DESIGN SPEED CHOICES

FOR

CANADIAN TWO-LANE RURAL HIGHWAYS

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Abstract

Design speed is defined as “a speed selected as a basis to establish appropriate geometric design for a particular section of road” in the 1999 TAC Geometric Design Guide. While the TAC Design Guide has enhanced the various definitions of speed and placed an emphasis on the need for designers to recognize that operating speeds may be different from design speed assumptions, it does not provide specific guidance on how to choose an appropriate design speed. As part of TAC’s commitment to update the Geometric Design Guide on a regular basis two working papers have recently been completed to reflect new international developments in the areas of design consistency and design speed. This paper presents an overview of the salient findings from the working paper on design speed choices. The working paper is based on an analysis of design speed practices around the world.

There are several differences in the design speed concept as applied to the design of rural alignment in Canada and other countries (except for the United States). Whereas the United States and Canada continue to adhere to the design speed concept as classically applied, many European countries and Australia have enhanced their use of design speed to incorporate explicit consideration of actual driver speed behaviour in terms of 85^{th} percentile operating speed. Basically, design speed and operating speed research in a number of countries has found that, on curves with design speeds less than about 90 km/h, actual speeds are typically in excess of the design speed. Formal design procedures based on operating speed have been developed in Australia, France, Germany, Great Britain, Sweden and Switzerland. While the procedures differ, all place greater emphasis on the consistency of alignment standards rather than the traditional design speed approach.

The TAC working paper recommends that an operating speed approach be adopted for rural two-lane highways in Canada. The recommended approach incorporates feedback loops in the alignment design procedures to identify and resolve operating speed inconsistencies. The proposed operating speed approach begins with selecting a nominal design speed; selecting design parameters for highway geometric elements; developing a trial alignment, and estimating the 85^{th} percentile speeds on the trial alignment. A consistency check is then made to determine if the estimated speed matches the design speed. If the estimated speed does not match the design speed a new trial alignment is developed. If this is not possible another nominal (trial) design speed is selected and the process repeated until the estimated speed matches the design speed.

Acknowledgement

This paper is based on a recently completed review of design speed choices which was commissioned by TAC to update the 1999 Geometric Design Guide to reflect new developments in the area of design consistency and design speed. The authors gratefully acknowledge TAC for supporting this project.

1.0 DESIGN SPEED

1.1 Background

From 1954 to 2000, design speed was defined by AASHO(1) as "the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern. The assumed design speed should be a logical one with respect to the character of terrain and type of highway. Every effort should be made to use as high a design speed as practicable to attain a desired degree of safety, mobility, and efficiency". The 1986 RTAC Manual(2) stated that design speed is "the highest continuous speed at which individual vehicles can travel safely on a road when weather conditions are so favorable and traffic density is so low that the safe speed is determined by the geometric features of the road".

NCHRP Report(3) 400 recommended a revised definition of design speed which AASHTO adopted for the 2001 Green Book(4) as follows:

"a selected speed used to determine the various geometric features of the roadway." The NCHRP Report(3) also redefined operating speed as the "speed at which drivers are observed operating their vehicles during free flow conditions. The 85th percentile of the distribution of observed speeds is the most frequently used descriptive statistic for the operating speed associated with a particular location or geometric feature."

Fitzpatrick and Carlson(5) noted that concerns with the older AASHO and AASHTO definition of design speed included the use of the term "maximum safe speed" and the knowledge that several roadways have operating speeds and posted speeds (in some cases) that are higher than the design speed.

This paper is based on a recently completed review (40) of design speed choices and the implications of recent work for the 1999 TAC Guide(6). The report (40) is based on an analysis of design speed practices around the world and in particular Europe. The review is part of TAC's commitment to update the 1999 Geometric Design Guide on an ongoing basis to reflect new developments in the area of design consistency and design speed.

1.2 Historical Development of Design Speed

The design speed approach had its origins in both Germany and the United States in about 1930 with the acceptance of the concept of using a particular design speed to design roads to be compatible with vehicle behaviour. Prior to and during this early period of road design, most road geometric requirements were based on railway engineering. In the 1930s, autobahn designer Hans Lorenz used smooth, continuous, and mathematical defined road curves that could be driven at constant speed. This method linked curve design to the design speed approach. By 1934 common design speeds were 80, 100, and 130 km/h, depending on the class of road(7).

Design speed and operating speed research in a number of countries has found that, on curves with design speeds less than about 90 km/h, actual speeds are typically in excess of the design speed. Formal design procedures based on operating speed have been developed in

Australia, Germany, and Switzerland. While the procedures differ, all place greater emphasis on the consistency of alignment standards than the traditional design speed approach(8). While the 1954 AASHO Policy provided the basis for design standards in many countries, operating experience in the 1960's resulted in some questioning of underlining concepts.

2.0 Overview of International Design Speed Practices

2.1 Introduction

- There are several differences is the design speed concept as applied to the design of rural highway alignment in Canada and other countries (except for the United States). Whereas the United States and Canada continue to adhere to the design speed concept as classically applied, Australia, Germany, Switzerland, Great Britain, France and Sweden have enhanced their use of design speed to incorporate explicit consideration of actual driver speed behaviour in terms of 85^{th} percentile operating speed. While specific details(9) vary, these countries include feedback loops in their alignment design procedures to identify and resolve operating speed inconsistencies.

In all countries reviewed(9, 10) design speed is used to determine the minimum radius of curvature for the preliminary alignment design. In most countries, however, super elevation rates and sight distances are designed based on the estimated 85^{th} percentile speed when it exceeds the design speed. In addition several countries provide quantitative guidelines on the radii of successive horizontal alignment features. France and Germany specify the minimum radius following long tangents. Germany also has a comprehensive guideline indicating acceptable and unacceptable ranges for the radii of successive curves.

2.2 Survey of Design Speed Practices Definition and Selection of Design Speed

A survey of design speed practices in 18 countries concentrated on the definitions and application of design speed(10). The three most commonly mentioned principles found in the definitions of design speed were:

1. The maximum or highest speed a motorist can travel

2. The speed at which the motorist is safe or comfortable

3. The speed resulting from the influence of geometric features

While most countries responded that design speed is set for favourable weather conditions, England and the Netherlands responded that design speed is a measure of the speed under wet pavement conditions. The variation of design speed ranges is shown in Figure 1. Approximately one-third of the respondents identified that their country's low-speed design procedures deviated from high speed design procedures.

2.3 Design Speed Practices in Selected Countries

Australia

The 1980 NAASRA(11) adaptation of the design speed concept was based on the findings of a working group established in 1976 to undertake a review of the NAASRA Policy for Geometric Design of Rural Roads. The working group determined that different design philosophies should be applied for determining alignment standards for high and low speed alignments(8, 12).

High Speed Alignments – for alignments with design speeds of 100 km/h or greater, the traditional practice of providing conservative designs for high-speed alignments should continue as it is consistent with the high levels of safety and operational efficiency expected of highways of this type.

Low-Speed Alignments – for alignments with design speeds of 90 km/h or less, design standards were based as follows:
(i) design speed will be the predicted 85^{th} percentile speed; and (ii) the limiting values for the design criteria directly related to driver speed behaviour should be consistent with the 85^{th} percentile driver.

In other words for low-speed alignments (≤90 km/h), the predicted 85^{th} percentile speed is used as the design speed. For high speed (>100 km/h) alignments the classical design speed concept is used, because for such alignments studies revealed that the 85^{th} percentile speeds were less than the design speed.

It is useful to compare Australian and Canadian design standards with respect to design standards and design speed(12). Design values for stopping sight distance (SSD) given by Austroads(23) and RTAC(2) are shown in Table 1. The Canadian values assume a perception-reaction time (PRT) of 2.5 s and tires in poor condition operating on a pavement in poor conditions with a wet surface. Austroads employs different values of PRT for different alignment types. PRTs of 2.5s and 2.0s are employed in the derivation of normal design stopping sight distance for high and low speed alignments, respectively. For continuously constrained alignments the driver is assumed to be in an alert state and SSD can be reduced to values corresponding to a 1.5 s PRT. The advice given for these situations is to provide the greatest sight distance feasible, and then check that it is not less than the 1.5 s PRT value.

The difference in meaning of design speed again complicates any direct comparison of the sight distance values. For design speeds less than 100 km/h, the Austroads design speeds correspond to an 85^{th} percentile operating speed, which is greater than the conventional design speed. One way around this is to compare by geometric feature rather than design speed. Figure 2 shows the SSD standards plotted against minimum curve radius for design speeds up to 100 km/h. On this basis, the Austroads(23) and RTAC(2) SSD standards are much closer than implied by Table 1.

In summary, some 30 years ago horizontal alignment design standards in both Australia and Canada closely resembled those recommendations in the AASHO(1) ("Blue Book").

Subsequent developments in curve design in both countries have resulted in a divergence in design practices. To a large extent, the divergence reflects the differences in climatic conditions and their implications for design. Developments in Canada have largely been in response to concerns with the very low levels of friction provided by icy roads and have involved reductions to design friction factors for high-speed alignments and changes to super elevation practice. Road surface friction is less of a problem in Australia and the major change has been the development of operating speed approaches to designing lower speed alignments with a view to providing satisfactory low cost alignments in difficult terrain. However, when allowance is made for the different design speed concepts in Australia and Canada, the actual differences in practice and not as great as would appear from a cursory comparison of the specific standards(12).

Germany

German design guidelines(10, 14) use both design speed and 85th percentile operating speed for alignment of rural highways. German research in the 1970's indicated that actual speeds often exceeded traditional design speed values. In response to this German design procedures considers both design speed and 85th percentile speed. The design speed is used, as in Canada and the United States, to determine minimum radii of horizontal curves, maximum grades, and minimum k – values for crest vertical curves. The 85th percentile speed is estimated from empirical relationships based on the curvature rate and pavement width. The expected 85th percentile speed should not exceed the design speed by more than 20 km/h, otherwise the guidelines require that either the design speed be increased or the design be modified to reduce the expected 85th percentile speed. Thus, the design process involves a feedback loop in which the driver speed behaviour resulting from the designed alignment is estimated and compared with the assumed design speed.

Lamm(13) has noted that design speed depends on environmental and economic conditions based on the assumed network function of the road and the desired quality of traffic flow. The design speed determines the: maximum tangent lengths; minimum radii of curve; minimum parameters of clothoids; maximum longitudinal grades; required parameters for vertical curves.

Thus design speed decisively influences road characteristics, traffic safety, quality of the traffic flow, as well as costs. An important contribution of Lamm's(13) work is that design speed is used in the safety evaluation process of highway geometric design. Lamm(13) introduced the following safety criteria:

- Safety Criterion I: Achieving Design Consistency

The design speed should be constant for longer roadway sections and the design speed and 85th percentile speed should be balanced. Lamm(13) notes that the designer must make sure that the road characteristics are adjusted to the driving behaviour of motorists.

- Safety Criterion II: Achieving Operating Speed Consistency

For this safety criterion Lamm(13) recommends that the design speed and operating speed should remain consistent along longer roadway sections. In this way, the road characteristics are balanced for the motorist along the course of the road section. If, in the case of a longer road section, a definite change in topography occurs, necessitating a change in road characteristics and a corresponding change in the design speed, then the design elements in the transition section must be carefully adjusted to each other so that any change between them is gradual.

Safety Criterion III is concerned with one individual curved roadway section. Lamm(13) introduces the concept of relation design to include a well-balanced design between independent (long) tangents and curves. Figure 3 shows the relation design based on Canadian data. As shown in Figure 3 from the relation design background for Canada, a radius of 500 m, combined with the following radii of curve gives:

R = 100 m	poor design
R = 150 m	fair design
R = 300 m	good design
R = 1000 m	good design

For the transition independent tangent - spiral - tangent circular curve, the good design range shown in Figure 3, indicates a curve radius of at least 300 m.

In summary, relation design allows the designer to quantitatively determine if an alignment is consistent or whether an alignment change which is necessary for the required consistency, meets driver expectancy in order to achieve safer operation. In other words relation design(13) means "that design element sequences are formed, in which the design elements following one another are subject to specific relations or relation ranges". Relation design results in a more consistent road design than is generally attained by the individual element/maximum-minimum design speed approach in which single elements are put together more or less arbitrarily.

United Kingdom

Design standards(10, 14) in the United Kingdom (U.K.) accommodate design exceptions whereby a given design speed corresponds to the 85th percentile speed on a roadway with that design speed, the 99th percentile speed on a roadway with the next lower design speed, and the 50th percentile speed on a roadway with the next higher design speed(13). The U.K. design standards emphasize that sections of two-lane roadways should have either clearly adequate or clearly inadequate passing-sight distance and that sections with marginally adequate passing-sight distance should be avoided in alignment design. This is based on the premise that small radius curves with inadequate passing-sight distance will not be misjudged by drivers when adequate road signs are posted. Curves with intermediate radii that drivers might incorrectly judge as having adequate passing sight distance are not recommended. The U.K. standards emphasize the effects of alignment and layout constraints on operating speeds in selecting a design speed. The alignment constraint is a function of "bendiness" which is defined as the total degree of curvature/km and the harmonic mean of available sight distance. The layout constraint is a function of the road type and access density. The U.K. approach attempts to balance design and operating speeds to achieve cost savings and minimize impacts on the natural and the built environments by using an interactive procedure for the selection of design speed and the geometric alignment design.

Switzerland

The Swiss design procedure(10, 14) is conceptually similar to the German procedure in that a design speed is used in the traditional manner to define minimum standards, and operating speed estimates are used to check alignment consistency. The alignment consistency procedure estimates the speed profile along an alignment and identifies excessive speed differentials between successive elements. The speed profile is estimated based on the speed on horizontal curves, maximum speed on tangents, and the deceleration and acceleration rates entering and existing horizontal curves. A surrogate for operating speed known as project speed in Switzerland is used to check for excessive differences between successive elements, and iterate to reduce these differences to acceptable levels. The Swiss have retained the original speed-radius relationships which are used as a design tool for safe speed on sharper curves.

France

The most recent French guidelines(14) were introduced in 1991 and are considerably different from the 1975 guidelines which were classical in approach and relied on the design-speed concept. The new guidelines depart from the design-speed concept and emphasize that the driver-roadway interaction influences speed behaviour and must be taken into account. Previous French guidelines had five road categories and each had a design speed range of 40 km/h to 120 km/h. All alignment features were related to the design speed. It was recognized that this approach did not consider the effect of alignment on the actual speed behaviour of drivers and in fact may permit higher speeds. The new guidelines specify only a 20 km/h range of design speeds for each of the three new road categories.

2.4 International Summary

At one time, most of the design speed policies in the countries reviewed were similar to current design speed policies used in the United States and Canada. While design speed is based on class of roadway, terrain, and or rural urban environment in the countries reviewed it has been supplemented with explicit consideration of operating speed. Countries such as Australia, England, France, Germany, and Switzerland include feedback loops in their alignment design procedures to identify and resolve operating-speed inconsistencies. In all the countries reviewed, design speed is used to determine the minimum radius of curvature for the preliminary alignment design(9). Three countries (France, Germany, and Switzerland) have speed-profile estimation techniques for evaluating speed consistency along an alignment. Superelevation design is based on the estimated 85^{th} percentile speed when it exceeds the design speed(14).

3.0 Recent Design Speed Approaches and Research in Canada and the United States

3.1 United States

Operating-speed-based rural alignment procedures have been proposed by Leisch & Leisch(18), Lamm et al(19) and Fitzpatrick(5) et al.

Leisch and Leisch

Although this proposal for an operating-speed-based rural alignment consistency procedure was published 25 years ago, it represents a major contribution to the question of design speed choices. The authors(18) note that one problem in the use of design speed as it is applied today is that, primarily at lower speeds, the changing alignment causes variations in operating speeds. Another problem is that the design speed sometimes is lower than the driver's expectation and judgement of what the logical speed should be. The design speed must appear to be reasonable to the driver, and a speed that nearly meets the driver's natural tendency must be used. The objective in alignment design is not only a logical and acceptable design speed but also one that produces a relatively uniform operating speed. The authors note(18) that this is fully met where high design speeds are used, but at low and intermediate design speeds, the portions of relatively flat alignments interspersed between the controlling portions tend to produce increases in operating speed that may exceed the design speed by substantial amounts.

A new concept of design speed is introduced which recognizes the inadvertent increase in driver's speed but limits it to 16 km/h (10mph). Design speed designations remain the same (50 – 125 km/h), but for speeds less than 100 km/h recognize a potential overdriving speed of 16 km/h. For example, a design speed designated for 65 km/h means a design speed range of 65 to 80 km/h.

The proposed procedure estimates speeds for both passenger cars and trucks and considers the effect of both horizontal and vertical alignment. It also includes procedures for estimating deceleration and acceleration distances entering and departing a curve. The new speed design a concept requires the plotting of a speed profile of automobiles and trucks in each direction. The authors(18) describe in detail complete procedures for the development of speed profiles for free-flowing conditions

In summary the proposed new design speed approach is the 16 km/h (10mph) rule which has three basic principles.

1. Within a given design speed, the potential average automobile speeds should not vary more than 16 km/h (10 mph/h).

2. When a reduction in design speed is necessary it should normally be no more than 16 km/h (10 mph).

3. On common lanes, potential average truck speeds should generally be no more than 16 km/h lower than average automobile speed.

Although the 16 km/h (10 mph) design speed rule was suggested 25 years ago and the speed estimates are derived from the 1965 AASHO(1) "Blue Book", it serves as a major contribution to the question of design speed choices.

Lamm et al

This operating-speed based consistency evaluation procedure(19) is based on an adaptation and refining German procedures for use in the United States. The procedure estimates that change in 85th percentile speed from a tangent to a horizontal curve on two-lane highways, depending on whether the tangent is independent or non-independent. The procedure involves developing a speed profile horizontal alignment consistency is rated as follows:

Rating	Change in Degree of Curvature (ΔD)	Change in 85th Percentile Operating Speed DΔ85
Good	$\Delta D \leq 5°$	$\Delta V \leq 9.7$ km/h
Fair	$5° < \Delta D \leq 10°$	9.7 km/h $< \Delta V85 \leq$ 19.3 km/h
Poor	$\Delta D > 10°$	$\Delta V85 >$ 19.3 km/h

Fitzpatrick et al

The new definition of design speed adopted by AASHTO(4) in the 2001 Green Book states:

"Design speed is a selected speed used to determine the various geometric design features of the roadway. The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use, and the functional classification of highway." This definition was first proposed in 1997 in a NCHRP Report(3).

Fitzpatrick et al(5) note that while the new definition is believed to resolve the liability concern of having design speed being the "maximum safe" speed in excess of the design speed the question of selection of appropriate design speed remains. Four possible solutions for selecting the most appropriate design speed value to lead to a better relationship between design speed and operating speed are presented(5). The potential solutions proposed include:

1. Limiting the range of design speed values available within each functional class, rural v. urban or terrain type.
2. Using anticipated posted or operating speed (or using these speeds plus a preset incremental increase).
3. Incorporating a feedback loop that would check the predicted speed along an alignment.
4. Managing speeds on the tangent by controlling tangent length.

The intent of the proposed design process is to create a roadway that provides motorists consistent messages regarding the appropriate operating speed.

3.2 Canada

In reviewing design speed choices in Canada it is instructive to consider international opinions of Canadian practice.

A Federal Highway Administration (FHWA) Report(14) commented that "the design speed concept is applied in the classical manner in Canada. In most respects, the Canadian policy on rural alignment is similar to U.S. policy".

This assessment of design speed policy in Canada was made prior to publication of the 1999 TAC Guide(6) and did not include practices of some provinces such as Alberta(20). However, the FHWA observation is a reasonably accurate description of the design speed concept as interpreted and applied throughout Canada. The Alberta Transportation(20) definition closely follows the 1994 AASHTO(21) definition; "Design speed is considered to be the highest continuous speed that vehicles can safely travel on a road when weather conditions are favourable and traffic density is so low that the safe speed is determined safely by the geometric features of the road." However, the Alberta design speed approach also relies on speed studies conducted on Alberta highways that have shown that the 85^{th} percentile driver generally exceeds the normal speed limit on high-speed rural facilities by six to 10 km/h. The Alberta(20) guidelines state: "Consequently, the normal speed limit on the finished roadway is an important consideration in selection of design speed. It is desirable that the design speed exceed the normal speed limit by a margin of at least 10 km/h."

The 1999 TAC Guide(6) defines design speed as "a speed selected as a basis to establish appropriate geometric design elements for a particular section of road". The TAC(6) definition is identical to the design speed definition in the 2001 AASHTO Green Book(4). Other similarities include selecting an appropriate design speed with respect to topography, driver expectations, anticipated operating speed, operating environment and adjacent land use and functional classification of the road. The 2001 AASHTO(4) Green Book provides specific guidance for design speed choices whereas the TAC Guide(6) is silent. The TAC Guide(6), however, has a useful section on the limitations of the design speed approach.

4.0 Design Speed Recommendations

In attempting to provide guidance on design speed choices, observations by Hauer(22)have some relevance: "Design speed used in geometric design standards has only the vaguest relationship to analytical rarity of occurrence". Research(8, 9) findings of speed on curves is quoted and Hauer notes "this is not a rare occurrence. Naturally, the driver can have no knowledge of the design speed that has been used in the designer's calculations. Since the design speed has no clear relationship to either the speed limit or the speed expected to be exceeded by only a very small proportion of drivers, it is entirely unclear what it represents or why it ought to be relevant to curve design."

The purpose of this section is to present specific recommendations for selection of design speed. The recommendations are based on the world-wide literature review.

4.1 Design Speed Definition

It is recommended that the current 1999 TAC Guide(6) definition of design speed be retained, namely:

"Design speed is a speed selected as a basis to establish appropriate geometric design elements for a particular section of road."

To add to the definition:

The selected design speed should be a logical one with respect to the character of terrain, anticipated operating speed, adjacent land use (ie. urban or rural in character), and the road classification system as described in the TAC Guide(6). For urban and rural freeways and primary rural arterials the designer should consider selecting as high a design speed as practical to attain a desired degree of safety, mobility, and efficiency within the constraints of environmental quality, economics and aesthetics. Local roads are often subject to speed controls through measures such as traffic calming and hence the design speed is likely to be dictated by a speed management policy.

4.2 Design Speed Factors and General Guidelines

The following factors influence the choice of design speed and are presented in the form of guidelines only.

- Terrain (level, rolling, mountainous).
- Driver expectations.
- Roadway classification.
- Speed distributions and 85th percentile operating speed.
- Traffic characteristics, volume, traffic composition and trip length.
- Environmental constraints.
- The view from the road.
- A lower design speed should not be automatically be assumed for a secondary rural highway or low volume primary rural highway, where the terrain and speed environment are such that drivers are likely to travel at higher speeds.
- The overall range in design speeds is 20 km/h to 130 km/h and the design speed increments are 10 km/h.
- Design speed should be greater than or equal to the legal posted speed.
- Design speed choice should reflect the 85th percentile desired speed.

- A design speed equal to the posted speed may be warranted by such factors as low traffic volumes, mountainous terrain, or economic considerations. This practice is appropriate for minor collectors, local roads, municipal district roads, and some secondary highways.

4.3 Design Speed Choices for Rural Two-Lane Highways

It is recommended that an operating speed approach be adopted for rural two-lane highways. The existing design speed approach and proposed operating speed approach for Canadian roads is shown in Figure 4.

The proposed operating speed approach consists of the following steps:

- Select a nominal (trial) design speed.

- Select the design parameters for vertical and horizontal alignment and other highway geometric elements.

- Develop a trial alignment.

- Estimate the 85th percentile speeds on the trial alignment.

- Check consistency; does the estimated speed match the design speed?

- If it does finalize the design.

- If the estimated speeds does not match the design speed can the alignment be modified? If so, develop a new trial alignment. This is part of the feedback loop.

- If the alignment cannot be modified, the other branch of the feedback loop is to select another nominal (trial) design speed and follow the flowchart in Figure 4 as before.

4.4 3R/4R Design Speed Choices

Identifying the design speed is one of the initial steps in evaluating a 3R/4R project. As noted in the TAC Guide for 3R/4R(26), "there is often a poor relationship between the 85th percentile speed, the original design speed and the posted speed. In many cases, in particular with older roads that have evolved over time, a design speed may never have been established or is not known. For 3R/4R projects the design speed should reflect actual operating speeds, not necessarily the legal speed limit. Drivers are more apt to accept a lower speed limit where a difficult condition is obvious than where there is no apparent reason for it. In most cases, drivers adjust their speeds to physical limitations and traffic."

The recommended practice for 3R/4R projects is to define the design speed as the existing 85th percentile speed on a roadway. Desirably, the 85th percentile speed should be measured for each project and the operational design speed procedure shown in Figure 4 followed. Where this is not practical, system wide typical values, for specific roadway classifications and other influencing characteristics such as roadway geometry, terrain and adjacent land use can be utilized. In some cases, due to policy or the desire to promote corridor continuity, for example, it may be desirable to define the 3R/4R design speed as a value other than 85th percentile speed(26, 27). Selection of design speed on this basis is part of contextual design(31) or design for ambient conditions(28, 29, 30, 32).

5.0 Safety and Design Speed

5.1 Safety and Design Speed Overview

There is clear evidence of the effect of speed on collision rates and collision severity, although most researchers acknowledge the relationship between speed and collisions is very complex(13). The energy to be dissipated in a collision is proportional to the square of the impact speed(33). For example, an impact speed of 130 km/h involves more than twice the energy of one at 90km/h.

The speed at which a driver travels depends on perception of the safety and comfort of the road, driver characteristics, vehicle characteristics, speed limit, and driver perception of speed enforcement(34). Stopping sight distance is proportional to the square of the speed. As speed increases the following four major factors occur(34).

- The vehicle becomes less stable, especially on curves.
- The driver has less time to react to a hazard.
- Other road users have less time to react to the speeding vehicle.
- The severity of collisions increases.

Thus it is reasonable to assume that higher speeds result in a higher probability of being involved in a collision(13).

Rural Areas

In Canada(36), two-thirds (approximately 67 percent of the 2,566 fatal collisions) of fatal collisions in 2000 occurred on rural roads, on primary and secondary highways and local roads where speed limits exceed 60 km/h. Of all injury collisions, 42,700 or 28 percent occurred on rural road in 2000.

The Organization for Economic Cooperation and Development(35) (OECD) has qualified the effect of speed on collisions and collision severity, based upon Swedish data as follows: “the percentage drop in accident rates outside built up areas is n times the percentage drop in mean speed, where n = 4 for fatal collisions, 3 for personal injuries, and 2 for all collisions.

Each year, more than 75,000 people are killed on rural roads in OECD countries(37). In OECD countries, single vehicle collisions constitute 35% or more of all fatal rural road collisions. This type of collision is the most prevalent because all three elements of the family of hazard factors; driver behaviour, vehicle, and road environment contribute to these collisions and increase their severity. The OECD report(37) notes that inappropriate and excessive speeds are a key factor in rural road collisions because the actual speeds on rural roads are relatively high under circumstances where these high speeds cannot be safely maintained. For example, because of their historical origins, rural roads generally have inconsistent design characteristics over their total length as well as problems in individual design elements. This requires constant speed adaptation to account for regularly changing situations and circumstances thus increasing the opportunities for human errors and leading to higher risks for collisions. The OECD report(37) concludes that reducing inappropriate and excessive speed together with safe road and roadside design are the key elements to improve rural road safety.

Given that driving speeds are influenced by geometric elements such as horizontal curvature, cross-sections, and grade, it should in principle be possible to control speed through the appropriate selection of geometric design standards for these elements(38). Thus, efforts to enhance safety by designing horizontal and vertical alignments and cross-sections on highways for vehicle speeds greater than the posted speed limit might conflict with efforts to enhance safety through speed control(39). It is argued that it is both possible and desirable to review road design practice to encourage lower speeds and questions the common philosophy of encouraging the highest possible design standards(39).

5.2 Explicit Evaluation of Safety and Design Speed

An international survey(10) identified the following research needs with respect to design speed:

- Greater determination of the relationship between design speed and operating speed.
- Investigation of the relationship between design speed and cross-sectional elements.
- Development of safety criteria for design speed and operating speed consistency.
- Investigation of advisory speed signing for horizontal curves following tangent sections.
- Implications of snow and ice to design speed.

As noted by Lamm et al(13), speed has the greatest impact on traffic safety. In terms of the explicit evaluation of safety and design speed the three safety criteria developed by Lamm et al(13) are the most recent and quantitative safety criteria relevant to two-lane roads. The three safety criteria discussed in this paper allow the evaluation of new designs, redesigns, and 3R/4R projects with respect to good, fair (tolerable), or poor design practices. All three criteria are related to speed (design speed/operating speed), and it can be expected that their application will lead to sound highway geometric design and a reduction in collision frequency and severity(13).

In summary, the three safety criteria based on operating speed and the relation design approach should be an integral part of highway design guidelines when the overall objective is for a curvilinear alignment which is consistent and has higher levels of safety.

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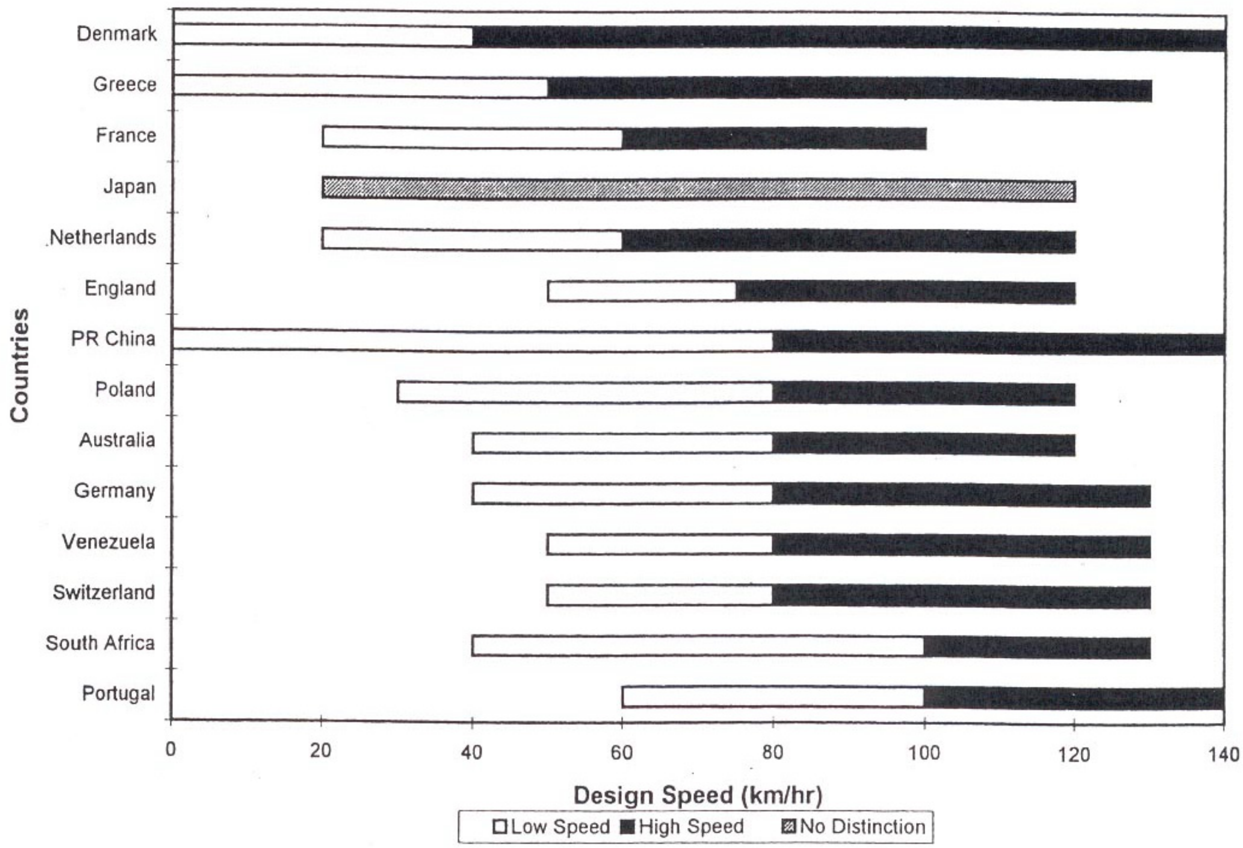

FIGURE 1: Design Speed Ranges (10)

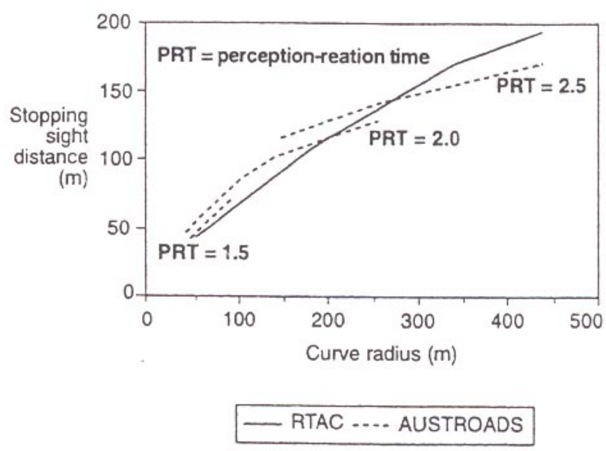

FIGURE 2: Comparison of Australian and Canadian SSD Standards Applicable to Curves of Minimum Radius (12)

TABLE 1

Australian and Canadian Design Stopping Sight Distance (12)

Australia				Canada
Design Speed (km/h)	Normal Design (m) PRT[b] = 2.5s	PRT = 2.0s	Constrained Situation (m)[a] PRT = 1.5s	Design Values for Minimum Stopping Sight Distance (m)
50		45	40	65
60		65	55	85
70		85	70	110
80	115	105		140
90	140	130		170
100	170			200
110	210			220
120	250			240
130	300			260

a Driver assumed to be in alerted state – not to be used for isolated geometric features.
b PRT – Perception-reaction time

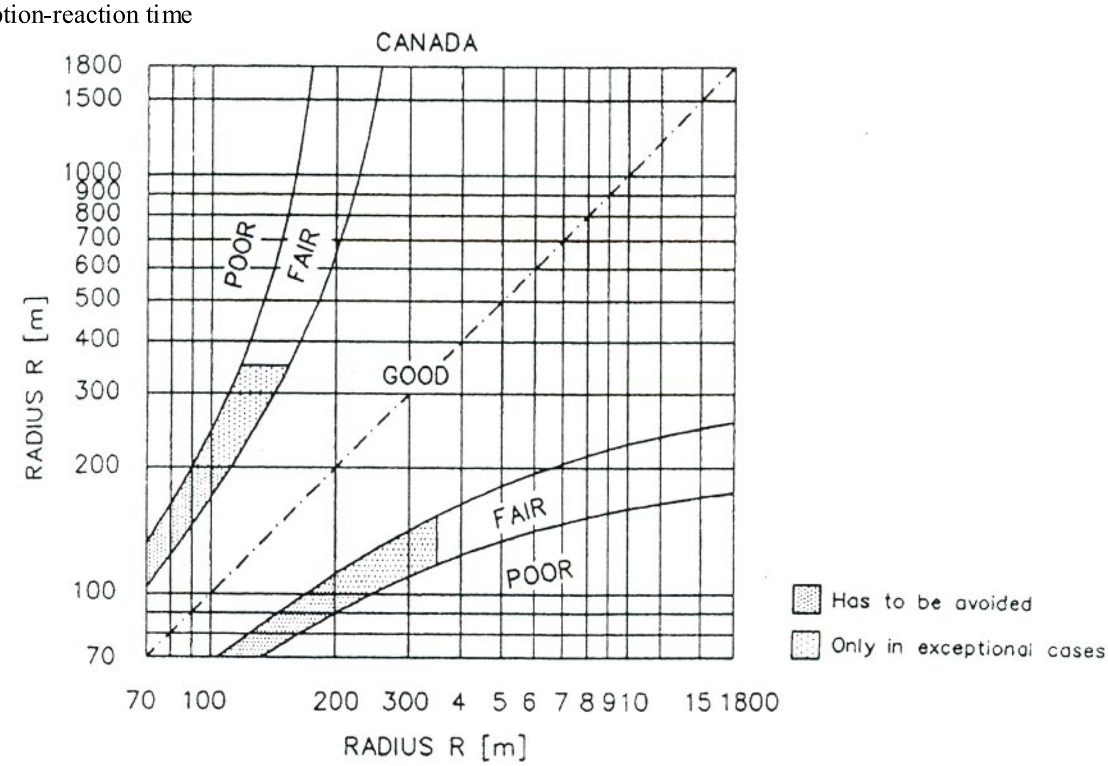

FIGURE 3: Relation Design Background, Canada (13)

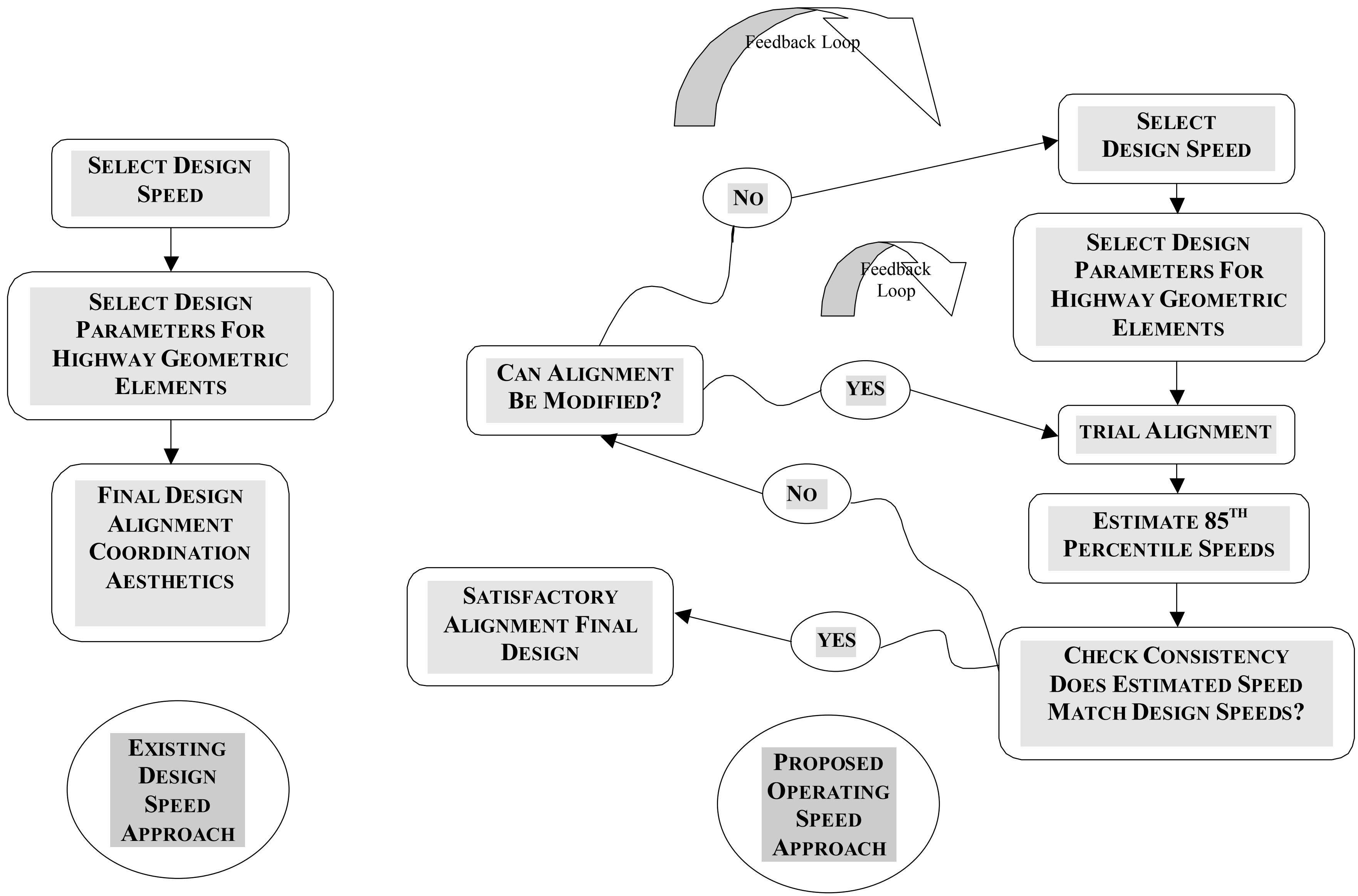

FIGURE 4: Proposed Operating Speed Approach for Canadian Roads(40)