Using Visual Simulation to Evaluate Bicyclists' Perceptions of Selected Risk Factors

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ABSTRACT

Casual and experienced bicyclists were immersed in a 'virtual' or computer-generated simulation of a two-lane roadway environment in order to elicit ratings of the perceived risk associated with various lane conditions as well as different vehicle speeds and volumes. Ratings were made under cyclist, driver, and roadside viewing conditions. Levels of perceived risk varied inversely with lane width as well as the presence/absence of lane markings delineating vehicle from non-vehicle areas of operation. Effects were most pronounced for older subjects (over 20) and under conditions where ratings were made from a driver's eye point. With respect to the influence of vehicle speeds and volumes on perceivd risk, speed exerted the more pronounced effect. Outcomes obtained in the present study under virtual conditions showed the same functional relationships between risk and design variables as those obtained under actual roadway conditions (Harkey and Knuiman, 1997), although there was a trend toward lower levels of perceived risk under virtual conditions. The results suggest that simulation may, where appropriate, represent a cost effective alternative to the use of traditional field data collection methods, with the chief advantages being the degree of experimental control possible over dynamic variables and the ability to systematically vary the presence/absence of key design variables.

BACKGROUND

In designing facilities for joint bicycle and motor vehicle use, it is important to understand how the bicycle user responds to different levels of traffic speed and traffic volume as well as to the conditions of the curb lane (principally, its width and the extent to which some form of marking is used to imply separate areas for vehicle and bicycle operation). To the extent that these operational factors may be perceived as sources of significant risk and/or personal discomfort, the rider may tolerate these conditions only for short periods of time, or not at all.

An assessment of the relative risks attached by cyclists to these factors could provide a useful tool for evaluating a roadway for joint bicycle and motor vehicle use (Sorton and Walsh, 1994). Obtaining reliable measures of cyclists' perceived risk can be difficult, however, under "real world" conditions where precise control over operational traffic volumes and speeds can be difficult across a range of different curb lane conditions. Because of the potential risks to subjects associated with certain conditions of interest, 'experiments' in the real world may also be considered prohibitive for safety reasons. Thus far, the alternative has been to have subjects observe such conditions either from a safe vantage point on the side of the roadway, or to view video recordings filmed from a stationary eye level position approximating that of an individual riding along side the travel lane.

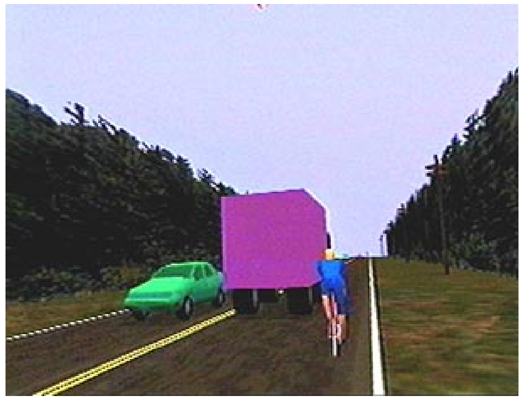


Figure 1. Bicyclist in "Virtual" Environment

Whereas Harkey and Knuiman (1997) showed that equivalent ratings could be obtained using direct roadside observation and video recordings of those same roadside conditions, the present study sought to determine whether reliable estimates of perceived risk could be obtained under "virtual" or simulated conditions; that is, by placing the observer within an interactive, *simulated* environment where curb lane conditions, traffic speed, and traffic volume could all be precisely controlled. Although real-time, manned simulation is widely recognized as a valuable tool for vehicle simulation (NHTSA, 1993; Evans, et al., 1994; Stoner and Haug, 1990; Turpin, and Evans, 1995), as far as we know, the Florida DOT is the first to seriously explore the potential for applying this technology to engineering and behavioral issues associated with the design of facilities for the non-motorized traveler.

An effective demonstration would add to the growing support for *visualization* as an important design tool; for example, within FHWA's Interactive Highway Safety Design Model (Reagan, 1994; Harwood, Mason, and Graham, 1994), not only for the design and evaluation of facilities for motorized, but for non-motorized (e.g. ped/bike) use as well.

Figure 2. Subject wearing helmet display during cyclist viewpoint condition

APPROACH

Twenty-three (23) *casual* and 12 *experienced* cyclists served as subjects for the study. Using a 1-to-6 rating scale, each subject provided separate ratings of the perceived risk associated with the traffic speed, traffic volume, and curb lane characteristics of 16 different test conditions representing two levels of traffic speed, two levels of traffic volume, and four curb lane configurations. A rating of '6' indicated a high level of perceived risk; a rating of 'l' indicated little or no perceived risk. Curb lane configurations consisted of (a) a standard 12 ft (3.7 m) lane, (b) a 15 ft (4.58 m) wide-curb lane, (c) the same 15 ft (4.58 m) lane with a white edge line stripe four feet (1.22 m) from the edge of the pavement (urban paved shoulder or "silent" bike lane), and (d) a 4 ft (1.22 m) marked bike lane as part of the 15 ft(4.58 m) curb lane.

Ratings were made from three different viewing positions: (a) from the eye point of a cyclist riding through the scene (see Figure 3); (b) from the eye point of the driver of a motor vehicle traveling in the curb lane (see Figure 4), and (c) from a stationary eye point along the side of the roadway (see Figure 1). Roadside trials were presented both with an without cyclists in the scene.

Figure 3. View from cyclist's eye point.

All scenarios took place on a simulated straight, two-lane roadway under daylight conditions. Traffic moved at either 30mph (48 kph) or 50 mph (80.5 kph). Traffic volumes (both directions combined) were either 66 vehicles per minute or 34 vehicles per minute. In all scenarios, ten percent of the traffic moving in either direction consisted of trucks.

When viewing the test conditions from either the cyclist or driver perspective, the volunteer viewed the scene through a stereoscopic, color, helmet display (see Figure 2) that provided the volunteer an approximate 60 degree instantaneous field of view and an unlimited overall field of regard. The dynamic sounds associated with each vehicle in the scenario were provided to the subject through stereo headphones..

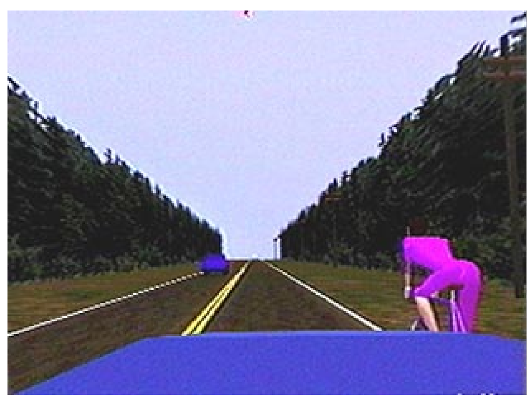


Figure 4. View from Driver's Eye point

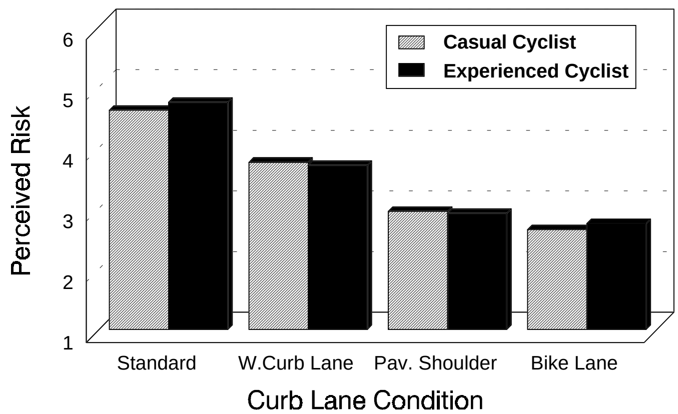
For the cyclist viewing condition, the volunteer was seated on a stationary exercise bike. Although the subject was encouraged to peddle, he/she had no control over steering or speed. A simulated rider, riding in advance (downstream) of the subject and at the same speed as the subject, was always in the subject's field of view. For those trials when the subject observed from the driver's eyepoint, the observer was seated in a chair while viewing the scene through the helmet display. During a trial, the driver passed simulated individual cyclists in the roadway. The display was masked to provide a representative out-the-window view (see Figure 4). As in the bike condition, the volunteer had no control over vehicle speed or steering. For the roadside trials, volunteers sat in a chair while viewing (without use of the helmet display) a large screen, videotaped presentation of the same imagery as viewed in the helmet display trials. The subject's field of regard in the roadside trials was fixed. ‘Roadside’ viewing conditions approximated as closely as possible those in the Harkey and Knuiman (1997) study.

RESULTS

Figure 5 shows that there was little, if any, difference between casual and experienced cyclists’ level of overall perceived risk for the four different curb lane conditions. There was, however, a systematic difference between curb lane conditions, with the highest level of perceived risk being associated with the standard 12 ft (3.66 m) lane and the lowest with the 15 ft (4.58 m) lane with a 4ft (1.22 m) marked bike lane. The two intermediate conditions, both representing 15 ft (4.58 m) lane widths, show the wide curb lane to have been perceived as somewhat higher in risk than the paved shoulder/silent bike lane. In terms of overall perceived risk, there was little or no reliable difference between the paved shoulder and the bike lane conditions.

Figure 5

Perceived Overall Risk as Judged From Cyclist's Eyepoint for Casual and Experienced Riders

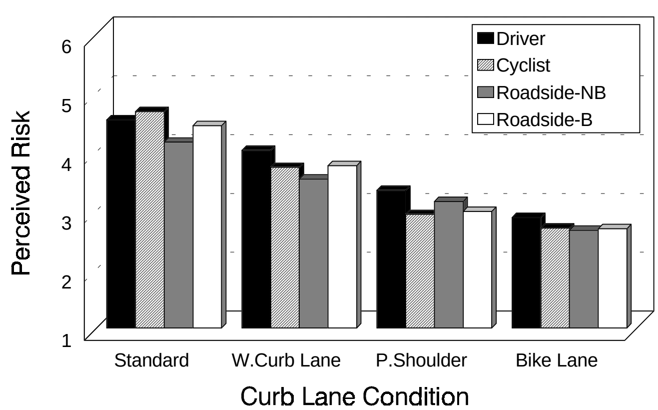


Note: Ratings have been collapsed across two levels of traffic speeds and two levels of traffic volume.

Figure 6 shows subjects' perceived level of risk as a function of viewing condition. For each viewing condition, there is a systematic decline in perceived risk as lane width increases and as marking is provided to distinguish between intended areas of motor vehicle and bicycle use. Differences associated with viewing condition for a given lane condition are small, with a slight tendency to judge risk as being higher when rated from the vehicle driver's viewpoint, perhaps due to a different perception of speed from the

Figure 6

Perceived Overall Risk as a Function of Viewpoint for Four Different Curb Lane Conditions



Note: Ratings have been averaged over cyclist experience levels and across two levels of traffic speed and two levels of traffic volume driver viewpoint condition.

Figure 7 shows the mean ratings associated with the lane, speed, and volume components of overall perceived risk. It is clear that the greatest component of overall risk for the standard lane condition was the lane variable. The relative risk associated with the lane condition decreases as lane width increases from 12 ft (3.66 m) to 15 ft (4.58 m) and as some form of delineation is added to separate areas of bicycle and motor vehicle travel.
Subjects' sensitivity to differences in traffic speed and volume are difficult to assess from Figure 7. Figures 8 and 9 address subjects' relative sensitivity to speed and

Figure 7
Relative Overall Perceived Risk of
Curb Lane Condition, Traffic Speed, and Traffic Volume

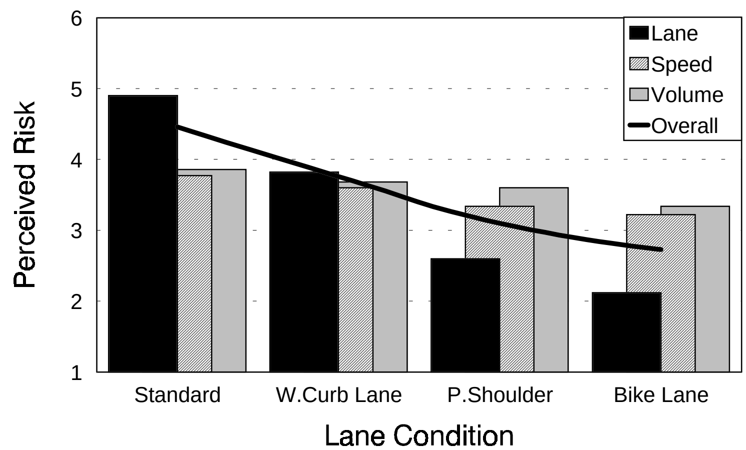


Figure 8
Risk Associated with Traffic Speed as a Function of Traffic Speed and Traffic Volume

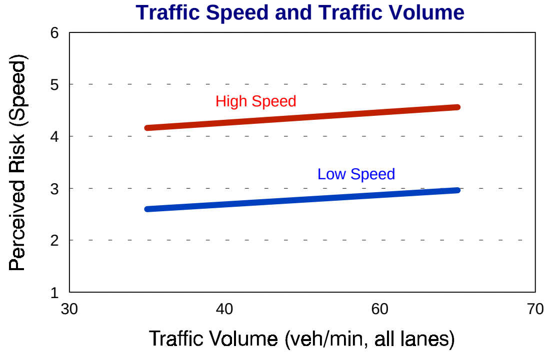
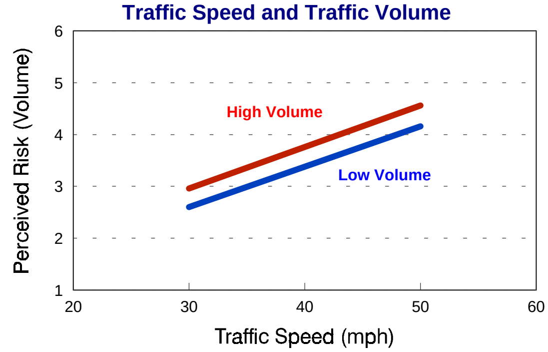


Figure 9
Risk Associated with Traffic Volume as a Function of Traffic Speed and Traffic Volume



volume differences. Figure 8 plots subjects' perception of the risk associated with speed as a function of the particular combination of speed and volume conditions presented. The vertical separation of the two speed plots indicates that subjects were sensitive to the 20 mph (21.2 km) differences presented in the test trials, but less so to the differences in traffic volumes. Figure 9 plots subjects' ratings on the volume dimension of risk as a function of the particular volume and speed conditions present. The sharp slope of the plots indicates the effect of speed, while the small vertical separation indicates the smaller effect of traffic volume. It may have been the case that the 25-second duration of the test trial was too brief for subjects to effectively orient to changes in traffic volume.

One last comparison addresses differences in perceived risk as a function of age and the particular perspective from which the ratings were made. In Figures 10a,b comparisons are presented in terms of whether ratings were made from the driver's or cyclist's eye point. When ratings were made from the driver's eye point, there were clear age differences in the level of risk assigned to each of the four roadway conditions. Whereas perceived risk for older subjects was a function of lane width and delineation, risk for the younger subjects showed little sensitivity across these

Figure 10a

Under 20 Versus Over 20
From Driver's Eyepoint

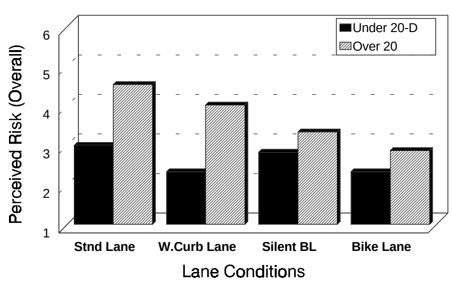
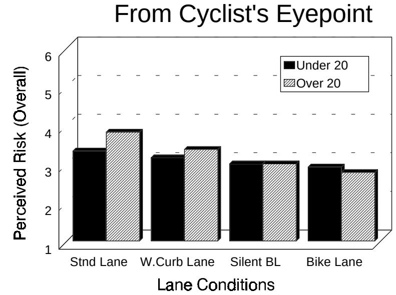


Figure 10b

Under 20 Versus Over 20
From Cyclist's Eyepoint



conditions. When ratings were made from a cyclist's eye point, sensitivity to lane conditions was markedly reduced for both age groups, suggesting that the lane design and operational traffic effects reported earlier should perhaps be attributed, for the most part, to the older cyclist. The apparent reduction in sensitivity on the part of the younger cyclist does not necessarily imply that the younger cyclist is more careless (willing to accept greater risk) than the older cyclist. It may simply mean that he/she had yet to develop any clearly defined relationship between 'risk' and the types of factors addressed in this study.

RELATIONSHIP TO 'REAL-WORLD' DATA

Partial validation of the present data can be achieved through comparions with results obtained by Harkey and Knuiman (1997) who had subjects use the same 6-point scale as that used in the present study to rate the perceived risk (from video with no cyclists present) associated with lane conditions, traffic speed and volume.

The authors discuss ratings of perceived risk in terms of a Bicycle Compatibility Index (BCI). A regression model for calculating the BCI is given below.

$$BCI = 3.67 - 0.15CLW - 0.97BL - 0.13BLW + 0.51PKHD + 0.04SPD + 0.17CLV + 0.04OLV - 0.26AREA$$

where CLW is curb lane width; BL is presence/absence of a bike lane; BLW is bike lane width; PKHD is presence of medium to high density roadside parking; SPD is 85th percentile speed, CLV is curb lane volume; OLV is 'other' lane(s) volume; and AREA is 'type' of developed area (for example, residential or commercial). A '+' sign preceeding a factor indicates that as the value of that factor increases, there is an increase in the level of perceived risk (i.e., a direct relationship between that factor and level of perceived risk). Similarly, a '-' sign preceeding a factor indicates that as the value of that factor decreases, the result is an increase in perceived risk (i.e, an inverse relationship between the factor and level of perceived risk). These are summarized in the table below. The suitability of the model for prioritizing alternative bicycle treatment approaches is discussed by Harkey and Knuiman.

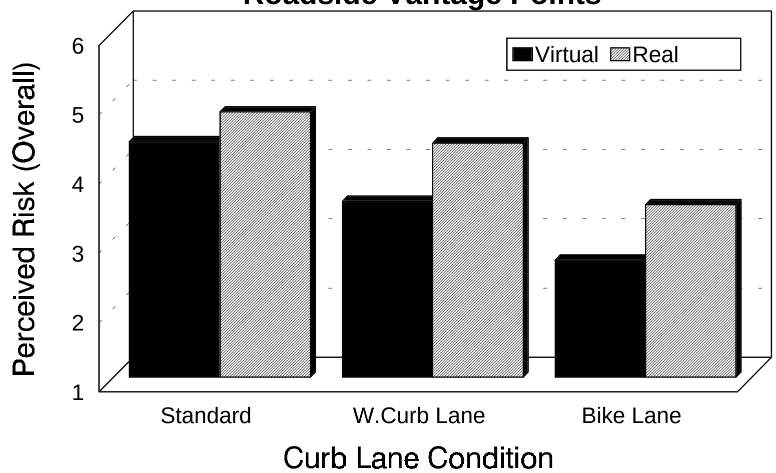
Risk is Perceived to *Increase* as the Following Variables Increase	**Risk is Perceived to *Decrease* as the Following Variables Increase**
Mid to High Density Parking (PKHD)	Presence of Bike Lane (BL)
Curb Lane Volume (CLV)	Residential vs Commercial (AREA)
Traffic Speed (SPD)	Curb Lane Width (CLW)
'Other' Lane Volume (OLV)	Bike Lane Width (BLW)

Table 1. Factors Contributing to the Perception of Risk
(from Harkey and Knuiman, 1997)

Of interest in the present case is the extent to which subjects' perceptions of risk elicited under simulated/virtual conditions agree with those generated by the Harkey and Knuiman model, where ratings were based upon observation of 'real world' conditions.

Figure 11 shows a comparison of ratings for overall perceived risk made under 'real world' and 'virtual' conditions for the standard lane, the wide curb lane, and the bike lane. Ratings under virtual conditions are those made from the roadside vantage point with no cyclists within the observer's field of view. While the basic pattern of the results is the same for 'real' and 'virtual' conditions, there was an apparent tendency for ratings of overall perceived risk to be consistently *lower* in the virtual environment than in the video taped version of the 'real world'

Figure 11.
Perceived Overall Risk as Judged From Virtual and 'Real' Roadside Vantage Points



Note: Ratings have been collapsed across two levels of traffic speeds and two levels of traffic volume.

environment, all other things being equal. It must be remembered that the 'real' and 'virtual' ratings of risk compared here come from two different groups of subjects. Such a difference, even if shown to be reliable, would not be considered unusual however. The important point is not whether *virtua*l and *real* ratings are numerically identical, but rather that subjects' perceptions of risk vary as a function of the same conditions in both environments. Even in 'engineering' simulations of man-in-the-loop systems, the most careful attempts to accurately model the physical parameters of the system are no guarantee that the behavior of the operator under real and simulated conditions will match point for point. Literal agreement is not a requirement for the demonstration of functional fidelity.

SUMMARY

From a methodological standpoint, the importance of the present study lies not in its identification of the effects of lane conditions and traffic operations on bicyclists' perceptions of risk, but rather in its demonstration that the same functional relationships observed between these variables and cyclists' perceptions in the 'real world' (Harkey and Knuiman, 1997) were also observed under 'virtual' or 'simulated' conditions. These findings are encouraging in that they suggest that geometric design and operational factors can be represented well enough under virtual/simulated conditions to support the formation of such complex multi-dimensional perceptions as 'risk.'

Experienced cyclists and researchers alike would, however, be quick to point out the 'limitations' of the present simulation. Not the least of such limitations was the fact that the subject was not in direct control of the vehicle (car or bicycle depending upon the particular viewing perspective). As such, the simulation study provides no information about dynamic lane placement on the part of the driver (see Harkey and Stewart, 1997), the likelihood of lane excursions when overtaking and passing a cyclist, or the ability of the cyclist to maintain effective control over the range of conditions studied. Such limitationds n no way invalidate the simulation results, but simply limit the availability of simulation data from which to generalize to the real world environment. The decision not to develop fully interactive control capabilities for the driver and cyclist was based solely on cost considerations. The technical capability to do so certainly exists.

A related criticism has to do with the simulation not providing for the ‘stress’ associated with crashes or potential crashes. To the extent that this is a valid criticism of the simulated conditions, it is also a valid criticism of the conditions under which the Harkey and Knuiman data were collected. In fact, in the Harkey and Knuiman study, the observer is not even given the opportunity to view a cyclist (real or otherwise) in relationship to vehicles in the travel lane. Given the low probability of a crash, if one were to provide sufficient exposure (trials) to occasion even a single crash, the time required to conduct the study. . . even in the real world, would be prohibitive. What both the real world (Harkey and Knuiman) study and the simulation study have in common is their attempt to systematically expose observers to differences in lateral separation occasioned by differences in curb lane geometry and to systematic differences in vehicle speeds and vehicle volumes under each of these conditions.

One cannot conclude a discussion of simulation without pointing to its practical benefits. The simulation environment, in the present case, provided the ability to precisely control for desired levels of vehicle speed and traffic volume for each of the four different curb lane conditions. A similar level of control in the ‘real world’ would be difficult, if not impossible, to achieve. The simulation environment also has the advantage of being modifiable; for example, adding and manipulating the frequency of occurrence of driveways, intersections, on-street parking, and other factors influencing rider’s perceptions of risk.

In short, the present study has demonstrated that real-time, manned simulation can be an effective tool for addressing the relative contribution of geometric design and operational traffic factors influencing individuals’ perception of the risk associated with bicycle operation on a multi-use facility. Criticisms of the present study reflect decisions on the part of the experimenter to limit the scope of the effort rather than a lack of the current technology to support the manipulation of other relevant parameters. At a minimum, the results suggest that simulation might be effectively applied to the investigation of other design and operational issues for non-motorized modes of travel (e.g, pedestrian behavior).

ACKNOWLEDGEMENTS

All virtual environments used in the study were developed by Division, Inc. Key hardware components included: Silicon Graphics Deskside Onyx RED2; 4x250Mhz R4400; Dual Raster Managers (RM4); Multi-Channel Option; Integrated Peripheral Unit; Non-Ferris Peripheral Stand with FASTRAK Source; Division's 6D mouse; Virtual Research's VR4 Head Mounted Display (HMD); and Crystal River's Acoustetron II 3D Sound System. Software and software modeling packages included: dVISE, AutoCAD and 3D Studio, Multi-Gen, and other necessary converters supplied by Division, Inc. All data were collected at Division's Chapel Hill, NC location using in-house Division hardware/software. We also acknowledge the support of Mr. Richard Long of the Florida DOT and Mr. Dan Burden (now with Walkable Communities).

REFERENCES

Harkey, D.L. and Stewart, J.R. Evaluation of Shared-Use Facilities for Bicycles and Motor Vehicles. Transportation Research Board (TRB) Paper No. 970840, 76th Annual Meeting, Washington, DC, January 1997.

Harkey, D.L. and Knuiman, M. Assessing the Bicycle Compatability of Roadways. To be presented at ASCE Conference, Traffic Congestion and Traffic Safety in the 21st Century, Chicago, IL, 1997.

Harwood, D.W., Mason, J.M., and Graham, J.L. Conceptual Plan for an Interactive Highway Safety Design Model, FHWA-RD-93-122, USDOT/FHWA, Washington, DC, 1994.

National Advanced Driving Simulator (NADS) Functional Specification Document (FSD). USDOT/NHTSA, DTNH22-93-R-07261, Washington, DC, July 1993.

Reagan, J.A. The Interactive Highway Safety Design Model: Designing for Safety by Analyzing Road Geometrics. In Public Roads, Summer 1994, vol 58, No 1, USDOT/FHWA Office of Reserach and Development, 1994.

Stoner, J.W., Haug, E.J., et al. Introduction to the Iowa Driving Simulator and Simulation Research Program. Center for Simulation and Design Optimization, Technical report R-66, University of Iowa, August, 1990.

Turpin, D.R. and Evans, D.F. High-Fidelity Road-Tire Interaction Models for Real-Time Simulation. SAE Technical Paper Series, No. 950170, SAE International, Warrendale, PA, March 1995.