A Web-Based Roadway Geometry Design Software for Transportation Education

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ABSTRACT
Traditionally, students use pencil and ruler to lay out lines and curves over contour maps for roadway geometry design. Numerous calculations of stopping sight distance, minimum turning radius, and curve alignments are required during the roadway design process in order to ensure safety, to minimize economic and environmental impacts, as well as to reduce construction costs. Iterative computations during the design process are usually performed manually by the students in order to meet any given design criteria and environmental constraints. The traditional design process of roadway geometry design is often cumbersome and time consuming. It limits students from taking a broader perspective on the overall roadway design process. An Internet-based roadway design tool (ROAD: Roadway Online Application for Design) was developed to enhance the learning experience for transportation engineering students. This tool allows students to efficiently design and to easily modify the roadway design with given economic and environmental parameters. A 3D roadway geometry model can be generated by the software at final design to allow students immerse themselves in the driver’s seat and drive through the designed roadway at maximum design speed. This roadway geometry design tool was deployed and tested in a civil engineering undergraduate class in spring 2006 at University of Minnesota, Department of Civil Engineering. Feedback was collected from instructors and students that will lead to additional enhancements of the roadway design software.

KEYWORDS
Roadway Geometry Design, Distance Learning, Transportation Visualization
INTRODUCTION

The design of the modern roadway system is a sophisticated process that provides the transportation engineer with many challenges. A roadway designer often has to consider design controls and criteria which go beyond the basic application of standards. Increasing traffic, cost of construction, the price of real estate, mix and sizes of vehicles, and environmental and ecological considerations are all part of the challenges that civil engineers face. A properly designed roadway takes into consideration mobility and safety issues while addressing economic impacts and environmental constraints [1].

There are many geometric elements involved in roadway design. The key elements of roadway alignment are the most important components of geometric design. Detailed design guidelines were discussed in the "A Policy on Geometric Design of Highways and Streets 2004" [2] published by American Association of State Highway and Transportation Officials (AASHTO). Traditionally, students use pencil and ruler over contour maps to design roadway geometry. Substantial calculations of stopping sight distance, minimum turning radius, and curve alignments are conducted during the geometric design process in order to ensure safety, to minimize economic and environmental impacts, and to reduce construction costs. Iterative calculations during the design process are usually performed manually by students in order to meet certain design criteria and environmental constraints.

The traditional design process of roadway geometry design is often cumbersome and time consuming. The traditional approach limits students from considering the overall roadway design process from a broader perspective. Many commercial software tools were developed by incorporating active digital maps, 3D design models and virtual reality walkthroughs to enhance the intelligence and connectivity for roadway design and planning process [3]. The commercial tools, designed for professionals, are usually complicated and expensive, and thus inappropriate for classroom use. We do not intend to duplicate or even compete with the commercial packages. Our goal is to provide a simple web-based tool that allows student to better understand roadway geometry design.

Internet-based roadway geometry design software (ROAD: Roadway Online Application for Design) was developed to simplify the road planning and design process. Our objective is to assist students conducting the roadway geometry design on a computer screen using a contour map as background for graphical design reference. Students will be able to design the geometry of a roadway more efficiently and effectively and thereafter spend more effort focus on transportation planning and potential environmental and economic impacts. Furthermore, the final roadway geometry design can be visualized in a 3D virtual reality environment using Virtual Reality Model Language (VRML) [4] from a web browser to examine the final roadway design in different perspective.

WEB-BASED ROADWAY GEOMETRY DESIGN

There are several commercially available software packages that offer flexible design of roadway geometry [5] and evaluate the impact of potential roadway design. However, these tools are generally complicated, expensive, and have a steep learning curve. Our intent is not to re-invent the wheel but to provide a simpler tool with easy access for undergraduate students to better understand the design of roadway geometry. Web-based education has become a popular way of complementing classroom instruction. Online learning tools bring the classroom laboratory right to a student’s computer. Web-based tool offer the benefit of platform independence and location independence. Users can access the learning tool virtually anytime and anywhere around the world using computers with Internet access.

Clearly, this approach can be integrated with other distance learning approaches already in place for teaching transportation technologies. For example, several web research modules were developed by ITS institute at University of Minnesota for high school students, [http://www.its.umn.edu/education/modules.html#webmodule](http://www.its.umn.edu/education/modules.html#webmodule). Liao et al. [6] developed a web-based traffic simulation framework for transportation training and education. Chen and Levinson [7] investigated the efficacy of using online simulation tool in teaching the topic of transportation network growth. Results from their experiment, conducted in a senior/graduate class in transportation system analysis, show that the use of online simulation tool enhanced students’ learning effectively. Helbing et al. [8] developed multilane freeway traffic models to help people better understand on-ramp vehicle merging, lane-changing, car following, lane-closing, and signal control through online traffic simulation and visualization, [http://www.mtreiber.de/MicroApplet/index.html](http://www.mtreiber.de/MicroApplet/index.html).
Our Approach

The initial development of ROAD focuses on the geometric design components and criteria. A contour map is used as background image for users to lay out roadway designs. The web-based tool provides ease of design and modification of construction lines and horizontal and vertical curves. It also allows students to place the roadway construction line/curve on appropriate location with respect to the contour map and other environmental constraints. Vertical design includes the additional capability of adjusting vertical curve intersect point (PVI) in order to minimize earthwork (cut and fill). The roadway design software tool can automatically generate reports and mass diagrams for earthwork estimation. The ROAD software also includes features to allow users to save or load horizontal or vertical design separately. More detail information about how to use the ROAD software is included in the user’s manual [9], which is available online at http://128.101.111.90/Lab_Mod/jmanualv02.pdf.

Horizontal Geometry Design

A digital contour image file is imported to ROAD as background. Information on image resolution and map scale is to be entered by users in the design settings screen (Figure 1a). Other design settings such as speed limit, maximum cut and fill, maximum grade, reaction time, minimum vertical curve length, minimum horizontal curve radius, maximum super elevation, road width, and lane width (Figure 1b), need to be specified at the beginning of the roadway geometry design. After identifying the start and end location of desired roadway construction, students can initially use the line construction tool from the toolbar to lay out the design of the roadway by following the direction tangent to contour curves. For example, we would like to design a two-lane roadway from point C to D as shown in Figure 2. Horizontal construction line segments is generated by clicking on a desired starting location over the contour map then drag the mouse to a desired ending location. End points of linear segments can later be modified using the editing tool for further adjustment. A curve segment can be generated by using the curve construction tool with desired curve radius. Users can check the minimum curve radius requirement based on the design speed and maximum grade of the roadway. The newly created curve segment can thereafter be placed inside two crossover lines, as shown in Figure 2, as curve transition between two linear segments. The curve segment doesn’t need to be placed exactly tangent to both lines initially. By selecting two crossover linear segments and a nearby curve, users can use the alignment tool under option menu to automatically calculate the tangent points and adjust the curve segment tangent to both adjacent line segments.

The major considerations in horizontal alignment design are safety, grade, type of facility, design speed, topography and construction cost. In design, safety is always considered, either directly or indirectly. Topography controls both curve radius and design speed to a large extent. The design speed, in turn, controls sight distance, but sight distance must be considered concurrently with topography because it often demands a larger radius than the design speed. All these factors must be balanced to produce an alignment that is safe, economical, in harmony with the natural contour of the land and, at the same time, adequate for the design classification of the roadway or highway [2].

The elevation information is labeled on the 2D contour map but not included in the image data file. Students will have to sequentially create stations at every location where the contour curve intersects with the proposed roadway by using the station/landmark tool. Elevation information at each station is entered in the database. List of stations can be view by clicking on the view/station landmarks tool as shown in Figure 3. The elevation of each station needs to be specified first in order to prepare for the vertical curve design.

Vertical Curve Design

After completing the horizontal geometric design, vertical curve design is required to ensure continuous grade variation for safety and driving comfort. Elevation information of each station is plotted versus the calculated horizontal road distance from the starting station to the end station based on the horizontal design as shown in Figure 4. Users can use the vertical curve construction tool to lay out the construction lines for vertical curves. Preliminary construction lines begin at the starting station by clicking on the first landmark on the graph (Figure 4). Users then sequentially click on desired vertical point of intersect (PVI) over the elevation profile until reaching the ending station by double-clicking the last landmark. A vertical curve calculation tool is used to compute the vertical point of curvature (PVC) and the vertical point of tangency (PVT) of each vertical curve. The PVC, PVT, and PVI points are identified in Figure 4 with different markers. Stopping sight distance and curve length are calculated using the formulas suggested in AASHTO manual [2].
The cut and fill profile based on the designed vertical curve can also be displayed by clicking on the fill/cut icon from the toolbar as shown in Figure 4 & 5. The zero line in the cut and fill profile, as shown in Figure 5, represents the proposed vertical curve. Lines above zero means elevation is higher than designed vertical curve which requires earth removal and lines below zero requires earth fill. Maximum cut and fill constraints specified in design settings are also plotted for references. When maximum cut/fill constraints are not met, users can easily identify the location that exceeds cut/fill constraints from the cut and fill profile, clear the designed vertical curve using the clear curves tool under the edit menu, and then adjust vertical curve by modifying the end points of the vertical curve construction lines in elevation profile. Users can also redesign a different vertical profile by using the clear design feature under the edit menu to remove both vertical curves and construction lines.

The mass diagram of the roadway design can also be plotted as shown in Figure 6 to estimate the amount of earth work required along the roadway design. The final design report, as shown in Figure 7, includes the station location and elevation information, grade, and amount of total earthwork, can also be created automatically by the software after the final geometry design.

3D Animation

The 3D roadway model was created based on the data from horizontal geometry design and the vertical curve design using Virtual Reality Modeling Language (VRML, www.web3d.org) [4]. A VRML client is required (for example, Cortona VRML client is available for freely download at www.parallelgraphics.com) to render the animation. Other VRML clients are also available from the Web3D consortium (http://www.web3d.org)

Virtual reality models have been widely used for education (for example, virtual solar system; introductory astronomy at Indiana University, http://vss.crlt.indiana.edu). Virtual reality offers many benefits such as allowing observation from a great distance, close-up examination, and providing students the opportunity for insights [10]. Traditionally, students validate their final roadway geometry design by verifying all design criteria are met. They do not have the opportunity to visualize and examine the final roadway design prior to deployment. Generating 3D roadway model in virtual reality environment allows students to examine any potential sight distance issue at vertical curves. In the 3D view, as shown in Figure 8, students can experience themselves in the driver’s seat and drive through the designed roadway at maximum design speed. The 3D animation also provides the invaluable opportunity for students to evaluate potential safety and comfort concern at maximum design speed.

FUTURE WORK

ROAD (http://128.101.111.90/Lab_Mod/RoadDesign.html) was deployed and tested in a civil engineering undergraduate class in spring 2006 at University of Minnesota, Department of Civil Engineering. An online forum was setup to provide technical assistance and share information among students. Feedback was collected from instructors and students that will lead to additional enhancements of the roadway design software. In coming semesters, we may conduct an experiment to evaluate the effectiveness of learning roadway geometry design using the ROAD software.

Currently we use the 2D contour image as background for the roadway geometry design. Elevation information at each station has to be entered sequentially and manually. In the future, we also would like to develop an interface to import Digital Terrain Model (DTM) data. Elevation information can be extracted from the digital terrain model automatically. The digital terrain model can also be integrated in the 3D animation model to enhance the realism of the drive-through experience at the final roadway design.

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We would like to acknowledge the Intelligent Transportation Systems (ITS) Institute and the Department of Civil Engineering at the University of Minnesota for supporting this work. We would like to thank Ted Morris at ITS laboratory for sharing his experience and comment from his previous involvement with roadway geometry design using the traditional pencil and ruler method in a transportation engineering class. We also would like to thank the...
teaching assistant, Nebiyou Tilahun, of the Civil Engineering Department who ran the instructional lab and obtained feedback from students.

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Figure 1b. Settings of Roadway Geometry Design
Figure 2. Horizontal Geometry Design
Figure 3. List of Stations

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Figure 4. Vertical Curve Design – Elevation Profile
Figure 5. Vertical Curve Design – Fill and Cut Profile
Figure 6. Vertical Curve Design – Mass Diagram
**Roadway Geometry Design Report**

**Vertical Curve Design Summary**

Total road length = 4147.991 m = 4.147991 Km.

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**Curves Location and Elevation**

- **Curve(1)** Length = 194.45001 m
  - PVC (distance, elevation) = (2.0000048, 431.6) m
  - PVI (dist_prj, elevation) = (103.950005, 431.6) m
  - PVT (distance, elevation) = (196.45001, 433.28293) m
  - Min. elevation (distance, elevation) = (11.450005, 431.6) m

- **Curve(2)** Length = 204.03852 m
  - PVC (distance, elevation) = (1069.7195, 449.5171) m
  - PVI (dist_prj, elevation) = (1181.25, 451.2) m
  - PVT (distance, elevation) = (1273.75, 449.7869) m
  - Max. elevation (distance, elevation) = (1189.3104, 450.4319) m

- **Curve(3)** Length = 333.0774 m
  - PVC (distance, elevation) = (2370.6472, 432.5922) m
  - PVI (dist_prj, elevation) = (2551.5, 430.2666) m
  - PVT (distance, elevation) = (2703.7248, 438.3339) m
  - Min. elevation (distance, elevation) = (2467.4, 432.07184) m

- **Curve(4)** Length = 368.94385 m
  - PVC (distance, elevation) = (2735.3525, 442.03716) m
  - PVI (dist_prj, elevation) = (2938.95, 450.8) m
  - PVT (distance, elevation) = (3104.2964, 449.0503) m
  - Max. elevation (distance, elevation) = (3049.2556, 449.34152) m

- **Curve(5)** Length = 274.11884 m
  - PVC (distance, elevation) = (3344.9788, 445.99722) m
  - PVI (dist_prj, elevation) = (3505.95, 444.9) m
  - PVT (distance, elevation) = (3619.0896, 438.68076) m
  - Max. elevation (distance, elevation) = (3392.8103, 445.99722) m

Figure 7. Report of Roadway Geometry Design
Figure 8. Drive Through Animation