Highway Geometric Modeling Method by Curvature and Gradient Functions

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ABSTRACT: Highway alignments are designed as the sequences of elements such as lines, arcs and spirals. This method makes the difficulty to build and edit the 3-D highway models on CAD systems, because horizontal/vertical alignments and cross-sections are defined individually and each kind of elements has different parameters for shape definition. This paper shows that highway alignments can be determined by functions of curvature and gradient, and shows the schema to build the 3-D geometric models. Utilizing this method, the 3-D highway geometric models can be built with fewer data systematically, and it can be applied to the highway product models for computer-based design in future.

1 INTRODUCTION

The 3-D highway geometry is the composition of horizontal alignments, vertical alignments and cross-sections. In the current design method, a horizontal alignment is designed as a sequence of elements such as lines, spirals, and curves (arcs), and a vertical alignment is designed as a sequence of elements such as lines and arcs. This method makes the difficulty to build and edit the 3-D highway models on CAD systems because horizontal/vertical alignments and cross-sections are defined individually and each kind of elements has different parameters for shape definition. Furthermore this problem is an obstacle to build auto-designing systems for highway.

This short paper proposed the highway geometric modeling method utilizing curvature/gradient functions.

2 FUNCTIONALIZATION OF HIGHWAY ALIGNMENT

On the assumption of an automobile traveling at a constant velocity, a time-velocity-curvature system can be expressed by distance. Time-velocity-curvature and time-velocity-gradient systems can be regarded to be equivalent to distance-curvature and distance-gradient systems, respectively. Here, functions with the horizontal distance along a highway alignment as a parameter in each system are defined as the curvature and gradient functions. The method proposed in this paper handles these curves as functions that determine highway alignments and thereby tries to design highway alignments in a process reverse to conventional methods. Horizontal and curvature functions can be represented by continuous piecewise linear functions and can be specified by the list of turning points of curvature and gradient with the distance.

A driver traveling along a continuous highway alignment turns the steering wheel continuously. Then curvature function $\Theta(l)$ is becomes also continuous. $\Theta(l)$ may thus be regarded as a continuous piecewise linear function. $\Theta(l)$ at distance l in section n (n = 1, 2, 3…) is expressed as shown in Equation 1. Curvature function $\Theta(l)$ can be defined by given (l_n, θ_n) as a boundary condition.

$$\begin{cases} \Theta(l) = \Delta\theta_n (l - l_{n-1}) + \Theta(l_{n-1}) \\ \Delta\theta_n = \dfrac{\theta_n - \theta_{n-1}}{l_n - l_{n-1}} \end{cases} \tag{1}$$

where,

l_n : *distance at the end of section n (where* $l_0 = 0$*)*

θ_n: *curvature at the end of section n (*θ_0 *is the initial curvature)*

$\Delta\theta_n$: *rate of change in curvature in section n*

For existing design methods, elements of a vertical alignment consist of straight lines and vertical curves. For vertical curves, parabolic curves are generally used. Gradient, which is a differential of vertical alignment, is then represented by a linear expression. Since vertical gradient is continuous as well as horizontal alignment, gradient function $J(l)$ at distance l in section n (n = 1,2,3…) is represented

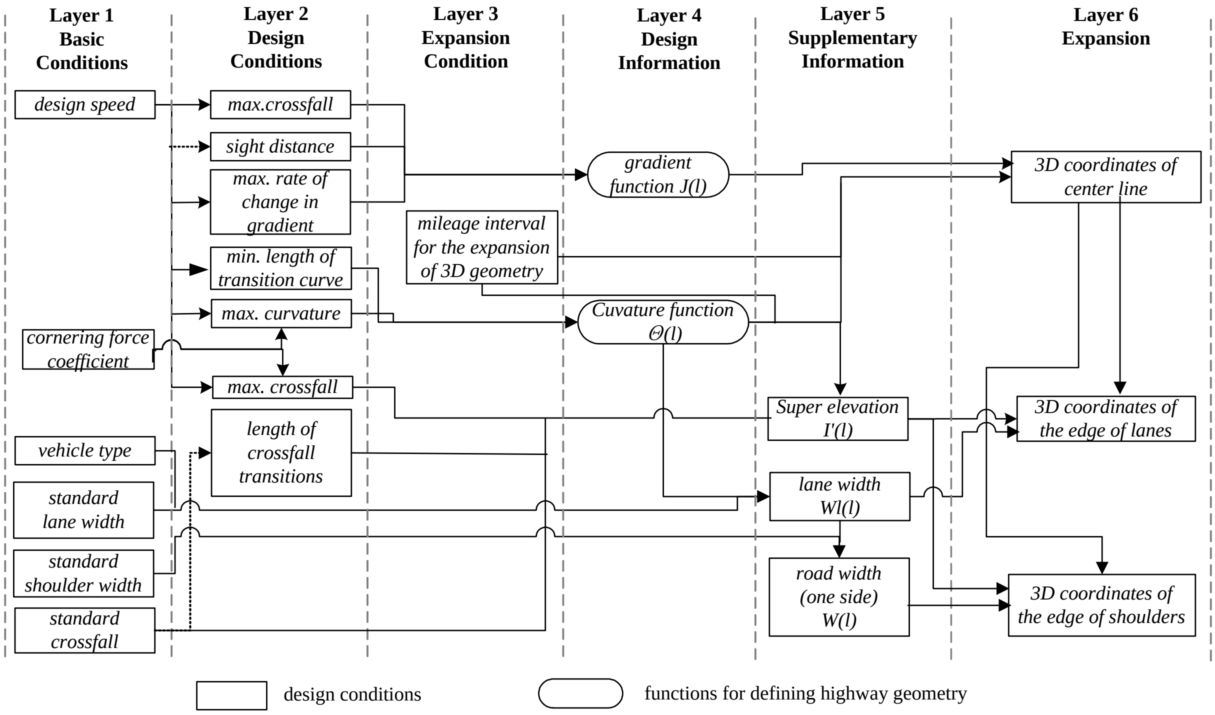

Figure 1. Schema of highway geometric model

by equation shown in Equation 2. Thus, gradient function $J(l)$ can be defined by boundary condition $(l_n,\ j_n)$

$$\begin{cases} J(l) = \Delta j_n (l - l_{n-1}) + J(l_{n-1}) \\ \Delta j_n = \dfrac{j_n - j_{n-1}}{l_n - l_{n-1}} \end{cases} \tag{2}$$

where,

j_n : gradient at the end of section n (j_0 is the initial gradient)

Δj_n :rate of change in gradient in section n

3 SCHEMA OF GEOMETRIC DESIGN MODEL

Based on the boundary conditions for curvature and gradient functions, 3D coordinates of the highway alignment can be defined. Crossfall and widths of the lane can be determined by the curvature functions automatically. Thus, a 3D highway geometric design model can be built in the design space.

The modeling process of the 3D highway geometry can be classified into 6 layers schematically (Figure 1).

4 BENEFITS OF GEOMETRIC DESIGN SYSTEM

The highway geometric model using curvature and gradient functions produces the following benefits.

- Setting only of curvature and gradient functions enables automatic definition of geometric design and immediately provides the 3-D geometric model.
- Curvature and gradient functions are always continuous and guarantee the continuity of the highway alignment.
- Transmission of precise design information is possible only with a few data. Data processing is also easy.

5 CONCLUSIONS

This paper shows that highway geometric design can be determined basically by curvature and gradient functions with distance l as a variable.

In the field of highway engineering as well as in other fields, product models are now being developed (OKSTRA, LandXML etc.). For defining highway alignments, however, existing paper-based methods based on alignment parameters are still being used. The method proposed in this paper can build the 3-D highway geometric models with fewer data, thus it can be applied to the product models for computer-based design in future.

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