

Interactive Highway Safety Design Model (IHSDM)

Design Consistency Module (DCM) Engineer's Manual

Developed for
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1. Introduction

This engineer's manual is one component of the documentation supporting the Interactive Highway Safety Design Model (IHSDM). This introductory section: (1) provides a brief overview of IHSDM, (2) summarizes the capabilities and intended uses of the Design Consistency Module, and (3) states the purpose of this particular manual.

1.1 Overview of IHSDM

IHSDM is a suite of software analysis tools for evaluating safety and operational effects of geometric design in the highway project development process. The scope of the current release of IHSDM is two-lane rural highways.

IHSDM is intended as a supplementary tool to augment the design process. This tool is designed and intended to predict the functionality of proposed or existing designs by applying chosen design guidelines and generalized data to predict performance of the design. This tool is NOT a substitute for engineering judgment and does not create a standard, guideline or prescriptive requirement that can be argued to create any standard of care upon a designer, highway agency or other governmental body or employee. The use of this tool for any purpose other than to aid a qualified design engineer in the review of a set of plans is beyond the designed scope of this tool and is not endorsed by the Federal Highway Administration (FHWA).

The suite of IHSDM tools includes the following evaluation modules. Each module of IHSDM evaluates an existing or proposed geometric design from a different perspective and estimates measures describing one aspect of the expected safety and operational performance of the design.

- Policy Review Module (PRM) - The Policy Review Module checks a design relative to the range of values for critical dimensions recommended in AASHTO design policy.
- Crash Prediction Module (CPM) - The Crash Prediction Module provides estimates of expected crash frequency and severity.
- Design Consistency Module (DCM) - The Design Consistency Module estimates expected operating speeds and measures of operating-speed consistency.
- Intersection Review Module (IRM) - The Intersection Review Module leads users through a systematic review of intersection design elements relative to their likely safety and operational performance.
- Traffic Analysis Module (TAM) - The Traffic Analysis Module estimates measures of traffic operations used in highway capacity and quality of service evaluations.

Intended users of IHSDM results are geometric design decision makers in the highway design process, including project managers, planners, designers, and reviewers. The Federal Highway Administration's Flexibility in Highway Design document (Publication No. FHWA-PD-97-062) explains the context within which these decision makers operate:

An important concept in highway design is that every project is unique. The setting and character of the area, the values of the community, the needs of the highway users, and the challenges and opportunities are unique factors that designers must consider in each highway project. Whether the design to be developed is for a modest safety improvement or 10 miles of new-location rural freeway, there are no patented solutions. For each potential project, designers are faced with the task of balancing the need for the improvement with the need to safely integrate the design into the surrounding natural and human environment.

The measures of expected safety and operational performance estimated by IHSDM are intended as inputs to the decision making process. The value added by IHSDM is in providing quantitative estimates of effects that previously could be considered only in more general, qualitative terms. The advantage of these quantitative estimates is that, when used appropriately by knowledgeable decision makers, they permit more informed decision-making.

The following general cautions should be considered in using IHSDM:

- Measures of expected safety and operational performance from IHSDM are only a subset of the large number of inputs that must be considered in making design decisions.
- Estimates from IHSDM are expected values, in the statistical sense, i.e., they represent the estimated average performance over a long time period and among a large number of sites with similar characteristics. Actual performance may vary over time and among sites. The estimates from IHSDM should not substitute for, but rather should supplement and complement local knowledge.
- While derived from the best available data using the best available methods, both the available data and methods have limitations. The engineer's manuals for each module document limitations that should be understood to apply appropriately the resulting estimates.

1.2 Overview of Design Consistency Module

Design consistency refers to a design's conformance with drivers' expectations. It is a goal of design. In general terms, and with all other factors being constant, one would expect crash frequency to decrease as design consistency increases.

One of drivers' expectations on rural two-lane rural highway alignments is to be able to maintain a relatively uniform speed; complete uniformity (e.g., being able to set one's cruise control and never having to adjust it), however, is neither common nor, therefore, expected. While it has been the subject of research for several decades, commonly accepted procedures for estimating operating speeds and evaluating speed consistency have been lacking. The Design Consistency Module represents a significant milestone in efforts to produce such a procedure.

The Design Consistency Module evaluates operating speed consistency through a speed-profile model that estimates expected 85th percentile, free-flow, passenger vehicle speeds along a highway. The speed-profile model combines estimated 85th percentile speeds on curves (horizontal, vertical, and horizontal-vertical combinations), desired speeds on long tangents, acceleration and deceleration rates exiting and entering curves, and an algorithm for estimating speeds on vertical grades.

The module estimates two measures:

- The expected difference between estimated 85th percentile speeds along the highway and the design speed of the highway, and
- The expected reduction in estimated 85th percentile speeds from an approach tangent to its succeeding horizontal curve.

The intended use of these measures is to highlight locations where additional attention and evaluation may be warranted.

With respect to the first measure, it is not uncommon and not necessarily a problem for estimated 85th percentile speeds to be greater than the design speed of the highway. It is not necessarily a problem because, in part, design policy and practice incorporate considerable margins for safety

in design parameters based upon design speed. On many sections of highway, drivers can and, therefore, do comfortably operate at speeds higher than the highway's design speed. The additional evaluations that may be warranted include, for example, checking Policy Review Module output for available sight distances near minimum recommended policy values, and checking actual crash history for speed-related crash patterns.

The second measure estimates the expected speed reduction from an approach tangent to a horizontal curve. Locations where the expected speed reduction is large may warrant additional evaluations; for example, whether adjustments to the alignment would be cost effective. Often, physical constraints dictate and cannot be overcome. Where large expected speed reductions cannot be reduced, then consideration should be given to warning drivers and possible accommodations through cross section and roadside design.

While design consistency has long been considered in general terms, the quantitative measures provided by the Design Consistency Module have not been routinely available to project decision makers. Some general cautions that should be exercised in using these measures include:

- The measures reflect nationwide average conditions on State-maintained, paved, two-lane rural highways with 55 mi/hr posted speed limits. The speed-profile model was calibrated using data from more than 200 sites on two-lane rural highways in six States. This database is relatively large and is considered nationally representative, but the resulting model should not be expected to reflect all sources of regional and highway-specific variations. Therefore, it is important to apply local knowledge in interpreting model results.
- There is no accepted "standard" for acceptable or unacceptable values of the two measures. The output is color-coded to help users distinguish larger values from smaller values. The color-coding was not intended and should not be interpreted as categorizing outputs as acceptable or unacceptable.

1.3 Purpose of This Manual

The Design Consistency Module Engineer's Manual documents the basic information that users should understand in order to make appropriate use of the Module. It details the data input requirements, explains the procedural elements of the module, enumerates the steps in the crash prediction algorithm, and describes the presentation of model outputs. Throughout, this manual highlights limitations of the Module that users should consider in applying it and interpreting results.

2. Data Input Requirements

In order to run the Design Consistency Module, the following data must be provided:

Station limits for the check.

Horizontal alignment data.

- Begin/end tangents.
- Begin/end of curves and curve radii.

Vertical alignment data.

- tangent grades.
- vertical curves: begin/end, VPI, type (sag or crest).

Design Speed

Desired Speed

Speed at Analysis Start Station

Speed at Analysis End Station

Vehicle Type

3. Estimated 85th Percentile Operating Speed Profile Algorithm

This section describes the procedures used in the Design Consistency Module to develop the speed profile using a simple alignment consisting of two horizontal curves and a steep grade approaching a vertical curve as an example. Report No. FHWA-RD-99-171, Speed Prediction for Two-Lane Rural Highways, provides details on the formulation and calibration of the speed profile algorithm.

3.1 Speed Profile Algorithm

A brief description of how to use DCM is provided in Figure 1, *DCM Quickstart Procedural Guide* .

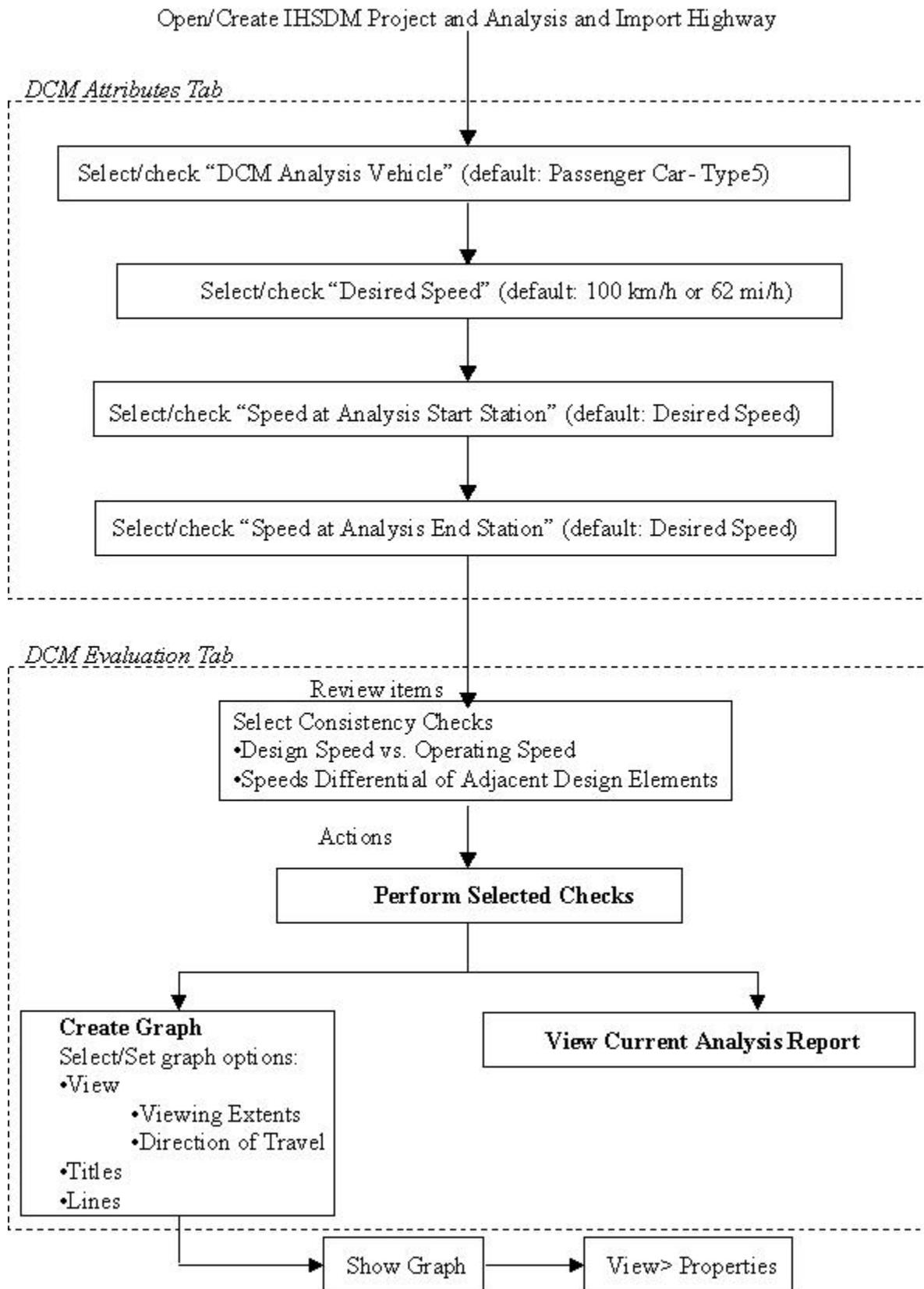


Figure 1 DCM Quickstart Procedural Guide

The DCM evaluates the operating speed consistency of two-lane highways. The first step in this process is to estimate the 85th percentile speed (V_{85}) along the analysis section for a given vehicle type. The steps in developing the speed profile are described in this section and illustrated in the Figure 2, *Speed Profile Model Procedure Flowchart*.

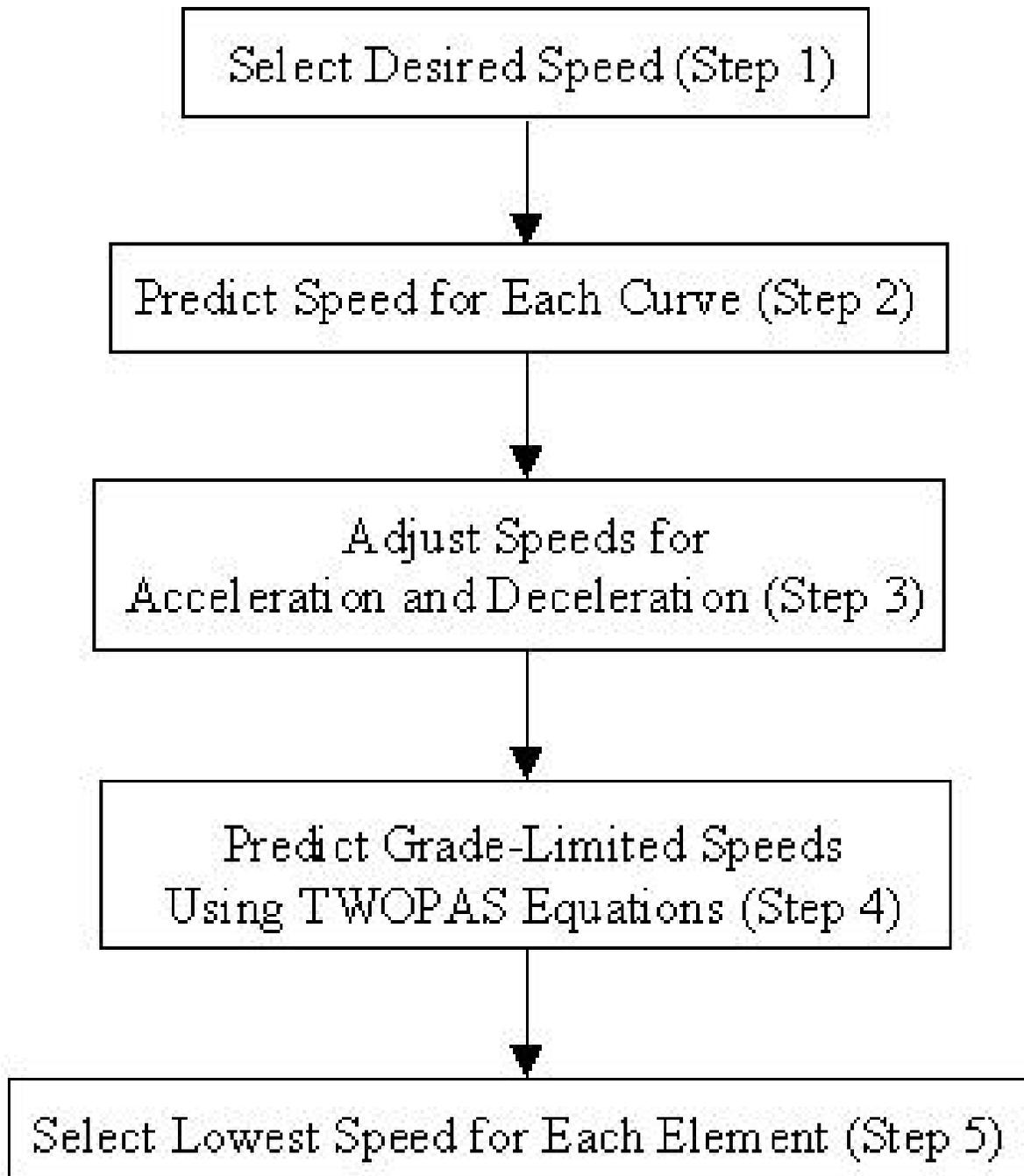


Figure 2 Speed Profile Model Procedure Flowchart

1. Select desired speed on tangents (default desired speed = 100 km/h or 62 mph).
2. Predict speed for each horizontal curve using empirical speed prediction equations, based on data collected from curve sites around the U.S. Curve speed is a function of curve radius and is affected by the vertical alignment. Speed is assumed to remain constant throughout a horizontal curve.

3. Adjust speeds for acceleration and deceleration (Result of steps 2 and 3 is an estimated 85th percentile speed profile as shown in Figure 3, *Estimated 85th Percentile Speed Profile for Example Alignment (Steps 1-3)*). The distance available for acceleration/deceleration between curves (i.e., the tangent length) is compared to the required length for acceleration from the estimated speed on Curve n to the desired speed, plus the length to decelerate from the desired speed to the estimated speed on Curve n+1. The available tangent length versus the required acceleration/deceleration length, in conjunction with the estimated speed on Curve n (V_n) versus the estimated speed on Curve n+1 (V_{n+1}), determines the acceleration/deceleration condition for a given curve-tangent-curve section. Acceleration/deceleration rates are based on the curve radii. For a curve-tangent-curve combination, acceleration is a function of the radius of the first curve (Curve n), while deceleration is a function of the radius of the second curve in a series (Curve n+1). If the tangent is not long enough, the speed might not reach the desired speed.

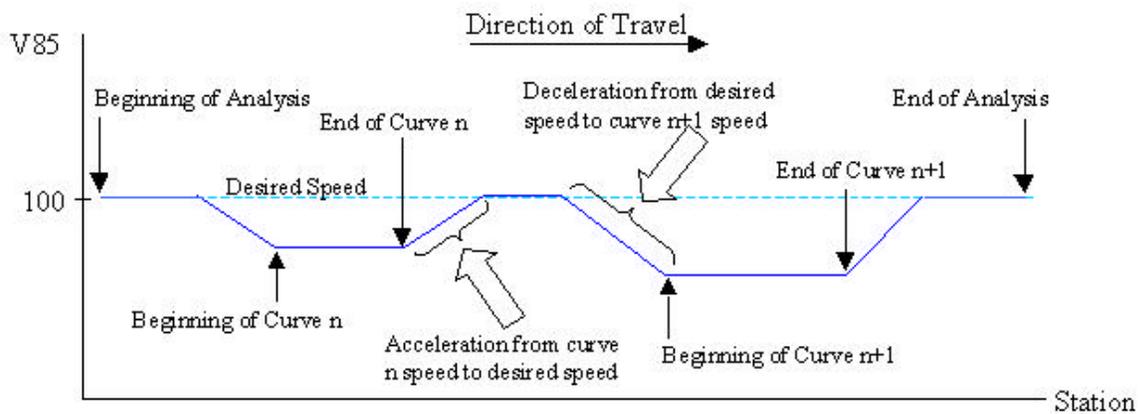


Figure 3 Estimated 85th Percentile Speed Profile for Example Alignment (Steps 1-3)

4. Predict grade-limited speeds using TWOPAS equations. A second speed profile is generated, based on the vertical alignment and the DCM analysis vehicle chosen (Figure 4, *TWOPAS Speed Profile for Example Alignment (Step 4)*).

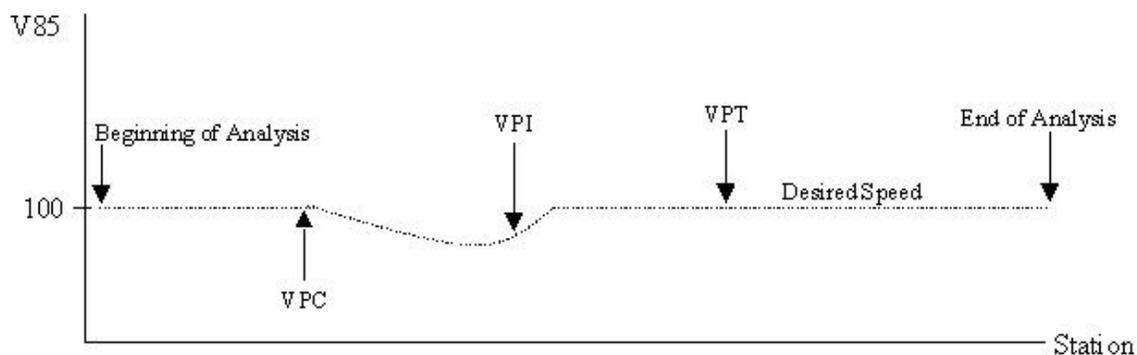


Figure 4 TWOPAS Speed Profile for Example Alignment (Step 4)

5. Select lowest speed for each element. The speed profiles from Steps 3 and 4 are compared (Figure 5, *Speed Profiles from Steps 1 through 4 of the Speed Profile Algorithm for Example Alignment*) and the lowest speed selected at each point along the alignment to create a final speed profile (Figure 6, *Final Estimated 85th Percentile Speed Profile for Example Alignment (Step 5)*).

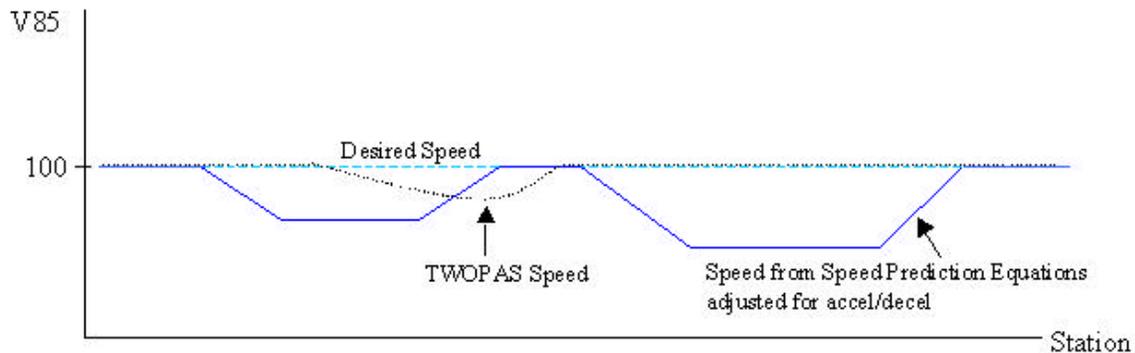


Figure 5 Speed Profiles from Steps 1 through 4 of the Speed Profile Algorithm for Example Alignment

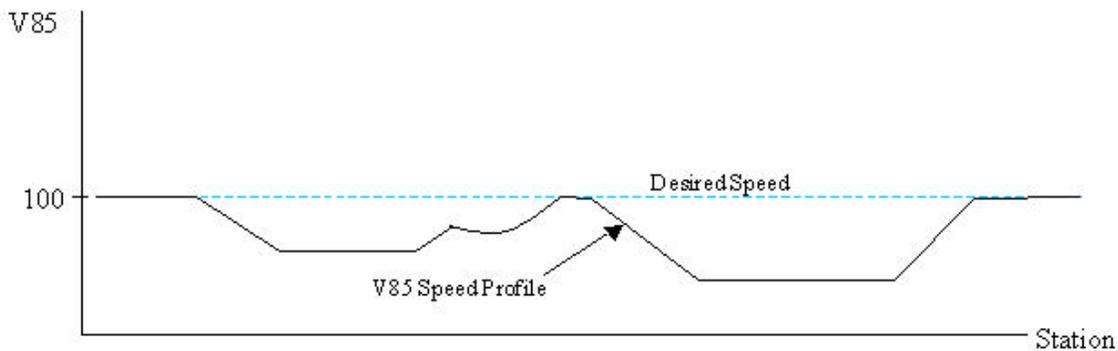


Figure 6 Final Estimated 85th Percentile Speed Profile for Example Alignment (Step 5)

3.2 Special Considerations

Certain geometric features and conditions require special consideration and are handled as follows by the design consistency algorithm.

3.2.1 Intersections

The design consistency algorithm does not consider the presence of intersections. Unsignalized intersections with no stop control on the road being analyzed and signalized intersections can be treated in the same manner as highway segments.

Highways with stop-controlled intersections must be divided and analysis limits specified in sections between the stop-controlled intersections.

3.2.2 Driveways

Driveways are ignored by the design consistency algorithm. Their presence does not affect the speed profile.

3.2.3 Spirals

The design consistency algorithm treats spirals as tangent sections.

3.2.4 Curve-Curve Pairs

For any combination of adjacent curves (compound/reverse), the predicted speed on each curve is computed as described in Step 2 of the design consistency algorithm. The speed profile shows an instantaneous change in speed between the curves.

3.2.5 End Conditions

Speeds predicted near the beginning and end of the analysis section (i.e., the end conditions) might not be valid, because conditions upstream and downstream of the analysis section are unknown. Several rules have been developed to approximate these conditions and are described in this section.

3.2.5.1 Beginning of Analysis Section

Highway alignments that begin at a stop, start at/near a curve, or start at a speed other than the desired speed require special consideration. By default, the DCM sets the speed at Analysis Start Station equal to the desired speed selected by the user. In this case, the speed at the beginning of the analysis section will be equal to the desired speed (Figure 7, *Speed Profile Where Speed at Analysis Start Station is Equal to the Desired Speed*), unless there is not enough distance to decelerate from the desired speed to the curve speed as predicted by Step 2 of the speed prediction algorithm. When this occurs, the start speed is calculated as the speed from which the vehicle can decelerate to the speed on the first curve (Figure 8, *Speed Profile Where the Tangent Length to Decelerate from the Desired Speed to the Speed on the First Curve is Insufficient*).

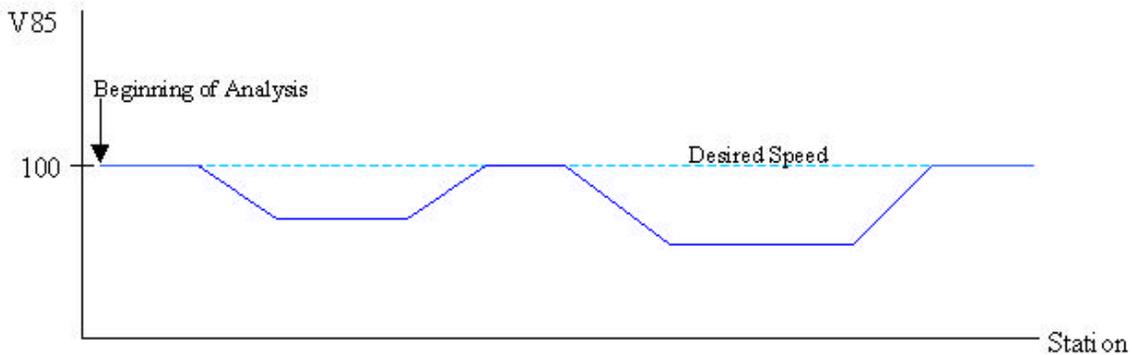


Figure 7 Speed Profile Where Speed at Analysis Start Station is Equal to the Desired Speed

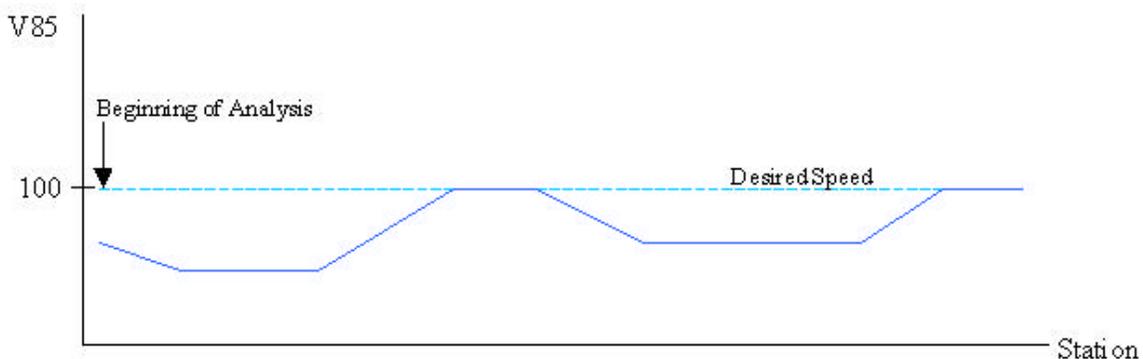


Figure 8 Speed Profile Where the Tangent Length to Decelerate from the Desired Speed to the Speed on the First Curve is Insufficient

When the user enters a speed at Analysis End Station that is not equal to the desired speed, the speed prediction algorithm uses the TWOPAS equations to accelerate the vehicle to the desired speed (Step 4). The speed profiles from Steps 3 and 4 are then compared and the lowest speed selected at each point along the alignment to create a final speed profile (Figure 9, *Speed Profile*

Where Speed at Analysis Start Station is less than the Desired Speed).

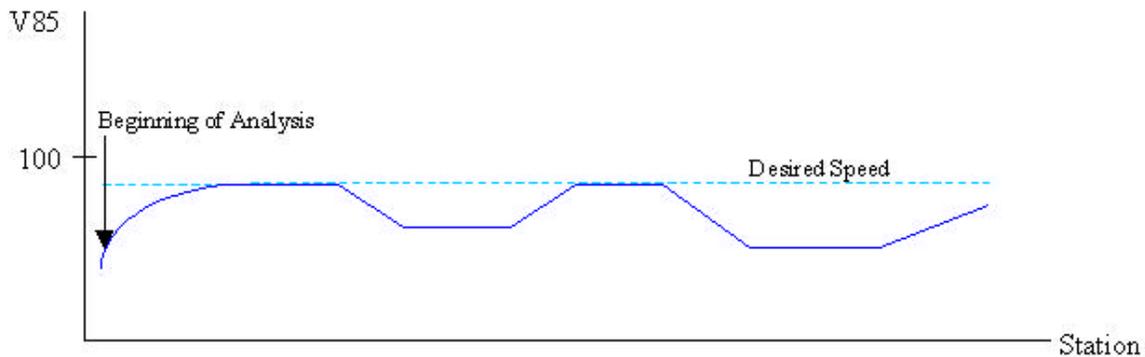


Figure 9 Speed Profile Where Speed at Analysis Start Station is less than the Desired Speed

3.2.5.2 End of Analysis Section

Highway alignments that end at a stop, end at/near a curve, or end at a speed other than the desired speed require special consideration. By default, the DCM sets the speed at Analysis End Station equal to the desired speed selected by the user. In this case the speed at the end of the analysis section will be equal to the desired speed (Figure 10, *Speed Profile Where Speed at Analysis End Station is Equal to the Desired Speed*), unless there is not enough distance to accelerate to the desired speed from the curve speed as predicted by Step 2 of the speed prediction algorithm. When this occurs the end speed is calculated as the speed to which the vehicle can accelerate from the speed on the last curve (Figure 11, *Speed Profile Where the Tangent Length at the end of the Alignment is Insufficient to Accelerate to the Desired Speed*).

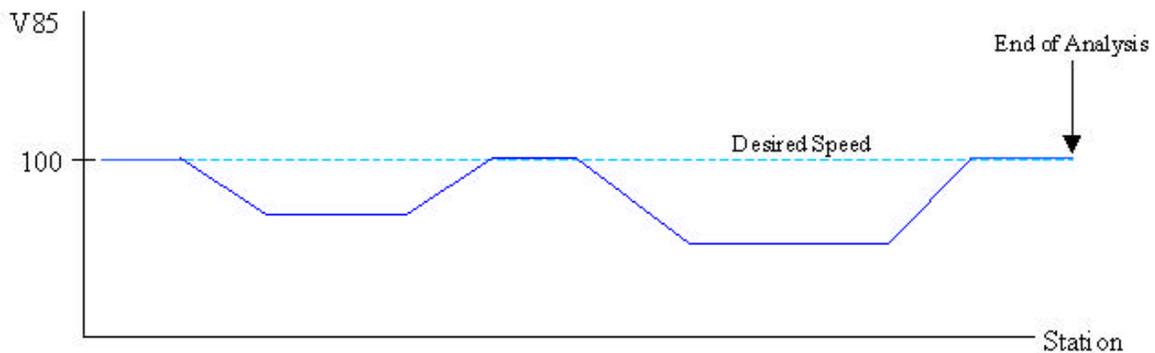


Figure 10 Speed Profile Where Speed at Analysis End Station is Equal to the Desired Speed

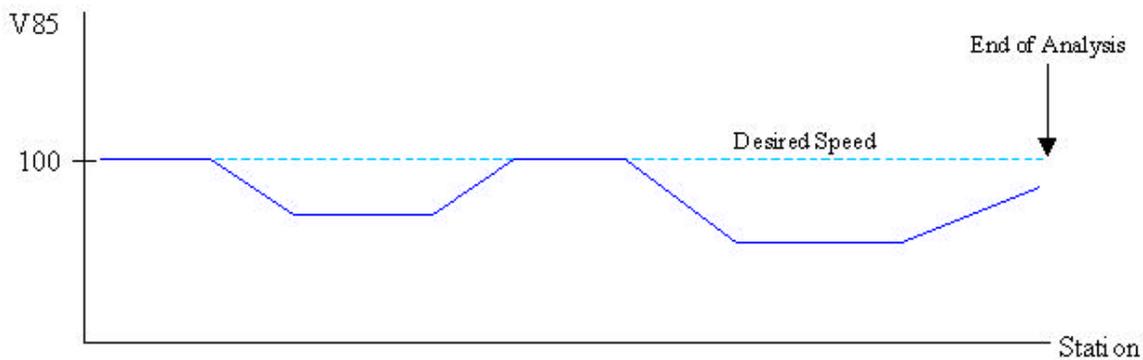


Figure 11 Speed Profile Where the Tangent Length at the end of the Alignment is Insufficient to Accelerate to the Desired Speed

When the user enters an end speed that is less than the desired speed, and there is sufficient length to accelerate to a speed above the speed at the analysis end station, the speed prediction algorithm uses a constant deceleration rate of 2.5m/s^2 to reach the user input end speed (Figure 12, *Speed Profile Where Speed at Analysis End Station is less than the Desired Speed*).

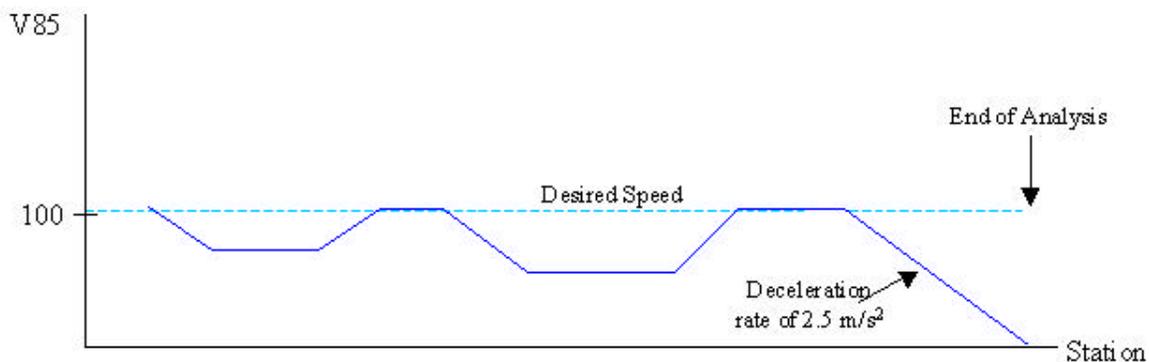


Figure 12 Speed Profile Where Speed at Analysis End Station is less than the Desired Speed

4. Design Consistency Evaluation

Two design consistency checks can be performed:

- Design speed vs. operating speed assumption.
- Speed differential of adjacent design elements.

4.1 Design Speed vs. Operating Speed Assumption Check

The design speed vs. operating speed assumption check evaluates the consistency of estimated 85th percentile speeds and the design speed of the highway. The measure of consistency for this check is the difference between the estimated 85th percentile speed (V_{85}) and the design speed (V_{design}) of the highway.

AASHTO's 2001 A Policy on Geometric Design of Highways and Streets suggests the selected design speed "should be consistent with the speeds that drivers are likely to expect on a given highway facility," "should fit the travel desires and habits of nearly all drivers expected to use a particular facility," and on a cumulative distribution of free-flow vehicle speeds "should be a

high-percentile value."

Design policy generally incorporates generous margins for safety in recommended ranges of values for design elements related to design speed. Furthermore, design policy encourages and design practice uses above-minimum values where practical. Therefore, operating speeds higher than the design speed of the highway are not necessarily a concern. Where the differences are relatively large, however, some additional attention may be appropriate to verify no concerns exist.

To assist users in visual inspection of the results of this check, ranges of values for this measure are grouped and color-coded in the graphical and tabular output (Section 5) as follows:

Condition 1 (Green): $(V_{85} - V_{\text{design}}) \leq 10 \text{ km/h (6 mph)}$

Condition 2 (Yellow): $10 \text{ km/h (6 mph)} < (V_{85} - V_{\text{design}}) \leq 20 \text{ km/h (12 mph)}$

Condition 3 (Red): $20 \text{ km/h (12 mph)} < (V_{85} - V_{\text{design}})$

The grouping of ranges of values and their color-coding are intended to distinguish larger differences from smaller differences. The research upon which DCM is based does not provide evidence of any direct correlation between this measure and crash experience. There is no "standard," and the color-coding is not intended to imply that any range of values is unacceptable.

The intent is to help prioritize where additional attention may be appropriate. The priority should be on sections of highway color-coded red, and to a lesser extent those color-coded yellow. On these sections, local knowledge should be brought to bear and consideration should be given to:

- Whether local knowledge of the segment suggests the estimated 85th percentile speeds are reasonable,
- Whether (for an existing highway) crash history suggests an unusually high frequency of speed-related crashes,
- Whether the selected design speed is appropriate,
- Whether the use of above-minimum design values inappropriately promotes the higher operating speed, or
- Whether any design elements (e.g., sight distance) are near or below the lower end of the range of recommended values for the assumed design speed and might, therefore, have relatively narrow margins for safety at the higher estimated operating speeds.

4.2 Speed Differential of Adjacent Design Elements Check

The primary measure of design consistency on two-lane rural highways is the expected reduction in 85th percentile speed between adjacent horizontal design elements.

The module checks the differences between the estimated 85th percentile speeds of adjacent horizontal elements, i.e., between each tangent ($V_{85\text{Tangent}}$) and its succeeding curve ($V_{85\text{Curve}}$), and between adjacent curves. Intuition suggests and analyses of crash data generally support the hypothesis that crash rates on curves increase with increases in the estimated speed reduction from the approach tangent to the curve.

To assist users in visual inspection of the results of this check, ranges of values for this measure are grouped and color-coded in the graphical and tabular output (Section 5) as follows:

Condition 1: $(V_{85Tangent} - V_{85Curve}) \leq 10$ km/h

Condition 2: $10 \text{ km/h} < (V_{85Tangent} - V_{85Curve}) \leq 20$ km/h

Condition 3: $20 \text{ km/h} < (V_{85Tangent} - V_{85Curve})$

The groupings of ranges of values and their color-coding are intended to distinguish larger differences from smaller differences. The research upon which DCM is based (documented in Report No. FHWA-RD-99-171, Speed Prediction for Two-Lane Rural Highways) estimated that average crash rates for curves requiring greater than 20 km/h (12 mi/h) speed reductions were six times the average crash rates for curves requiring less than 10 km/h (6 mi/h). Estimated average crash rates for curves requiring 10-20 km/h (6-12 mi/h) speed reductions were three times the average crash rates for curves requiring less than 10 km/h (6 mi/h). It must be understood, however, that there is no policy or standard for what is acceptable or unacceptable, and these groupings and their color-coding is not intended to imply and should not be construed as inferring such.

The intent is to provide a quantitative measure that helps prioritize where additional attention may be appropriate. The priority should be on adjacent horizontal elements where the estimated reduction in 85th percentile speeds is relatively large; i.e., greater than 20 km/h (12 mi), and, to a lesser extent, between 10 and 20 km/h (6 and 12 mi/h).

On alignment segments where relatively large speed reductions are estimated, local knowledge should be brought to bear and consideration should be given to:

- Whether local knowledge of the segment suggest the estimated reductions in 85th percentile speeds are reasonable,
- Whether (for an existing highway) crash history suggests an unusually high frequency of related crashes,
- Whether adjustments to the alignment are possible to reduce the estimated speed reduction,
- Whether adjustments to cross section and roadside design may be effective and would be possible in order to accommodate higher than average expected frequency of run-off-road incidents,
- Whether available sight distance provides drivers adequate visibility to the curve,
- Whether appropriate traffic control devices are installed or planned to warn drivers of the condition.

In many cases, alignment combinations producing large estimated speed reductions result from physical constraints (e.g., topography or water features) and represent a good design solution given those constraints. These physical constraints may preclude additional adjustments to the alignment, cross section, and roadside. The above-listed bullets suggest a sequence of considerations that reflects the challenges of dealing with these constraints.

5. Design Consistency Module Output

The Design Consistency Module creates a graph and an analysis report to show the results of the design consistency evaluation. The DCM Graph shows the results of the evaluation on the speed profile along with various geometric characteristics of the alignment analyzed. The DCM Analysis Report contains the both graphical and tabular summaries of DCM results.

5.1 DCM Graphical Output

The DCM Output (Figure 13, *Example of DCM Graphical Output*) is displayed graphically through the "Create Graph" button on the Evaluation Tab.

An estimated 85th percentile speed profile showing results of the user-selected consistency measures can be displayed for either direction of travel (increasing or decreasing stations), as described in Section 5.1.1. See Section 4: Design Consistency Evaluation, for more information on design consistency measures (i.e., design speed vs. operating speed, and speed differential of adjacent design elements).

At the users option, several plots representing the geometric characteristics of the highway being analyzed can also be displayed, as described in Section 5.1.2.

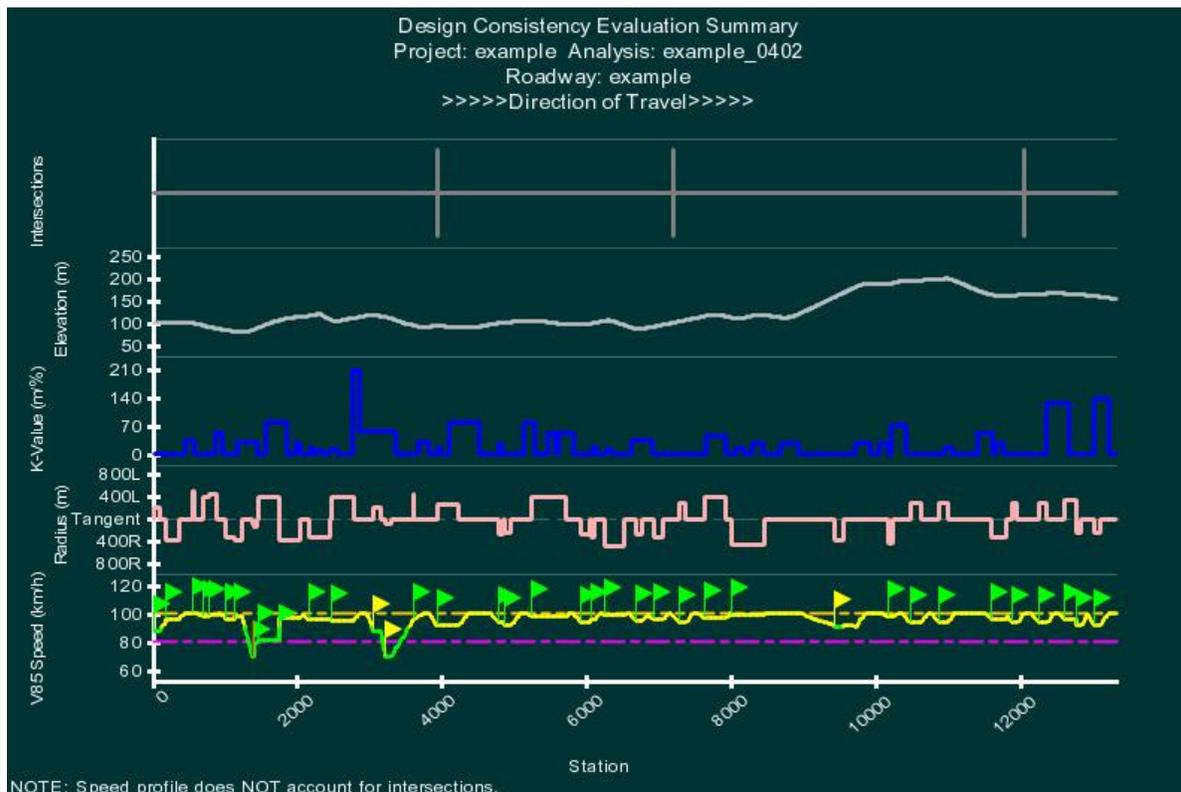


Figure 13 Example of DCM Graphical Output

5.1.1 Estimated 85th Percentile Operating Speed Profile Plot with Design Consistency Measures

An Estimated 85th Percentile Speed Profile can be displayed for either direction of travel (increasing or decreasing stations). Results of the consistency checks performed are shown via color-coding and "flags" added to the speed profile. See Section 3 and 4 for more information on the estimated 85th percentile operating speed profile algorithm and design consistency measures.

The speed profile is color-coded based on the conditions (1 through 3) that are used to group ranges of values for the design speed vs. operating speed measures (design speed assumption check), as described in Section 4.1. For example, for sections of the highway where the estimated 85th percentile operating speed is more than 20 km/h greater than the design speed, the speed profile is colored red (Condition 3).

To represent the results of the speed differential of adjacent design elements check, colored flags are placed on the estimated 85th percentile operating speed profile at stations where horizontal circular curves begin (e.g., at the PC, PCC, or SC). The flag color relates to Conditions 1 through 3, as described in Section 4.2. For example - given a tangent and a succeeding circular curve with PC at station 1+000, if the speed on the curve is more than 20 km/h less than the maximum speed on the preceding tangent, a red flag would be placed on the estimated 85th percentile operating speed at station 1+000, pointing in the direction of travel.

Desired speed and design speed can also be displayed on the same plot at the user's option.

5.1.2 Plots Representing Geometric Characteristics of Highway

In addition to the estimated 85th percentile operating speed profile, the user has option of displaying the following plots:

- Intersections.
- Vertical profile.
- K-value.
- Horizontal curve radius.
- Estimated 85th percentile speed profile.

5.1.2.1 Intersection Locations

Intersections can be displayed when an intersecting highway has been added and defined through the Edit>Edit Intersection interface, and the intersection has been described in the Edit/View Highway Information Dialog. All types of intersections that can be displayed are described in Section 3.2.1, *Intersections*. Intersections are represented by a long hash-mark which is orthogonal to a horizontal line that represents the length of the analysis road. When the cursor is dragged over the hash-mark, a pop-up window or "tooltip" appears listing the name of the cross street. When no intersections are present on the alignment being analyzed, the intersection plot appears as a straight, horizontal line.

Intersections are not factored into the design consistency analysis. The purpose of this plot is to simply show the locations of intersections.

5.1.2.2 Vertical Profile/Elevation

This is a plot of the vertical profile. The y-axis shows the elevation of the profile.

5.1.2.3 K-value

This is a plot of the rate of vertical curvature, or length per percent of difference in grade. When the cursor is dragged over the plot at the beginning of a vertical curve, K-value is shown at the bottom left corner.

5.1.2.4 Horizontal Curve Radius

The horizontal curve radius graph shows the direction, radius, and length of the horizontal curves on the selected alignment. Lines plotted along the x-axis represent tangent sections while curves to the left are plotted above the x-axis and curves to the right are plotted below the x-axis. The radius of the curve is plotted along the y-axis. When the cursor is dragged over the plot of the curves the PC or PT station is shown along with the curve radius and direction, 'L' for left and 'R' for right.

5.1.2.5 Horizontal Degree of Curvature

Similar to Horizontal Curve Radius with degree of curve is plotted rather than radius.

5.2 DCM Analysis Report

5.2.1 Graphical Output

The graphs showing the estimated 85th percentile operating speed profile, consistency measures and geometric characteristics for the analysis section (described in Section 5.1) are included in the DCM Analysis Report.

5.2.2 Tabular Output

Tabular output provided in the DCM Analysis Report includes the following:

- V85 Speed Profile Coordinates
- Design Speed Assumption (Design Speed vs. Operating Speed) Check Results
- Speed Differential of Adjacent Design Elements Check Results

5.2.2.1 V85 Speed Profile Coordinates

The V85 Speed Profile Coordinate Tables list the coordinates where the slope of the speed profile changes. Coordinates are denoted by a station and a predicted speed. Stations with an asterisk indicate locations where the deceleration to the following station (i.e., from Curve n to the Curve n+1) was greater than the approximated comfortable deceleration rate between curves (1.25 m/s²). The estimated deceleration can be found as follows:

$$d = \frac{V_{n+1}^2 - V_n^2}{25.92(LSC_a)}$$

Figure 14 Estimated Deceleration Equation

where

d = deceleration rate (m/s²)

V_n = speed on curve n (km/h)

V_{n+1} = speed on curve n+1 (km/h)

LSC_a = distance between curves or length of tangent between curves (m)

5.2.2.2 Design Speed Assumption Check Results

The Design Speed Assumption Check Results Tables illustrate the locations where a specified condition exists (Conditions 1 through 4) as described in Section 5.1. The rows in the table are color-coded to match the condition the row represents, as is shown by color-coding in the speed profile in the graphical output. Columns in the table are as follows:

Station (From): Beginning station for condition specified in given row.

Station (To): End station for condition specified in given row.

$V_{85} - V_{\text{design}}$ Speed (Min.): The minimum difference between the 85th percentile and the design speed for the station range specified on the given row (km/h or mi/h).

$V_{85} - V_{\text{design}}$ Speed (Max.): The maximum difference between the 85th percentile and the design speed for the station range specified on the given row (km/h or mi/h).

Condition: The condition (1 through 3) as determined by the differential between the 85th percentile and the design speed. See Section 4.1 Design Speed Assumption Check for more information.

5.2.2.3 Speed Differential of Adjacent Design Elements Check Results

The Speed Differential of Adjacent Design Elements Check Results Tables compare the 85th percentile speed between adjacent elements and specifies the condition (Conditions 1 through 3) as described in Section 5.2. The rows in the table are color-coded to match the condition the row represents, as is shown by the color-coded flags on the speed profile in the graphical output. Columns in the table are as follows:

- Station of max speed on preceding element: Location where the speed is greatest on the element preceding the analyzed curve.
- Max speed on preceding element (km/h or mi/h): Maximum speed on element preceding the analyzed curve.
- Start Station of curve color-coded: Flags are placed at this location on the V85 speed profile in the DCM graphical output to indicate the condition (i.e., the speed differential from the preceding element).
- Speed on curve (km/h or mi/h): The predicted 85th percentile speed at the beginning of the curve.
- Speed Differential (km/h or mi/h): the maximum speed differential between adjacent elements (i.e., the Max speed on preceding element - Speed on curve).
- Condition: The condition (1 through 3) as determined by the magnitude of speed differential between adjacent design elements. See Section 4.2: Speed Differential of Adjacent Design Elements Check for more information.

6. Glossary

85th Percentile Speed (V85)

The 85th percentile of a sample of observed speeds is the general statistic used to describe operating speeds on a geometric feature. It is the speed at or below which 85 percent of the drivers are operating.

Design Speed

The design speed is defined by the American Association of State Highway and Transportation Officials (AASHTO) in its 2001 A Policy on Geometric Design of Highways and Streets as "a selected speed used to determine the various geometric design features of the highway." Design speed can be edited through the "Edit/View Highway Information" dialog under the General Tab.

Desired Speed

In the speed-profile model, desired speed is the 85th percentile speed that drivers select when not constrained by the vertical or horizontal alignment. Empirically, desired speed is estimated by measuring speeds on portions on long tangents where speed is not constrained by either vertical gradient or horizontal and vertical curvature. In IHSDM, the default value for desired speed is 100 km/h (62 mi/h). This default value is based upon the average of 85th percentile speeds on long tangents in the research used to calibrate the model. The average was based upon speeds measured in six States at 64 long tangents on highways with 88.5 km/h (55 mi/h) posted speed limits. Among the six States, the averages ranged from 93 km/h (58 mi/h) in New York and Pennsylvania to 103 km/h (64 mi/h) in Texas. Users may specify a different desired speed on the DCM Attributes Tab.

Speed at Analysis Start Station

The 85th percentile initial speed when traveling in the direction of increasing stations or the end speed when traveling in the direction of decreasing stations. This speed cannot be greater than the desired speed. It is set to the desired speed by default and may be edited by the user from the DCM Attributes Tab.

Speed at Analysis End Station

The 85th percentile end speed when traveling in the direction of increasing stations or the initial speed when traveling in the direction of decreasing stations. This speed cannot be greater than the desired speed. It is set to the desired speed by default and may be edited by the user from the DCM Attributes Tab.

Speed Profile

One of the ways in which operating speeds are used in ensuring design consistency is through the use of speed profiles. Speed-profile models are used to detect speed inconsistencies along road alignments. A speed profile is a plot of operating speeds on the vertical axis versus distance along the highway on the horizontal axis.

TWOPAS

Description:

TWOPAS is a microscopic model that simulates traffic operations on two-lane highways by reviewing the position, speed, and acceleration of each individual vehicle on a simulated highway at 1-second intervals and advancing those vehicles along the highway in a realistic manner. The model takes into account the effects on traffic operations of road geometrics, traffic control, driver preferences, vehicle size and performance characteristics, and the oncoming and same direction vehicles that are in sight at any given time. The model incorporates realistic passing and pass abort decisions by drivers in two-lane highway passing zones. Spot data, space data, vehicle interaction data, and overall travel data are accumulated and processed, and various statistical summaries are printed.

Use of TWOPAS in the Design Consistency Module:

Steep upgrades reduce passenger car speeds. The TWOPAS traffic simulation model contains equations that can be used to represent the effect of grades on the speed of passenger cars.

Upgrades have the effect of limiting the accelerations that vehicles can achieve, thus making it difficult for drivers to maintain their desired speed. If the grade a vehicle is ascending is steep enough, the vehicle will be forced to decelerate. If the grade is also long enough, the vehicle will eventually decelerate to a crawl speed. A vehicle at its crawl speed can continue up the grade at a constant speed without decelerating further, but cannot accelerate. A vehicle's crawl speed on a

specific grade is a function of the steepness of the grade and the performance characteristics of the vehicle. The length of grade required for a vehicle to reach its crawl speed is a function of the steepness of the grade and the performance characteristics of the vehicle, as well as the vehicle's initial speed as it enters the grade.

In the DCM, TWOPAS equations are used to check the performance-limited speed along the highway. If, at any point, the grade-limited speed is less than the tangent or curve speed predicted using the speed prediction equations or the assumed desired speed, then the grade-limited speed will govern.

The procedure for predicting the grade-limited speed using the TWOPAS equations can be summarized as follows:

1. Calculate vehicle performance speeds along the alignment at one-second intervals.
2. Calculate speeds based on the driver's preferred acceleration rate at one-second intervals.
3. At each time interval, compare the speeds predicted in Steps 1 and 2, and select the lowest speed. The speed selected is used as the initial speed for the next one-second interval in Steps 1 and 2. This process is continued for the entire analysis section.

The result is an estimated operating speed profile for the selected design vehicle, based on the effects of the vertical alignment.

Vehicle Type

There are five passenger car vehicle types included in the DCM. Passenger Car- Type 5 is set as the default vehicle, and has the highest acceleration and top speed of all the loaded vehicles; it is also the most common vehicle, making up 30% of the passenger car population. Conversely, Passenger Car- Type 1 has the lowest acceleration and top speed and represents the smallest portion of the passenger car population at 10%. Changing the vehicle type for a given analysis with all other variables remaining constant, may change the 85th percentile speed profile. This depends upon whether or not the speeds predicted by the TWOPAS equations in Step 4 of the speed profile algorithm are lower than the speeds predicted by the speed prediction equations in Steps 2 and 3. If the speeds predicted by the TWOPAS equations are lower, then the final 85th percentile speed profile will reflect a decrease. The grade-limited speeds predicted by the TWOPAS equations are most likely to control on long, steep grades. Vehicle type may be edited from the Parameters Tab.

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