The Application of Virtual Driving Simulation to Enhance Infrastructure Design

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Abstract. This paper describes the application of virtual driving trials to the design of a tunneled highway junction in Tokyo, Japan. A 3-panel virtual reality simulator allowed for road plans to be experienced from a driver's perspective in a 3D interactive, real-time environment. Driver reactions were then used to assess the visibility of signs, road markings, guidance information, and evacuation routes. Virtual driving trials were performed in two series with the first results indicating that changes in size, coloring and placement were necessary. The second series re-enforced that the changes were beneficial for drivers. Finally, on-site trials were also performed to confirm the feedback from simulation and prepare for construction completion. This paper presents the driving results and implementation into the highway design as well as an analysis of the VR tool's application to the safety assessment study.

1. INTRODUCTION

Virtual reality driving simulation is often used for behavior studies and driver training; it is less often applied as a tool for infrastructure design. The Ohashi Junction simulator experiment sets a precedent for using immersive VR simulation as a way to test the safety of a highway design before it is opened to drivers.

The combination of 3D modeling software and a hardware setup for driving allowed for controlled, replicable and immersive driving trials to be performed. The software platform allowed for engineering plans to be translated into virtual spaces in a way that was both accurate and easily editable.

In this case we see interactive visualization being used not only to educate drivers about a particular driving environment, but more importantly to elicit their feedback to improve the infrastructure design itself. In this sense, instead of trying to adjust driving behaviors, transport engineers aimed to adapt the built environment to better fit driver instincts. The purpose of this paper is to document experiment results in an attempt to expose one way in which advances in simulation technology can enable better consideration for human experience and safety during road design and traffic planning.

2. BACKGROUND & MOTIVATION

2.1 Ohashi Junction

The Ohashi Junction links three major arteries of the greater Shuto Expressway in Tokyo (Figure 1). 4.3km of the Shibuya line were recently opened in March 2010 while 9.4km of the Shinagawa line are still in the midst of construction. The junction, as pictured in Figure 1, is comprised of a 4-tiered spiral that drops in elevation by about 70m [1]. Upon entering the loop, drivers descend upon a steep curve and must decide the direction they will go on the freeway. This difficult tunnel driving environment was the impetus for examining how drivers can be best supported by visual cues such as signs and road markings. The creation of a virtual simulation was seen as the most efficient way to assess and incorporate driver behavior back into design. The simulation experiment focused on determining signage that could give drivers an awareness of their location and speed, a sense for the vertical gradient, and clear guidance for tunnel exits.

Figure 1: Overview of Ohashi Junction [1]

2.2 Interactive Simulation Development

With these issues in mind, editable and interactive simulation, as opposed to pure animation was the chosen method for visualization. UC-win/Road software provided the platform upon which the engineering plans were created and presented in 3D real-time [2]. The UC-win/Road software was first launched in 2001 and initial versions were primarily used as tools for visualizing alternative road designs. Recent versions have been adapted to include 3D models, animated traffic and human characters, and 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 investigation.

Beyond research, VR's capacity to elucidate technical plans with realistic imagery has been used to facilitate dialogue between transportation engineers and the general public. The program is often used as a visual tool for engineers to discuss traffic flows, road alignments and land-use issues with stakeholders [3].

3. METHODOLOGY

3.1 From Plan Drawings to Virtual Environments

Before driving simulation could be performed, engineering plans were first translated into virtual spaces within the UC-win/Road software interface.

Figure 2: Simulation interface: aerial and overview perspectives of Ohashi Junction [4]

The visualization data was created and viewed on a desktop PC with an nVIDIA GeForce 7800 graphics card, ATHRON FX-60 x 2/64X2 CPU and 2GB of memory. The 3D environment was created on the basis of engineering drawings, allowing it to be both technically accurate and editable to conform with design changes.

Road alignments formed the skeleton of the simulation. Alignments were defined in terms of both horizontal and vertical curve parameters and placed with satellite imagery upon a digital terrain model. Road cross sections were then designed to mimic both their geometric and material properties. The 3D VR space was detailed with the addition of models and textures. As seen in Figure 2, these included sign models, road markings, barrier cones, foliage, and buildings.

Traffic was automatically generated within the VR environment so the finished simulation included both static and dynamic models (Figure 2). The interface and simulation engine allowed for users to navigate through the data in real-time, either by automatic driving along a selected road alignment or by freely panning through the space with a computer mouse.

3.2 System Components

In full, the basic components of the applied simulation system included not only the software program for visualization, but also motion and audio hardware systems that reproduced vehicle behaviors, and a force control loading system that linked the driver and simulator [3]. A set of "scenarios" were designed in order to create controlled and replicable situations that could react to user behavior during the driving trials.

Driving hardware beyond just the PC was necessary for interaction with scenarios. A 3-panel simulator was created and is pictured here in Figure 3. As depicted in Figure 4, with input from the user during driving "scenarios", interplay between the real-time vehicle

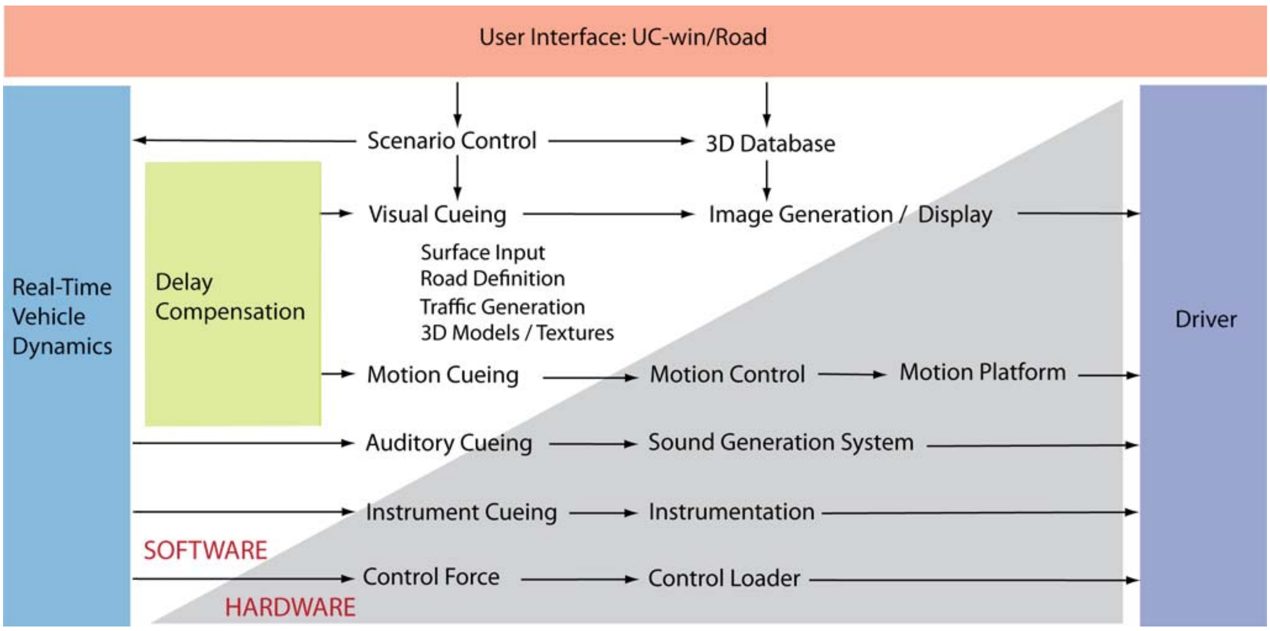

Figure 3: Software and Hardware system components [3]

dynamics, motion platform, and sound/image generation were synchronized.

A link with simulator hardware was inherent in the packaged software. Therefore the most time-consuming task proved to be the visual modeling and interaction design necessary to replicate the Ohashi Junction tunnel driving experience.

Figure 4: 3-panel simulator [5]

4. DRIVER TESTING

Driving trials were performed in two series separated by a period of six months. In order to become accustomed to the simulator, subjects practiced on a sample road prior to testing. Pre-programmed scenarios were used to expose subjects to various stretches of the junction.

For the initial series of trials, a variety of road markings, signs and wall marking designs were applied to the environment. These included sidewall signs in blue and red, triangle wall surface markings, overhead signs relaying exit/junction distances, and overhead warning signs [6] (Figure 5). The blue and red road markings were used to represent different exits off of the junction.

Figure 5: Simulation interface: driver's perspective [4]

Logs of the drivers' responses as well as surveys were used to elicit feedback. Each car's instantaneous position, lane center offset, speed, and acceleration were extracted from the simulator system. Surveys asked participants about sign visibility, clarity of exit directions, and preferences for color and design.

The second series of trials were performed once adjustments were made according to the first series of results. These results confirmed the efficacy of the design changes that had been updated in the VR model.

5. RESULTS

Survey results from the first series of trials showed that drivers called for larger overhead signs at a greater density. For example, surveys showed that the overhead sign depicted in Figure 5 should be made larger, and this change was implemented in the updated model created for the second trial. Triangular sidewall markings were generally considered unhelpful. Therefore other methods for conveying a sense of elevation will be evaluated. Zebra zone marking was added to the sides of the carriageway to help mark its limits. The red and blue colors used in the first trial were considered too strong and irritated the subjects' eyes. The Munsell color value was changed so that the red and blue were gentler and could be differentiated by people with partial color blindness.

In addition to driving trials, the VR model was also used as a basis for creating instructional videos that were used to explain evacuation routes. As shown in Figure 6, still shots of the emergency exits give drivers an image of where to go in urgent situations. Although detailed driver position logs were extracted, they have not yet been used for analysis.

Figure 6: Simulation interface: handicapped emergency exit [4]

6. IMPLEMENTATION

Real-life trials were also used to both verify the simulation results, and check additional environmental factors. Despite being very helpful for assessing sign visibility and driver opinions, there were certain qualities that could not be properly mimicked in the virtual model.

Therefore short sections of the actual tunnel length were painted to implement the designs on-site. As asphalt had not yet been laid during this phase, a black waterproof sealant was first applied below the paint.

As the colors in the virtual model differ from those produced by the paint, more trials were performed in the tunnel space prior to the finalization of the design. The effects of lighting were difficult to simulate in the virtual environment. Therefore lighting testing was also performed on-site to determine the interaction between white pro beams and the reflectivity of the paint.

Added friction in the zebra zone areas was also incorporated in the on-site tests as the simulator system did not include a motion platform and could not take this road resistance into account. Electronic flashing signs with traffic jam information were also tested out in life-size. The virtual overhead sign pictured in Figure 5 was photographed on-site and can be seen in Figure 7.

In addition, eye cameras were used during these trials to track where drivers were looking for guidance. This would have been difficult to perform using computer simulation as driver's eyes are focused on the screen and don't need to adjust to longer distances.

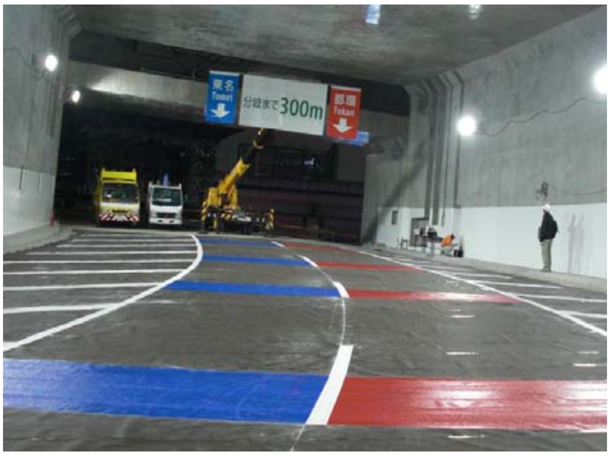

Figure 7: Post-experiment on-site testing [7]

7. FUTURE DEVELOPMENT & APPLICATIONS

The next stretch of Ohashi Junction that is anticipated to be difficult for drivers will also be simulated prior to being opened to the public. The area involves a curve (R = 50 to R =200) in the junction where cars will merge with traffic before choosing an exit ramp. As the drivers' viewing angle will be important for merging, the 3-panel simulator system will be replaced by a 5-panel one.

As for the simulation platform, UC-win/Road software development projects are focusing on improving traffic, and for example, accounting for different driving behavior profiles in standard traffic. Other advancements include work on lighting as well as fire and smoke effects that can improve disaster and evacuation visualization. Functions for driving scenarios are being expanded, particularly with an emphasis on integration with larger-scale motion platform driving simulator hardware that can better mimic vehicle dynamics. A recently developed Eco Drive plugin outputs fuel use and CO^2 emissions to advise drivers on their efficiency [3]. These new simulation functions may be useful for future road planning that looks beyond safety to also consider fuel efficiency.

8. CONCLUSION

This simulation project was unique and particularly efficient for its ability to both 1) receive behavioral feedback from drivers and simultaneously 2) re-edit and visualize different design decisions.

As highway projects are often characterized by continuously changing geometric configurations, the ability to simulate and edit both road alignments and visual qualities simultaneously was efficient for planning [7]. For example, sign models could be moved easily in a 3D view, so the model could be quickly updated in preparation for future use. Driver reactions extracted from the simulation informed crucial design changes that would have been time-consuming and expensive to test at full-scale.

Although the Ohashi Junction experiment efficiently incorporated virtual driving trials into the design process, VR simulation alone could not answer some questions concerning implementation. Support from real-life testing was necessary. On-site implementation when used as a final indicator of sign visibility and color appropriateness became a valuable part of the planning process [5]. The qualities that the chosen simulation system could convey, for example road friction and lighting, would have been costly to implement in a motion platform setup, for example. As the project was in its later phases of implementation when the simulation was created, it was cost efficient to weave both "real" testing with virtual trials in this method.

ACKNOWLEDGEMENTS

We would like to thank Seiya Tazawa of Metropolitan Expressway Company Ltd., and Hidenori Goto of Oriental Consultants Company Ltd. for their assistance. Thank you also to FORUM8's Virtual Reality Support Group, and especially Katsumi Matsuda and Jun Imaizumi for their help.

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