Research Report
ARR 304

BE WARNED!
A review of curve warning signs and curve advisory speeds

Deborah Donald

Transport Research

ARRB Transport Research Ltd
ACN 004 620 651

500 Burwood Highway
Vermont South
Victoria 3133
Australia

Tel: (03) 9881 1555
Fax: (03) 9887 8104

International
Tel: 61 3 9881 1555
Fax: 61 3 9887 8104

Email: info@arrb.org.au
Internet: www.arrb.org.au

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Contents

Information Retrieval

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ABSTRACT: This study reviews the practice of erecting signs to warn drivers that they are approaching a substandard curve and also the setting and signing of curve advisory speeds. The study (which includes information from Australia and 23 other countries) develops a number of options and conclusions relating to the future use of such signs. The study concludes that curve advisory speeds are generally extremely conservative. However, possible safety implications in increasing these advisory speeds would appear to rule out a major change in the basic criteria for setting curve advisory speeds. Instead it is considered more important to encourage the consistent setting of curve advisory speeds across Australia. The report also suggests that improving delineation on some curves would possibly enable advisory speed signs on these curves to be removed.

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Executive Summary

Since the early days of motoring, signs have been used to warn drivers that they were approaching a substandard curve. Advisory speed signs giving an indication of the desirable speed for comfortable travel through a substandard curve were first trialled in Australia in 1959. The use of advisory speed signs was first included as an **option** in the 1975 revision of the Australian Standard, with the 1994 revision **recommending** their use on sealed roads.

Many drivers are aware of the significant safety margin that exists between the posted advisory speed (based on comfort) and the point at which friction is lost (safety), and there is evidence that drivers regularly exceed some posted advisory speeds by large amounts. Further, it has previously been reported that different jurisdictions use different methods of setting curve advisory speeds, leading to a lack of consistency across Australia.

This study reviews the practice of signing curves and the setting and signing of curve advisory speeds both within Australia and internationally.

As part of the study 23 countries were surveyed about their use of curve warning signs and curve advisory speed signs. All 23 countries used curve warning signs, however three different approaches were reported to the use of curve advisory speed signs. These were:

- no curve advisory speeds provided
- curve advisory speeds provided on curves where warranted (although warrants differ from country to country) and
- curve advisory speeds not used but regulatory speed limits applied to curves where warranted.

The most commonly used methods of setting curve advisory speeds reported were:

- driving over the curve a number of times and 'picking' a suitable speed, and
- using a ball-bank indicator and then a table to convert speed and ball-bank readings into an advisory speed.

Most countries reported that advisory speeds were based on comfort factors and were considered to be highly conservative. None of the countries reported specifically considering heavy vehicles when setting curve advisory speeds.

Within Australia it appears that there is now more consistency between jurisdictions in the setting of curve advisory speeds than was reported in an earlier study.

Executive Summary *continued*

This current study has concluded that there are a number of practical difficulties associated with markedly changing the basis for setting curve advisory speeds. Rather than change curve advisory speeds to be more appropriate for one type of vehicle (modern passenger cars), it is considered more important to encourage the consistent setting of curve advisory speeds across Australia.

This can be achieved by better standardising the equipment and calibration methods used in each jurisdiction, and by encouraging increased compliance with recommended current practice as described in AS 1742.2.

The report also suggests that improving delineation on some curves would possibly enable advisory speed signs on these curves to be removed (although the curve warning sign would, of course, remain).

1 Introduction

Since the early days of motoring, signs have been used to warn drivers that they were approaching a substandard curve. Advisory speed signs giving an indication of the desirable speed for comfortable travel through a substandard curve were first trialled in Australia in conjunction with curve warning signs in 1959 (Main Roads 1963).

Over the years improvements to roads and vehicles have increased the safety margin that exists between the posted advisory speed (based on comfort) and the point at which friction is lost. There is evidence that drivers regularly exceed some posted advisory speeds by large amounts. Further, it has previously been shown that different states use different methods of setting curve advisory speeds, leading to a lack of consistency across Australia.

This project has been established to review the signing of curves and the setting and signing of curve advisory speeds.

2. Background

The construction of roads to accommodate motor vehicles accelerated after the introduction of mass produced cars in the 1920s. The design of these roads borrowed heavily from railroad practice, employing superelevation (where the outer side of the curve is elevated above the inner side to counteract the effect of the centrifugal force of the vehicle) to reduce the need for speed reduction on curves. Before long, advances in passenger car dynamics meant that the provided superelevation was inadequate to balance the lateral forces acting on a vehicle whilst cornering. Drivers were required to apply judgement to the selection of a safe cornering speed and road agencies began to provide warning signs to remove the element of surprise from the driving task.

In Australia, curve warning signs consisting of a red triangle placed below a text-only rectangular board were included in the first Road Signs Code (SAA 1935), while the first revision of this code introduced a range of yellow diamond shaped symbolic warning signs to illustrate the nature of the curve(s) (SAA 1946). Examples of these signs are shown in *Figures 1 and 2*.

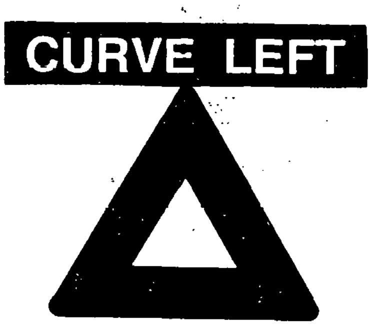


Figure 1
Early curve warning signs
(introduced SAA 1935)

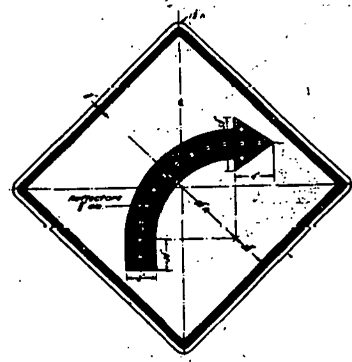


Figure 2
Symbolic curve warning sign
(introduced SAA 1946)

While the first curve advisory speed signs were trialled in Australia in 1959 (Main Roads 1963), a further revision of the signing code in 1960 (SAA 1960) did not significantly alter the type of curve warning signs recommended.

An advisory speed plate was included in the 1975 revision of the signing code (SAA 1975). The Standard advised that this advisory speed plate **'may'** be used in conjunction with another warning sign to 'indicate the **desirable** speed in good weather, traffic and road conditions for comfortable travel through the hazard referred to on the warning sign' (my emphasis). An example of this sign is shown in *Figure 3*.

While no major changes have been made to the appearance of the curve warning signs in the most recent revision of the Standard (SA 1994), the advisory speed is now defined as 'the **maximum** speed at which a curve may be comfortably negotiated under good road and weather conditions'. Further, the Standard now states that curve warning signs **'should** be supplemented with advisory speed signs'; thus **recommending** the use of advisory speed signs rather than simply presenting them as an option as in the 1975 Standard (my emphasis).

While the earlier Standards make no distinction between sealed and unsealed roads, the 1994 Standard states that

> *'advisory speed signs are generally recommended for use on sealed roads only. They should not be used on unsealed roads unless it can reasonably be expected that the advisory speed will remain constant over time and will not be subject to significant variations due to change in surface conditions caused by weather or pavement wear.'*

The 1994 revision also introduces a 'tilting truck' symbolic sign (*Figure 4*) for use where there 'is a history of trucks toppling even where all other required curve warning and delineation devices are provided'.

Figure 3
Curve advisory speed sign supplementing curve warning sign (introduced SAA 1975)

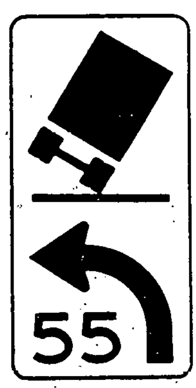


Figure 4
Truck tilting sign (introduced AS 1994)

The most common device used to establish curve advisory speeds is the ball-bank indicator. There are many types available, one of which is shown in *Figure 5*. Ball-bank indicators were developed from use within the aircraft industry to provide a measure of 'side-pitch'. They consist of a small ball within a curved tube which subscribes an arc of a circle, graduated outward in degrees from the vertical. The device is mounted vertically within the test vehicle and indicates the sum of the lateral forces and body roll minus the road's superelevation when rounding a curve (at constant speed and constant radius path). The ball-bank reading is then compared to a table to convert a reading of degrees to one of speed.

There are a number of problems evident with the ball-bank indicator method including:

- repeatability is poor when the chosen test speed differs markedly from the resultant advisory speed; and
- the ball-bank indicators are imprecise devices.

It has been suggested that equipment errors are a leading contributor to the inconsistency of posted advisory speeds (McLean 1974), with previous studies showing that some ball-bank indicators are giving erroneous readings. The latest Australian Standard, AS 1742.2 Appendix I (SA 1994), describes a survey methodology designed to minimise the measurement error when using the ball-bank indicator method (which does not help if the ball-bank indicator itself is wrong).

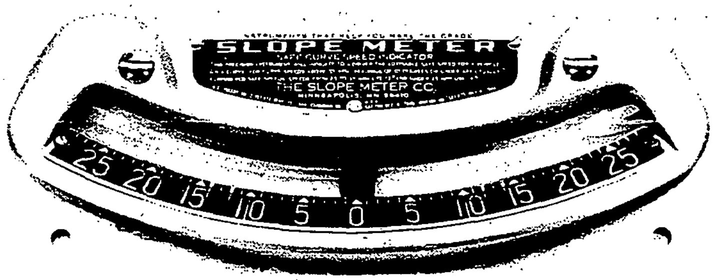


Figure 5
A ball-bank indicator

Many of the field studies that established comfortable curve speeds based on ball-bank readings were conducted in the 1930s and 1940s. Considering the advances made over the last 50 years in vehicle dynamics and pavement surfaces, it is perhaps surprising that road design and advisory speed setting criteria remain based upon these early figures (Merritt 1988, McLean 1993).

3 International Practice for the Signing of Curves and the Setting of Curve Advisory Speeds

In April 1994, letters were sent to 102 organisations in 48 countries regarding their national practice relating to curve signing and the setting of curve advisory speeds. The organisations were targeted through ARRB Transport Research's information data base and included Departments of Transport, Road Authorities, Road Safety Organisations, Traffic Engineering Departments and Universities. Where there was more than one appropriate organisation in a country, multiple letters were sent.

Responses were received from organisations in 22 countries, including almost all of the major countries surveyed, with the notable exceptions of China and Japan, where language difficulties may have been too difficult to overcome.

The following section summarises the information received (in alphabetical order by country). It should be noted that many countries provided information about signing practice but not on how the advisory speeds are set. Those that did provide some information relating to how the curve advisory speeds were set often mentioned that the original basis for the charts (used in conjunction with the ball-bank indicator) was not known.

Austria

Curve advisory speeds are not used in Austria. Curve signing practice involves the use of a warning sign to European Union [EU] standards with supplementary information limited to the length of winding road sections (*Figure 6*).

Figure 6
Curve warning sign - Austria

Belgium

Individual curve warning signs are used on curves having a much smaller radius that the rest of the surrounding road. When the whole road section has many similar curves, individual curves are not signed separately. Advisory speeds for curves are not used.

Canada

The responsibility for traffic control devices in Canada comes under the jurisdiction of the provincial ministries of transportation. Responses were received from Ontario (the largest province) and Quebec.

In Ontario, black and yellow curve warning signs are erected on all curves where the maximum safe speed is less than the operating speed (85th percentile speed). Advisory speed tabs are provided where the maximum safe speed is 20 km/h or more below the operating speed and is 10 km/h or more below the speed limit (*Figure 7*).

Figure 7
Curve warning sign and advisory speed tab - Canada

The advisory speed is based on a safe curve speed established using a ball-bank indicator or similar device with a nomograph used to determine the safe speed from the ball-bank angle and test speed. Advisory speeds are in multiples of 10 km/h.

The reliability and accuracy of the ball-bank indicator method is questioned by some practitioners who recognise that the results gained using this method are conservative. They report that driver expectancy is generally that advisory speeds can be exceeded by a significant margin without risk. This poses problems where curves are severe and reduced safety margins may apply. In this situation, additional delineation is recommended.

In Quebec, curve advisory speeds are also set using the ball bank indicator, however they end in the numeral 5. The method used is based on American practice, with the graph shown in *Figure 8* used to establish the recommended curve speeds from the ball-bank indicator reading.

VITESSE SÉCURITAIRE (km/h)
(INCLINOMÈTRE À BILLE)
47 (Angle)

Speed of vehicle during test 43

km/h	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	km/h
20			44	40	38	35	33	31	30	28	27	25								20
25			56	49	44	40	38	35	34	33	32	30	28	27	26	24	22	20	19	25
30			62	58	53	49	46	43	40	37	35	33	32	31	30	29	27	25	24	30
35			67	64	58	54	51	48	45	42	40	38	37	36	34	33	31	29	28	35
40			72	68	64	61	56	53	51	48	47	43	40	39	37	35	34			40
45			77	74	69	66	61	58	54	51	49	47	45	44	41	39				45
50			82	79	74	71	66	63	58	55	53	51	49	48	45	44				50
55			88	84	79	76	71	68	63	60	57	55	53	51	48	47				55
60			96	91	84	81	76	73	68	65	61	58	56	53	52	50				60
65			102	98	90	87	81	78	73	70	65	62	58	56	54	52				65
70			105	102	97	94	88	83	78	75	70	67	63	60	57	55				70
75	113	113	109	105	102	98	92	88	83	80	76	72	67	64	60	58				75
80	113	113	113	108	106	101	98	93	88	83	80	77	72	69	64	61				80
85	113	113	113	111	109	105	102	96	93	90	86	81	76	73	68	65				85
90	113	113	113	113	111	109	106	102	99	94	89	86	81	78	73	70				90
95	113	113	113	113	113	112	109	106	102	98	95	90	86	83	78	78				95
100	113	113	113	113	113	113	112	110	105	102	98	94	91	88	83	80				100
105	113	113	113	113	113	113	113	113	109	106	101	98	96	92	88	86				105
km/h	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	km/h

safe speed
44

Figure 8
Graph for use with ball-bank indicator - Canada

Denmark

Curve warning signs and curve advisory speeds of the type shown in *Figure 9* are used in Denmark.

Figure 9
Danish curve warning sign with supplementary advisory speed plate

A two step process is used to establish the advisory speed.

Step 1:
A suitable lateral friction coefficient is established for the curve using:

S_f = (lateral frictional force)/(acceleration due to gravity), and

$S_f \approx$ ((Speed[km/h])²/(127*Radius[m]))-(superelevation angle[%]/1000).

Typical coefficients range from 0.18 to 0.32. A low Sf is used for large radius curves, for high roughness or if skid resistance is low. A high value of Sf would be used with a high radius curve and small centre angle but shorter curve length. The friction coefficient is used as a component of the advisory speed selection criteria from a safety perspective, ie to ascertain the likely frictional demands on drivers through the curve.

Step 2:
The curve is driven a number of times (in a passenger car) to determine a safe and comfortable speed. The same person performs all tests to reduce the subjective influence. The recommended speed is then rounded to the nearest 10 km/h (or occasionally nearest 5 km/h). However, as it is well known that many drivers exceed the posted speeds a further drop of 10 km/h is applied to the established speed in order to increase the margin of safety.

Fiji

Fiji has not used advisory speeds in the past but is currently considering introduction of such signs as part of a 2 year Fiji Road Safety Action Plan.

If curve advisory speeds are introduced, they would most likely be based on Australian Standards practice as defined in AS 1742.2 (SA 1994).

Finland

Curve warning signs used in Finland are the European standard shape (triangular) however they have a yellow background instead of the standard white background to allow for the winter conditions experienced in the country.

Curve advisory speeds are rare in Finland (approx 150 curves) and are restricted to dangerous curves and sections with high speed limits. Advisory speeds are always 20 km/h or more lower than the speed limit. They consist of a square sign with white text on a blue background (*Figure 10*).

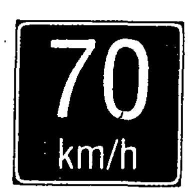


Figure 10
Finnish curve warning sign and advisory speed sign

The primary basis for the setting of advisory speeds is safety and they are usually installed as a response to a perceived accident problem.

No formal procedures exist for the setting of these advisory speed limits, however, a table of recommended maximum speeds for differing curve radii and curve speeds, based on curve speed observations, is available for selection of recommended maximum curve speeds (*Figure 11*). Local conditions, sight distance, crossfall and the levels of driver expectation are also considered.

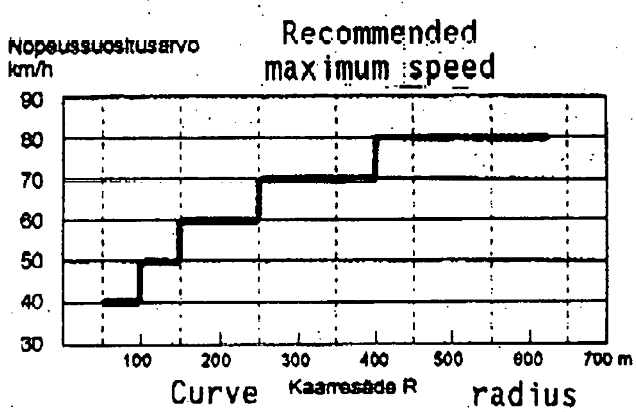


Figure 11
Chart employed by Finnish practitioners to establish recommended curve speeds

While general speed limits in Finland are reduced during the winter months, there is no corresponding reduction in advisory speeds for curves.

France

Triangular curve warning signs are used in France (*Figure 12*).

While some curves are subject to a speed limit as a function of the radius of curvature and the transverse slope, this limit is applied as a regulatory speed limit rather than as an advisory speed limit. Such a limit is indicated by use of a circular speed limit sign in conjunction with a triangular warning sign.

Figure 12
Curve warning sign and speed limit sign - France

Germany

In Germany a triangular curve warning sign with a range of curve symbols is used to indicate the severity of the road curvature and direction change required. If warranted, hazard marker boards may supplement the warning sign.

Advisory speeds are not used, however enforceable speed zones may be applied (indicated with a round speed sign supplementing the triangular warning sign). These signs arc as indicated in *Figure 13*.

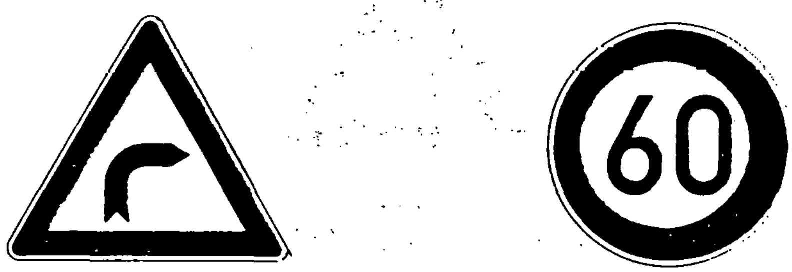


Figure 13
Curve warning sign and speed limit sign - Germany

Hong Kong

Hong Kong discontinued the use of curve advisory speeds in the 1980s after they decided that advisory speeds were not meaningful because of the different performance of different vehicle types (and even of the same vehicle in different weather conditions).

Hungary

Hungary does not include curve advisory speeds in its Highway Code.

Israel

Advisory speeds on curves are not used in Israel. Instead, speed zoning is applied to curves using regulatory signs. The response from Israel noted that these regulatory speed limits around curves were rarely enforced.

Netherlands

Warning signs are commonly used on curves in the Netherlands (*Figure 14*) with supplementary advisory speed plates used under restricted circumstances. The warning signs have a black symbol, a white background and a red border.

Advisory speeds are established from a ratio of design speed to measured speed, where the design speed is derived from the curve radius and cross-fall and frictional factors for wet pavement. If the difference between the design speed and the approach speed exceeds 20 km/h, then an advisory speed is required. This speed does not incorporate a large margin of safety so drivers are encouraged to not exceed the speed posted.

Heavy vehicles are not considered in the establishment of advisory speeds but operate under a lower general limit of 80 km/h.

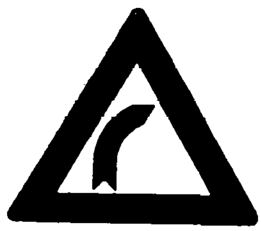


Figure 14
Curve warning sign - Netherlands

As the advisory speed applies for a defined road length, it is applied by an advisory speed section commencement sign and removed by an 'end advisory speed limit' sign which is the same sign but with a red diagonal stripe added (white on blue and white on blue with red stripe as shown in *Figure 15*).

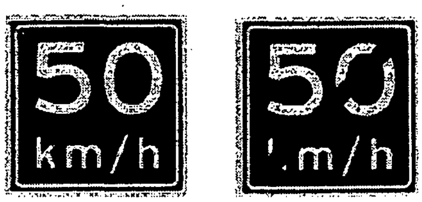


Figure 15
Start and end signs for Advisory Speed Section

New Zealand

Curve warning signs are installed in advance of curves where the controlling authority believes the curve is deceptive, not obvious to approaching drivers and constitutes a hazard.

Curve advisory speeds are used where warranted. The signs used are as indicated in *Figure 16*.

The New Zealand guidelines state that curve advisory speeds should be set using a ball bank indicator, with the reading taken at constant speed from at least two runs in both directions. A nomograph (*Figure 17*) is used to establish the measured advisory speed and this is then rounded down to the nearest numeral ending in 5. The advisory speeds are based on work carried out in the late 1950s and early 1960s when comfort, rather than safety, was used as the basis for setting curve advisory speeds.

The warrant for whether an advisory speed sign is erected is as shown in *Figure 18.*

Figure 16
New Zealand curve warning sign with advisory speed plate

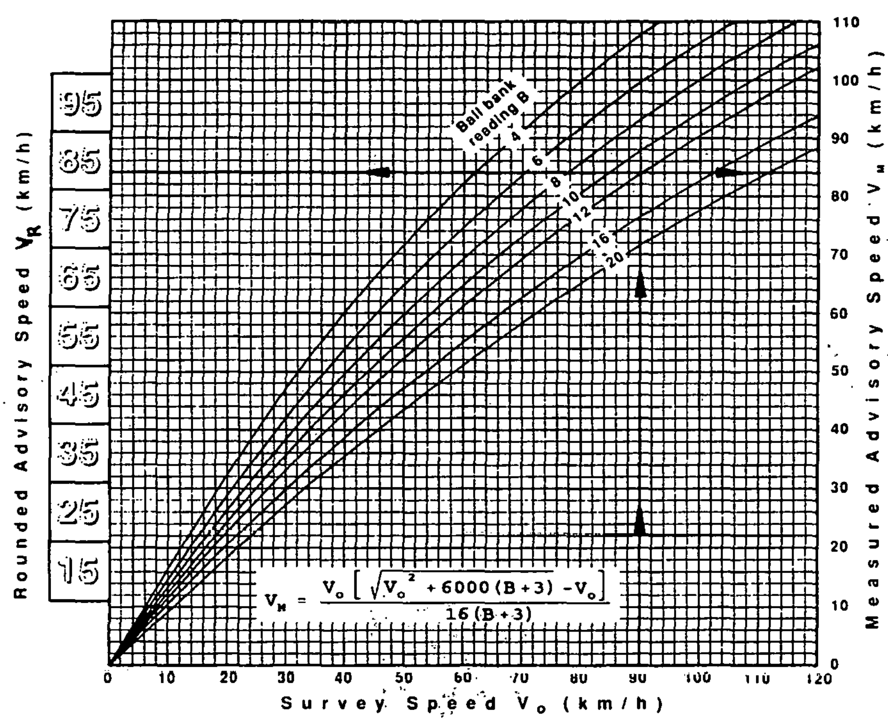


Figure 17
Table used for establishing advisory speeds
(Appendix A3, NZ Manual of Traffic Signs and Markings)

A recent review of curve signing policy in New Zealand recognised the shortcomings of the existing system, particularly the fact that drivers are able to exceed the advised speed with no detrimental safety implications. However, proposed changes to more closely align the advisory speeds with vehicle performance were thought to have possible serious safety consequences (particularly during the implementation phase) and a decision was made to remain with the existing method.

Anecdotal comments suggest that notwithstanding the prescribed methods, the setting of curve advisory speeds is not consistent throughout the country.

Rounded Advisory Speed V_R (km/h)	Signing warranted when V_{85} meets of exceeds these values (km/h)
15	30
25	40
35	50
45	60
55	80
65	90
75	110
85	120
95	130

Figure 18
Warrant for erection of curve advisory speeds

Poland

Advisory speeds on curves are not used in Poland but a regulatory speed limit is used if thought necessary on safety grounds.

Portugal

Advisory speeds are used on select curves (*Figure 19*), however the criteria applied is not clear. The advisory speeds are sign posted with a 'start' (blue background and white numerals) and 'end' advisory speed sign (same as 'start' advisory speed with a red stripe).

Figure 19
Advisory speed sign - Portugal

South Africa

Triangular curve warning signs are used in South Africa.

Advisory speeds are used where the safe speed is lower than the existing speed limit. The advisory speed is marked on a supplementary plate placed underneath the curve warning sign (*Figure 20*).

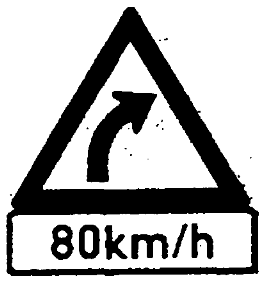


Figure 20
South African curve warning sign with advisory speed plate

Where a regulatory speed limit is applied to a section of road containing curves, signs similar to those shown in *Figure 21* are used.

The recommended method of setting advisory speed limits is to conduct a number of trial runs through the curve under study using a vehicle equipped with a ball-bank indicator and a calibrated speedometer. A table is then used to determine the advisory speed.

Figure 21
South African combined sign indicating speed and warning of tight curves

South Korea

Curve warning signs are used in South Korea with curve advisory speeds set according to need ('need' not defined). The signs used are of the type shown in *Figure 22*.

Figure 22
Curve warning sign and advisory speed plate - Korea

Sweden

Triangular (European standard) curve warning signs are used in Sweden. Curve advisory speeds are not used.

Switzerland

Triangular (European standard) curve warning signs are used in Switzerland. Curve advisory speeds are not generally used, however, local jurisdictions are responsible for sign installations and differences in application exist. Some jurisdictions have set speed limits for particularly dangerous curves (the criteria used for determination of 'dangerous curves' is not clear).

Thailand

Curve warning signs with advisory speeds are used on sub-standard curves.

Traffic signs in Thailand follow those agreed at the United Nations Conference on Road Traffic, Vienna, Austria (UN 1968).

United Kingdom

Triangular curve warning signs are used in the United Kingdom.

Curve advisory speeds were used in the past however current use of advisory speeds is restricted to road works and 'difficult' curves (*Figure 23*). The curve advisory speeds at these locations are based on safety factors.

The Department of Transport has commissioned TRL to investigate the effectiveness of curve advisory speed signs but no guidelines have yet been made available to local authorities.

Figure 23
Curve warning sign with accompanying advisory speed plate - UK

United States

Curve warning signs (consisting of a yellow diamond with black legend and borders), are used where the recommended speed on a curve is greater than 30 mph and is equal to or less than the speed limit.

The Manual of Uniform Traffic Control Devices allows, but does not require, the use of advisory speeds in conjunction with curve warning signs to indicate the maximum recommended speed around a curve. The advisory speed plates are placed beneath the curve warning sign and are rectangular in shape and yellow and black in colour (*Figure 24*). The advisory speed is given in a multiple of 5 mph.

The Federal Highways Administration (FHWA) recommends three alternative methods for establishing a 'recommended' curve speed:

1) the use of a FHWA developed nomograph with known design and operational conditions;

2) a ball-bank indicator survey; or

3) by mathematical equation with an assumed coefficient of friction (FHWA 1983).

Figure 24
US curve advisory speed plate

The values for curve frictional coefficients and ball bank indicator angles originate from the American Association of State Highway and Transportation Officials (AASHTO) design guides and prior to that, back to the work of Moyer and Berry in the 1940's.

A poll conducted in 1988 indicated that most US states employed the ball-bank indicator and allied criteria from either AASHTO design guides, ITE handbooks, the FHWA *Manual of Uniform Traffic Control Devices Handbook* or a modified version of one of these (Merrit 1988). However, a number of alternative technologies are being employed by some agencies as part of pavement inventory systems.

Discussion

While curve warning signs were used in all of the 22 countries surveyed, three different approaches were reported to the use of curve advisory speeds:

- no curve advisory speeds provided;
- curve advisory speeds provided on curves where warranted;
- curve advisory speeds not used but regulatory speed limits applied to curves where warranted.

In those countries where curve advisory speeds were used, they were set using a number of different methods. The most commonly used methods were:

- to drive the curve a number of times before selecting a 'safe' speed; and
- using an instrumented vehicle (ball-bank indicator) and then a graph to select an appropriate advisory speed.

Where ball-bank indicators were used, the original basis of the graphs used to convert ball-bank readings into advisory speeds was most generally not known. It was commonly assumed that such graphs were based on comfort, rather than safety, due to the conservative nature of advisory speeds gained through this method.

None of the respondents reported that heavy vehicles were specifically considered in the processes used for setting curve advisory speeds.

4 Australian Practice for Setting Curve Advisory Speeds

Following a detailed review of the setting of curve advisory speeds conducted by Preisler *et al* in 1992, Australian Standard 1742.2 (Manual of uniform traffic control devices - Part 2: Traffic control devices for general use), was revised and republished (SA 1994).

The revised Standard adopted the criteria reported by Preisler *et al* as being used by Queensland, with an aim of achieving national consistency through a standardised criteria and survey methodology.

The remainder of this chapter covers Australian recommended practice and actual practice (as reported by the State Road Authorities in 1995).

Recommended Practice

According to Australian Standard 1742.2 - Manual of uniform traffic control devices, Part 2, Traffic control devices for general use (SA 1994), curve warning signs should be used in advance of substandard horizontal curves. Sub-standard curves are defined as those curves having an advisory speed at least 10 km/h less than the 85th percentile speed observed on the approach to the curve.

The Standard further advises that (on sealed roads) the curve warning signs should be supplemented with advisory speed signs, where the advisory speed is 'the desirable speed for comfortable travel for the driver and passengers when weather, traffic and road conditions are good' (*Figure 25*). Advisory speeds are set in multiples of 5 (that is they may end in 5 or 0).

Figure 25
Curve warning sign and supplementary advisory speed sign - Australia

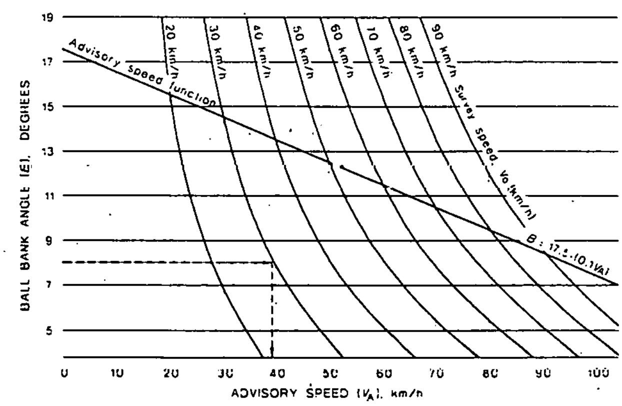
Two methods are described in Appendix I of Australian Standard 1742.2 (AS 1994) for calculating curve advisory speeds:

- the ball bank indicator method; and
- the RGDAS method.

The former has a clearly defined survey procedure to minimise measurement errors and reduce the level of subjectivity. A nomograph is provided (Figure 26) to assist in selecting the correct advisory speed using a defined relationship between an observed ball-bank angle reading and the test speed:

$$B = 17.5 - (0.1)\, V_A$$

where B is ball bank reading in degrees and V_A is the advisory speed.



NOTES:

1 The example shows an observed reading of 8 degrees at a survey speed of 30 km/h. The advisory speed is 39 km/h.

2 The graph is based on the matching of ball bank angle to advisory speed as shown in the following Table:

Ball bank angle degrees	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
Advisory speed km/h	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25

Figure 26
Nomograph from AS 1742.2 Appendix I used to calculate the advisory speed from ball-bank angle and test speed.

The RGDAS method involves the use of an ARRB Transport Research designed Road Geometry Data Acquisition System (RGDAS) instrumented vehicle. This device produces recommended advisory speeds for horizontal and vertical curves as part of its reporting routine.

Actual Practice

As part of this project, Road Authorities were asked to outline their current procedures for the setting of curve advisory speeds. This survey was carried out in 1995.

The aim of including standardised criteria and a recommended survey methodology in AS 1742.2 was to achieve national consistency in setting curve advisory speeds, and it appears that some jurisdictions have accordingly amended the procedures they reported using to Preisler *et al* (1992).

New South Wales

The Roads and Traffic Authority (RTA) of NSW has its own procedures in place and has not formally adopted the AS 1742.2 guidelines. Both the ball bank indicator and RGDAS methods are being used, the latter employing the following relationship between test speed and ball bank angle:

$$B = 20.4 - 0.125V$$

Those regions that responded to the questionnaire indicated that curve advisory speeds are set consistently within their particular region, although different methods are used in different regions (eg Northern Region reported using the ball bank indicator method while Southern Region derives advisory speed using RGDAS outputs). Neither Region considered that interstate drivers were experiencing difficulties as a consequence of inconsistent practices, although concerns were raised about some Regions and Councils that are known to disregard the set procedures and use 'seat-of-the-pants' methods.

A number of run-off-road accidents have been reported in Southern Region. Investigations of lengths of road revealed problems with posted advisory speeds with either:

- no advisory speeds posted;
- poor maintenance or inspection frequency resulting in poor quality, missing or vandalised signs; and/or
- sections of road had not been surveyed.

Attention to correct signing and advisory speed setting procedures, additional delineation and duplication of signs on right hand road shoulders have seen a reduction in these accidents (no statistical analysis provided).

Northern Territory

The Northern Territory uses curve warning signs according to AS 1742.2 (SA 1994), together with chevron alignment markers where warranted. However, the role for curve advisory speeds is considered limited due to the difficulties of prescribing preferred speeds when vehicle, road and environmental conditions vary considerably.

A significant proportion of rural roads in the Northern Territory are unsealed and AS 1742 recommends against the use of curve advisory speeds on unsealed roads.

Isolated, sub-standard curves are relatively rare on sealed roads in the Northern Territory.

A warning sign aimed at reducing the risk of rollover for heavy vehicles has been installed on the Stuart Hwy at the request of the transport industry. The speed selected (55 km/h) was based on consultation with the freight industry and engineering judgement.

Queensland

The criteria for setting curve advisory speeds included in AS 1742.2 (SA 1994) were adopted from the Queensland Department of Main Roads (formally Queensland Transport) Manual of Uniform Traffic Control Devices. Consequently, no change to the advisory speed criteria has occurred in Queensland, ie the relationship between the ball bank angle and advisory speeds remains as

$$B = 17.5 - (0.1)\,V_A$$

However, concerns exist about inconsistent posted advisory speeds that result from incorrect use of the ball bank indicator method. Evidence for this comes from a review of advisory speed signs in Townsville District in 1990 which revealed:

- 43.8% of posted speeds were correct;
- 29.6% of posted speeds were too high; and
- 26.6% of posted speeds were too low.

The large proportion of inaccurate posted advisory speeds could be attributed to:

- different criteria being used to establish the speed;
- changed surface since the last survey;
- incorrect survey methods; or
- sign removed for maintenance and not returned;

The Queensland respondent reported that an analysis of accidents within the same District from 1984 to 1988 suggested that accident rates increased once the discrepancy between the 'correct' and the posted speeds exceeds 20 km/h. It is not clear whether this analysis included all accidents or just run-off road accidents nor is it clear whether this increase in accidents was statistically significant.

Currently the Queensland Department of Main Roads uses the ball bank indicator method to set curve advisory speeds, but they have developed (although not yet trialled) an electronic advisory speed calculator. This system has been developed to produce advisory speed and curve radius data for horizontal and vertical curves from a single pass.

To date, the particular stability requirements of trucks have not be considered in the survey methods or selection criteria, other than the need to demonstrate a significant truck accident problem before installing truck tipping signs.

South Australia

South Australia has adopted the AS 1742.2 procedures using the ball-bank indicator method. The DoT - SA has a single ball bank device fitted within a test vehicle and all curve assessments are made using the same device and personnel.

Accident statistics for 1992 to 1994 (part) indicate that loss of control and single vehicle run off road accidents are a small proportion of total reported accidents (1-2%). Consequently, the Department does not consider curve accidents to be a significant problem with South Australian or interstate drivers.

Tasmania

The Department of Transport and Works has adopted the procedures outlined in AS 1742.2 and uses the ball-bank indicator method.

Tasmania has retained its practice of differentiating advisory speeds and regulatory speeds with the former ending in the numeral 5 and the latter ending in zero.

Because the Department of Transport and Works is the sole authority responsible for traffic control devices in Tasmania, consistency in application is considered to be good. Interstate drivers have not reported difficulties with the advisory sign procedures encountered in Tasmania.

Victoria

Victoria has not formally adopted the Australian Standards provisions but does employ the ball-bank indicator method.

The VicRoads Traffic Engineering Manual (Vols 1 and 2) reference both AS 1742.2 procedures and a modified version of AS 1742.2 procedures as the guide for determining advisory speed warning signs. In the modified version the relationship between ball-bank indicator and advisory speed is taken as $B = 15 - 0.067V$ (the same as that reported to Preisler *et al* (1992). Changes to the manual are anticipated but it is not clear whether this will include adoption of the Australian Standards.

Relatively few surveys of curve speeds have been carried out in recent years making it difficult to make a judgement about the level of consistency.

VicRoads officers recognise the shortcomings associated with the existing methods and criteria for establishing a 'comfortable' speed, but consider the resulting large margin of safety a suitable outcome. Considerable advances in long and short range curve delineation techniques are also felt to have reduced driver reliance on posted advisory speeds.

Western Australia

Main Roads Western Australia defines a sub-standard curve as one where the 'comfortable speed' is equal to or greater than 15 km/h below the 85th percentile speed on approach.

The Australian Standard's ball bank method is generally followed consistently throughout the state using either a standard ball bank indicator or electronic slopemeter.

Main Roads recognises that the speeds are set for average family vehicles and no allowances are made for heavy vehicles. It is assumed that heavy vehicle drivers are aware of their vehicle's constraints.

Discussion

While all States and Territories report using the ball bank indicator method (*Table 1*), there are still a number of different formulae used to calculate the advisory speed from ball-bank angle and test speed (although consistency has improved since the findings reported by Preisler *et al* in 1992).

Table 1
Formulae used to calculate advisory speed

State (Territory)	Relationship	Posted advisory speeds
New South Wales	$B = 20.4 - (0.125)V$	increments of 10 km/h, end in 5
Northern Territory	$B = 17.5 - (0.1)V_A$	
Queensland	$B = 17.5 - (0.1)V_A$	increments of 5 km/h
South Australia	$B = 17.5 - (0.1)V_A$	increments of 5 km/h
Tasmania	$B = 17.5 - (0.1)V_A$	increments of 10 km/h, end in 5
Victoria	$B = 15 - (0.067)V$	increments of 5 km/h
Western Australia	$B = 17.5 - (0.1)V_A$	increments of 5 km/h

Where V_A = advisory speed (km/h), V = speed (km/h), B = ball bank angle in degrees

The actual differences in advisory speeds obtained by using the different formulae are extremely small in almost all jurisdictions. For example, for a ball-bank indicator reading of 10°, the above formulae would indicate advisory speeds of 75 km/h in most jurisdictions, 74.6 km/h (rounded to 75) in Victoria and 83.2 km/h (rounded to 85) in New South Wales.

The relationship used in New South Wales is believed to be the only relationship based on observed speeds rather than assumed comfort criteria and hence results in higher advisory speeds.

A number of comments with regard to existing criteria and methodologies were made by the respondents to the questionnaire. These comments are summarised below.

- The ease of use and low price of the existing ball-bank indicator method made it an attractive means of establishing advisory speeds. It was suggested that more elaborate or expensive methods would be unattractive;
- States may be willing to adopt the amended criteria but would firstly carry out their own independent assessment. The differences between the states' criteria prior to the amended standard were small and hence adoption of the new relationship between ball-bank angle, test speed and advisory speed would not make a significant impact;
- The true value of the new standard was in a consistent test methodology but there was scepticism about whether this would be followed strictly in practice;
- Little attention had been paid to the needs of vehicle types other than passenger cars. Most engineers consulted assumed that heavy vehicle drivers were aware of their vehicle's constraints and drive within these limits. Whilst a large safety margin was known to exist for passenger cars, there was no empirical knowledge of the size of safety margins that trucks operate under;
- Because of the safety margin involved and the coarse increments adopted, an experienced but subjective evaluation was considered suitable to achieve the same result as the more objective ball-bank and RGDAS methods;
- The AS 1742.2 advisory speed selection procedure does not represent a significant improvement over past methods, but merely a refinement of them to achieve national uniformity;
- Relatively few advisory speed surveys have been conducted recently and as such, there has been only minor attention paid to this area. Furthermore, the attitudes towards the suitability or effectiveness of advisory speeds are not consistent between the States and Territories nor even amongst regions within the states. Such differences are hardly surprising considering the variation in topology and hence likelihood of sub-standard curves.

5 Literature Review

An examination of the literature was made to review the available knowledge on the effectiveness of providing information to drivers about appropriate curve speeds and the ways in which this can be achieved. As many similar reviews have been conducted in the past only the more recent material has been included below. It is divided into three categories: reviews of criteria and methodology, observed curve speed and accident studies.

Reviews of criteria and methodology

Australia

A major review by McLean (1974) had recognised the shortcomings of the ball-bank indicator and side force criteria as employed by NSW and Victoria at that time. McLean compared four states' side force criteria, finding only small differences in the results (4-5 km/h) which pointed to the feasibility of adopting a national criteria. However, greater inconsistencies were observed arising from the survey procedures employed.

The most recent and pertinent review of Australian practice was by Preisler *et al* (1992). At that time, all Australian states and territories reported using ball-bank indicators to determine advisory speed but each state used a unique assumed relationship between ball-bank angle, test speed and advisory speed. Incorrect or uncalibrated ball-bank indicators, and differences in the rigour to which the agencies applied their own procedures, were sources of error that contributed to the inconsistencies in posted advisory speeds. Only South Australia had adopted the procedures in the then current Australian Standard AS 1742.

Preisler *et al* accepted the shortcomings of relying on ball-bank indicators and side friction factors to model vehicle curve negotiation but considered that consistency of application was a higher goal than precision. Correspondingly, they recommended that:

- the fundamental basis of the ball-bank indicator method be validated or updated through a program of research;
- that the procedures and equipment used be standardised; and
- that attention be directed towards assessing the effectiveness of providing advisory speeds to drivers in addition to providing symbolic warning of curvature.

The findings of Preisler *et al* were supported by a Tasmanian working group examining speed zoning practice (DOT 1993). They recommended:

- adoption of a national standard criterion for setting curve advisory speeds;
- that the equipment used be appropriately calibrated; and
- that further research into the validity of the existing ball-bank indicator method be undertaken.

No such further research has been published to date.

Other Countries

Concern about inconsistencies in the criteria used for establishing advisory speeds was expressed by North American practitioners polled by Zwahlen (1983). The poll also revealed considerable difference of opinion over warning sign location procedures and recommended a need for policies on consistent procedures for setting advisory speeds.

Merritt (1988) plotted the development path of the US criteria for advisory speed setting, and polled US states to determine the methods and criteria employed. Nearly all states used the ball-bank indicator but the sources of criteria for establishing the advisory speed varied. They included:

- AASHTO 1984 A Policy on Geometric Design of Highways and Streets;
- FHWA Traffic Control Devices Handbook;
- ITE Transportation and Traffic Engineering Handbook; and
- Modified versions of the FHWA criteria.

Merritt surmised that, despite advances in vehicle dynamics since the 1930s and 40s when the existing assumptions regarding 'comfortable' side friction coefficients were established, the criteria for selecting advisory speed are still acceptable. However, it appears that operational practice does differ from that defined in guidelines and policy.

Bhuller *et al* (1993) polled Californian regional engineers to determine the criteria used for installation of curve warning signs and advisory speeds. Most used the ball-bank method in conjunction with accident histories when establishing advisory speeds for curves. This report included an analysis of accident reductions related to curve warning signs and advisory speeds (the findings are reported later in this report).

A most authoritative analysis of advisory speed setting criteria was undertaken by Chowdhury *et al* (1991). This study observed curve speeds in three states and compared these speeds to advisory speeds derived using the criteria used in those states. The three methods included the ball bank indicator method and nomograph method (based on standard curve formula and assumed side frictional coefficient of 0.16) both derived from the FHWA's *Traffic Control Devices Handbook,* and the observed 85th percentile curve speed. Considerable variation in the application of these methods was encountered.

The results of the comparison of the methods based on speed studies are presented in the following section on observed curve speeds. The report makes it clear that most advisory speeds are set too low, and that many drivers do not respect them and drive at speeds consistently above the signed speed (up to 16 km/h). If, however, a driver encounters a curve with an advisory speed that closely models the true 'safe' curve speed, safety may be jeopardised.

The shortcomings in the existing criteria are well documented. This review confirms the results from the survey of local and overseas practice reported earlier, that inconsistent application of survey methods and obsolete assumptions about driver literature pertaining to the effectiveness of advisory speeds through speed surveys and accident analysis is valuable.

Observed speeds at curves

Chowdhury *et al* (1991), in response to a number of prior US surveys, established that observed 85th percentile curve speeds were considerably higher than posted advisory speeds irrespective of the method used to determine the advisory speed. Furthermore, they suggest that the posted advisory speeds have little relevance to motorists because the frictional basis for the criteria are too conservative.

The study involved speeds collected on 28 curves using radar. The curves were then carefully surveyed using a ball-bank indicator. The results indicated that compliance with posted limits ranged from 43% to 0% depending on the advisory speed (*Table 2*). Speeds did reduce within the curves but only by half (on average) of the expected drop according to the posted advisory speed (*Table 3*).

It is important to note that no information is available as to the period when the data was collected and it is unknown if traffic patterns during such times were representative. It may be, for example, that there is poor compliance during low crash risk periods and higher compliance during higher crash risk periods.

Advisory speed (mi/h)	% compliance
15-20	0
25-30	8
25-40	5
45-50	43

(CHOWDURY *et al* 1991, p67)

Table 2
Percentage compliance with advisory speeds

State	Suggested speed drop (mi/h)	Actual speed drop (mi/h)
Virginia	15.8	4.6
Maryland	18.7	10.4
West Virginia	7.9	4.9
All curves	15.1	6.1

(CHOWDURY *et al* 1991, p68)

Table 3
Observed average speed reduction

The survey revealed that the 85th percentile friction value observed (0.29) was almost twice the assumed value of 0.16 applied in the existing advisory speed setting techniques. The authors recommended that the friction values be revised to 0.3 for low speeds and 0.2 for higher speeds, and also that changes be made to the accepted threshold ball-bank readings, in the absence of an alternative approach based on observations of speeds.

An evaluation of the application of AUSTROADS horizontal curve design standards for New Zealand (Bennett and Dunn 1994) included a curve speed survey. Observations from 23 curves indicated that at only 39% of sites were speeds below the design standard. At sites with advisory speeds, 85th percentile speeds were 10-28 km/h higher than the advisory speed.

Johnston (1983) summarised the findings of studies conducted into the effectiveness of curve warning signs and advisory speeds. Speeds observed after the introduction of curve warning signs and advisory speeds appear to increase or decrease after installation, depending on the study.

An early study of curve speeds and lateral forces on 162 curves in Ohio was conducted by Ritchie (1972). The author was attempting to determine the factors that influence speed selection. A series of curves were traversed by 50 drivers whilst speed and lateral acceleration was measured. The speeds of subjects were grouped and analysed by curve type or presence of warning signs and presence of advisory speed signs. For each of the speed groups, higher lateral accelerations were observed on curves with signs. A 2-way Analysis of Variance revealed a significant increase (to 1% level) in speeds for curves with warning signs and a similar significant difference for the presence of advisory speeds. Furthermore, below 40 mph (64 km/h), drivers exceeded the advisory speed whereas above this limit they did not. These findings may be explained by increased driver confidence arising from the provision of better information.

Lyles (1982) attempted to differentiate between the effect of different treatments on two substandard curves using lateral position and speed data. These treatments included a standard curve warning sign, and a warning sign with one of three alternative advisory speed plates. Speeds were not available for the sites minus the signs. The results did not point to any particular sign configuration being superior. Drivers did reduce speed to within 4 mph of the advisory speed but did not record these values until the curve exit. Lyles considered that injudicious use of the signs lowered respect for the treatment which may mean advisory speeds are ineffectual when they really count (ie on severe curves).

Zwahlen (1983) concluded that advisory speeds are not particularly effective in reducing curve speeds and offer little benefit for passenger cars over curve warning signs alone under dry weather conditions. This resulted from a detailed study of driver eye fixation and vehicle dynamics during unobtrusive observations and from an instrumented vehicle study. The author suggested that advisory speed signs may be of greater value for heavy vehicles and motorcycles than cars but that further research was warranted. The effectiveness of advisory speeds in adverse weather conditions was not known.

The majority of studies carried out to date examining the impact of advisory speeds on curve speeds suggest that observed speeds tend to be higher than advisory speeds and that advisory speeds appear to not offer significant informational benefit over and above a curve warning sign. Advances in passenger car dynamic capabilities appear to have increased the effective margin of safety to make the existing criteria too conservative contributing to reduced respect for the signs used.

A number of comments can be made about these studies.

- The provision of better information about the curve may in fact contribute to higher speeds through increased driver confidence. Drivers may rely on previous experience and apply a standard offset to the posted speed, knowing a large margin of error has been applied. Furthermore, drivers may reduce their reliance on visual cues and adequate sight distance on the basis of a level of expectancy provided by numeric information about the curve's standard.

- The studies described above were conducted in dry weather and in daylight, yet it is possible that drivers rely on and, comply with, the posted speeds under wet or low light conditions. Studies of driver behaviour under adverse conditions are required to confirm this.

- No reference is made to heavy vehicles in these studies, reflecting a neglect of their particular stability requirements in the current criteria, methodology and assumptions about friction demand. Whilst the problem of trucks capable of speeds similar to passenger cars is a relatively recent one, consideration of the impacts of increases in the friction factors must consider the needs of this critical road user group.

- Another issue arises as to the ways the speeds are collected. Bias may be introduced into speed surveys by the use of obtrusive speed measurement methods. The use of manual radar collection or pavement mounted detectors could impact on the observed speeds, although confirmation of this effect is unavailable.

Accident studies

While it perhaps could be assumed that accident analyses would offer the best performance measure of advisory speed effectiveness, inadequacies in the data mean this is not the case. Although many curve accident studies have been published, only a few have addressed the specific issue of advisory speeds. Even fewer such studies have been based on reliable and pertinent accident records.

An early study of curve warning signs on the Hume Highway by Kneebone (1964) produced highly significant reductions in casualty accidents of 62% and similarly significant reductions of 56% for all accidents. It must be noted however that the trial section had a particularly bad accident history, and one could question whether the application of this reduction rate to other sites is reasonable.

Sanderson *et al* (1985) summarised the expected accident reductions, calculated from previous studies, for a range of countermeasures. Advance warning signs on two-way highways were considered to produce a 30% reduction in accidents, however, no estimates were made for the inclusion of supplementary advisory speed plates.

highways were considered to produce a 30% reduction in accidents, however, no estimates were made for the inclusion of supplementary advisory speed plates.

A study of Dutch curve accidents (Oei and Schoon 1988) highlighted the roles that driver, vehicle and roadway variables have in accidents on curves. The majority of those accidents evaluated occurred on rural highways. Consequently, the countermeasures recommended concentrated on rural highways and included warning signs, improved delineation, safety barriers and advisory speed signs.

Bhullar *et al* (1993) attempted to establish the effectiveness of curve warning treatments from three years of mass accident data. It appears that limited accident numbers and an inappropriate methodology have conspired to limit the worth of the analysis. Despite this, some reductions in run off road accidents were reported after the installation of curve warning signs advisory speed plates and chevron alignment markers.

6 Heavy Vehicles

The AS 1742.2 provisions for determining advisory speeds on horizontal curves require the test vehicle to be a medium sized car or station wagon (SA 1994). Neither the survey methods nor the criteria for setting advisory speeds in use locally or overseas considers the particular dynamics of heavy vehicles.

Trucks exhibit different performance dynamics to cars. Cars or motorcycles will respond to excessive lateral acceleration and yaw movement by skidding. Trucks will roll over once they exceed a critical value of lateral acceleration called the roll limit. This limit is a function of the vehicle's centre of gravity height (COG) and track width, with suspension type, combination configuration, tyre frictional characteristics and articulation angle all having an impact.

Furthermore, different types of trucks exhibit different roll-over characteristics, with rigid trucks, having higher centres of gravity and narrower tracks, tending to be less stable than articulated trucks.

Typical roll limits for trucks vary considerably, but a recent Australian review of the fleet's dynamic capabilities indicates a mean of 0.3g and a range from 0.25 to 0.35g with most articulated vehicles being between 0.3 to 0.4g (NRTC 1993). Navin (1992) reports that passenger cars may achieve lateral accelerations approaching 0.85g (on dry pavement) before becoming unstable and are unlikely to roll over unless they strike an object.

The roll stability of a truck varies to a greater degree than a passenger car between loaded and unloaded conditions. Furthermore, the types of load and load configuration will significantly influence a truck's dynamic performance through alterations to its COG and roll stability.

It is not clear how heavy vehicle drivers use existing advisory curve speeds to optimise their safety. However, if truck drivers operate **at** the advisory speeds, depending on the vehicle's configuration and the curve's design, they may in fact be operating within a small margin of the critical roll over speed.

Any increase in advisory speeds, justified on the grounds of improved passenger car dynamics etc, will require truck drivers to adapt their curve negotiation strategies to recognise the widening gap between the car based curve advisory speed and a safe speed for their vehicle.

A further example of curve warning systems being based around car drivers is curve delineation, an area where considerable advances have been made in recent times. These advances have included long and short range delineation such as chevron alignment markers, improved line marking materials with better reflective qualities, raised reflective pavement markers, guide posts and post mounted reflectors. While it is not possible to quantify the direct benefits to be gained through individual delineation treatments, the evidence suggests that such improvements as described above reduce the reliance on curve advisory speed signs and contributes to reduced single vehicle accidents on curves.

The retroreflective performance of delineators, line markings and reflective sheetings is very sensitive to what is referred to as the observation angle. This is the angle formed between the delineator, the light source (headlight) and the light receiver (eye).

Cars typically present an observation angle of 0.2° at 160 metres distance and rarely larger than 0.5°. Trucks however, being larger and with greater separation between the headlights and driver, present observation angles over 0.5° any closer than 180 metres. Most reflective materials are optimised to provide good retroreflectivity at small observation angles and over long distance and as such, passenger cars appear much better served by delineators than trucks.

Having recognised this problem, manufacturers of reflective devices are developing improved products that perform better at larger observation angles. There remains little research into the specific delineation requirements of truck drivers and this would appear to be an area requiring further attention. In the meantime, although the improved delineation products and implementation guidelines are serving to better guide and warn all drivers regarding changes in road alignment, truck drivers are not benefiting to the same degree as car drivers.

7 Discussion and Conclusions

The major points that have emerged from this review of curve warning signs and curve advisory speeds are outlined below.

- While all countries surveyed use curve warning signs, advisory speed signs are used to a varying extent in different countries;
- While the value of using curve warning signs has not been questioned, some countries have questioned the use of curve advisory speeds (mainly for the reasons that follow);
- Where used, curve advisory speeds are based on comfort not safety;
- Many of the field studies that established comfortable curve speeds based on ball-bank readings were conducted in the 1930s and 1940s. Considering the advances made over the last 50 years in vehicle dynamics and pavement surfaces, it is perhaps surprising that road design and advisory speed setting criteria remain based upon these early figures (Merritt 1988, McLean 1993);
- There is a greater range of vehicles on the roads today compared with the days when the original trials were conducted (Preisler *et al* 1992). This means that the 'family sedan', as used to determine the advisory speed, may be representative of a much lower portion of the total of road users now than at the time of the original experiments;
- Trucks exhibit different performance dynamics to cars and are not well served by current curve advisory speeds;
- While it may be argued that curve advisory speeds are conservative, it appears that there is now more consistency between jurisdictions in their setting than was recorded in 1992 (Preisler *et al* 1992);
- Consistency appears to be more important than accuracy. For example, it would seem that individual drivers will accept advisory speed signs that are not accurate as long as they are consistently not accurate (eg drive at advisory speed plus 15 km/h), however inconsistent inaccurate signing will be totally disregarded (Preisler *et al* 1992).

As the continued use of advance curve warning signs does not appear to be at issue, the remainder of this section will concentrate on a number of options that could affect the setting and signing of curve advisory speeds.

Option 1 Make no major changes to current practice (increase compliance with AS 1742.2)

Under this option the existing system of curve warning signs and curve advisory speeds as described in AS 1742.2 would be continued. Those jurisdictions that have not yet amended their procedures in accordance with this method would need to be encouraged to do so.

To achieve better consistency in advisory speed limits between and within states it would be necessary to better standardise the equipment and calibration methods used in each jurisdiction.

It is suggested that drivers be made more aware that advisory speed signs relate to comfort and not safety.

This is the preferred option in most cases (see option 2 for exceptions).

Option 2 Improve delineation

Under this option, improved delineation treatments would be installed on curves with the aim of reducing the number of curves requiring advisory speeds.

It would be hoped that improved delineation would provide feedback to the driver about the severity of curvature and complement the curve warning sign. As improved delineation would reduce the amount of uncertainty with which drivers approached the curve, speeds may increase, allowing the removal of advisory speed signs where the (usually very conservative) curve advisory speed is close to the speed limit applicable on the road.

It is thought that the limiting of advisory speed signs to those curves where the information is critical to the safety, rather than just the comfort, of road users would go some way towards raising the credibility of the signs.

In further considering this option possible safety implications would need to be examined.

Option 3 Reduce the friction factor

It has been suggested that a reduction in the friction factor used would better cater for heavy vehicles. Such a reduction in friction factor would result in a reduction in the advisory speed. Although this would provide less stable vehicles with a greater safety margin, it is expected that the credibility of the warning message among passenger car users would be reduced.

Further, trying to sign curves for trucks is not straightforward as the type of truck, types of load and load configuration will significantly influence a truck's dynamic performance through alterations to its centre of gravity and roll stability (ie the same truck can perform differently depending on the type of load and how it is loaded).

This option is not considered to be feasible.

Option 4 Increase the friction factor

Increases to the friction factor (which would increase the advisory speed) to more accurately represent the reality of modern passenger car performance have been suggested (Chowdhury *et al* 1991).

The assumptions implicit in this argument are that drivers of other vehicle types (eg trucks) will be required to adjust their curve speeds to suit the dynamic capabilities of their particular vehicle. Because passenger cars operate with such a large safety margin on existing curves, the reduction in this margin is unlikely to be significant but the implementation of this option holds many traps.

In New Zealand, for example, proposed changes to more closely align the advisory speeds with vehicle performance were thought to have possible serious safety consequences (particularly during the implementation phase) and a decision was made to remain with the existing method (which is similar to that used in Australia).

Even if curve advisory speeds were increased, some car drivers (and many heavy vehicle drivers) would not find the suggested speeds suitable, resulting in little gain over the current system.

This option is not considered to be feasible.

Option 5 Install separate truck advisory speed signs

Adding a separate advisory speed sign aimed solely at heavy vehicles would initially appear logical however there are a number of problems with this option:

- the truck fleet possesses considerable diversity in roll stability making the selection of a suitable speed very difficult;
- further, the same truck can perform differently depending on the type of load and how it is loaded (facts that the driver is often not fully informed about);
- the costs of development, retrofit, capital and maintenance would be considerable and many of the benefits intangible;
- the environmental impacts of additional signs would need assessment; and
- the risk of confusion to car and truck drivers resulting form two signs would be high.

This option is not considered to be feasible.

Option 6 Remove all curve advisory speed signs

From the survey of international practice conducted as part of this study it is apparent a number of countries do not use advisory speeds. The reasons for this include:

- the difficulty of selecting an appropriate speed for variable road, vehicle and climatic conditions;
- insufficient evidence as to the added worth of advisory speeds;
- lack of sub-standard curves with poor visual indication;
- adequate warning provided by symbolic representation of curve severity; and
- use of regulatory speed limits to achieve the same effect.

Under this option, curve advisory speeds would be removed and curve warning signs replaced by a system of 'graded' curves. A sign showing a gentle curve could be regarded as a slight speed reduction required, while a sign showing a right angle bend would indicate that a larger speed reduction would be required.

Notwithstanding the removal of curve advisory speed signs by some European countries, it is considered that there is enough evidence that curve speed advisory signs result in reduced numbers of accidents (as quoted in McLean 1974 and Preisler *et al* 1992) that their wholesale removal could not be recommended.

In conclusion:

- following the introduction of AS 1742.2 in 1994, a more consistent method is now being used to set curve advisory speeds than that reported by Preisler *et al* (1992), although progress towards standardisation and calibration of equipment (as recommended by Preisler *et al*) is not known;
- notwithstanding the extreme conservatism of many curve advisory speeds, possible safety implications in increasing these advisory speeds, particularly during the installation phase, as well as the lack of consideration of non-car vehicles, would appear to rule out a major change in the basic criteria for setting curve advisory speeds;
- better comunication with drivers about the fact that advisory speeds are set based on comfort rather than safety (unlike speed limits) may avoid the need to change how these speeds are set;
- the simplest and cheapest method of setting curve advisory speeds remains the ball bank indicator, although the development of new technologies better placed to overcome the problems of the imprecision and inconsistency of ball-bank indicators but retaining the simplicity of operation and low cost should be encouraged.

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