VIRTUAL REALITY DRIVING SIMULATION:
Integrating Infrastructure Plans, Traffic Models, and Driving Behaviors

Thea Lorentzen
Road Support Group,
FORUM8 Co., Ltd.
2-1-1 Nakameguro GT Tower 15F
Kamimeguro Meguro-ku
Tokyo, Japan 150-0032
+81-3-5773-1888,
thea@forum8.co.jp

Yoshihiro Kobayashi, PhD.
Advisor, FORUM8 Co., Ltd
School of Architecture and Landscape Architecture,
Arizona State University,
PO Box 871605, Tempe, AZ, 85287-1605 USA
(480) 965-7322
ykobaya@asu.edu,

Yuji Ito
President,
FORUM8 Co., Ltd.
2-1-1 Nakameguro GT Tower 15F
Kamimeguro Meguro-ku
Tokyo, Japan 150-0032
+81-3-5773-1888,
ito@forum8.co.jp

Summary: This paper presents a virtual reality (VR) system that enables large-scale transportation plans to be simulated and viewed from a driver's perspective. Components include a visualization software program and optional motion and audio hardware systems that reproduce vehicle behaviors and link the driver and simulator. The visualization creation process is outlined from digital terrain model and road alignment input to photo-texture detailing and animation scripting. Recent applications, limitations, and presentation methods are also described. Case studies include the use of VR simulation for road design, urban planning, defensive driving training and driving behavior research.

Key words: virtual reality, driving simulator, transportation visualization, driver behavior, driver training

INTRODUCTION

Recent work in transportation visualization is evolving from a focus on how projects look to a desire to see how they actually work (1). As many walk-through simulation methods focus on a scene's aesthetic qualities, there has been a growing need for visualization of processes. As such, developments in virtual reality simulation come as a result of an increasing recognition of the value of visualization for representing not just infrastructure, but "operations" (1).

Virtual reality can be defined as technology that enables users to interact with a simulated world. When applied to transportation, VR has the potential to not only model traffic flows; it also allows for driving simulation. Observing built and natural environments from a driver's perspective provides a viewpoint that is often ignored in traditional planning methods.

Particularly for cases where driving safety or complicated transportation networks are being negotiated, real-time immersion is an alternative to other visualization tools such as image rendering and simulation, where perspectives are already chosen and the viewer's role is more passive. Here we will discuss the development and application of a system that allows for interaction with both still and dynamic transportation and infrastructure plans.

MOTIVATION AND DEVELOPMENT HISTORY

The purpose of this system development is to implement virtual reality so that it can serve as a common visual and experiential language for presenting, discussing, and ideally improving civil engineering design and driving behavior. The UC-win/Road software was first launched in 2001 and initial versions were primarily used as tools for visualizing alternative road designs. With an engineering platform, the program continues to be used as a visual tool for engineers to discuss traffic flows, road alignments and land-use issues. Recent versions have been adapted to include 3D models, animated traffic and human characters, as well as functions that allow users to take a driver's perspective along a certain route. Integration with driving simulator hardware and vehicle mechanics software allows users to interact directly with the virtual environment and has opened up more possibilities for experimenting with driver behavior and providing output logs for training or research. Also, VR's capacity to elucidate technical plans with realistic imagery has been used to facilitate dialogue between transportation engineers and the general public.

METHODS

Virtual Environment Creation

UC-win/Road software provides the interface and simulation engine for the virtual reality modeling (2). As seen in Fig. 1, with input from the user during driving "scenarios", interaction between the real-time vehicle dynamics, motion platform, and sound/image generation are synchronized.

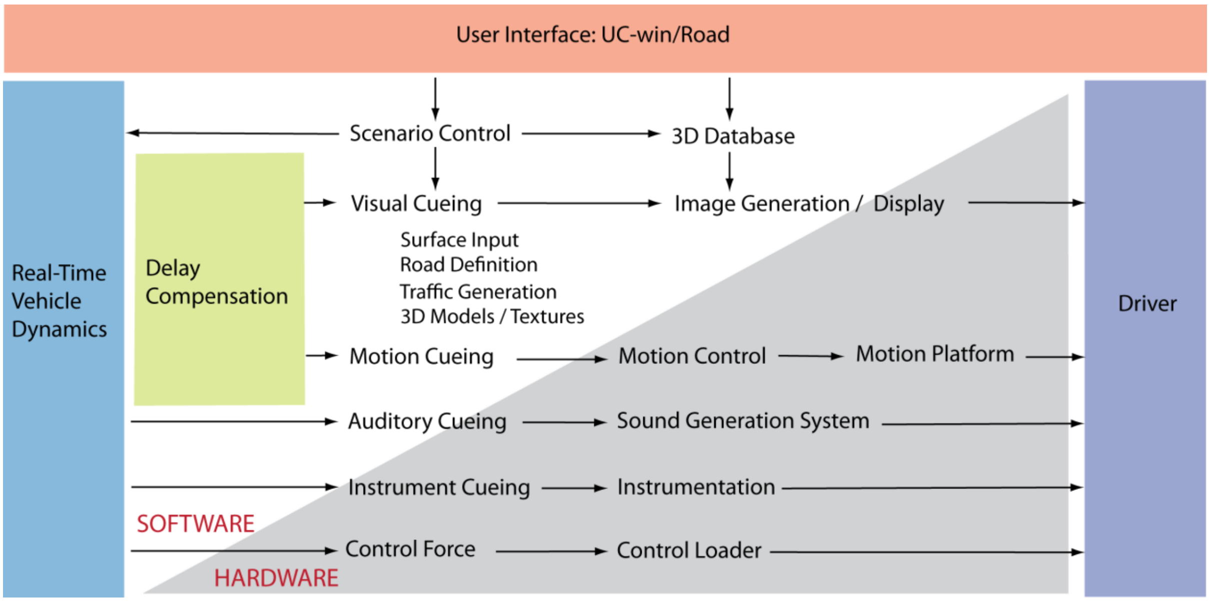

Fig. 1. UC-win/Road and driving simulator configuration.

<u>Surface Input and Road Definition</u>

Terrain information and digital imagery create a visual basis for the simulation. Digital Elevation Models can be imported and later edited by hand in patches. Aerial photographs and maps are projected upon the terrain models to provide orientation. Roads can be hand-drawn on top of a map or orthoimage; alternatively their alignments can be imported in LandXML format. As seen in Fig. 2, road alignments are defined separately in terms of their horizontal (plan) and vertical curve parameters and are placed upon the terrain models. Users alternate between the 2D (Fig. 2) and 3D (Fig. 4) interfaces as the alignments are edited.

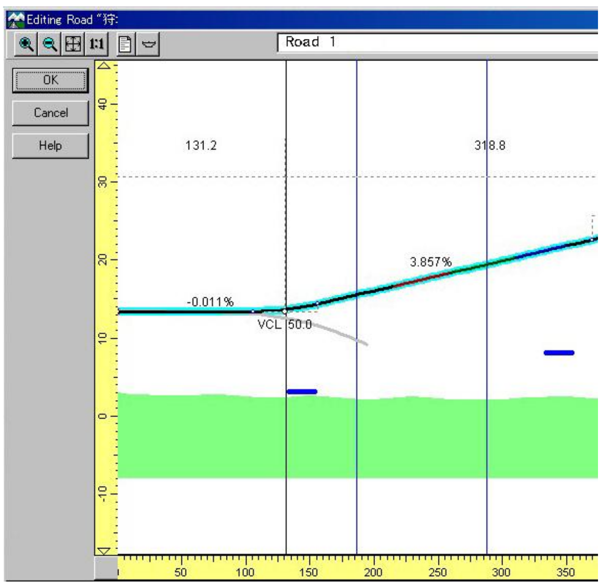

Fig. 2. Vertical road alignment editing interface: Blue horizontal lines represent a bridged road length and vertical lines show cross section changes (3) *(left)*, Plan view interface: Includes aerial imagery, horizontal road alignments, model footprints, and flight paths (3) *(right)*.

While setting alignments, cross section elements are applied at certain distances along each road to detail changes in road width, structure, texture or number of lanes. As seen in Fig. 3, cross sections are divided into individually textured elements. Road lengths can also be considered as tunnel or bridge sections, allowing different attributes of a cross section to be displayed.

Road and Traffic Generation

Once road alignments are defined, default traffic is automatically generated from the designated start and finish points. Traffic elements perform “ideally” by obeying traffic lights, moving around road obstacles, and changing speeds in recognition of nearby vehicles. Traffic volumes, speeds, profiles and the proportion of car models can be edited. Vehicle models and representative traffic profiles are selected. Intersections are edited individually allowing not only their textures to be detailed, but also the traffic settings to be adjusted (Fig. 3). Vehicle drive paths, stopping points, queue lengths, and signal settings are all tuned to mimic real-life conditions.

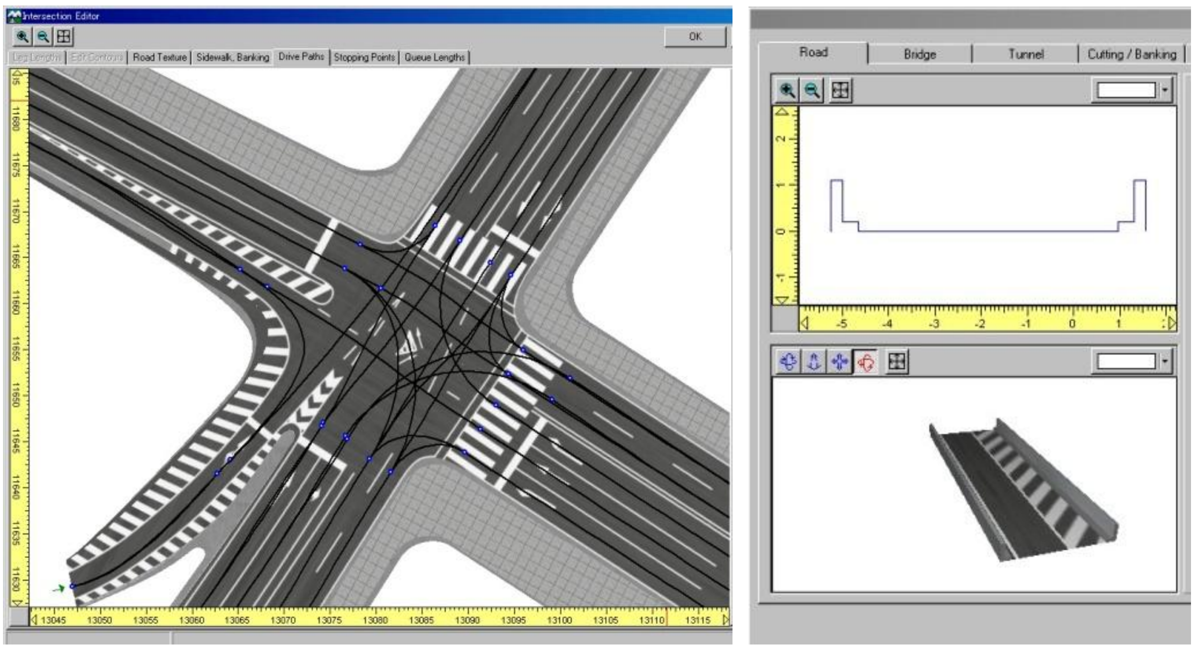

Fig. 3. Intersection editing interface: Individual drive paths, stopping points, and signal settings are applied (3) *(left)*, Road cross section design: Section element attributes include width, slope, number of lanes, texture and transparency *(right)* (3).

Creating Visual Cues with Model and Texture Input

After the basis for road and traffic simulation has been set, the VR space is further edited in order to create realistic scenarios. A compelling visual cue environment is composed with photo-textures and 3D models that can be created within the interface or imported from a database. Textures are applied to landscapes, buildings, roadways and moving models.

Model Editing

Once the model is created, the VR space can be constantly updated and re-edited for planning purposes. In the case of the Ishikawa-cho Junction simulation in Yokohama, Japan, sign visibility was a primary concern (Fig. 4). Sign placement was adjusted to enable safer merging conditions for the new highway ramps. As sign models can be moved freely in 3D view, there is very little time lag between placement, visualization, and real-time driving. Designs were tested from a driver's perspective alternatives could be immediately tried out.

Fig. 4. Sign position editing in 3D interface *(left)*, Detail Tool for adding foliage models *(right)* (3).

Visual Adjustments

Visual options are tuned in order to mimic various environmental conditions. Various aspects of the model can be turned invisible, and transparency can be applied to terrain in order to focus presentations on a particular aspect of the model. Sun flare, sun light, eye light and spotlight features express different driving conditions. Compasses, dashboards, car mirrors and position maps can also be added to the driver's perspective. In addition to weather effects such as snow, rain, and fog, various sky and cloud patterns can be introduced. Day and nighttime shadows and sun positions can be accurately adjusted to the minute based on global coordinates.

PRESENTATION

When the visualization data is opened on a desktop PC, it can be displayed within the software itself. Users freely navigate through the 3D VR space in real-time with a normal mouse. A driver's perspective can be taken to move along created roads, and flight paths are also input for traveling at varying elevations.

In order to show time series or different design alternatives, the display can switch between "before" and "after" scenes. Oftentimes scripts are also created to convey a sequence of shifting viewpoints between different roads and locations within the virtual environment.

Integration with external devices allows drivers to navigate their own way through a road network. Programmed driving scenarios can be run with a steering control device, allowing users to react to a series of pre-planned events. Gaming pads, steering wheel and pedal devices, and full-size driving simulators can also be used, and the VR space responds to the driver's input.

Fig. 5. Full-size 3-panel simulator allows for interaction with the virtual driving environment.

LIMITATIONS

Current versions of UC-win/Road system do not include functions for multi- user editing and this tends to limit the number of people who are familiar with a particular project. In this sense, a VR model may be used primarily by planners to present plans, as opposed to involving more people in the editing and drafting phases. As texture and geometry can weigh down the data, the scope of a given project may be subject to a PC's processing power. There is no artificial intelligence built in for pedestrians, so unpredictable situations such as collisions are difficult to simulate unless pre-programmed.

APPLICATIONS

The Ishikawa-cho Junction Simulation was pictured in Figs. 2-4 to illustrate a basic VR model creation process. This project employs several fundamental road and traffic simulation functions and fulfills its purpose of giving ordinary citizens a driver's perspective on how to merge onto a newly constructed, complicated interchange (3). Although this VR system has been used extensively for transport simulation projects, other applications have also included construction and evacuation visualization. Urban planning models allow for changes in both transportation networks and the built environment to be visualized in the same space. Integration with full-size simulators and customization of the software has also allowed recent projects incorporate driving behavior.

Road Design and Safety Assessment

A main expressway in central Tokyo is being constructed to join with a spiraling tunnel junction and a VR simulation has been developed mid-construction schedule to help assist with safety design. Optimal roadway marking visibility has been tested out by running driving trials and videotaping subjects' eye movements as they use the simulator. Subjects also took surveys on their perceptions of road curvature, signs and message boards. As seen in Fig. 6, comparisons between road marking and sign colors and styles can be immediately edited in the VR space.

Fig 6. Screenshots of the Ohashi Junction Drive Simulation Experiment's road markings and signage (4).

Urban Planning and Public Consensus

As visualizations have the potential to be understood by broad audiences, UC-win/Road has recently been used as a tool for conveying technical information to non-experts. Two city planning projects that have been ongoing this year include a simulation of the implementation of a new LRT line in Sakai City, Japan, created by Osaka University, and an urban model of the downtown Phoenix area, created by Arizona State University. The Sakai City model has been presented at monthly meetings to inform and involve citizens in decision-making. The ASU team is also experimenting with presentation methods for making the simulation more accessible to the public through the use of an immersive theater (Fig. 8).

Fig. 7. Digital Phoenix Project: I-10W highway simulation screenshot *(left)*, VR model projected at ASU's Decision Theater *(right)* (5).

Training and Driving Behavior Research

Japan's National Agency for Automotive Safety and Victims' Aid has also used this VR system to create a driving simulation and diagnostic test to train and evaluate taxi and bus drivers on skills that are hard to practice in real-life, e.g. defensive driving and eco-driving. Driver output is recorded from the simulators and sent to a central system for scoring students. Similarly, research on senior-citizen driving behavior has been conducted at Meijo University, Nagoya, Japan, and logs of reaction time and braking distance were exported from the simulator system.

Fig. 8. NASVA defensive driving training system screenshot (6) *(left)*, Meijo University assessment of senior-citizen drivers (7) *(right).*

ITS Technology Testing

In order to test how new in-car ITS technologies might function, VR technology has been used to simulate familiar driving conditions with different devices. With the Toyota motion platform simulator shown in Fig. 9, the VR model allows drivers to see how road-to-vehicle and vehicle-to-vehicle technology affects their driving experience. For example, users can see what it might be like to drive a car with a "pre-crash safety system", or radar collision detection. This was also the case with Japan's National Institute for Land and Infrastructure Management Smartway project where the use of a car navigation device is simulated to propose a new obstacle warning and merging support system.

Fig. 9. A motion platform simulator for Toyota's "Integrated Safety Management Concept" system (8) *(left)*, Screenshot of an obstacle warning system in the Smartway 2007 VR Simulation (9) *(right)*.

Evacuation and Construction Visualization

In an effort to improve Japan's infrastructure to better accommodate a growing population of senior citizens, a study was performed by Taisei Engineering Corporation to simulate emergency scenarios in tunnels. The VR system links analysis results from an evacuation simulation program, EXODUS (10) to the UC-win/Road software, where animated human models can be seen climbing out of their cars and walking towards the stairs, in real-time (Fig. 10). For construction work performed in a narrow space between train platforms, VR simulation was used to rehearse a sequence that would be completed without the use of cranes. The erection of temporary girders for building elevators and underground passageways was visualized to identify process clashes.

Fig. 10. Animated models observe signage and move from their cars to emergency exits (11) *(left)*, Erection of construction girders for underground construction in train stations (12) *(right)*.

FUTURE DIRECTIONS

UC-win/Road software development projects are focusing on improving traffic and rail simulation, as well as accounting for different driving behavior profiles. Other directions include advancing lighting and shading, crowd flow simulation, and tsunami/fire/smoke visualization to enable better disaster infrastructure and evacuation visualization. A Level of Detail (LOD) function for terrain will also allow larger areas to be modeled. Functions for driving scenarios are being expanded, particularly with an emphasis on integration with large-scale driving simulators. For example, an eight degree of freedom motion platform is being linked to VR driving environments to better simulate vehicle dynamics. Another plug-in in development is an Eco Drive simulator that will output fuel use and CO2 emissions to advise drivers on their efficiency. Finally, multi-user editing in UC-win/Road will be a new addition with potential to enable better collaboration and work-flow. Plans to include a history of edits will assist communication between model editors, particularly if they are working in different locations.

CONCLUSION

Virtual reality has many potential applications; here we see the development of a configuration that is specialized for transportation planning. Although this system makes certain compromises in traffic analysis and visual details, it is effective in its ability to combine large scale traffic and infrastructure visualization with individual driving behavior simulations. Ideally, developments in visualization will not only assist transportation engineering planning itself, but will help involve more people in the process. It is our hope that VR simulation will continue to enable drivers and travelers to be more aware of their roles and direct influence on future landscapes and transportation environments.

References

(1) Ronald G. Hughes, Visualization in Transportation: Current Practice and Future Directions, *Transportation Research Record: Journal of the Transportation Research Board*, 1899, pp.167-174, 2004.

(2) FORUM8 Co., Ltd., UC-win/Road, http://www.forum8.com, available on 4/30/2009.

(3) Kanagawa Construction Bureau, Metropolitan Expressway Company Limited, Ishikawa-cho Junction Simulation, 2007.

(4) Metropolitan Expressway Co., Ltd., Ohashi Junction Driving Simulator Experiment, 2009.

(5) Arizona State University, College of Design, Digital Phoenix Project by UC-win/Road

III, http://www.digitalphoenix-asu.net/dp/, 2008.
(6) National Agency for Automotive Safety & Victims' Aid (NASVA), Simulated driving diagnosis system using CG simulation, 2008.
(7) Meijo University, Faculty of Science and Technology, Department of Information Engineering, Driving Ability Measurement for Senior Citizen VR Simulation, 2007.
(8) Strategy Planning Dept., IT & ITS Planning Div., Toyota Motor Corporation, 3D VR Trial Simulator, 2009.
(9) National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure and Transport / Highway Industry Development Organization, SMARTWAY 2007 VR Simulation, 2007.
(10) University of Greenwich, School of Computing and Mathematical Sciences, Fire Safety Engineering Group, EXODUS, http://fseg.gre.ac.uk/, available on 4/30/2009.
(11) Taisei Engineering Co. Ltd., Simulation of an Evacuation in an Aging Society using 3D VR (in Japanese), 2008.
(12) Noda Engineering Co., Ltd., Erection of Construction Girders for Underground Passageway Construction in Train Stations (in Japanese), 2008.
(13) Osaka University, Graduate School of Engineering, Division of Sustainable Energy and Environmental Engineering, Sakai City Oshoji LRT Project VR Data (in Japanese), 2009.