (e.g. Semi-trailer) is specifically excluded or discouraged.

Table 4 shows the turning roadway widths and shifts associated with the three centred curves for current design vehicles. These are intended primarily as a starting point for layout design and all turns should be checked by generating specific swept path plots for each turn. Where larger vehicle types are to be discouraged, checks should still be made to see what problems may occur with them. The widths in Table 4 are compiled from the tables and graphs in Appendix 1. The widths are based on a 90 degree turn and are equal to the maximum swept path width (including the front overhang component) plus 0.6m clearance each side of the swept path. This is different to Austroads (1988) which applies the clearance to the wheel paths (at least with single lane operation), because the front overhang component of the current design vehicles on small radius curves is much larger than 0.6m and there is no longer any additional steering allowance.

Table 4. Widths of Free Flow Left Turn Slip Lanes

Inner		One Lane Operation			Two Lane Operation	
Kerb		Service	SU Truck/	Semi-	Car/Car	Service Tk/
Radius,m	Shift	Truck	Bus	Trailer		Service Tk
12	2.0	5.0	6.1	7.5	6.8	9.8
14	1.9	4.9	5.9	7.2	6.7	9.5
16	1.8	4.8	5.7	7.0	6.6	9.4
18	1.7	4.7	5.6	6.8	6.5	9.2
20	1.6	4.6	5.4	6.6	6.5	9.1
22	1.5	4.5	5.3	6.4	6.4	9.0
24	1.4	4.5	5.2	6.2	6.4	8.8
26	1.3	4.4	5.1	6.1	6.4	8.8
28	1.2	4.4	5.0	5.9	6.3	8.7
30	1.1	4.3	4.9	5.8	6.3	8.6
45	0.9	4.1	4.5	5.2	6.2	8.2
60	0.9	4.0	4.4	4.8	6.1	8.1
90	0.8	3.9	4.1	4.5	6.0	7.8
120	0.7	3.9	4.0	4.3	6.0	7.7
150	0.7	3.8	4.0	4.2	6.0	7.7

Table 4 does not include the case of allowing for a vehicle to pass another stalled vehicle. This is because of the somewhat unrealistic tracking assumed for the stalled vehicle (AASHTO 1994) and that the provision of a sealed and paved shoulder of 1.5m to 2.0m width would be more consistent with current construction practice; even in rural areas. For the stalled vehicle, it has been assumed that the vehicle has been able to pull over to the inner kerb but maintains offtracking as though it was then continuing to travel around the curve. The assumption that vehicles passing the stalled vehicle would do so with reduced clearances is realistic and has been observed in practice and is equally relevant for passing a vehicle stopped on a shoulder.

Turns to suit B-double and road train operation should always be designed with the aid of specific swept path plots so that the shape of the turning lane properly matches the vehicle swept path.

The shape of turns designed to suit a particular vehicle type always suits smaller vehicles which have the scope to take a path with a with a higher standard of curvature (see **Figure 3**). The biggest problem is the possibility of two lane operation or overtaking occurring with cars. Table 4 shows that the width of turns with an inner curve radius less than or equal to 22m and designed for semi-trailer operation is greater than the width required for full two lane operation by cars.

Given that the design semi-trailer has significantly increased in size since the Austroads turning roadway widths were developed in 1965, the question of how the current 19m semi-trailer has been able to operate without significant road user complaints needs to be addressed. This can be answered by looking at the widths needed for turns with an inner radius of 12m and 14m, the two worst cases. With these turns, the 19m semi-trailer can still just fit with 0.1m clearance each side and with the vehicle impeding traffic flow as the driver has to very carefully position the vehicle in the lane. Also, the vehicle has to encroach further into adjoining lanes when entering and exiting the turn (see **Figure 4**). This means that the increases in vehicle size have been accommodated by the lateral clearances and steering allowance component that were originally used, but these margins have now been used up. It is now necessary to ensure that turning roadways are designed to properly accommodate current vehicles so that vehicle speeds are not unnecessarily restricted and to provide some scope of accommodating future increases in vehicle size.

ROUNDABOUTS

Roundabouts provide a now common form of intersection control in Australia. They perform better at the intersection of roads with roughly similar traffic flows and a high proportion of right turning traffic. Roundabouts can improve safety by simplifying conflicts, reducing vehicle speeds and providing a clearer indication of the driver’s right of way compared to other forms of channelisation (Austroads 1993). In Queensland, there are even some roundabouts designed for B-double and road train operation.

Given that some roundabouts at local street intersections have been designed to discourage heavy vehicle operation, roundabouts are normally designed for semi-trailer operation on arterial roads and single unit / truck bus operation on collector roads (Austroads 1993).

The geometric design procedure in Austroads 1993 stipulates that all turning movements should be checked by turning templates or, preferably, specific swept path plots for each turning movement. The table of widths for the circulating roadway is intended as a starting point only and it is this table which needs updating since some of the widths are based on the Austroads widths for free flow left turn lanes and hence, are not based on current design vehicles. Because of the range of turning angles, types of design vehicle and the possibility of 1, 2 or 3 lane circulating roadways, it is probably better to derive “first pass” circulating roadway widths from the offtracking graphs in Appendix 1 rather than work from a table that covers a more limited range of conditions.

In order to accommodate current design vehicles, including B-doubles and road trains, and to eliminate the need to check and refine the layout, the Roads and Traffic Authority of New South Wales has developed a geometric design procedure for roundabouts (RTA 1996). This procedure incorporates desirable steering path characteristics for the relevant design vehicle and tracking characteristics for the vehicle.

Equally important to the geometry of a roundabout is the geometry of the approach roadways. This is because the geometry of the approaches is used to control vehicle speeds and to ensure deflection of the vehicle paths in order to reduce the angle between entering and circulating traffic (Austroads 1993). Research leading to the ability to predict and minimise accident frequencies due to roundabout geometry has been carried out by the Queensland Department of Main Roads (Arndt 1995).

The main problem with the design of roundabouts due to increases in commercial vehicle size is that the extra width required to accommodate vehicle offtracking gives cars greater scope to deviate from the intended path for safe operation. Commonly, the need to accommodate larger vehicles leads to a smaller central island and less deflection for cars because it is not feasible to increase the size of the roundabout. This is why some roundabouts are designed so that the occasional large commercial vehicle is able to traverse part of the central island. Also, the width of approaches designed to suit large vehicles allows cars to cut corners and enter the circulating roadway at higher speed.

MEDIAN OPENINGS

It has always been Australian practice to design median openings with the aid of turning templates. This is why there have been figures showing general requirements but no tables of median opening lengths in Austroads standards. In contrast, AASHTO (1965, 1994) gives guidance on acceptable turning manoeuvres for different vehicle types under different conditions and provides tables of median opening lengths based the different vehicle types and median nose treatments.

Given that turns designed for large vehicle types result in longer median openings, there is again the problem as with other geometric design elements of the requirements for the large vehicles being contrary to those needed for optimum operation of cars. In this case, the longer median opening allows a much larger area of conflict to occur at an intersection. Consequently, there is the scope for Austroads standards to provide guidance on how to accommodate different vehicle types. **Figure 5** gives examples of how a larger vehicle can be expected to make a right an intersection that has been designed primarily for a smaller vehicle.

It is also worth making the point that with the current design semi-trailer, there is little to be gained by assuming a 12.5m steering path radius with a 90 degree right turn in constrained conditions. In fact, it will be found that the semi-trailer will be able to take a 15m steering path radius if median openings have been designed about a swept path for a 12.5m steering path. This phenomenon can be readily checked by superimposing two turning templates and also occurs to a lesser extent with the current design single unit truck.

DRIVEWAYS

Driveways provide access between a road and property abutting the road. Until 1989, any standards covering driveways for commercial vehicle operation were a local development. Most road authorities and local authorities developed their own of obtained them from some other authority. In 1989, AS2890.2 which covered parking facilities for commercial vehicles, included standard driveway types. These were based on the turning requirements of vehicles which were similar in size to the Austroads design vehicles of that time. This standard is currently being revised and will include driveway types to suit the current Austroads design vehicles.

CONCLUSION

Over the last 25 years there has been continual pressure by the transport industry to allow increases in the size of various types of vehicle and for the introduction of new types of vehicle (e.g. B-doubles). This can be seen from the evolution of the sizes and types of design vehicles used by Austroads. Underlying this trend has been the productive benefits made possible by the larger and/or newer vehicles. Indeed, Austroads and the National Roads Transport Commission have carried out major studies over this period into all aspects of commercial vehicle operation.

The adoption of new vehicle limits has only been approved after careful study of the effects on the existing road network. With respect to swept path, the changes in vehicle size have been allowed because each incremental change was considered to be a small enough increase over what was currently acceptable; either vehicles had to operate with slightly reduced (but available) clearances, or the driver had to make more skilful and complex steering manoeuvres, often by encroaching into adjoining lanes. Australian road rules were changed over 15 years ago to allow large vehicles to make use of adjoining lanes.

Over this time, computer models for predicting the swept path of turning vehicles became available and for the last 10 years in particular, all Australian road authorities, many local authorities and many consultants have been making use, to varying degrees, of specific swept path plots for the design of turning movements at intersections, interchanges and roundabouts. The offtracking data in Appendix 1 and the turning roadway widths in Table 4 are intended to complement the use of templates for specific turning movements rather than reduce the need for such templates. The tables and graphs aid the selection of a steering path for a specific turning movement.

Besides having to accommodate the increasing size of particular vehicle types, the existing road network has had to accommodate new vehicle types. With vehicles such as the articulated bus, the 14.5m long rigid bus and the stinger mount car carrier, the dimensional components were skillfully designed to ensure that the vehicle offtracking characteristics were no worse than those of existing vehicle types that were operating where these vehicles would be expected to operate. With vehicles such as B-doubles, the dimensional components were designed to provide improved dynamic tracking performance and provide good offtracking performance so that they could operate on restricted routes such as existing highways and arterial roads that had a high geometric standard. All new roadworks on routes where the new vehicle types operated would be expected to be designed to suit those vehicles. This would mainly be at intersections and the need to provide curve widening on some curves where it was not needed previously. The same approach will apply with the likely introduction of vehicles such a B-triples and AB-triples.

Besides increases in the size of particular vehicle types, changes in the type of vehicle in operation on a given section of road can lead to a change in the basis of some geometric design standard. Alternatively, it may lead to an expansion of the standard so that it covers a greater range of cases. Both cases apply with respect to curve widening standards. Semi-trailer operation should now be the base case for highways with provision for B-doubles or road trains being made when these vehicles operate on a particular section of highway. Both cases also apply with turning roadways where tables of standard (or 'starting point') widths must reflect the latest semi-trailer size plus a range of other vehicle types and operating conditions.

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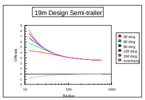
APPENDIX 1- SWEPT PATH WIDTHS FOR DESIGN VEHICLES

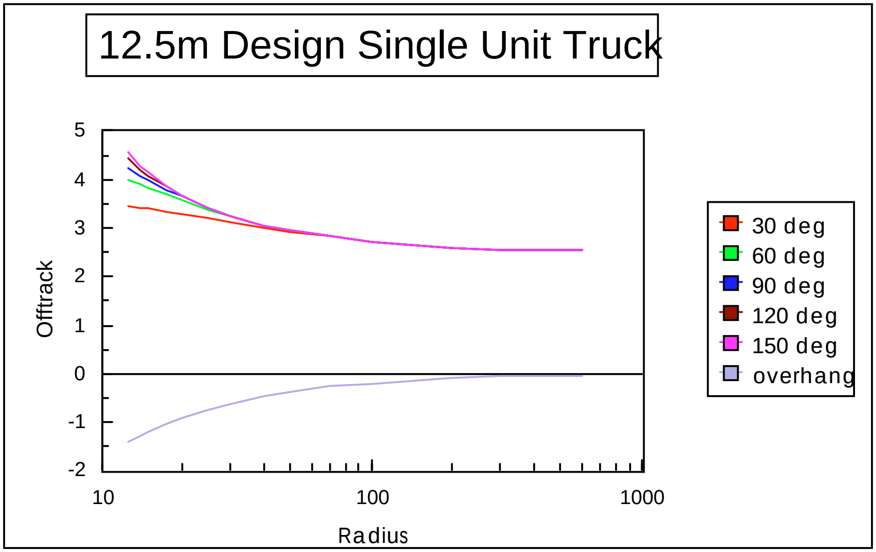
19m Design Semi-trailer (articulated vehicle)

	Front	Rear offtrack for Angle of turn, m				
Radius	Overhang,m	30 deg	60 deg	90 deg	120 deg	150 + deg
12.5	-0.77	4.36	5.74	6.77	7.58	8.22
14	-0.70	4.32	5.59	6.48	7.12	7.58
15	-0.65	4.30	5.50	6.30	6.85	7.21
17.5	-0.55	4.22	5.28	5.90	6.27	6.48
20	-0.48	4.17	5.08	5.56	5.81	5.92
25	-0.39	4.05	4.74	5.02	5.13	5.17
30	-0.32	3.93	4.46	4.62	4.68	4.69
40	-0.24	3.74	4.04	4.09	4.10	4.10
50	-0.20	3.58	3.75	3.76	3.76	3.76
70	-0.14	3.34	3.39	3.39	3.39	3.39
100	-0.10	3.11	3.11	3.11	3.11	3.11
200	-0.05	2.80	2.80	2.80	2.80	2.80
300	-0.03	2.70	2.70	2.70	2.70	2.70
400	-0.02	2.65	2.65	2.65	2.65	2.65
500	-0.02	2.62	2.62	2.62	2.62	2.62
600	-0.02	2.60	2.60	2.60	2.60	2.60



12.5m Design Single Unit Truck

Radius	Front Overhang,m	Rear offtrack for Angle of turn, m 30 deg	60 deg	90 deg	120 deg	150 + deg
12.5	-1.4	3.46	3.99	4.22	4.43	4.57
14	-1.26	3.43	3.89	4.08	4.21	4.29
15	-1.19	3.40	3.83	3.99	4.09	4.14
17.5	-1.03	3.35	3.69	3.80	3.85	3.86
20	-0.91	3.30	3.57	3.65	3.67	3.67
25	-0.74	3.22	3.38	3.42	3.42	3.42
30	-0.62	3.14	3.25	3.26	3.26	3.26
40	-0.47	3.02	3.06	3.06	3.06	3.06
50	-0.37	2.93	2.95	2.95	2.95	2.95
70	-0.27	2.82	2.82	2.82	2.82	2.82
100	-0.19	2.72	2.72	2.72	2.72	2.72
200	-0.09	2.61	2.61	2.61	2.61	2.61
300	-0.06	2.57	2.57	2.57	2.57	2.57
400	-0.05	2.56	2.56	2.56	2.56	2.56
500	-0.04	2.54	2.54	2.54	2.54	2.54
600	-0.03	2.54	2.54	2.54	2.54	2.54



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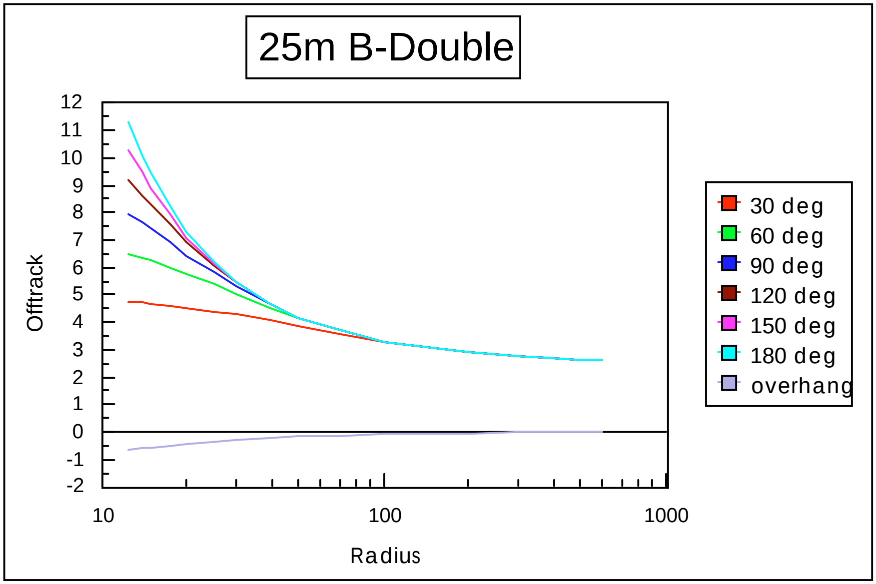
25m B-Double

Radius	Front Overhang,m	Rear offtrack for Angle of turn, m 30 deg	60 deg	90 deg	120 deg	150 deg	180 deg
12.5	-0.67	4.75	6.53	7.98	9.21	10.28	11.30
14	-0.60	4.71	6.36	7.64	8.64	9.45	10.10
15	-0.56	4.68	6.27	7.42	8.30	8.90	9.47
17.5	-0.48	4.61	6.02	6.95	7.56	7.95	8.22
20	-0.42	4.54	5.80	6.45	6.96	7.10	7.33
25	-0.33	4.41	5.40	5.85	6.07	6.16	6.18
30	-0.28	4.29	5.06	5.36	5.44	5.47	5.48
40	-0.21	4.07	4.53	4.64	4.65	4.66	4.66
50	-0.17	3.89	4.17	4.19	4.19	4.19	4.19
70	-0.12	3.60	3.69	3.69	3.69	3.69	3.69
100	-0.08	3.31	3.32	3.32	3.32	3.32	3.32
200	-0.04	2.91	2.91	2.91	2.91	2.91	2.91
300	-0.03	2.77	2.77	2.77	2.77	2.77	2.77
400	-0.02	2.70	2.70	2.70	2.70	2.70	2.70
500	-0.02	2.66	2.66	2.66	2.66	2.66	2.66
600	-0.01	2.64	2.64	2.64	2.64	2.64	2.64



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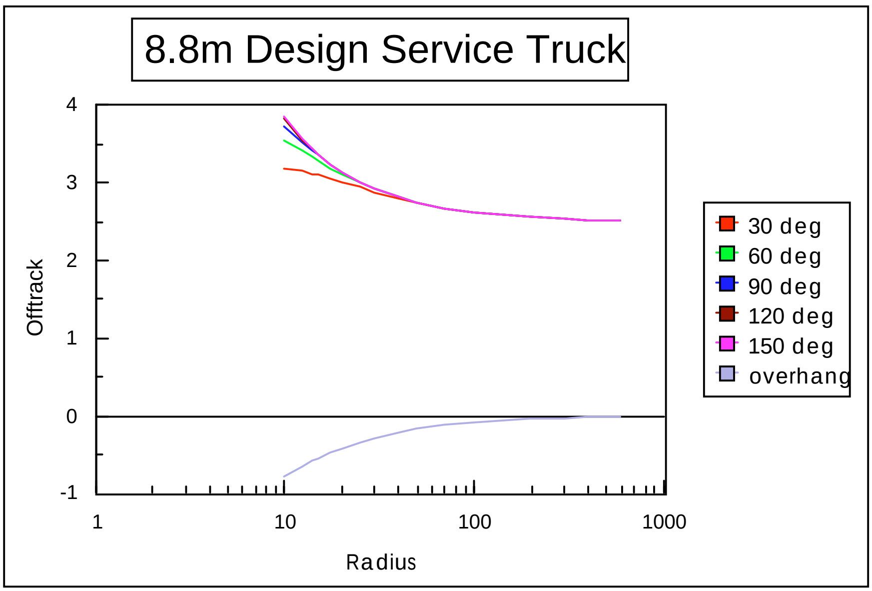
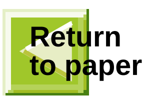
8.8m Design Service Truck / AS2890.2 Medium Rigid Vehicle (MRV)

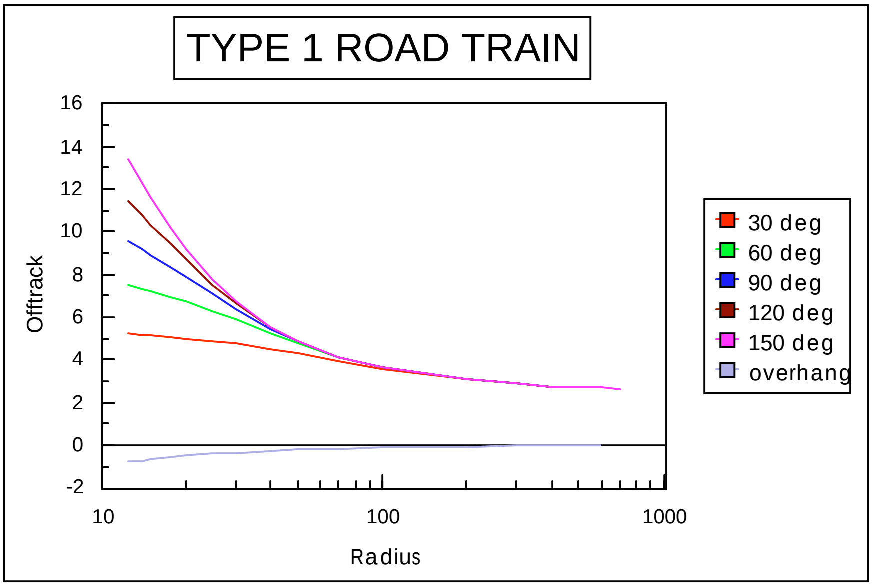
	Front	Rear offtrack for Angle of turn, m				
Radius	Overhang,m	30 deg	60 deg	90 deg	120 deg	150 + deg
10	-0.78	3.20	3.56	3.74	3.82	3.87
12.5	-0.65	3.15	3.42	3.52	3.55	3.57
14	-0.58	3.12	3.34	3.41	3.44	3.44
15	-0.55	3.10	3.30	3.36	3.37	3.37
17.5	-0.47	3.05	3.20	3.23	3.24	3.24
20	-0.42	3.02	3.12	3.14	3.14	3.14
25	-0.34	2.95	3.00	3.01	3.01	3.01
30	-0.28	2.89	2.92	2.92	2.92	2.92
40	-0.21	2.81	2.82	2.82	2.82	2.82
50	-0.17	2.75	2.75	2.75	2.75	2.75
70	-0.12	2.68	2.68	2.68	2.68	2.68
100	-0.09	2.63	2.63	2.63	2.63	2.63
200	-0.04	2.56	2.56	2.56	2.56	2.56
300	-0.03	2.54	2.54	2.54	2.54	2.54
400	-0.02	2.53	2.53	2.53	2.53	2.53
500	-0.02	2.52	2.52	2.52	2.52	2.52
600	-0.01	2.52	2.52	2.52	2.52	2.52





TYPE 1 ROAD TRAIN

Radius	Front Overhang,m	Rear offtrack for Angle of turn, m 30 deg	60 deg	90 deg	120 deg	150 + deg
12.5	-0.77	5.24	7.54	9.56	11.44	13.45
14	-0.70	5.20	7.36	9.18	10.79	12.28
15	-0.65	5.17	7.26	8.94	10.37	11.63
17.5	-0.56	5.10	6.99	8.40	9.46	10.28
20	-0.49	5.03	6.74	7.91	8.69	9.22
25	-0.38	4.90	6.30	7.10	7.55	7.75
30	-0.33	4.76	5.90	6.43	6.65	6.74
40	-0.24	4.53	5.27	5.49	5.55	5.56
50	-0.20	4.32	4.79	4.88	4.89	4.89
70	-0.14	3.98	4.16	4.17	4.17	4.17
100	-0.10	3.62	3.66	3.66	3.66	3.66
200	-0.05	3.07	3.07	3.07	3.07	3.07
300	-0.03	2.88	2.88	2.88	2.88	2.88
400	-0.02	2.78	2.78	2.78	2.78	2.78
500	-0.02	2.73	2.73	2.73	2.73	2.73
600	-0.02	2.69	2.69	2.69	2.69	2.69
700	-0.01	2.66	2.66	2.66	2.66	2.66



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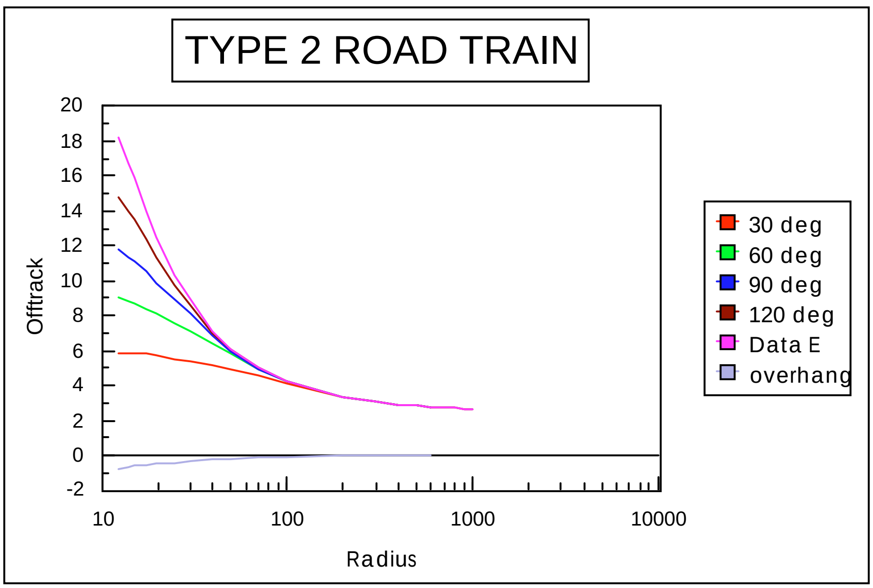
TYPE 2 ROAD TRAIN

	Front		Rear offtrack for Angle of turn, m			
Radius	Overhang,m	30 deg	60 deg	90 deg	120 deg	150 + deg
12.5	-0.75	5.90	9.00	11.80	14.80	18.20
14	-0.70	5.90	8.80	11.40	14.00	16.70
15	-0.62	5.90	8.70	11.15	13.50	15.90
17.5	-0.55	5.80	8.40	10.50	12.38	14.02
20	-0.50	5.70	8.10	9.90	11.40	12.50
25	-0.40	5.55	7.60	8.90	9.80	10.35
30	-0.35	5.40	7.10	8.10	8.60	8.90
40	-0.25	5.15	6.40	6.85	7.00	7.10
50	-0.20	4.95	5.80	6.00	6.05	6.05
70	-0.10	4.58	4.90	4.98	5.00	5.00
100	-0.10	4.10	4.20	4.20	4.20	4.20
200	-0.05	3.34	3.34	3.34	3.34	3.34
300	-0.03	3.06	3.06	3.06	3.06	3.06
400	-0.02	2.92	2.92	2.92	2.92	2.92
500	-0.02	2.83	2.83	2.83	2.83	2.83
600	-0.02	2.78	2.78	2.78	2.78	2.78
700	-0.01	2.74	2.74	2.74	2.74	2.74
800	-0.01	2.71	2.71	2.71	2.71	2.71
900	-0.01	2.69	2.69	2.69	2.69	2.69
1000	-0.01	2.67	2.67	2.67	2.67	2.67



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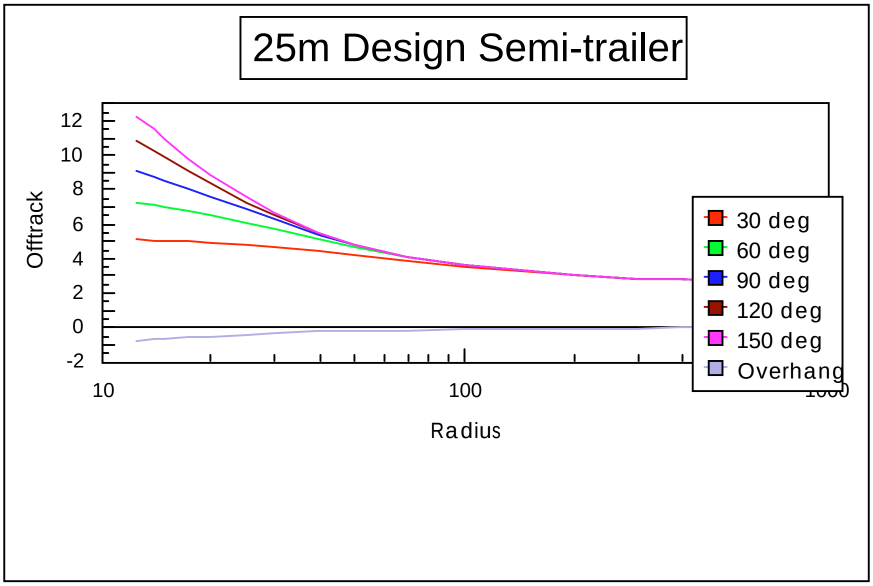
25m Design Semi-trailer (articulated vehicle)

	Front	Rear offtrack for Angle of turn, m				
Radius	Overhang m	30 deg	60 deg	90 deg	120 deg	150 + deg
12.5	-0.77	5.12	7.27	9.13	10.83	12.22
14	-0.69	5.07	7.12	8.80	10.23	11.50
15	-0.65	5.04	7.01	8.58	9.87	10.95
17.5	-0.56	4.98	6.77	8.08	9.05	9.79
20	-0.49	4.90	6.53	7.63	8.37	8.88
25	-0.39	4.78	6.11	6.88	7.30	7.54
30	-0.33	4.66	5.75	6.28	6.52	6.63
40	-0.25	4.43	5.16	5.41	5.49	5.51
50	-0.20	4.24	4.72	4.83	4.86	4.86
70	-0.14	3.92	4.13	4.15	4.15	4.15
100	-0.10	3.58	3.64	3.64	3.64	3.64
200	-0.05	3.06	3.07	3.07	3.07	3.07
300	-0.03	2.88	2.88	2.88	2.88	2.88
400	-0.02	2.78	2.78	2.78	2.78	2.78
500	-0.02	2.72	2.72	2.72	2.72	2.72
600	-0.02	2.69	2.69	2.69	2.69	2.69



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Introduction Content

AUTHOR BIOGRAPHY

Ricky Cox is the Principal Advisor (Design Systems) in the Transport Technology Division of the Queensland Department of Main Roads. He is primarily responsible for the development and enhancement of computer systems used in road design but has also been involved in the development and application of computer simulation tools for vehicle swept path analysis, vehicle performance analysis and traffic flow analysis.

The simulation tools have been for assessing specific operational problems on the road network and verifying proposed improvement alternatives. They have also been used to develop new guidelines or standards relating to varying aspects of road design.

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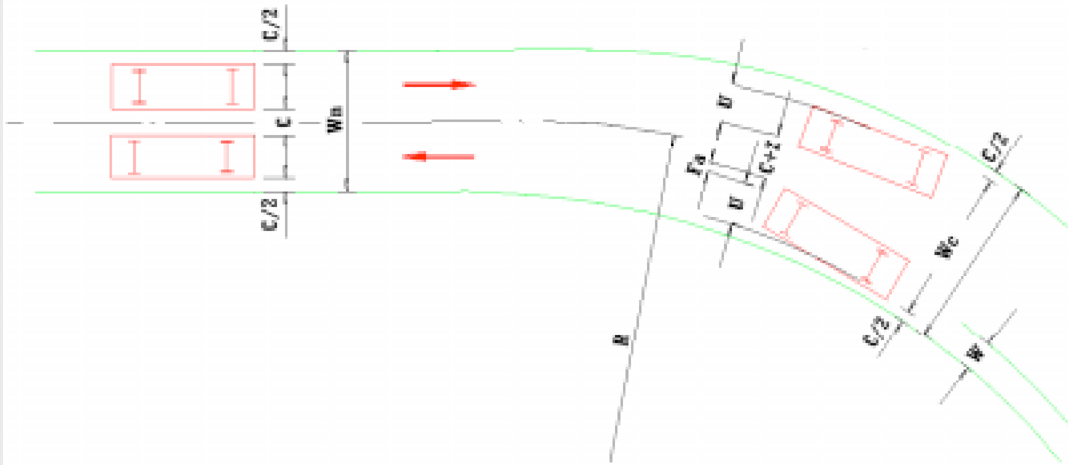

W = Widening for two-lane pavement on curve (m)
Z = Steering allowance for difficulty for driving on curves $(v/10/\sqrt{R}, m)$
We = Width of two-lane pavement on tangent (m)
Fa = Additional width of front overhang of vehicle on curve (m)
Wn = Width of two-lane pavement on tangent (m)
R = Radius of centre line of two-lane pavement (m)
V = Design speed for curve radius (km/h)
U = Track width of vehicle, outside to outside of tyres (m)
C = Lateral clearance between vehicles in adjacent lanes (m)

Figure 1: Lane Width Components on a Horizontal Curve

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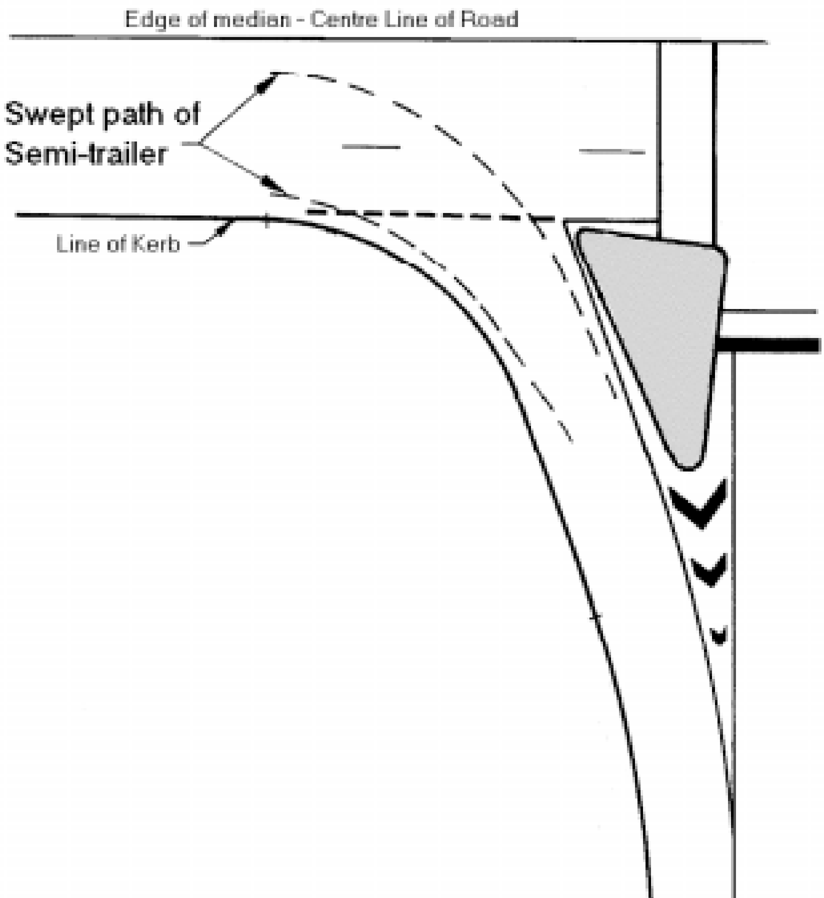

Figure 2: Large Vehicle Operation on a High Entry Angle Free Left Turn

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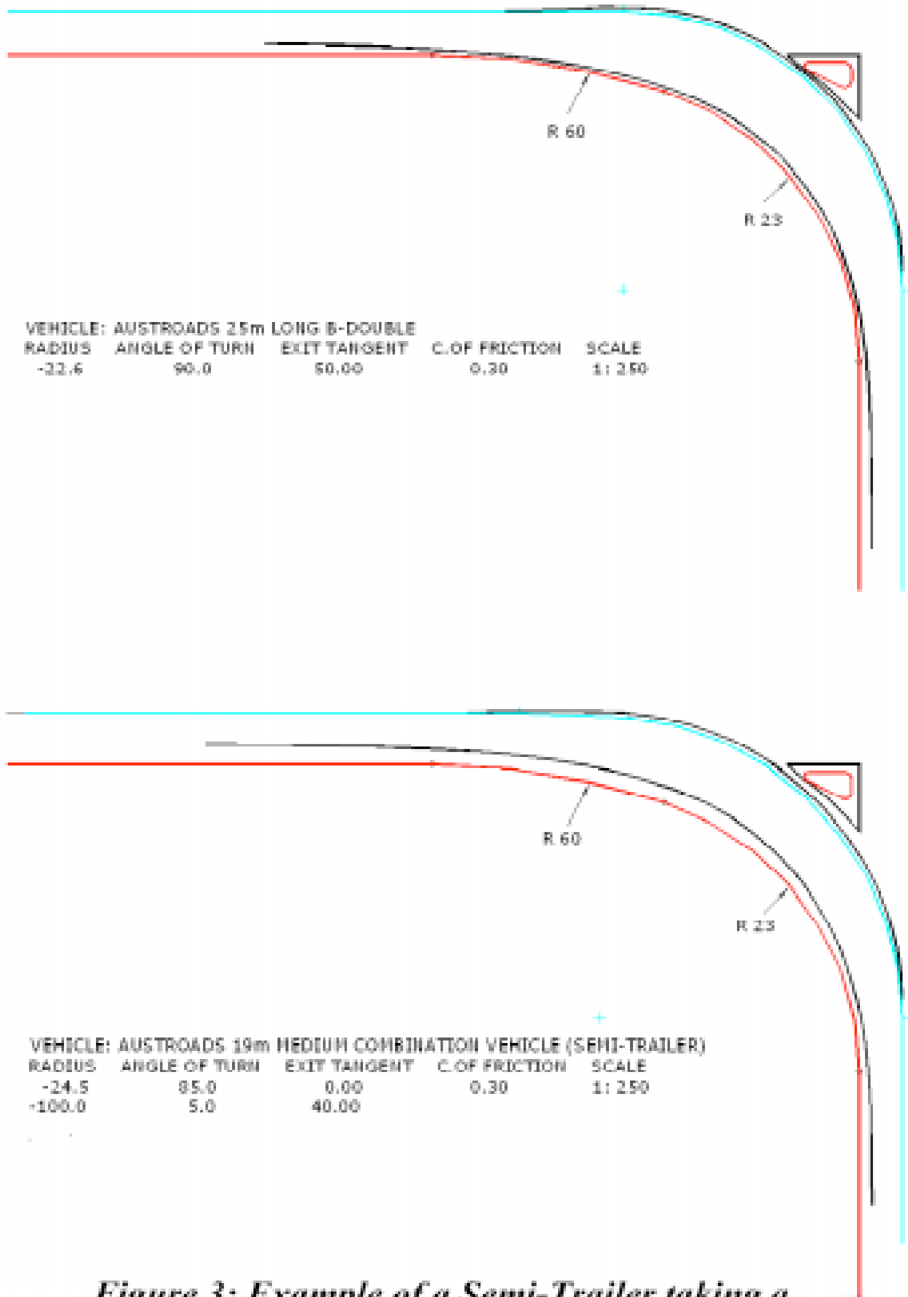

Figure 3: Example of a Semi-Trailer taking a Higher Standard Steering Path on a Turn Designed for a B-double.

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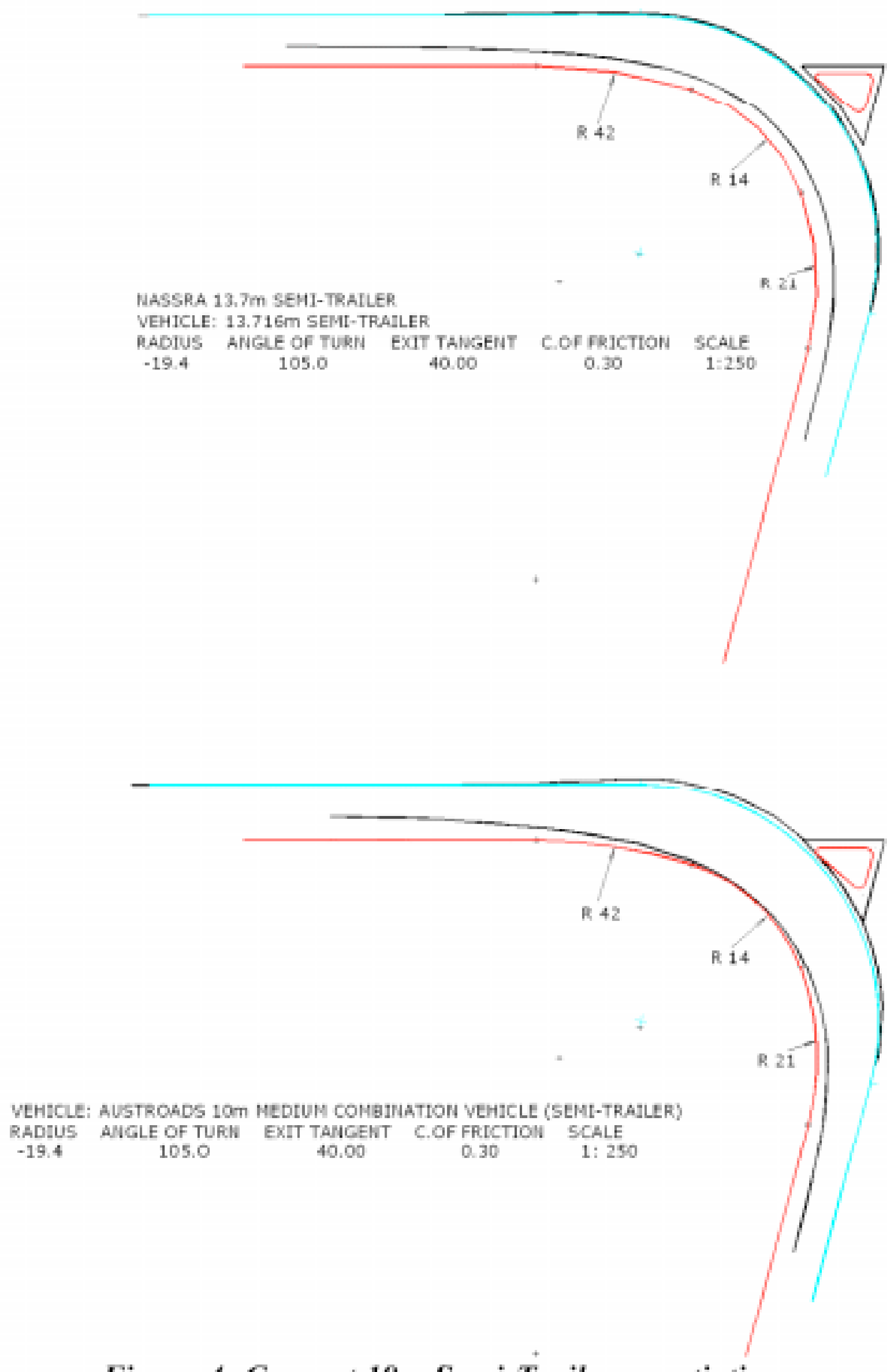

Figure 4: Current 19m Semi-Trailer negotiating a Turn Designed for a 13.7m Semi-Trailer

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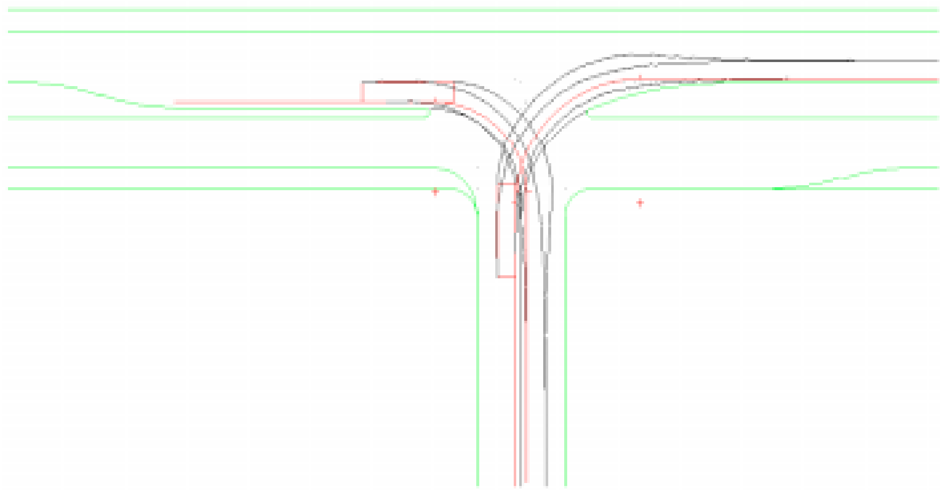
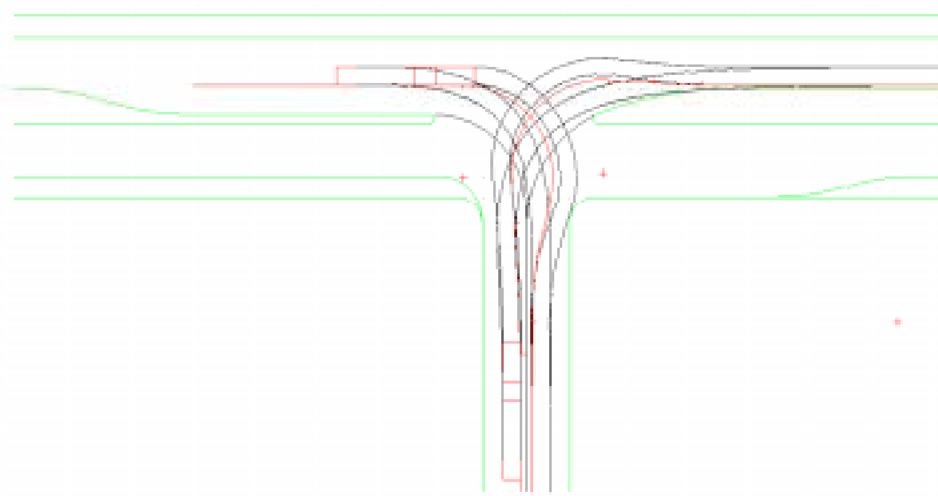


Single Unit Truck/Bus Right Turns



Semi-Trailer Right Turns

Figure 5: Examples of how a 19m Semi-Trailer can make a Right Turn at an Intersection Designed for a Single Unit Truck/Bus

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