Changes in Geometric Design Standards on Interurban Undivided Roads

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ABSTRACT

This paper outlines how geometric design standards for undivided interurban roads have changed over time in response to financial, safety and environmental constraints. Initially, the dimensions of each road element were selected to provide a safe road layout and a desirable level of service. For example, the minimum sight distances were based on conservative reaction times and friction factors for each design speed, while horizontal curve radii were selected on assumed safe stability requirements. In restricted areas or difficult terrain, applying these standards increased costs. With better information on speed / flow relationships and on the safety of geometric elements, design standards were amended and reductions were permitted in difficult conditions. Combinations of elements were also taken into account. However, geometric standards still mainly consist of individual design elements which the designer must fit to the terrain, the intersections and the adjacent land use.

To illustrate the principal factors which have modified geometric standards for undivided roads in all countries, the different versions of the Irish geometric design guidelines are described. Originally based on US standards, they are now almost identical to the current UK standards. The Irish design guidelines are used to show how geometric standards evolved in response to better knowledge on safety, increased traffic capacities, environmental considerations and to changes in design and construction practices. The principal changes in cross section, alignment and intersection elements are described. Also, the different intermediate road types used to fill the large gap in capacity between undivided two lane roads and divided four lane roads and the changes for roads in sensitive locations.

It is pointed out that geometric design standards have not always been based on actual driver behaviour, speed limits or enforcement regimes. Also, that designers seldom depart from standards due to legal concerns which can result in suboptimum road layouts. In an era of "safety & health" regulations, design standards do not aim at eliminating road fatalities but implicitly assume an "acceptable" number of fatalities and injury accidents per year. Consumer choice is not considered. Modifications to design standards for undivided roads, including the use of intelligent transport systems to achieve balanced networks without reconstruction, and climate change considerations are suggested to give more sustainable standards.

INTRODUCTION

Geometric design standards for undivided interurban roads were originally based on desirable values of individual design elements. The standards in most countries were strongly influenced by the US AASHO guidelines (1). However, national standards were specified by local experts which resulted in differences between countries although the vehicles and drivers were similar. As more information on safety and vehicle dynamics became available, standards have become more uniform. However, there are still significant differences in the national standards for undivided roads, particularly for design elements such as intersections, hard shoulders and signing. The changes to the Irish design standards are used to illustrate some of the factors which have modified geometric standards worldwide. This paper is based on the author's work on geometric design standards and his involvement with the Irish National Roads Authority over many years.

BEFORE THE CAR

The Irish are among the great road builders. The largest preserved Iron Age road in Europe was built across a bog at Corlea in Ireland in 148 BC. About 2km (1.3 miles) long and 3.7m (12 feet) wide, it was constructed of oak planks laid on birch runners and was wide enough for two carts to pass. Irish roads were first classified as "Sligheanna" (highways) and "Bohereens" (bo is the Irish for cow). Cormac's Glossary defines a Bohereen as "a road of such breadth that two cows fit upon it, one lengthwise, the other athwart and their calves and yearlings fit on it along with them". Most roads in Ireland up to the 18th century were merely tracks for pack horses. The planning of roads on a large scale followed the first Turnpike Act in 1729. Road maps of 1778 indicate that the average width of a road at that time was about 14 feet. The Post Office Act for making new roads, passed in 1804, resulted in rigorous standards being laid down by Post Office engineers for Mail-Coach roads. For example, gradients had to be less than 1 in 35 and a width of 42 feet was an indispensible requirement. The Grand Jury Act of 1836 provided that new

roads should be laid at widths varying from 16 to 50 feet, but seventy years later Leebody (2) remarked "for some reason probably an Irishman's love for a bit of land and his objection to parting with it – the great majority of our roads have widths much more the former figure". The maximum speed of the fastest mail coach was about 12 miles per hour, consequently curvature was not of great importance and the emphasis was on width and grades. When the motor car arrived around the end of the nineteenth century, speeds were limited to 4 mph (Red Flag Act) up to 1896, then to 12 mph until 1903, and to 20 mph until 1933. The removal of the speed limit then brought a new problem - the realignment of curves and the provision of superelevation. The great era of geometric design had arrived. As in most countries, World War 11 stopped major road realignment in Ireland but permitted an investigation into road design standards.

THE 1946 STANDARDS

Although colloquially known as "standards", all Irish government geometric design publications have been "guidelines" or "manuals". Presumably, this is to avoid legal cases where guidelines have not been strictly applied. The first "modern" Irish geometric design guidelines were contained in the "Report on Standards for the Classification and Lay-Out of Roads" issued by the Department of Local Government in 1946 (3). This short report formed the basis of road design and practice in Ireland until the 1960's.

The "1946 Standards" were prepared by a famous Irish road engineer, P.J. Hogan. They were based on the best available international practice for driver comfort and safety. The basis for the dimensions of each design element was clearly specified. The recommendations for many elements, such as the minimum stopping sight distances or the use of the predicted 30th highest hourly volume in the design year as the design traffic volume, are similar to those in use today. Other design elements such as the 600?? vehicles per hour design capacity of a 7.3 m (24 ft) undivided road were very low by today's standards; dual carriageways were recommended where this design capacity was exceeded. The 1946 Standards also specified "non-passing sight distances" as the minimum sight distances on two lane roads. These were considerably longer than the minimum stopping sight distances and allowed an opposing vehicle in the same lane to be seen in time to avoid a collision. Non-passing sigh distances were also specified in the standards used in France and Russia at that time but not in the standards of West Germany, the UK or the US (4).

After World War 11, many of the interurban roads in Ireland were redesigned to the 1946 Standards but only a few lengths were actually constructed due to financial constraints.

THE 1977 RT STANDARDS - THE RT SERIES

Recognising the need to modify the 1946 Standards because of developments in road and vehicle design, the Irish Department of Local Government asked An Foras Forbartha (The National Institute for Physical Planning and Construction Research) to develop revised recommendations for the layout of roads. The resulting Geometric Design Guidelines (5), first published in 1977 and revised up to 1986, consisted of a series of design manuals and reports known as the RT Series in Ireland and are referred to in this paper as the "1977 RT Standards". These manuals were more comprehensive and user friendly than the 1946 Standards and were used for geometric road design in Ireland up to the late 1990's. The principal changes from the 1946 Standards for undivided interurban roads included:

- The use of metric rather than imperial units.
- The specification of design speeds of 40, 60, 80 and 100 km/h. The choice of design speed was an administrative decision. In practice the design speed used for most new interurban undivided roads was either 100 km/h (62 mph) or 120 km/h (75 mph); the use of 80 km/h (50 mph) was restricted to difficult conditions and to low volume county roads.
- The use of US Highway Capacity Manual (6) levels of service and design capacities. Limited field studies indicated that Highway Capacity Manual data, apart from heavy commercial vehicle equivalency factors, was applicable in Ireland. Design capacities for Levels of Service C and D were specified in passenger car units per hour in terms of the Carriageway Width and Percent Sight Distance greater than 460m (1500 ft) as in the Highway Capacity Manual (6).
- Tentative design capacities for wide two lane 10m (33 ft) carriageways were included. These were based on the extrapolation of Highway Capacity Manual data supplemented by capacity data in UK

Department of the Environment publications. Wide two lane roads were seen as intermediate capacity roads between standard 7.3m (24 ft) single carriageways and four lane divided dual carriageways.

- The recommended minimum stopping sight distances were slightly longer than in the 1946 Standards; the assumed reaction time was increased from the previous low value of 1 second to 2 seconds but the braking distances were reduced. The 1946 Standards braking distances were calculated by assuming a constant friction coefficient of 0.026 based on comfort, whereas the 1977 RT Standards used AASHO friction coefficients based on safe braking criteria (as in the standards of most other countries).
- Minimum non-passing sight distances were now only required for two-lane National Roads (the principal interurban roads) without hard shoulders.
- Based on a study of the vehicle population in Ireland and a similar study in the UK, the driver eye height for the measurement of sight distances was reduced from 1.22m (4 ft) to 1.05m (3.5 ft). The object height for the measurement of stopping sight distances was reduced from 0.61m (2 ft) to 0.15m (6 inches), the point of diminishing returns for excavation of vertical curves. The object height for passing sight distance was reduced from 1.22m (4 ft) to 1.15m (3.8 ft). This was assumed to be 0.15m (6 inches) below the roof height of an opposing low vehicle.
- Based on standards elsewhere and on limited observations of slow moving vehicles on horizontal curves during icy conditions, the maximum permitted superelevation rate on horizontal curves was reduced from 0.08 to 0.07. This increased the recommended absolute minimum radius by a small amount.
- The 1946 Standards did not specify maximum gradients. Based on the standards of other countries, maximum gradients were now recommended. These varied from 9% for a design speed of 40 km/h (25 mph) to 4% for undivided National roads with 100 km/h (62 mph) design speeds.
- The lengths of sag vertical curves in the 1946 Standards (based on a vertical acceleration of 0.45 m/s^2 (1.5 ft/s^2) were significantly shorter than those specified by any other country. Longer curves based on a headlamp sight distance criterion were recommended although the use of this criterion was considered dubious, since for night driving the headlamp range was insufficient to meet safe stopping requirements for speeds in excess of 80 km/h (50 mph).
- Hard shoulders were not included in the 1946 Standards. The new 1977 RT Standards specified hard shoulders varying from 1m (3.3 ft) to 3m (9.8 ft) in width for rural National undivided roads, depending on the design hour volume and the design speed (shoulders were optional on National Secondary roads). This was a subjective decision influenced by US practice and by the large rural population in Ireland. At that time no other European country specified hard shoulders for standard 7.3m (24 ft) single carriageway undivided roads (4).
- Detailed design layouts for junctions, including priority junctions and roundabouts were recommended. These were mainly based on UK practice contained in UK Department of the Environment Technical Memoranda. Irish warrants for the provision of auxiliary lanes (turning lanes), for the installation of isolated traffic signals and for pedestrian crossing facilities were also specified for the first time.

Comment on the 1977 RT Standards

As for the 1946 Standards, the values of the design elements in the new 1977 RT Standards were subjectively selected following studies of the available international knowledge, supplemented by limited field studies. The recommended values for each element were desirable values calculated using theoretical assumptions. However, as in all standards, there were large differences between these desirable values and those considered necessary by drivers. For example, between the assumed and actual speeds on horizontal curves or between the safe stopping distances or passing sight distances as perceived by drivers and the design standard values. The safe stopping distances in road safety publications were also shorter than the design standards values.

The dimensions of the design elements in the 1977 RT Standards were different from those in the standards of other European and North American countries which also varied (7). For many design elements these differences were substantial but perhaps not obvious to drivers who contend with a wide variety of roads of varying standards. .

Substantial lengths of undivided interurban roads designed to the 1977 RT Standards were constructed in Ireland between the 1970's and the 1990's. Generally these new roads were considered satisfactory but some operational and safety issues arose. For example, the 1977 RT Standards resulted in

designs with long horizontal curves and flowing alignment which reduced the number of passing opportunities. This resulted in dangerous passing and accidents on large radius curves designed with the recommended minimum stopping sight distances.

A comprehensive study of accident rates on the interurban National roads in Ireland was undertaken in 2003 (8). The National Road Database was used to determine the relationship between a number of road layout variables and road safety. Particular attention was paid to the road cross sections recommended in the 1977 Standards. After vehicle kilometres of travel, the number of junctions, roadside developments and lay-bys was the most important variable which indicated the importance of access control on high speed undivided roads. This study showed that divided roads were substantially safer than undivided roads but raised questions on the value of improving undivided roads due to the increased fatality rate on improved roads; two-lane roads constructed to the 1977 Standards had a significantly higher fatal accident rate than unimproved roads. This probably resulted from higher speeds on the improved roads. Another conclusion from this study was the high percentage of fatal accidents on undivided roads with climbing lanes. These results suggested that the enforcement of speed limits needed attention as part of the design process. It was also found that undivided roads with wide 10m (33 ft) carriageways had a slightly lower accident rate than standard 7.3m (24 ft) carriageways.

Other studies in Ireland showed that roundabouts were the safest type of at grade intersection but that they were not as safe as roundabouts in the UK (9). Also that intersection capacities in Ireland were significantly less than the UK values specified in the 1977 Standards. This resulted in severe traffic congestion at a number of roundabouts designed to the UK capacity values**.**

THE 2001 NRA DESIGN MANUAL FOR ROADS AND BRIDGES

The 1990's brought a period of accelerated prosperity for Ireland and greatly increased vehicle ownership (which had been considerably lower than in other Western European countries). This resulted in widespread traffic congestion. A major road construction programme and more efficient methods of road building were required. Up to about 1990, the Local Authorities had carried out almost all road design in Ireland and also supervised all road construction. No comprehensive design manual existed. While the 1977 RT Standards were used for geometric design, other documents and standards were used as considered necessary. For example, bridge and pavement design followed UK practice. Now various new forms of road design and build contracts were introduced. These required comprehensive road design and construction documentation. Also, new information on road safety indicated that design standards could be reduced without compromising on safety (10). A major objective was to ensure value for money without any significant reduction in safety by providing greater flexibility in difficult circumstances. Consequently, the National Roads Authority (the successor to An Foras Forbartha the publishers of the 1997 RT Standards) set up by the Irish government to provide a safe and efficient network of National roads, decided that new comprehensive design standards were required.

An initial study concluded that this should be done by adapting the UK Highways Agency's Design Manual for Roads and Bridges, DMBR (11). This adaptation was carried out by consulting engineers, Roughton & O'Donovan – Maunsell Alliance. In 2001, the National Roads Authority Design Manual for Roads and Bridges (NRA DMBR) (12) was introduced for use in Ireland. This was a modified version of the UK DMRB (11) which was originally introduced in 1992 and regularly updated. The UK DMRB covers all aspects of road and bridge design and assessment including pavement and bridge design, drainage design, lighting, signing and traffic management. Both the UK and Irish DMRB versions are in loose leaf format, are available electronically and are regularly updated. Differences between the UK and Irish standards are mainly limited to the administration of road schemes, to road signs and to the road network classifications. Some of the UK DMRB Standards and Advice Notes are not formally implemented for use in Ireland but are recommended as good practice. The detailed geometric design recommendations in the Irish version are almost identical to the UK manual. The new NRA DMRB involved very substantial changes from the 1977 RT Standards for geometric design which had been based on US practice (apart from intersection design which followed UK standards). The major differences relating to the geometric design of undivided roads included:

- The provision of comprehensive guidance on the planning, design, assessment and maintenance of road projects.
- The design speed, now defined as the 85% speed, was to be based on an estimate of the traffic speeds for the alignment and layout constraints. On single carriageway roads with a speed limit of 80 km/h

(50 mph) or greater, the design speed to be used is the calculated value or 100 km/h (62 mph), whichever is less. New design speed increments were specified: 50, 60, 70, 85, 100 and 120 km/h.

- *Relaxations* (reducing desirable design values by up to two design speed increments) from the NRA DMRB were permitted at the discretion of the designer and *Departures* (reducing design values by more than two design speed increments) after obtaining permission from the National Roads Authority. *Relaxations* were limited to clean sites while combinations of *Relaxations* were generally not permitted. The designer was not given choices over the widths of running lanes, hard strips or hard shoulders for a particular road type. Any such variation would be a *Departure*. The stated reason for permitting *Relaxations* was that Desirable Minimum Standards may lead to disproportionately high construction costs or environmental impacts and that research in the UK had shown that accident rates did not significantly increase until the reduction in standards below desirable minimum values is considerable. It is interesting to note that in the UK *Relaxations* of up to 4 design speed steps are permitted compared with only two design speed steps in Ireland.
- Road safety audits were formally required.
- Cross sections and head rooms at structures were specified.
- New standard cross sections were introduced. These had the same titles as the UK DMRB cross sections (11). Three types of undivided road were specified: Reduced Single (7.0m) Carriageway; Standard Single (7.3m) Carriageway and Wide Single (10m) Carriageway. In contrast to the UK DMRB which does not specify hard shoulders (just 1.0m hard strips) for single carriageways, 2.5m hard shoulders were specified except for Reduced Single Carriageways (0.5m hard strips).
- A minimum "overtaking value" (the total length of the overtaking sections divided by the road length) was required for each road type; 15% was required on Reduced Single Carriageways, 30% on Standard Single Carriageways and 40% on Wide Single Carriageways. These were identical to the recommended UK values.
- Junctions with major roads were to be priority junctions with ghost islands or roundabouts.
- The method for assessing the required carriageway type differed from both the 1977 Standards and from the UK DMRB method. In the NRA DMRB, the level of service objective for the interurban road network was an average journey speed of 80 km/h (50 mph); equivalent to the US Highway Capacity Manual Level of Service D. Annual Average Daily Traffic capacity values for Level of Service D were given for each road type. However, for national strategic reasons, the Irish government decided that five major National Primary routes should be developed to motorway / high quality dual carriageway standard in their entirety – providing a minimum Level of Service C. In contrast, the previous 1977 RT Standards had listed design capacity values in passenger car units per hour for both Level C and Level D and stated that the choice of level of service was a policy rather than a geometric design decision.
- Desirable Minimum Stopping Sight Distances were based on a 2 second reaction time and a 0.375g deceleration rate which could be achieved in the wet without loss of control. This was a small increase on the 1977 RT Standards values. For the measurement of stopping sight distances, the object height lower limit was increased from 0.15m (6 inches) to 0.26 m (10 inches) - the height of the rear lights of other vehicles, as in the UK DMRB.
- Full Overtaking Sight Distances (FOSD) were to provide "a reasonable degree of safe overtaking for 85% of traffic". These were based on UK studies of actual overtaking manoeuvres and were significantly shorter than the Passing Sight Distances in the 1977 RT Standards which had been calculated from theoretical assumptions.
- The 1977 RT Standards had recommended Absolute Minimum Horizontal Curve Radii for a 7% superelevation rate and AASHO (1) side friction factors. These standards had also included Minimum Design Radii based on a superelevation rate of 6% and a side friction factor of 0.09 and recommended the use of larger radii than the Minimum Design Radii where feasible. In contrast, the 2001 NRA DMRB specified longer Desirable Minimum Radii values with a superelevation rate of 5%, but also included radii for one and for two design speed steps below the Desirable Minimum values with a 7% superelevation rate; these were smaller than the values in the 1977 RT Standards.
- The Desirable Maximum Gradient for all single carriageways was increased from 4% to 5%
- To reduce the frequency of serious accidents, the design principles for single carriageways stressed the need to provide obvious lengths for overtaking. Consequently, traditional "flowing alignments" using mid-large radius curves were to be avoided. Also, Desirable Minimum Crest Curves were not be used on non-overtaking sections.

Comment on the 2001 NRA DMRB Standards

Unlike the 1977 RT Standards, the new comprehensive NRA DMRB standards (12) and the additional supporting documentation in the UK DMRB (11), give detailed guidance for almost all aspects of road planning and design including environmental considerations, the needs of the elderly and the disabled, etc. Much greater flexibility is given to the road designer compared with the 1977 RT Standards which were published as "guidelines" but were rigidly applied in practice. Although the new standards demand greater effort by the designer, advanced computer aided design packages are available which permit alternative designs to be quickly compared and evaluated and ensure compliance with layout and safety requirements. A slight regret is that the new standards end the existence of independent Irish standards. However, maintaining independent standards does not make sense for a small country!

A substantial road building programme has been carried out in Ireland since the early 1990's and the roads designed to the new NRA DMRB standards have been very satisfactory and have contributed to a substantial reduction in accidents. However, environmental and loss of heritage objections against many road schemes resulted in long delays and increased costs. These delays partly resulted from European Union Directives which required environmental impact assessments and extensive public consultations. The archaeological investigations required significantly increased costs. Land prices for road construction in Ireland increased substantially which reinforces the need to minimise land take in future.

As with previous standards in all countries, consumer choice had little influence on drawing up the 2001 standards. For example, many drivers, pedestrians and cyclists strongly dislike roundabouts but their use was recommended!

CHANGES IN STANDARDS SINCE 2001

The NRA DMRB (12) has been regularly updated since 2001. These changes mainly followed changes in the UK DMRB (11) or involved the formal inclusion of additional parts of the UK manual into the Irish version. Recent significant changes in the design of undivided interurban roads in Ireland include the following.

A policy of restricting new vehicle accesses onto interurban National roads outside 50 km/h (31 mph) urban speed limit zones.

Wide single carriageway (10.0m / 33 ft) roads were recommended in the NRA DMRB for road sections which exceeded the capacity of a standard single carriageway (7.3m / 24 ft) but did not justify the provision of a dual carriageway. However, such roads did not provide clearly identifiable sections for overtaking and special approval was required from the National Roads Authority for schemes which would create more than 2 km (1.2 miles) of wide single carriageway. It was initially considered that 2+1 roads with wire barriers separating traffic in opposing directions would be a more satisfactory alternative. 2+1 roads are three lane roads with two lanes in alternating directions to provide overtaking opportunities. They were very safe in Sweden and other European countries (13). A few experimental sections were constructed in Ireland which were also very safe. Consequently, in 2007 the Irish DMRB was amended to remove the wide single carriageway (10m) road type entirely (it is still included the UK DMRB) and two new divided road types were specified instead, the Type 2 dual carriageway and the Type 3 dual carriageway:

- Type 2 Dual: Divided **2+2** lanes carriageways (2 x 7.0m; 2 x 23 ft) separated by a median barrier and with a 0.5m (1.6 ft) hard strip at the outside edge of each carriageway.
- Type 3 Dual: Divided **2+1** lanes (7.0m + 3.5m; 23 ft +11 ft) separated by a median barrier and with 1.0m (3.3 ft) hard strips.

The NRA DMRB states that the Type 3 Dual (2+1) is primarily for retro fitting existing roads. The Type 2 Dual (2+2) reduced standard divided road is seen as a more satisfactory solution for new intermediate capacity roads between standard undivided single carriageway roads and standard dual carriageways. The cost of a Type 2 dual carriageway (2+2) is about 15% more than a Type 3 Dual (2+1) but provides a large increase in capacity.

Possible new designs for low volume interurban roads are being considered. The application of the DMRB standards on low volume National roads (below 5000 AADT) can result in schemes of significant cost that are not economically justified on traffic and safety grounds. Many of these low volume roads are in rugged and scenic terrain of high amenity value for tourism. The application of the DMRB standards can cause substantial environmental impacts. A pilot project is being considered by the Irish National Roads Authority to test a new approach. The key features are a narrow single carriageway of 6.0m (20 ft) with

narrow grass verges (0.5m / 1.6 ft absolute minimum), 4 steps *Relaxations* permissible from the NRA DMRB (as currently permitted in the UK), a design speed of 80 km/h (50 mph), a permissible maximum gradient of 10% and reduced visibility requirements at junctions. It is suggested that these roads be identified as "tourist roads" to distinguish them from other interurban road types.

PROBLEMS ON UNDIVIDED ROADS IN IRELAND

Undivided roads are by far the main type of interurban road in Ireland. Current problems include:

- The use of hard shoulders to permit passing on high volume roads. This can result in two lane undivided roads operating as three or four lane roads for short periods. There are also problems from drivers stopping on hard shoulders - the banning of non hands free mobile phones while driving has increased such stops.
- Cycling on high speed undivided roads without hard shoulders is hazardous. The provision of separate cycling facilities, as in some European countries, appears desirable where hard shoulders are not provided.
- The lack of consistency on high speed undivided roads is a significant safety problem in Ireland due to the mixture of unimproved and improved roads and to roads upgraded to different standards. There are accident black spot signs on many undivided roads.
- Over one third of fatal accidents in Ireland are single vehicle accidents. This suggests the necessity for consistent signing of the safe speed on horizontal curves and attention to the roadside edge zones.
- The enforcement of speed limits has improved in recent years but a high proportion of car and heavy vehicles still exceed the posted speed limits in rural areas.
- Transition zones from rural to urban areas on interurban roads cause safety problems. Traffic calming has been shown to improve safety on such roads (16) and needs widespread use.

THE IMPACT OF INTELLIGENT TRANSPORT SYSTEMS ON DESIGN STANDARDS

Intelligent transport systems (ITS) are having a large impact on how we plan, design and operate transportation systems. Highway agencies use them to count traffic, measure speeds, detect accidents, collect tolls, manage traffic signal systems and variable message signs, etc. Drivers use them for navigation, traffic congestion reports and vehicle monitoring. Vehicle guidance technologies such as collision avoidance systems and automatic speed enforcement are available but not in common use. In theory, ITS can substantially increase the capacities of roads, improve safety and permit reduced design standards in difficult locations:

- New roads: Lower physical standards + ITS = Desired operating standard
- Existing roads: Substandard roads + ITS = Improved standard / operation

Simulation studies indicated that the ITS systems with the greatest operational and safety benefits for undivided interurban roads were speed control, overtaking assistance and headway control (14). However, ITS has had little impact on geometric design standards to date due to perceived social, safety and legal consequences. ITS support for older drivers would seem particularly desirable. In future, ITS is likely to be included in the design standards for undivided interurban roads to permit more balanced road networks (such as the removal of bottlenecks) to be achieved. The use of ITS for price differentiation between peak and off peak hours should control congestion and permit reduced design standards.

DISCUSSION

Geometric design standards have changed substantially over time from short reports specifying the recommended lengths of the principal design elements to comprehensive planning, design and assessment documentation and methods. Design guidance now appears to be given for almost all possible road layouts and land uses. The geometric design standards in many countries now include detailed guidance on the provision of safe road layouts, including combinations of design elements, and methods for the evaluation and amelioration of environmental impacts.

The safety and performance of vehicles have improved over time, particularly braking and stability on horizontal curves and internal and external vehicle safety. Road surfaces and vehicle tyres have also improved although geometric design recommendations appear to be based on the same friction factors. *Relaxations* in design standards are permissible in most standards partly because of such improvements.

However, there has been relatively little change in the recommended design values of most individual geometric elements. Although the standards for motorways are similar in most countries, there are still large differences between the national standards for undivided roads. Particularly in the standards for at grade intersections and road signs.

The recommended design capacities of undivided interurban roads have been increased over time as driving and vehicles have improved without any increase in accidents; in terms of vehicle kilometres of travel, roads have become much safer.

Geometric standards do not involve direct communication or control over drivers apart from variable message signs, traffic signals and speed limits. Although the enforcement of speed limits has improved, the ideal 85% level of compliance is seldom achieved on interurban roads. Methods for examining the geometric consistency of undivided interurban roads are available (15) but they are not generally specified in national geometric design standards and inconsistencies frequently occur on undivided roads. These include warning drivers about the safe speeds for horizontal curves or about changes in road cross sections. Transition zones from rural to urban areas also cause problems.

There have been major advances in understanding driving behaviour including the identification of design elements which contribute to unsafe behaviour, loss of control and collisions. However, this understanding has not been incorporated into design standards to any significant extent. For example, design standards do not generally specify the use of "self explaining roads" which inform drivers of the road type or classification by the visual layout. According to Lamm et al (17), only a few modern guidelines incorporate human factors apart from the assumptions on which the design elements are based, Also, that these are limited to qualitative statements rather than detailed guidance. It appears that research findings on driver behaviour do not translate into clear recommendations for the modification of geometric design guidelines! However, the current EU 7th Framework Research Programme includes a number of projects aimed at putting the concepts of Self Explaining Roads and Forgiving Roads into practice. Also, the Transportation Research Board has published an excellent research problem statement on geometric design (18).

Although, the Nordic countries have introduced the "Vision Zero" concept which aims to eliminate serious road injuries, it seems remarkable in an era of "safety, health and welfare at work" regulations that we still design roads on the assumption that only a certain number of people will be killed or seriously injured each year. Vision Zero would require a much greater degree of control over individual drivers but it seems to be considered not feasible or politically unacceptable in most countries.

In an era of long distance driving, GPS route guidance and mobile phones, it seems strange that undivided road geometric standards seldom include the requirement of comfortable safe parking for drivers at regular intervals. The inclusion of internationally agreed signs to warn users of road works ahead would also be desirable.

Design standards are still produced by experts with little or no input from the consumer. As previously stated, many drivers, cyclists and pedestrians, particularly the elderly, dislike roundabouts but they are being used more frequently in many countries. Consumer surveys are advocated for more user friendly standards.

Climate change, energy shortages, protection of wild life and safety requirements are predicted to necessitate more control over vehicles in future. This would appear to require active speed control over individual vehicles and a maximum design speed of about 85 km/h (53 mph) on interurban undivided roads. Also, the incorporation of safe green roadsides (eco-design) and "forgiving roads" as fundamental parts of road design standards rather than as additions after the preliminary design stage.

Design provision for public transport is required to encourage modal shift from the car. Active traffic management, such as the use of hard shoulders as bus lanes on the approaches to urban areas, would require modifications to the intersection design standards for undivided roads.

CONCLUSION

Geometric design standards have always been conservative because of safety and legal implications. Although in-vehicle safety, vehicle performance, tyres and road surfaces have improved, the recommended design values for many undivided interurban road elements have varied little over time. The principal changes in geometric design standards have been the inclusion of comprehensive guidance on safe road layouts for complex locations and detailed methods for the evaluation of road projects. In future, design standards are likely to incorporate climate change and carbon content considerations and also intelligent transport systems for achieving balanced road networks and safer roads.

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