

The Exploratory Advanced Research Program

Utilizing Various Data Sources for Surface Transportation Human Factors Research

WORKSHOP SUMMARY REPORT • November 6-7, 2013



U.S. Department
of Transportation
**Federal Highway
Administration**

Notice

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The U.S. Government assumes no liability for the use of the information contained in this document.

The U.S. Government does not endorse products or manufacturers. Trademarks or manufacturers' names appear in this report only because they are considered essential to the objective of the document.

Quality Assurance Statement

The Federal Highway Administration (FHWA) provides high-quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.

Technical Report Documentation Page

1. Report No. FHWA-HRT-14-077	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Utilizing Various Data Sources for Surface Transportation Human Factors Research Workshop Summary Report • November 6–7, 2013		5. Report Date July 2014	
		6. Performing Organization Code:	
7. Author(s) Alicia Romo, Bianka Mejia, and C. Y. David Yang		8. Performing Organization Report No.	
9. Performing Organization Name and Address Volpe National Transportation Center 55 Broadway Cambridge, MA 02142		10. Work Unit No.	
		11. Contract or Grant No. N/A	
12. Sponsoring Agency Name and Address Office of Safety Research and Development and Office of Corporate Research, Technology and Innovation Management Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Workshop Summary Report, November 2013	
		14. Sponsoring Agency Code HRTM-30	
15. Supplementary Notes FHWA's Contracting Officer's Task Manager (COTM): Zachary Ellis, HRTM-30 Technical Contact: David Yang			
16. Abstract This report summarizes a 2-day workshop held on November 6–7, 2013, to discuss data sources for surface transportation human factors research. The workshop was designed to assess the increasing number of different datasets and multiple ways of collecting data that can be used to increase understanding of human errors. Participants discussed how to resolve the controversies among different datasets and how to choose the best datasets for particular applications. Expert speakers shared their research experience of using various datasets from sources such as driving simulators, field studies and field operational tests, and naturalistic driving studies. The expert panel identified several potential research topics to address the challenges that must be overcome to integrate data from multiple sources.			
17. Key Words Surface transportation, human factors research, data sources, human errors, datasets, data integration, driving simulators, field studies, field operational tests, naturalistic driving studies.		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 68	22. Price N/A
Form DOT F 1700.7 (8-72)		Reproduction of completed page authorized	

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

Executive Summary

On November 6–7, 2013, at the Turner-Fairbank Highway Research Center in McLean, VA, the Federal Highway Administration’s (FHWA) Office of Safety Research and Development, with support from the Exploratory Advanced Research (EAR) Program, convened the workshop, “Utilizing Various Data Sources for Surface Transportation Human Factors Research.” The workshop addressed the increasing number of different datasets and multiple ways of collecting data—from naturalistic driving and simulator studies to eye trackers and surveys—that can be used to increase an understanding of human errors.

Human errors are still a major cause of injuries and fatalities; however, a number of different datasets have recently become available to analyze human errors. These datasets point in different directions within different areas of interaction. Experts in human factors research, transportation safety, and driver behavior and performance analysis, met to discuss and determine which datasets were best and how one might resolve the differences. The information provided by the different datasets is sometimes complementary, sometimes competing, and sometimes confirmatory. The workshop brought together a panel of experts to share their research experience of using multiple methods to gain insights about different aspects of driver and traveler behavior and performance.

During day one of this workshop, participants heard seven presentations on using various

datasets from sources such as driving simulators, field studies and field operational tests, and naturalistic driving studies. The experts discussed various methods to study behaviors that lead to errors and shared strategies they have deployed to gain insightful information about what datasets to use to target one or more human factors or behavior issues. The workshop also presented the idea of using multiple data collection methods to “cross-reference” analysis results, validate conclusions, and enhance the understanding of behaviors.

On day two of the workshop, an expert panel discussed issues related to consolidating data from multiple types of collection methods. The experts discussed how datasets must be carefully examined when combined from different sources. For example, some data sources are contradictory, leaving researchers with the need to conduct additional research to resolve the controversies. Alternatively, other data sources can be complementary and provide information in the field and in the laboratory on driver behaviors that point in a similar direction. How best to create complementary datasets also needs to be carefully considered. In addition, very few data sources are comprehensive, and they do not provide information on both driver behavior and crashes. The ability to develop models that can link behavioral datasets with crash datasets, leading to comprehensive

datasets, is still in its infancy. The expert panel went on to identify several potential research topics to address the challenges that must be overcome to integrate data from multiple sources.

At the end of day two, the workshop sponsor divided the participants into three groups so that detailed discussion could be held to identify research gaps related to the following interactions of drivers: (1) with other road users, (2) with changing elements of the roadway and infrastructure, and (3) with their own vehicle. All three groups presented summaries of their discussion and recommendations to conclude this workshop.

Workshop panelists and participants noted two different ways of seeing how best to deal with multiple contradictory datasets, as follows:

- Bottom up—It is possible to take various known instances in which there are contradictions across datasets and identify why these inconsistencies arise and what can be done to avoid them in the future.
- Top down—A study across multiple sites would allow for the collection of various different types of data. It would then be possible to look for inconsistencies across sites in the same dataset and inconsistencies within sites across datasets.

Panelists were unanimous in recommending that there should be an attempt to understand how to use the different types of data in a study that includes the following components:

- Multiple sites (e.g. locations, geometries, traffic density, and environment).
- Multiple types of data gathered at each site (e.g., survey, simulator, and field).

- Multiple users (e.g., bicyclists, pedestrians, motorists, and drivers).
- Multiple methods of analysis (e.g., descriptive and inferential statistics, and quantitative behavioural models).

As part of the final workshop recommendations, participants identified many areas of priority for human factors research that could make use of the expanding datasets now available and soon to be available. These included modeling, safety, roadway departure, urban intersections, vehicle, pedestrian and bicyclist interaction, and data analysis. Participants suggested a number of specific items for further research, as follows:

- Evaluate the effectiveness of current signage used on roadways.
- Research speed perception.
- Develop solutions to improve roadway safety for pedestrians and bicyclists.
- Evaluate current Intelligent Transportation System technologies for pedestrian and bicycle safety.
- Develop a methodology to conduct research by using multiple data sources.
- Construct methods to measure exposure of pedestrians and bicyclists.

To further understanding and use of multiple data types, participants recommended a study, possibly focused at intersections, which includes multiple sites, multiple data types gathered at each site, multiple user types, and multiple methods of analysis. This study could provide critical information on how to resolve contradictions among datasets, how to put together complementary datasets that describe risky behaviors, and how to generate comprehensive datasets that link behaviors and crashes.

Table of Contents

Introduction	1
Day One: Presentations	2
Driver-Driver and Other Road Users' Data for Human Factors Research <i>Presented by Dr. Marco Dozza</i>	3
Driver and Pedestrian Recognition Behavior for Avoiding Conflict with Each Other at an Intersection <i>Presented by Dr. Toru Hagiwara and Dr. Hidekatsu Hamaoka</i>	9
Driver-Infrastructure and Roadway Data for Human Factors Research <i>Presented by Dr. Michael Manser</i>	14
Traffic Control Devices and In-Vehicle Systems <i>Presented by Dr. Susan Chrysler</i>	21
Triangulating Data Sources to Understand Driver-Vehicle Behavior <i>Presented by Dr. John Lee</i>	28
Driver-Vehicle Data for Human Factors Research <i>Presented by Dr. Linda Ng Boyle</i>	33
Day Two: Discussion and Summary	40
Expert Panel Discussion <i>Moderated by Dr. Donald Fisher</i>	41
Group Session Summary	45
Workshop Recommendations	49
Appendices	50
Appendix A: Agenda	51
Appendix B: About the Presenters	53
About the EAR Program	55

List of Figures

Figure 1. An instrumented traditional bicycle.	4
Figure 2. Average cycling behavior speeds.	5
Figure 3. Cyclists' speed profile.	6
Figure 4. An R-type accident.	9
Figure 5. Front-passing diagram.	10
Figure 6. Reproduced collision conflict between right-turning vehicle and pedestrian.	11
Figure 7. Pedestrian-vehicle dedicated short-range communications system.	12
Figure 8. Pedestrian crossing an experimental intersection.	13
Figure 9. Real-world research environments.	15
Figure 10. Expected research environments in terms of validity and experimental control.	16
Figure 11. Adjusted research environments in terms of validity and experimental control.	16
Figure 12. Tools and environments in relation to data sources.	17
Figure 13. Experimental signs used in laboratory study.	18
Figure 14. Trade-off between validity and experimental control.	22
Figure 15. Research methods.	26
Figure 16. Comparison of real maps and simulated scenarios.	29
Figure 17. Impacts on driver response when using adaptive cruise control.	34
Figure 18. Cluster analysis using simulation data.	35

List of Acronyms and Abbreviations

General Terms

ACC	adaptive cruise control
ASV-3	Advanced Safety Vehicle-3
CICAS-SSA	cooperative intersection collision avoidance system-stop sign assist
DOT	Department of Transportation
DSRC	dedicated short-range communications
EAR	Exploratory Advanced Research
FHWA	Federal Highway Administration
FOT	field operational test
GPS	Global Positioning System
HAWK	High-intensity Activated crossWalk
IEEE	Institute of Electrical and Electronics Engineers
IMU	inertial measurement units
ITS	Intelligent Transportation System
IV-DSRC	inter-vehicle dedicated short-range communications
LIDAR	light detection and ranging
MUTCD	Manual on Uniform Traffic Control Devices
NADS	National Advanced Driving Simulator
NHTSA	National Highway Traffic Safety Administration
NSF	National Science Foundation
OTL	observed time lag
PI	principal investigator
PTL	predicted time lag
PV-DSRC	pedestrian-vehicle dedicated short-range communications
SHRP 2	second Strategic Highway Research Program
STRADA	Swedish Traffic Accident Data Acquisition
TCD	traffic control devices
TMC	traffic management center
TxDOT	Texas Department of Transportation
UMTRI	University of Michigan Transportation Research Institute
USDOT	U.S. Department of Transportation
V2V	vehicle-to-vehicle
VehDAQ	vehicle data acquisition
VOQ	vehicle operator questionnaire
WTI	Western Transportation Institute

Introduction

Transportation safety is the top priority at the Federal Highway Administration (FHWA) and U.S. Department of Transportation (USDOT). A high percentage of transportation incidents and vehicle crashes are caused by human errors. As a result, it is important to continue investing in research resources to gain a comprehensive understanding of human errors and to try to answer the question, “Why do drivers and travelers do what they do?”

The motivation for this workshop was in large part a function of the increasing number of different datasets and multiple ways of collecting data—from naturalistic driving and simulator studies to eye trackers and surveys—that can be used to increase our understanding of human errors. Now is an ideal time to begin a discussion about how to resolve the differences and how to choose the best datasets for particular applications.

To initiate this discussion, FHWA’s Office of Safety Research and Development, with support from the Exploratory Advanced

Research (EAR) Program, convened the workshop, “Utilizing Various Data Sources for Surface Transportation Human Factors Research,” on November 6–7, 2013. Experts in transportation safety analysis and driver behavior and performance, were invited to the Turner-Fairbank Highway Research Center in McLean, VA, to share their research experience of using multiple methods to gain insights into different aspects of driver and traveler behavior and performance.

A primary question posed to researchers was how best to select the particular datasets most helpful for analyzing one of the following three major research topics: (1) the interaction between drivers and other road users, such as pedestrians and bicyclists; (2) the interaction between drivers and roadway and other transportation infrastructure; and (3) the interaction between drivers and their vehicles. This report captures highlights from the workshop and summarizes the discussions that took place.

Day One: Presentations

Expert presentations are summarized
in the following section.

Driver-Driver and Other Road Users' Data for Human Factors Research

Dr. Marco Dozza

Chalmers University of Technology

Overview

Dr. Marco Dozza reminded workshop participants that safety is an ongoing concern as the complexity of the roadway environment continually increases. This complexity particularly jeopardizes cycling safety. Roadway space is commonly shared among cyclists and other road users, such as drivers, and the interaction between these different modes of transportation creates a high risk for crashes and potential injuries and fatalities.

In Europe, 1,994 cyclists were killed in 2010 and accounted for 6.8 percent of total road fatalities, compared with 2 percent of road fatalities in the United States.^{1,2} Improving cycling safety is therefore crucial, because cycling is increasingly becoming a more popular mode of transportation. In addition, with an integrated electric motor available for propulsion, electric bicycles (e-bikes) heighten this concern because of their high speed and increasing prevalence. A better understanding of how cyclists behave in traffic is therefore needed to develop improved safety measures. This could be achieved by transferring existing methods of naturalistic data collection for cars and trucks to collect naturalistic cycling data.

1. European Road Safety Observatory (2012). *Traffic Safety Basic Facts*. Retrieved July 7, 2014, from http://ec.europa.eu/transport/road_safety/pdf/statistics/dacota/bfs20xx_dacota-swov-cyclists.pdf.

2. National Highway Traffic Safety Administration (2012). *Bicyclists and Other Cyclists*. Retrieved July 7, 2014, from <http://www-nrd.nhtsa.dot.gov/Pubs/811624.pdf>.

Dozza informed participants that the goal of this research is to understand how bicyclists, using traditional bicycles and e-bikes, behave in traffic and the extent to which safety-critical situations (i.e., crash and near crashes) are different for e-bikes compared with traditional bicycles. The researchers of this study collected and analyzed naturalistic cycling data and also acquired additional datasets from the Swedish Traffic Accident Data Acquisition (STRADA) database. Dozza informed workshop participants that, in Sweden, 70 percent of the bicycle crashes that occur are reported in accident databases. In accordance, cycling accidents within the STRADA database were isolated and combined with the former data to better address a number of issues. Dozza told workshop participants that this project is expected to provide the research and transportation industry with methods to gather naturalistic data, in particular naturalistic cycling data, to understand accident causation, to investigate cycling behavior, to inform regulations and infrastructure design, and to test intelligent systems.

Naturalistic Cycling Data

Naturalistic data collection refers to data collected in traffic by road users performing their usual daily activities. Traditionally, naturalistic data are recorded from instrumented cars and trucks. There are many reasons researchers are interested in collecting naturalistic data, summarized as follows:

- Understanding accident causation—Researchers for a 100-car naturalistic driving study concluded that off-road glances longer than 2 sec doubled accident risk.³
- Investigating driver behavior—Researchers for a 2009 commercial vehicle operation study showed that texting increases accident risk by 23 times.⁴
- Informing regulations and infrastructure design—Researchers for a Sweden–Michigan naturalistic field operational test examined the “kangaroo effect” of speed cameras and the relationship between curb design and lane departures.⁵
- Testing intelligent systems—Researchers for a 2011 study examining integrated vehicle-based safety systems and lane-departure warning systems demonstrated that these systems improve lane keeping.⁶

Dozza suggested that the same reasons researchers collect naturalistic driving data can also be applied to bicycles. In addition, with the increase in cyclists, it is important for researchers to understand other road-user behavior. All road users have to contend with issues of distraction and obedience to road rules, in addition to adapting to the speed of the new e-bikes.

Dozza highlighted that gathering naturalistic cycling data will make it possible to improve current regulations and road infrastructure in Europe. In 2012, there were 1.2 million new e-bikes on the road; however, bike lanes in Europe may not fully accommodate e-bikes, and they may require new infrastructure.⁷ For example, in Sweden, pedestrians and cyclists frequently share the same sidewalk. With naturalistic cycling data, researchers can test intelligent systems—such as new smartphone applications—that promise to help cyclists and test if they display destructive behavior. Overall, the study findings will contribute to the development of countermeasures to reduce cyclist trauma.

Dozza informed participants that naturalistic cycling data collection requires a sophisticated network of sensor processing and recording systems. In accordance, equipment requirements for bicycles differ from those of cars, for example, weight and weather resistance requirements are more important for bicycles than they are for cars. In this study, the researchers recorded naturalistic data by using an instrumented traditional bicycle, which was fitted with the following equipment, as shown in figure 1:



© Marco Dozza

Figure 1. An instrumented traditional bicycle.

3. Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J.D., Ramsey, D.J. (2006). *The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data*. Washington, DC: Department of Transportation, National Highway Traffic Safety Administration.

4. Olson, R.L., Hanowski, R.J., Hickman, J.S., & Bocanegra J. (2009). *Driver Distraction in Commercial Vehicle Operations*. Washington, DC: Department of Transportation, Federal Motor Carrier Safety Administration.

5. Victor, T., Bårgman, J., Gellerman, H., Hjälm Dahl, M., Hurtig, S., Kircher, K., Moeschlin, F., Svanberg, E., (2010). *Sweden–Michigan Naturalistic Field Operational Test Phase 1: Final Report*. Gothenburg, Sweden: SAFER Vehicle and Traffic Safety Centre at Chalmers.

6. Sayer, J., LeBlanc, D., Bogard, S., Funkhouser, D., Bao, S., Buonarosa, M.L., Blankespoor, A., (2011). *Integrated Vehicle-Based Safety Systems Field Operational Test Final Program Report*. Washington, DC: Department of Transportation, Research and Innovative Technology Administration.

7. Bike Europe (2013). *Europe's E-Bike Imports Indicate Market Size*. Retrieved July 7, 2014, from <http://www.bike-eu.com/Sales-Trends/Market-Report/2013/8/Europes-E-Bike-Imports-Indicate-Market-Size-1326022W/>.

- High-definition camera (30 frames per second, waterproof, lightweight, and efficient).
- Inertial measurement units (IMU, 100 Hz).
- Global positioning system (GPS, 10 Hz).
- Brake force sensors (100 Hz).
- Cyclist sensor to record starts and stops.
- Logger.
- Modem.
- Simple human-machine interface with a push button for time stamping.

Dozza informed participants that the data gathered in this cycling study are fundamentally very similar to those gathered in driving studies. The objective data collected includes videos, positions, and kinematics (e.g., GPS and IMU), in addition to controls (e.g., brakes and pedals). Subjective data collected includes interviews, diaries, demographics, and cycling behavior questionnaires. Other types of data were derived, such as glance behavior and use of maps. Analyses were performed by using *Matlab* (a high-level language and interactive environment for numerical computation, visualization, and programming) and *NatWare* (a toolkit developed at the Vehicle and Traffic Safety Center at Chalmers).

Cycling Behavior

Figure 2 shows average speeds using the naturalistic cycling data collected. This map of downtown Gothenburg, Sweden, is a

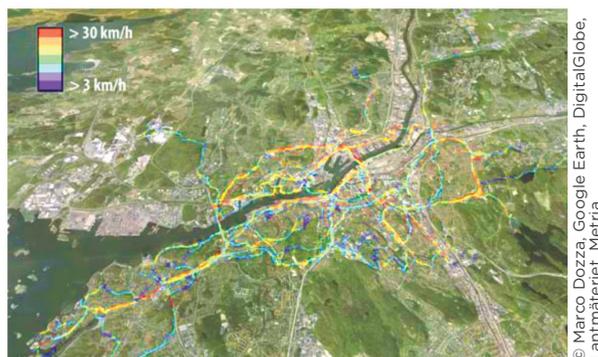


Figure 2. Average cycling behavior speeds.

representation of cyclist usage of different types of roads. In Sweden, 30 km/hr (18.6 mi/h) is the maximum speed for bicycles before riders may be fined. The red areas on this map shows that traditional bicycles are driving illegally. It is expected that when the same map is produced with e-bikes, it will show even higher levels of excess speed.

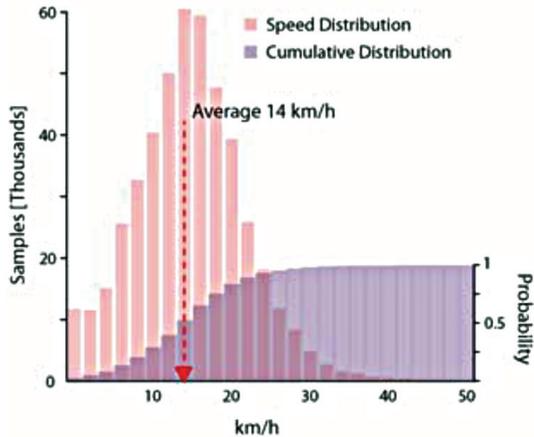
The researchers for this study went on to examine the speed profile of cyclists riding traditional bikes, as shown in figure 3. The average speed for cyclists was about 14 km/hr (8.6 mi/h).

The research team collected data for figure 3 in 2012 for 16 cyclists using traditional bikes. Currently, researchers are performing the same study for cyclists using e-bikes and, based on preliminary data, the average speed for e-bike users is expected to increase by almost 10 km/h (6.2 mi/h). This is important to note because some bike paths are shared with pedestrians in Sweden, and it is well known that increased speed increases the risk of an accident occurring.

The research team also used the naturalistic cycling data it gathered as observational data, which is considered one of the many benefits of gathering naturalistic data. The team examined cyclists' obedience to cycling rules and gathered information on gender, helmet use, crossing behavior, and proper light usage at night.

Accident Causation

The research team performed an event-based safety analysis for its study. The team examined 63 critical events (both crash and near crash) by using the button presses from the cyclists, who were instructed to press the button any time they experienced a safety



© Marco Dozza

Figure 3. Cyclists' speed profile.

or uncomfortable situation. These 63 events were complemented by 126 baseline events chosen at random. The team annotated factors related to the environment and road users' behavior for all events. The team also calculated odds ratios by looking at the difference between critical and baseline events in the prevalence of different factors. For this critical events' analysis, the team developed a map pinpointing where the baseline and critical events occurred around Gothenburg.

The team found that daylight was not a risk factor between baseline and critical events; however, the analysis indicated that cyclists are 10 times more likely to get into trouble when there are surface issues (e.g., holes) and are at even greater risk in proximity of intersections with reduced visibility. The team learned that risk also increased when there were other pedestrians and bicyclists on a potential collision path with the cyclist participating in the study.

Because the team only had six crashes to work with, it used near crashes in its analysis as well (safety-critical situations from the button presses); however, the potential

issue is whether one can assume that near crashes are predictive of crashes. To test this assumption, the team will combine its data with bicycle accident data from STRADA. For this analysis, the team will also account for exposure into account and the number of single-bicycle accidents during each hour of the day. The main purpose of this analysis is to show researchers that they can combine different data to address questions more effectively and that safety-critical situations are a sound surrogate for crashes.

Future Trends: Cooperative Systems and Wireless Communication

Dozza told participants that there is ongoing research focusing on wireless communication methods for bicycles. In particular, applications are being developed for smartphones that address safety for bicyclists. One example is *BikeCOM*, a cooperative application that assists drivers and cyclists at intersections. This application, developed by a student at Chalmers University, communicates with a bicycle and a car approaching an intersection by transmitting the positions of the two, calculating the estimated time to collision, and transmitting a warning to the bicyclist and the driver in the form of an audible alert. The application performs a threat assessment and warns both the bicyclist and driver, depending on the probability of collision. Although this application was originally designed for use by bicyclists, other road users, such as drivers and pedestrians, could also use it. This application is in the developmental stage and has been mainly used as a proof of concept for cooperative systems that address multiple road users, including cyclists.

In addition, *Safety Pilot* is a USDOT field operational test (FOT) of vehicle-to-vehicle (V2V) communication. Dozza told participants that the test is currently

gathering data from 2,843 vehicles and from one instrumented bicycle from Sweden to evaluate traffic patterns and behavior.

Lessons Learned and Future Directions

In summary, Dozza noted that future research can benefit from the use of naturalistic data. For example, with naturalistic data, one is able to combine video data with other data types to address accident causation, road-user behavior (including obedience to traffic rules and distraction), infrastructure design, and intelligent applications. In addition, there are important research questions that can be better answered by combining naturalistic data with other road data from accident databases. Dozza also noted that naturalistic datasets can be reused, and told workshop participants that the next step for this research is to compare behavior across electric and non-electric two-wheelers. Existing tools and methods from the naturalistic driving study and FOT analyses will be reused, and the new data will be integrated. Ultimately, wireless communication among road users will complement naturalistic data, providing new information about road users and their surroundings.

Discussion

After the presentation, the group discussed various topics, including the following:

- Combining crash data and near-crash data for bicycles—Although this has been discussed, the analysis has not been performed yet because of a lack of resources.
- Comparing motorcycle crashes—Motorcycle crashes are very different because they share the road with cars, so

the team did not perform a comparison with motorcycles.

- Downloading the study application—Dozza informed workshop participants that the student-developed application is not available for download. Its purpose is to demonstrate wireless connectivity and should be considered more of a feasibility study.

Additional Resources

Dozza made available to participants a selection of additional resources. These resources are outlined below.

Videos

- An example of naturalistic cycling data can be viewed here: http://www.youtube.com/results?search_query=prebikesafe&sm=3
- The bikeCOM application featured in this presentation can be viewed here: http://www.youtube.com/watch?v=kK_G9wShj2g

Papers

- Dozza, M, & Fernandez, A. (2014). Understanding Bicycle Dynamics and Cyclist Behavior from Naturalistic Field Data. *IEEE Transactions on Intelligent Transportation Systems*, 15(1) 376-384.
- o The authors of this paper present the hardware used for data collection and address cycling comfort in terms of bicycle dynamics. They also explore possible ideas for the development of an ITS for bikes.
- Dozza, M., & Werneke, J. (2014). Introducing naturalistic cycling data: What factors influence bicyclists' safety in the real world? *Transportation Research Part F-Traffic Psychology and Behaviour*, 24, 83-91.

- o The authors of this paper apply some of the basic epidemiology tools to determine what factors are associated with critical events for bicycles.
- Dozza, M. (2013). *What Is the Relation Between Bicycle Dynamics and Safety in the Real World?* Paper presented at the Bicycle and Motorcycle Dynamics Conference, Narashino, Japan.
- o The authors of this conference paper examine the relationship between kinematics and critical events for bikes by building classifiers models. They mainly show that speed and vertical acceleration are the best predictors for critical events and that speed is more related to near crashes (perceived safety), whereas vertical acceleration is more related to crashes (impacts). Implications for the development of ITS or simply for searching for critical events in the database are addressed.
- Dozza, M. (2012). What factors influence drivers' response time for evasive maneuvers in real traffic? *Accident Analysis and Prevention*, 58, 299–308.
- o The authors of this paper show the tools developed and used to analyze data. The same tools and data format are used for the second Strategic Highway Research Program (SHRP 2).
- Gustafsson, P., Muñoz, J., Lindgren, L., Boda, C., & Dozza, M. (2013, September) *BikeCOM—A Cooperative Safety Application Supporting Cyclists and Drivers at Intersections*. Paper presented at the Driver Distraction and Inattention Conference, Gothenburg, Sweden.
- o The authors of this conference paper present an application to warn two road users (a cyclist and a driver in the experiment) at risk of collision when passing an intersection. The application runs on smartphones and is based on threat assessment from trajectory estimation. The application was developed by four students who also wrote the paper and presented it at the conference.

Driver and Pedestrian Recognition Behavior for Avoiding Conflict with Each Other at an Intersection

Dr. Toru Hagiwara

Hokkaido University, Japan

Dr. Hidekatsu Hamaoka

Akita University, Japan

Overview

Dr. Toru Hagiwara and Dr. Hidekatsu Hamaoka informed participants that there are many fatal accidents involving pedestrians in crosswalks and right-turning vehicles every year in Japan, where vehicles travel on the left side of the road. For example, in 2012 there were 4,411 motor-vehicle-related fatalities, and more than 1,500 of these were pedestrian fatalities.⁸ Pedestrian accidents occur mainly at intersections and are frequently known as *R-type accidents*. An R-type accident occurs when a pedestrian approaches to cross the crosswalk from the same direction as a right-turning vehicle, as shown in figure 4. A driver's inability to detect pedestrians as they cross is one of the main reasons why these types of accidents occur. For this reason, drivers need help to become more aware of pedestrians in the crosswalk.

This presentation focused on three studies that investigated driver and pedestrian recognition behavior as a basis for developing ways to avoid conflict. These studies focused on the following:

- How do drivers recognize pedestrian behavior and how do they select a strategy to avoid conflict with pedestrians who approached from the right at intersections?

- What is the performance of a pedestrian-vehicle dedicated short-range communications (PV-DSRC) system in which dedicated short-range communications (DSRC) transmits data to drivers and pedestrians about the dynamic conditions at the intersection?
- What is the crossing behavior of pedestrians in crosswalks, and do they confirm the approaching right- or left-turning vehicle while crossing the crosswalk?

Driver Recognition Behavior

For the first study, the research team looked at how drivers recognized pedestrians in intersections. The team assessed driver behavior for avoidance of conflict with pedestrians who approached from the right and how the driver predicted the pedestrian's rate of crossing the intersection. The team conducted field experiments to measure the

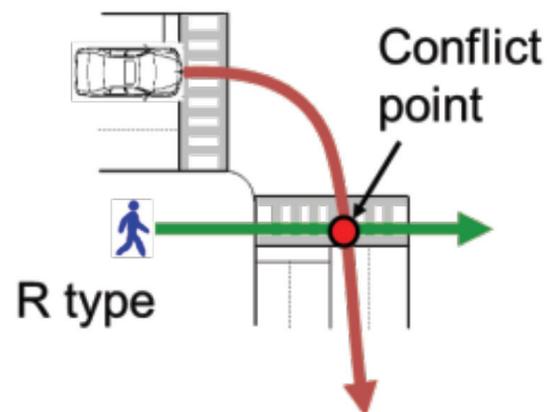


Figure 4. An R-type accident.

8. Japanese National Police Agency (2013). Retrieved July 7, 2014, from <http://www.worldhighways.com/sections/general/news/improved-road-safety-for-japan/>.

time it takes drivers to recognize a pedestrian and also measured drivers' avoidance behavior under various conflict conditions as a function of the pedestrian's visibility. To measure the driver's avoidance behavior, the team varied the interval between the time at which the pedestrian passed the conflict point, or the point of impact, and the time at which the right-turning vehicle passed the conflict point.

The team developed a time-space diagram and estimation for four types of driver-avoidance behavior. One of these avoidance behaviors is *front passing*, which is when the right-turning vehicle passes through the conflict point in front of the pedestrian, as shown in figure 5. Other behaviors include *stopping*, which is when the right-turning vehicle stops before the conflict point to avoid hitting the pedestrian; *avoidance*, which is when the driver brakes and slows to yield to the pedestrian after starting to turn right; and *passing behind*, which is when the right-turning vehicle passes through the conflict point after the pedestrian without braking and slowing.

The team used the following formulas to calculate the predicted time lag (PTL) and observed time lag (OTL):

$$PTL = \text{Time 1} - (\text{Time 2} + \text{running time}) \quad (1)$$

$$OTL = \text{Time 1} - \text{Time 3} \quad (2)$$

Time 1 is the time when the pedestrian passes through the conflict point, *Time 2* is the time when the first oncoming vehicle passes through the conflict point, and *Time 3* refers to the time when the right-turning vehicle passes through the conflict point. The running time from the start to the passage through the conflict point is 5.02 sec, if the driver does not perform any

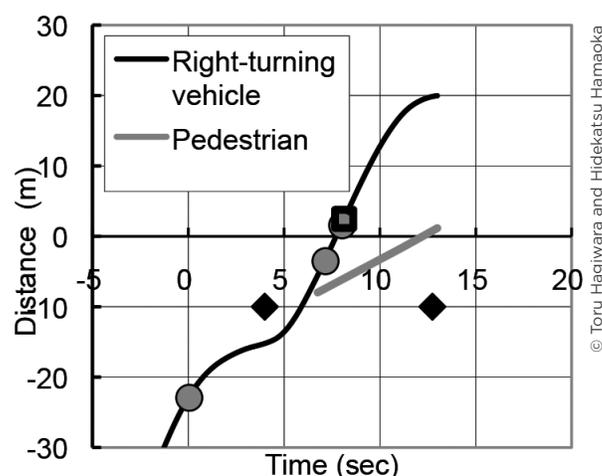


Figure 5. Front-passing diagram.

avoidance behavior. The team performed 315 runs in the field. Results showed that:

- For PTL exceeding 3 sec, the vehicle passing in front of the pedestrian predominates.
- For PTL between 2 and 4 sec, the vehicle stopping for the pedestrian predominates.
- For PTL of less than 2 sec, the vehicle braking and slowing or some other avoidance response predominates.
- For PTL of less than -1 sec, the vehicle passing behind the pedestrian predominates.

Overall, the authors of this study of drivers' pedestrian-recognition behavior found that the driver's choice of avoidance behavior correlated with the PTL to hit the pedestrian. The minimum PTL at which drivers will yield to the pedestrian at the conflict point was approximately 2 sec. In addition, drivers tended to choose the avoidance behavior of passing behind the pedestrian when the drivers focused on the pedestrians before starting the right turn.

Performance of a PV-DSRC System in which DSRC Transmits Data to Drivers and Pedestrians at Intersections

The researchers of this second study assessed the data transmission capability of a PV-DSRC system for situations with right-turning vehicles and pedestrians at intersections. The goal was to measure the performance of the PV-DSRC data transmission between the right-turning vehicle and the pedestrian under dynamic conditions at the experimental intersections. The researchers also evaluated the capability of a PV-DSRC data transmission system at actual intersections. To evaluate this system, the researchers reproduced the potential for collision conflicts between right-turning vehicles and pedestrians by using a test track in Tomakomai City, Japan, as shown in figure 6. For each run, the pedestrian starts from one of the four starting points (R1, R2,

L1, L2) shown in figure 6 and then crosses the intersection. The starting point is expected to affect the data transmission performance because of the positional relationship between the pedestrian and the DSRC device.

The PV-DSRC system used in these experiments is the same intervehicle DSRC (IV-DSRC) system that met the experimental guidelines for IV-DSRC systems that use the 5.8 GHz band (ITS FORUM RC-005 ver 1.0). Figure 7 shows how the pedestrian communicates with the vehicle. The researchers followed up by conducting a field experiment at three intersections in Yokosuka City, Japan, to evaluate the performance of data transmission between the pedestrian and a right-turning vehicle in a real-world setting. The purpose of this study was to assess the influence of intersection

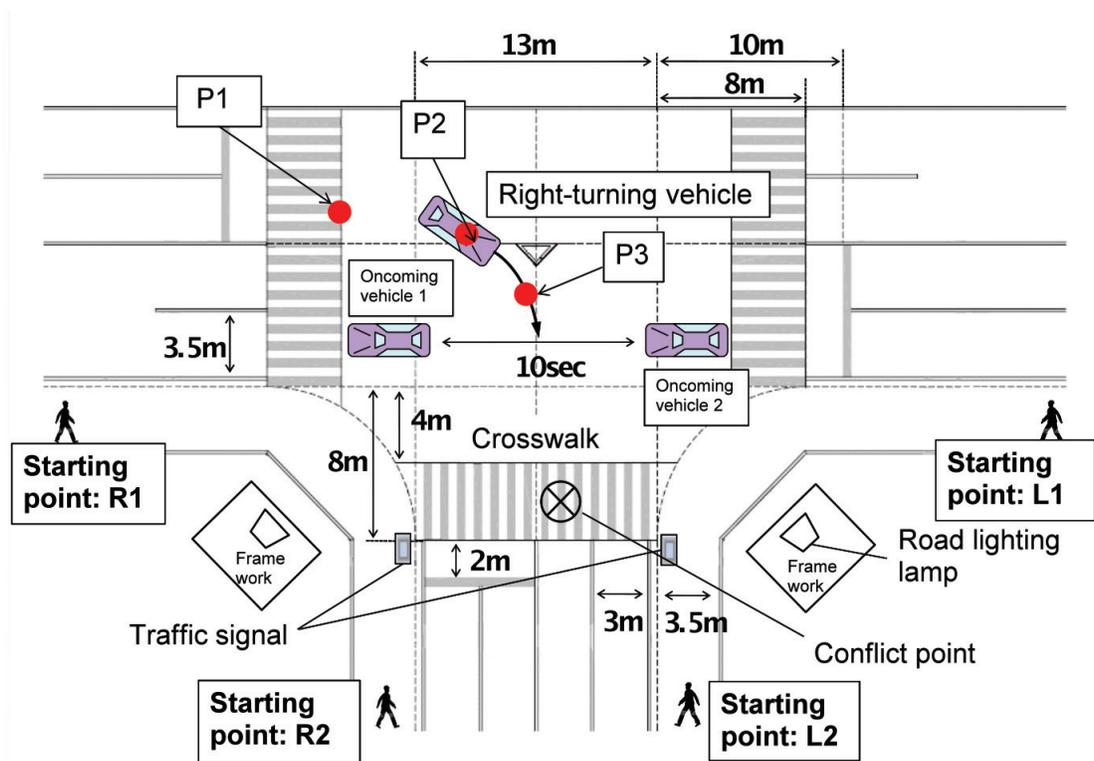
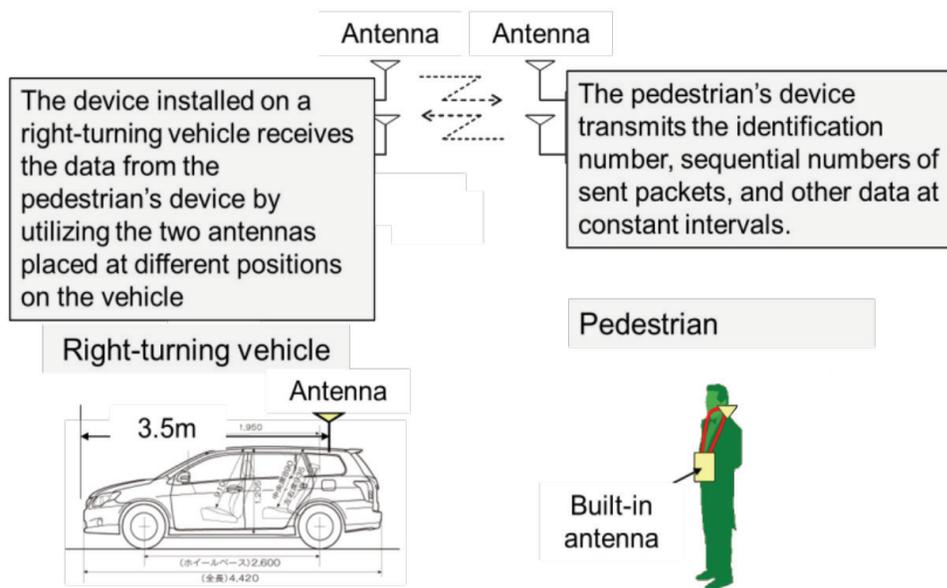


Figure 6. Reproduced collision conflict between right-turning vehicle and pedestrian.



© Toru Hagiwara and Hidekatsu Hamaoka

Figure 7. Pedestrian-vehicle dedicated short-range communications system.

size, location of the right-turning vehicles in the intersection, and the presence of an oncoming vehicle and a leading right-turning vehicle on data transmission performance. The experiment was performed by using multiple passes through the intersections at three different sized intersections: small, medium, and large. The receiving power at the large intersection showed that when the distance was between 50 m (164 ft) and -50 m (-164 ft), values of received power far exceeded the required level, but the received power values tended to be lower when there was an oncoming vehicle. Results of the packet-arrival rate, or throughput, show that they achieved the needed 80-percent packet-arrival rate required in Advanced Safety Vehicle-3 technology. When the right-turning vehicle is between 100 m (328 ft) and 30 m (98 ft) distance, the packet-arrival rates exceeded the 80-percent threshold.

Overall, the study indicated that the data transmission capabilities of a PV-DSRC system between right-turning vehicles and pedestrians at intersections were effective. If equipped with the IV-DSRC system, right-turning vehicles could communicate with

pedestrians in crosswalks who cannot be detected by the drivers or local sensors alone. Simultaneously, pedestrians could be alerted to their associated risk. Ultimately, the DSRC data transmission system could provide effective support to drivers who do not notice their risk of colliding with pedestrians both before and while making a right turn.

Behavior of Pedestrians in Crosswalks and Recognition of Approaching Turning Vehicle

The researchers conducted the third field experiment to understand the crossing behavior of pedestrians in the crosswalk. The researchers investigated how pedestrians identified the approach of right- or left-turning vehicles while crossing the crosswalk. They analyzed the head-turning behavior of pedestrians for right- or left-turning vehicles and considered the limitations of what a pedestrian can see and hear. The purpose of this experiment was to identify the point where pedestrians can confirm an approaching vehicle. The researchers achieved this by comparing the head-turning behavior of the subjects to assess whether they have an average confirmation or an appropriate confirmation.

Figure 8 shows the pedestrian-crossing experimental intersection scenario, which was implemented on a test track. Each pedestrian test subject was asked to proceed through the crosswalk as a vehicle makes a right or left turn toward the point. Only one vehicle can turn into the crosswalk. Each of the 44 subjects carried out this experimental procedure 16 times. The repetitions of the testing had the following variations:

- Two start positions (right or left).
- Two approaching vehicles (right or left).
- Two sight restrictions (day or night).
- Two hearing restrictions (wearing loose headphones or not).

By linking the head-turning angle with the location of intersection, the researchers showed characteristics of head-turning behavior. Subjects were both young and elderly, and some wore headphones. The tests were conducted during the day and at night. Subjects wore a hat with a head camera and a six-axis sensor to precisely measure head-turning angle (50 Hz, 0.001 deg/s unit).

This pedestrian study documented the importance of designing countermeasures for traffic accidents that involved a vehicle and a pedestrian from the viewpoint of the pedestrian. The field experiment analyzed



Figure 8. Pedestrian crossing an experimental intersection.

head-turning behaviors of crossing pedestrians relative to their starting position and the approach of vehicles.

Summary and Lessons Learned

By conducting field experiments, the researchers were able to study driver recognition behavior, pedestrian recognition behavior, and the potential effectiveness of PV-DSRC systems. In doing so they were able to conclude the following:

- Drivers tend to choose safety-avoidance behavior when they focus on pedestrians before starting to make a right turn.
- Locations where pedestrians confirm the imminence of a left- or right-turning vehicle depend on whether the vehicle was making a left or right turn and whether it is day or night.
- The PV-DSRC data transmission system can provide effective support to drivers and pedestrians who do not notice the potential for collisions.

Discussion

After the presentation, the presenters noted that the goal of the experiment was to test the most difficult intersection conditions, which is why an intersection without street lights was purposefully chosen. The presenters also noted that the pedestrians used a pair of headphones to block out noise and participants suggested that the researchers re-run the study with pedestrians listening to music with their headphones. One workshop participant observed that the interaction between pedestrian and vehicle maintains a constant speed dictated by the study parameters, and suggested that naturalistic data be gathered to capture that interaction. The presenters and participants noted that in the United States, there can exist blind spots for drivers turning into an intersection, especially when making a right turn.

© Toru Hagiwara and Hidekatsu Hamaoka

Driver-Infrastructure and Roadway Data for Human Factors Research

Dr. Michael Manser

*Center for Transportation Safety, Texas A&M Transportation Institute
Formerly with the University of Minnesota*

Overview

Dr. Michael Manser examined strategies for data collection and analysis of the relationship between the driver and infrastructure, with a focus on intersections and complex interchanges. He discussed four ways to conduct research on infrastructure: laboratory, simulator, test track, and real world. Manser informed workshop participants how these tools can be used to analyze the relationship among driver, infrastructure, and the roadway. He identified ways to conduct infrastructure research during the presentation. The objectives of this presentation were to (1) introduce the range of methods and emerging technologies to obtain and analyze driver-infrastructure and roadway data, (2) discuss the data sources that are used in analyses, and (3) consider more effective ways to approach this type of data.

Research Environment and Capabilities

Manser informed workshop participants that the relationship between driver and infrastructure (e.g., signage and electronic billboards above the roadway) and between driver and roadway (e.g., roadway geometrics or striping) can be examined in four types of research environments: laboratory testing, driving simulation, test track, or real-world field observations. Research conducted in the laboratory included tests such as computer-based testing, surveys, and questionnaires. Manser noted that there is a continuum of

fidelity across different simulators, ranging from desktop simulators to driving simulators; however, with the advances in technology they all have increasingly higher fidelity. Test tracks are closed-course facilities that can be highly controlled, and no other vehicles can impinge on the research protocol. Real-world research environments use vehicles with embedded data collection systems. These vehicles operate in largely uncontrolled environments on a prescribed course, route, or self-selected route, and researchers then mine the data.

In the last decade, real-world field research environments have matured significantly because of the power of computing. Manser identified the advantages of two types of real-world research environments: *on-road controlled* and *semi-controlled*. An on-road controlled real-world research environment uses an artificial scenario and a test vehicle with an extensive vehicle data acquisition (vehDAQ) system. For example, drivers proceed through an intersection multiple times under different conditions in a highly controlled on-road research environment and only proceed to cross when instructed to do so (i.e., when there are specific types of traffic gaps or streams of gaps). The researchers are able to determine which gap a driver would normally take and which gap they would select in response to alternative intersection signs. In semi-controlled research settings, drivers operate a test vehicle or their own

vehicle to exhibit natural driving behaviors, but the researchers retain control of where and when the driving occurs. A small vehDAQ system is installed in either vehicle, and drivers are instructed to follow a prescribed course at a prescribed time. This differs from naturalistic driving in which drivers choose their routes, timing, and sequence of driving, and therefore there is very little experimental control. Figure 9 shows examples of on-road controlled and semi-controlled studies conducted at the University of Minnesota.

Validity and Experimental Control

Different research environments result in tradeoffs between validity and experimental control. In terms of validity, researchers must ask whether they are measuring what they intend to measure. In terms of experimental control, researchers want to know how much control they have over the variables involved. To understand the driver and the infrastructure, certain variables of interest

are measured, including the driver, vehicle, intersection characteristics, time of day, and weather. As illustrated in figure 10, there is a positive linear relationship in validity moving from left to right or from surveys to in-field observations. The opposite is expected to be true for experimental control. Here, it is assumed that experimental control will decrease systematically, with more experimental control in a survey environment compared with an in-field observation or real-world environment.

Although figure 10 shows what is expected, in terms of the relationship between validity and experimental control by research environment, Manser proposed an enhanced model. Although not yet scientifically proven, the model offers a more realistic way to conceptualize the relationship among the research environments. The enhanced model adds on-road controlled and semi-controlled environments in between test



Figure 9. Real-world research environments.

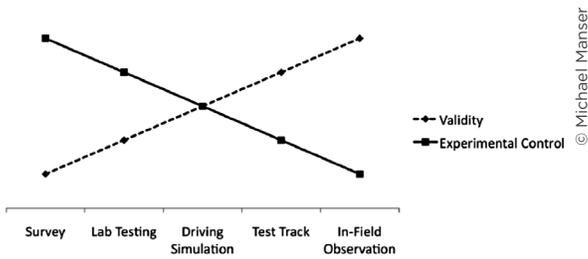


Figure 10. Expected research environments in terms of validity and experimental control.

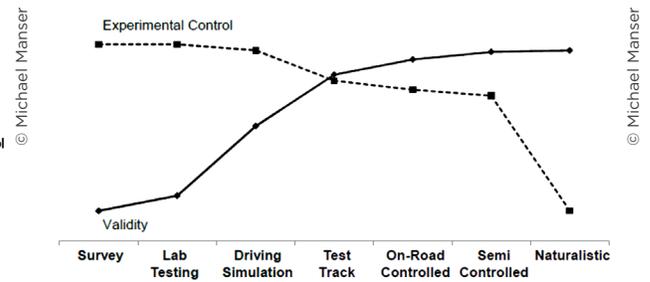


Figure 11. Adjusted research environments in terms of validity and experimental control.

track and naturalistic research environments. As figure 11 illustrates, experimental control can be high in surveys, laboratory testing, and driving simulation where the driving scenarios can be controlled. With the advent of better technology on the test track and in the on-road controlled and semi-controlled environments, experimental control has become significantly higher. Therefore, instead of a linear decrease in experimental control through the range of testing environments, the level of experimental control can be maintained from surveys to semi-controlled environments and naturalistic studies. Although naturalistic studies can have more experimental control, it has not yet achieved the same level as the other environments. Likewise, although validity is lower in survey and laboratory testing environments, it can increase substantially in the on-road controlled and semi-controlled environments. For example, drivers can be placed into real-life driving scenarios and in traffic while experimenters maintain a substantial amount of experimental control by deciding where they are driving and when.

Selecting a Research Environment

The choice of research environment may depend on the product development phase; for example, in the case of a safety intervention, this may include signs, roadway geometrics, and striping. A study of gap perception in drivers would be better suited to

a different research environment than would a study of a developed product or products. Researchers who studied a product concept might consider some laboratory testing to understand drivers' mental models and basic level of understanding when studying gap perception, in addition to how drivers select what gap or streams of gaps to accept. The use of a driving simulator can show if one product is better relative to another. As the product becomes more and more refined, it is important for researchers to move into naturalistic testing.

Identifying Data Sources

When looking at infrastructure-based as well as roadway-based safety solutions, there are four categories of data to consider: driver, objects, road or infrastructure, and traffic. Figure 12 illustrates the tools and environments in relation to these data categories. The driver data describes how the driver behaves and responds in terms of two variables. The first variable measures the primary control of the vehicle through acceleration, use of pedals and brakes, and steering. Physiological data is the second variable and measures driver reactions. For example, if researchers are interested in driver stress, then they can look at galvanic skin responses, or if they are interested in a faster-changing metric, then they can look at heart-rate variability or brain-wave activity.

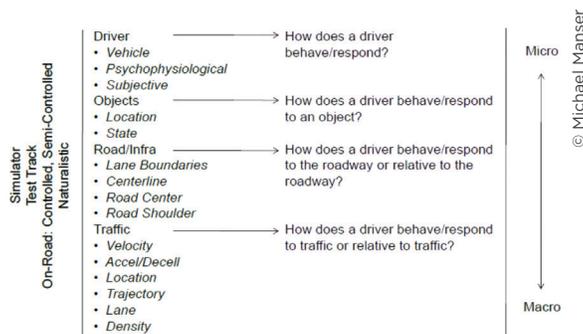


Figure 12. Tools and environments in relation to data sources.

The second data category includes objects in the environment. This is important for infrastructure research because there is a need to know where an object is, such as an overhead sign or a roadside traffic sign, and how drivers respond to these alternative locations. Drivers may change their behavior appropriately based on the location of that sign, or they might ignore or miss it. Researchers who study ITS may need to look at the particular state of signs and how they influence driver behavior.

The third category includes road and infrastructure because it is important to examine how a driver behaves and responds to the roadway or relative to the roadway. Some of the data elements to capture include lane boundaries, centerlines, and road geometrics. Researchers can use these data to understand driver response to specific roadway elements.

The traffic category refers to sources of data that are difficult to control. Traffic encompasses many factors, such as velocity, acceleration or deceleration, location, trajectory, and lane and traffic density. These factors affect driver decisions in traffic, such as speeding, maintaining speed, or crossing intersections. It is a challenge to control these variables.

These data categories should be thought of macroscopically as well as in terms of

microscopic driving behaviors, that is, how individual drivers react to something in the roadway. It is important to understand the aggregation of all the behavioral changes each driver makes and how they affect road transportation's efficiency and safety.

Cooperative Intersection Collision Avoidance System-Stop Sign Assist Project

In selecting a research environment to evaluate a safety measure, Manser informed the workshop participants of a cooperative intersection collision avoidance system-stop sign assist (CICAS-SSA) project in Minnesota, funded by FHWA. This project is one of many in the United States in which researchers are looking at different intersection technologies. The goal of the Minnesota research is to study gap-size rejection at particularly dangerous rural intersections in Minnesota. This intersection exhibits a higher crash rate than what would be predicted for this type of intersection. This intersection represents many intersections across the United States, and the researchers of this project are focused on determining what is problematic about the intersection and what can be done about it.

Manser told the workshop participants that the research team found that gap perception, that is the ability to determine an acceptable gap in traffic, is fairly poor for drivers. Based on previous research, the gap perception problem was considered to be the "root evil" of intersection crashes. This research began with laboratory studies in which the researchers presented several intersection concepts to participants, and the participants selected which sign they preferred, as shown in figure 13. By using the laboratory testing facilities, the researchers were able to narrow the field and conduct simulation testing with the more promising concepts. After evaluating their better sign concepts, the researchers

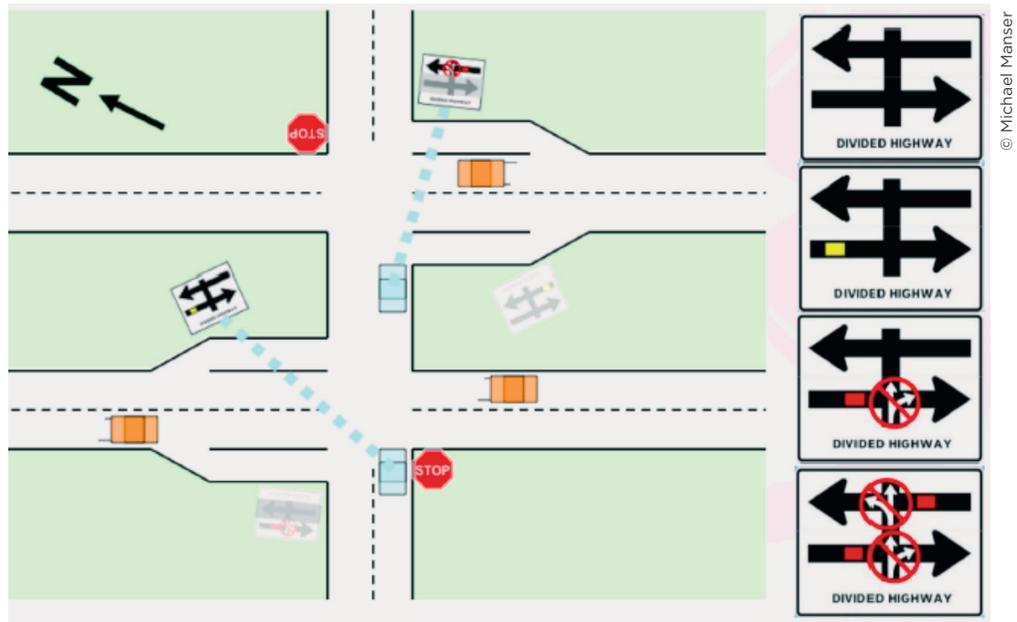


Figure 13. Experimental signs used in laboratory study.

moved to product evaluation and tested the best-rated sign in on-road controlled studies and semi-controlled studies. For the next step, the researchers have been performing an FOT funded by USDOT, which is underway to measure the effectiveness of a best-rated sign. This project provides an example of how researchers can take particular concepts and evaluate them early on, refine those concepts, take those concepts into the simulation studies, and eventually evaluate the best concept in FOTs.

Infrastructure-Based Driver and Traffic Data

To test whether a sign has an effect on traffic, researchers used an instrumented vehicle equipped with a GPS on the car roof. The instrumented vehicle measured driver behavior and location of the vehicle within centimeters. The researchers of the CICAS-SSA study also set up a fully instrumented intersection, equipped with radar sensors on all legs, to monitor traffic approaching the intersection according to factors that included location, speed, and velocity. Test drivers operated the vehicle both when the sign was on and off.

The researchers recorded variables, which included right, left, and crossing maneuvers, gap-safety margins, movement time and rejected gaps, eye-glance behavior toward sign and traffic, and subjective measures from random gap-simulation studies.

An interesting aspect that Manser highlighted for workshop participants was that, when these data are fed into the CICAS-SSA system, one can look at the interaction with drivers and the traffic. It was also possible to look at, dynamically and in real time, the gaps in front of or on the side of the driver, in addition to which gaps drivers reject in traffic. With the richness of these data, researchers were able to develop profiles of successful gap acceptance and gap rejections.

Research Challenges

On the basis of this research and knowledge of driver infrastructure and roadway data, Manser informed participants of the significant challenges that researchers face in the field. For example, increasing validity requires more complex research

environments, which generate higher costs. Unlike driver simulation studies, on-road studies often require an instrumented vehicle and an instrumented intersection outfitted with sensors. Researchers must coordinate multiple streams of data into one, but analyzing multiple data streams is a long and intense process, which raises the cost. In addition, efforts to increase generalizability require increases in sample size, which also generates higher costs. There are also costs related to staff time needed in the field because of the number of staff required at one time to monitor the instruments, multidirectional traffic flows, and cue the test vehicle. Finally, improving the validity of research depends on larger samples and use of differential GPS, which produces more accurate data but at higher costs. The bottom line is that to improve validity, costs will increase.

Research Gaps

Manser informed the workshop participants that eye trackers have the potential to be a strong tool to examine the efficacy of new infrastructure and roadway-based systems; however, there are research gaps with eye trackers that limited their use for the study of driver-infrastructure roadway data. There are error rates that cumulate with distance, and most eye-tracking manufacturers claim that their eye trackers have about 3-degree accuracy. The result is that when drivers look at signs at about 61 m (200 ft), the subtended angle becomes 3 m (10 ft), which is a distance that is too great to determine accurately if a driver is looking at a sign.

Differential GPS keeps track of head position and has an error rate of several centimeters. There are also lag times between the eye tracker and data collection system that produces an error rate. The driver's head movement as he or she proceeds through the intersection also produces an error

rate. All of these errors cumulate, reducing the accuracy of eye trackers for studying driver behavior in complex intersections. In summary, Manser noted that aspects of eye behavior that must be examined to study a specific infrastructure or roadway element include looking at the infrastructure or roadway element and the area around an infrastructure or roadway element.

New Tools for Accuracy

Manser also highlighted light detection and ranging (LIDAR) data as a promising new tool that portends to be useful for driver infrastructure and roadway data research. LIDAR is a scanning laser-based radar type system that is able to pick up objects, including cars, trees, pedestrians, and buildings, quickly and accurately. It offers tools to measure how drivers respond to objects in the environment and correlates driver behavior with environmental inputs in real time. One of the major challenges with the LIDAR data tool is that, although people can recognize the objects that the system is picking up as buildings, trees, or pedestrians, the computer sees them as zeros and ones. Therefore, the larger challenge is not collecting the data but understanding what the data means.

Manser told workshop participants that Google is one of the major innovators using this new tool and that it is implemented in the Google self-driving car. The Google car obtains information about its surroundings by using LIDAR data, along with other sensors. If researchers want to look at how drivers respond to objects in the environment that may be changed as part of an experimental study, researchers can begin to correlate how the drivers behave with the new objects in the environment in real time. Manser noted that there needs to be more effort and research to use LIDAR.

Discussion

In summary, participants raised questions about the challenges of using eye-tracking technologies and noted that use of these technologies depends on the research question under study. For example, if the goal is to measure a driver's attention to large signs that are close by, 3-degree accuracy is sufficient. Because analysis of eye-tracking data can be noisy, some researchers segment eye-tracking data into zones for ease of analysis. Although it is accepted that eye tracking is useful to study driver attention to features that are close by, it remains difficult to measure how drivers attend to objects in the distance.

Sampling rate can also be an issue when using eye trackers, as can individual differences, given that some people limit their scan to 1.5 degrees. Suggestions for analysis include looking at patterns as well as the accuracy of the data, which necessitates using good software able to pick up patterns. Manser noted that eye trackers are most effective in daylight but that this may not be a major constraint, because 90 percent of driving occurs during the day. Manser also noted that there are lower tech alternatives to eye tracking, such as video data, which can answer research questions including head position in relation to road activities and pedestrian movements.

Traffic Control Devices and In-Vehicle Systems

Dr. Susan Chrysler

National Advanced Driving Simulator, University of Iowa

Introduction

During this presentation, Dr. Susan Chrysler informed workshop participants how to find the most effective methods to address research needs based on target questions. Examples of research on traffic control devices (TCD) were used to demonstrate how a variety of methods could be applied to the same research question. The examples were drawn from materials prepared to educate traffic engineers on how to select effective evaluation methods for TCDs. The advantages and disadvantages of alternative research methods were also outlined, including focus groups and open and closed test courses.

Human Factors Research on Traffic Control Devices

TCDs include signs, pavement markings, and signals. FHWA's *Manual on Uniform Traffic Control Devices* (MUTCD) provides standards and specifications for the design and application of TCDs in the United States.⁹ Local and State governments use the MUTCD standards and guidelines to produce TCDs to manage their local road safety and traffic. Localities can modify options permitted in the MUTCD according to an FHWA process that requires evaluation of new candidate TCDs. Chrysler noted that TCD practices are selected for inclusion or modification based on data collected through experimentation and that the MUTCD provides extensive guidance about the review process to be used by State and local governments.

Chrysler informed workshop participants that, because of the importance of ensuring appropriate evaluation for new TCDs, State and local governments often conduct research to receive approval for their new TCD or new application of an existing TCD. The human factors research topics include visibility, legibility, comprehension, compliance, and preference. Chrysler highlighted that examining these topic areas, in relation to the specific application, will determine the effectiveness of TCDs to convey directions and warnings to drivers. For example, visibility human factors research topics include brightness, color, and shape aspects of signs, markings, and signals. In addition, legibility of signs is dependent on adequate font type, size, and proper color contrast in different road and environmental conditions. In addition, beyond visibility and legibility, TCDs need to be understood by drivers. Comprehension can be tested by using simple test methods within more complex methods involving traffic observations. Collecting preference data for TCDs identifies designs with which drivers are more comfortable compared with the other allowable options. This preference data, however, are not always predictive of driver behavior.

9. Federal Highway Administration. (2009). *Manual on Uniform Traffic Control Devices*. Washington, DC. Retrieved June 11, 2014, from http://mutcd.fhwa.dot.gov/kno_20091r2.htm

These considerations undergo a thorough examination to generate valid methods for evaluation. The FHWA publication, *Pedestrian and Bicycle Traffic Control Device Evaluation Methods* (Publication No. FHWA-HRT-11-035), recommends a variety of methods to evaluate TCDs for pedestrian and bicyclist TCDs. The methods presented in this report are applicable for the evaluation of any TCD.

Chrysler informed workshop participants of several key issues that can affect human factors data collection. The issues relate to data collection methods used to evaluate behavior as follows:

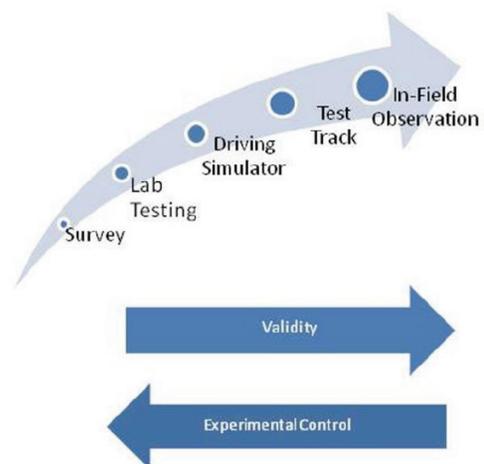
- Subject sample representativeness—The representativeness needs to be assessed to account for differences among the research sample and the general population. Decisions about who to test need to be made in the context of the problem tested. For example, if the problem is that school children are not obeying a signal, then school children should be tested, rather than adults. People who volunteer for experiments may be very different from people who do not participate. They are more likely to have higher socioeconomic status and level of education. Efforts should be made to recruit people with different reading abilities, education levels, and visual abilities.
- Self-selection bias—Volunteers may not be representative of the general population. For example, participants may be better drivers. People within a reasonable distance from a facility where a highway simulator or test track is located are often more likely to participate in the study. Any bias associated with location should be assessed.
- Human subjects’ protection regulations—Researchers must be aware of and

comply with human subjects’ protection principles to perform behavioral research. Conformance can be established by an institutional review board committee set up to monitor human research.

- Recruitment methods—Different populations for experiments can be obtained depending on how researchers recruit and compensate subjects.

Validity and Experimental Control in Experimental Methods

Researchers must make trade-offs between validity (i.e., the ability of the study results to predict behavior on the road) and experimental control when selecting research methods. As figure 14 illustrates, validity is inversely proportional to experimental control. On one hand, utilizing in-field observation, for example, allows a “natural” observation with no influence by experimenters on decisions made by road users. On the other hand, this method does not allow for any control of traffic or weather, so not every subject is exposed to exactly the same conditions. Surveys and laboratory testing are examples of controlled experiments in which the validity of a participant’s stated behavior is questioned because of desirable response bias, that is, in



© Susan Chrysler, University of Iowa

Figure 14. Trade-off between validity and experimental control.

which everyone reports that they will comply with the device but may not in real life.

Overview of Research Methods

Chrysler next gave workshop participants an overview of several research methods. These were categorized as surveys, focus groups, controlled experiments, and observational experiments.

Surveys

This category includes experiments in which researchers do not control the amount of time participants view the question. In addition, a survey may also allow for open-ended responses. In this context, laboratory tests in which researchers can control exposure time would not be considered part of the survey category. Survey methods may be considered either *interactive* (e.g., telephone surveys or intercept on-site) or *non-interactive*. Non-interactive survey methods include questionnaires that are conducted via mail or email, as well as self-paced questionnaires that use computer or paper.

Chrysler told workshop participants that, to measure what is intended, researchers need to ask the same question in different ways to verify the given answer. For example, instead of using a direct question that results in an open-ended response, questions can use illustrations or scenarios that provide a venue for subjects to demonstrate their understanding by indicating what action would be taken. This means that if people are asked, “What does a yellow line mean?” they may not be able to answer; however, when shown a photo of a one-way street with a yellow line, they can correctly identify the direction of travel, often without being able to identify why they answered in a particular way. Open-

ended questions are time-consuming to code and summarize, so multiple choice or true-or-false questions may be preferred.

Focus Groups

In this category, groups of people are selected based on specific demographics or other characteristics to represent a target population. Evaluation that uses focus groups can occur during early phases of research and can be conducted at multiple locations. Chrysler noted that focus groups are particularly useful to narrow down the number of TCD alternatives that should be tested in subsequent studies that used more controlled methods. They are also helpful to gain insight into baseline driver understanding of a new traffic operation so that a new TCD can be designed to match that native understanding. Chrysler also cautioned that a dominating personality in the group may influence opinions.

Controlled Experiments

- *Laboratory Experiments of Comprehension*

This tool is considered useful to analyze how well subjects comprehend signs, markings, and signals. Researchers can measure response time, accuracy, and limited viewing time of traffic signs. The use of a “button box” is suitable in these experiments because it provides a way to measure duration of viewing time, is easy to use, and is therefore accessible to much of the population. Button boxes are portable, can be connected to laptops, and allow experiments to be performed on a large scale.

- *Simulation*

TCDs can also be analyzed by using driving simulators. For example, the influence of changeable message signs on a driver’s decisions can be measured by

using verbal questions under the task load of driving. It is not necessary to record trajectory measurements (i.e., speed and acceleration). After driving in the simulator, subjects can be asked about the instructions displayed on a changeable message sign.

Simulators can also reveal the dynamic aspects of behavior. Lane changing over time is an example of an observed behavior with dynamic aspects. The flexibility of using simulators to conduct experiments permits different starting lanes and driving environments and can reveal speed changes and errors that usually precede vehicle crashes. Another advantage of driving simulators is that they provide a detailed, cost-effective way to test multiple versions of TCDs or in-vehicle displays and warning systems.

- *Closed Course, Test Track, and Open Road*
Closed-course test facilities are paved facilities that have availability for testing when not in use, such as unused fairgrounds or mothballed runways. In closed-course experiments, the test stimuli are actual roadways, and the closed courses use infrastructure (e.g., road intersections) as scenarios to perform evaluations. Test tracks are paved, dedicated runs without access to the outside world and generally have adjustable field instrumentation to measure vehicle performance parameters. Open-road testing refers to testing that uses roads that are in use or that may be temporarily closed for the test protocol. It is thought that drivers are under a more realistic attentional load when the study is conducted on an actual road.

Drivers can wear or use eye-tracking devices to monitor their visual behavior

during testing on closed courses or test tracks. Eye-tracking methods measure the position, duration, and movement of the driver's eyes, which is a proxy for where they are looking. Researchers have noted that this is useful data to correlate with the vehicle inputs and behavior in response to cues and prompts outside the vehicle. Because there are technical limitations with day time use of eye-tracking devices, glance behavior needs to be hand coded from in-vehicle video cameras. Researchers often prefer test tracks over closed courses because they can accommodate more dangerous and higher speed scenarios.

Observational Experiments

Chrysler told workshop participants that observational methods require no direct contact with drivers. The measurements usually sought in observational experiments account for driving behavior—speed can be measured by using tubes or radar, and video data collection can be used to observe lane changing and compliance with signs and markings. Using existing cameras and live coding of traffic from a traffic management center (TMC) provides additional resources for researchers to evaluate specific conflicts. Test devices can be installed, or researchers can use existing ones. Regardless of what method is used, Chrysler noted that finding comparable sites for data collection is a challenge. For example, signs might work for specific road geometries but may not be appropriate for others.

- *Open-Road Drives*

During the presentation, Chrysler informed workshop participants that some of the procedural limitations when performing open-road drives are the requirements involved when installing new signs or

pavement markings. These experiments are preceded by a long process that involves obtaining permission to install devices, material fabrication, and installation. In addition, this method has risks associated with insurance coverage and liability for participants, researchers, and operators. It is more efficient to conduct these types of tests on a closed course where the experimenter has more latitude to make changes in the environment.

Another challenge noted when performing open-road research is the lack of experimental control. Participants may be able to identify the purpose of the research upon seeing the first test device. To compensate for the lack of control and to avoid order effects, it is necessary to alternate routes so that the first device is not the same for every subject. Limitations of being able to control different external factors, such as weather, traffic, and time of day, also make it difficult to equate or measure driving behavior across participants. Another issue to be aware of is possible vandalism and theft of signs and vehicle equipment.

Chrysler noted that data collected from on-road tests accurately reflect observed driving performance under realistic conditions (e.g., lighting, workload, and traffic). Experiments on the road are justified because of their greater acceptance and validity for practitioners—traffic engineers are often more convinced of a finding if it has been tested on

the road. Researchers have to prove and demonstrate to the professional community that the use of test track, driving simulators, focus groups, and surveys to analyze behavior is valid.

On-road experiments can be tied to driving simulator experiments, for example, by using the same vehicle type in experimental simulations and then asking participants to drive the vehicle on road during the same day. The goal of having the same person during the same day using the same type of car is to predict their driving behavior. One example of this is eye-tracking studies during night conditions, which can be analyzed by using both research methods.

Comparison of Methods

Some of the factors considered important when comparing different sources were outlined as cost, time for study, experimental control, safety, diversity of sample, face validity, and the number of alternatives that can be tested. As figure 15 shows, there is no perfect method that can account for all aspects. It all depends on what the specific question is and the measure wanted.

One of the critical factors when choosing a research method is cost. Researchers select research methods that are most cost-effective and can answer the research question. Research methods that are simple to set up at a low cost are often the most difficult to score and to be used for comparison (e.g., traffic surveillance cameras). Research methods with automatic scoring are also difficult to set up (e.g., a properly constructed survey).

	Cost	Time for Study	Exp Ctrl	Safety	Sample	Face Validity	# of alt. tested
Traditional Survey	Low	Brief	Med	High	Large/Diverse	Low	High
Focus Group	Low	Brief	Low	High	Large/Diverse	Low	High
Laboratory Methods	Med	Med	High	High	Large/Diverse	Low	High
Simulator	Med	Med	High	High	Med / Similar	Med	High
Closed Course	High	Long	Med	Med	Med / Similar	High	Med
Test Track	High	Long	Med	Med	Med / Similar	Med	Med
On-Road Experiment	High	Long	Low	Low	Med / Similar	High	Low
Observational	Med	Long	Low	High	Large/ few locations	High	Low

© Susan Chrysler, University of Iowa

Figure 15. Research methods.

Research Needs

Chrysler highlighted several research needs for attention at the end of the presentation, as follows:

- Comparing different models—There is scarce previous research on how to do this and assumptions on validity are grounded in what is observed from the surface.
- Data mining—This is an alternative strategy to consider when evaluating different sources. Researchers tend to focus on their own experiments and exclude other researchers' process of analyzing data to extract useful information.
- Limited data—The number of experiments that use the same vehicle to collect data from a driving simulator and for on-road testing, for the same participants and on the same day, is limited.

Discussion

Following the presentation, the workshop participants discussed several topics, as follows:

- Testing comprehension—This allows researchers to measure understanding of alternative TCD formats. For example, typically a sign would be considered acceptable if 75 percent of people understand it; however, it may be necessary to compare results from surveys and driving simulators to confirm that drivers can demonstrate their understanding of the sign through their behaviors.
- Developing survey techniques—Results are often sensitive to the administration format and phrasing of the items. Different survey techniques, such as asking questions in different ways or including a scale, can help to factor out inconsistent responses.
- Ensuring validity—There are various views on whether a given technique will reveal actual behavior or desired responses. It may not be useful to analyze aggressive driving by using

surveys, because respondents may not give truthful responses or may not be aware of how to evaluate their driving rates. Driving in a driving simulator may also fail to evoke or capture aggressive driving because of its artificiality. Categorizing research methods based on validity can be complicated when the metrics are not clearly calibrated both to the subject as well as to the experimenter.

- Identifying the research phase—The method chosen may depend on what phase the research is in and the type of research question to be analyzed.
- Introducing variability—It is useful to have variability in the sample both in terms of participants and sites to account for a range of likely behavior.

Additional Resources

Chrysler made available a selection of additional resources to workshop participants. These resources are outlined as follows:

Papers

- Chrysler, S. T., Fitzpatrick, K., Brewer, M. A., & Cynecki, M. (2011). *Pedestrian and Bicyclist Traffic Control Device Evaluation Methods (Report No. FHWA-HRT-11-035)*. Washington, DC: Federal Highway Administration.
- Chrysler, S.T., & Nelson, A. (2011). Design and evaluation of signs and pavement markings using driving simulators. In Fisher, D. L., Rizzo, M., Caird, J. K., & Lee, J. D. (Eds). *Handbook of Driving Simulation for Engineering, Medicine, and Psychology* (ch.39). Boca Raton, FL: CRC Press.

Examples of Studies

- Clark, K. L., Hummer, J. E., & Dutt, N. (1996). Field evaluation of fluorescent strong yellow-green pedestrian warning signs. *Transportation Research Record*, 1538(1), 39–46.
- Gates, T. J., Carlson, P. J., & Hawkins, H. G. (2004). Field evaluations of warning and regulatory signs with enhanced conspicuity properties. *Transportation Research Record*, 1862(1), 64–76.
- Funkhouser, D., Chrysler, S., Nelson, A., & Park, E. S. (2008). Traffic sign legibility for different sign background colors: Results of an open road study at freeway speeds. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 52(23), 1855–1859.
- Golembiewski, G. A., Katz, B. J., Knoblauch, R. L., & Rousseau, G. K. (2006). Determining colors for traffic control devices at transponder-controlled tollbooth lanes with a sign simulator. *Transportation Research Record*, 1973(1), 48–54.
- Dutta, A., Fisher, D. L., & Noyce, D. A. (2004). Use of a driving simulator to evaluate and optimize factors affecting understandability of variable message signs. *Transportation Research Part F: Traffic Psychology and Behaviour*, 7(4), 209–227.
- Shinar, D., Dewar, R. E., Summala, H., & Zakowska, L. (2003). Traffic sign symbol comprehension: A cross-cultural study. *Ergonomics*, 46(15), 1549–1565.
- Dudek, C. L., Schrock, S. D., & Ullman, B. R. (2007). License plate and telephone numbers in changeable message sign amber alert messages. *Transportation Research Record*, 2012(1), 64–71.

Triangulating Data Sources to Understand Driver–Vehicle Behavior

Dr. John Lee

Department of Industrial and Systems Engineering, University of Wisconsin–Madison

Introduction

Dr. John Lee told workshop participants that combining different data sources through a strategy to triangulate methods provides new approaches to addressing research needs. Lee suggested that mixing on-road data with data collected from simulators, or from drivers themselves, provides a comprehensive approach that can compensate for the deficiencies of a particular method. Simulators provide meaningful parameters to take into account when comparing on-road driving behavior with simulator data. Lee presented a proof of concept study to workshop participants, which used existing infrastructure and data collected via social media, to triangulate multiple sources of data to investigate driving behavior.

Triangulating Data Sources to Understand Driver–Vehicle Behavior

Rather than picking the best method in an absolute sense (i.e., the most valid or selecting the best one for a particular problem), multiple methods can be combined to triangulate a problem. Lee told workshop participants that the proposed approach was to collect data with one method and combine them with other datasets to provide new insights.

Triangulation is a metaphor used in reference to position-fixing in navigation. First, a landmark is selected to establish a line of reference with which to compare the current position. When a second landmark

is identified, a location is determined by using the point where both reference lines from the two landmarks intersect. In light of this metaphor, a driving simulator and on-road test can represent the landmarks to determine whether results converge. Ideally, a third line from a third landmark will also intersect at the same spot; however, in geographic applications in the real world, the third line typically does not meet the other two bearings because of errors, such as mapping a region instead of limiting it to where a possible position exists.

Lee mentioned that one of the critical considerations when choosing landmarks in navigation is to select from orthogonal, highly separated choices, located at right angles from the current position. Lee stated that when translating this concept into the research context, it is important to select maximally different methods of collecting data to address the same question. The challenge that comes with triangulation is coordinating and synthesizing observations that come from using different methods.

The challenges with triangulating data include logistical problems, sampling issues, philosophical aspects, costs, and modeling. During the presentation, these challenges were outlined as follows:

- Logistical problems—These require that data structures be harmonized and that variables and units are measured the

same way and have consistent definitions. The goal is to make sure researchers use the same equations to calculate summary measures and, at the very least, use consistent units.

- Sampling issues—A second concern is to acquire a representative sample of participants who volunteer for the experiment and allow videotaping and other intrusions on their daily behavior. It is important to recognize potential biases in studies that are based on volunteers or self-selection. It is also necessary to acquire a representative sample of the driving context.
- Philosophical aspects—Conflicts regarding the “best” data or method can be addressed by recognizing the complementarity of methods, not by ordering them in terms of being less or more valid, but by recognizing there is no gold standard. All methods give an insight into different elements considered in the research.
- Costs—This can be expensive unless the research approach is inventive. One way to be inventive and enhance the value of the study is by making use of free or low-cost data by using existing sources. More expensive approaches include collecting data in driving simulators and replicating the study by using on-road tests.
- Modeling—The last challenge is to create a model to clarify, combine, and accumulate findings.

Research Approaches

Lee showed workshop participants three different approaches towards triangulating data. These included linking driving simulators to on-road behavior; determining ways to go beyond using existing infrastructure, such as loop detectors; and using drivers themselves as sensors of activity on the road.

Approach 1:

Linking Simulators to On-Road Behavior

The first project that Lee presented was a large-scale public-private collaboration, involving the National Advanced Driving Simulator (NADS), Iowa State University, Montana State University, and SAIC, which received funding from the EAR Program. The purpose of this research project was to replicate actual road segments in different driving simulators. One of the benefits of this approach was to improve the usefulness of simulator data for understanding driver behavior. Different road segments that all road users find particularly challenging, such as roundabouts and gateways, were sampled and recreated in a simulated environment. Figure 16 shows the replication in simulation and its match to what is seen in the real world.

Researchers analyzed how simulated driving data corresponded to data collected on the road. The driving speed for each state in the different simulators, in terms of mean and standard deviation, was compared with data from driving through roundabouts collected from the real world. Ideally, the mean for speed in simulations will follow the mean for real-world data. Lee noted that this is the same for standard deviation in simulated scenarios, with data from actual driving in the roundabout. Comparisons across different simulators demonstrated good



Figure 16. Comparison of real and simulated scenarios.

correspondence across the different roadway situations. One interesting outcome was that motion and visual complexity in a simulated environment had little effect on driving behavior, and similar results were obtained when motion was enabled or disabled.

Models for Transformation and Interpretation of Simulator Data

Lee examined the data by using two types of models, a linear regression and a generative process model. This was to understand how drivers actually negotiate a curve using a closed-loop model with perceptual cues, desired speed, and adjustments to speed.

Regression Model

Lee compared speed values across different roundabouts in simulators and in the real world. He noted that, ideally, simulators will have all data points lined up on the standardized diagonal, representing real-world conditions. Overall, results show a good correspondence between simulated and real-world data, indicating an absolute validity for the patterns observed.

Generative Model

The generative model uses data from a simulator, which provides for a deeper understanding of driving behavior in negotiating the curve in the roundabout. Lee noted that this model is a useful way to accumulate knowledge on driving performance based on a parameterized estimation of driving behavior. These simulator data were used to develop the driver model.

Lee informed workshop participants that harmonizing data resolution was one of the challenges of developing and validating this driver model. In this case, the data specifying the roadway were relatively coarse compared

to the fine-grained resolution of the response process of the driver model. The data specifying the road curvature in the simulator were different than the information about roadway curvature portrayed on the simulator screen, because the textures used to create the visual scene tend to mask discontinuities in the underlying road database. This created a database resolution that is not compatible for the driver model. The discontinuity on road segments, as in the case of roundabouts where straight segments are followed by curves, introduced errors in the driver model that had to be addressed by smoothing the segments that comprised the roadway database.

Lessons Learned: Triangulating Data in Roadway Design

During the presentation, Lee proposed the following recommendations to improve roadway scenarios replicated in driving simulation:

- Naturalistic data—This is a useful source to identify critical design issues to be replicated in the driving simulator. Scenarios to include are road geometry, traffic-control device placement, and traffic situations.
- Analog approach—Alternate between low-fidelity to high-fidelity simulations as an analog phase approach for human-computer interaction.
- Integrate data—To accomplish a comprehensive approach, it is necessary to integrate a driver model with simulator evaluation and naturalistic data (i.e., surveillance data).

Approach 2:

Determining Ways to Go Beyond Loop Detectors for On-Road Data

Researchers for the second research project underway at the University of

Wisconsin-Madison are collecting data beyond spot speed from loop detectors. They are analyzing intersection approaches by using on-road experiments and existing infrastructure to collect data at a relatively low cost. The researchers use existing infrastructure and radar sensors on traffic signals to capture trajectory data. Their objective is to identify vehicle trajectory (i.e., position and speed across time) and to compute the real-time safety performance measurements for vehicle movements. One of the applications of this research project could be the validation of data from simulators at very low cost by using existing and available data.

Approach 3: Using Drivers as Sensors

Drivers can be used as sensors in different ways to identify problems. By taking advantage of technology, drivers' surveillance may help researchers to identify problems and solutions. Two examples of how to do this include the safety complaints recorded in the National Highway Traffic Safety Administration (NHTSA) Vehicle Operator Questionnaire (VOQ) database and Twitter.

Safety Complaints

NHTSA compiles complaint data in an NHTSA database that contains drivers' entries on the NHTSA VOQs. These data can be downloaded at no cost and offer a low-cost tool to analyze problems with vehicles.¹⁰

Data can be analyzed by using a language-semantic-analysis, and the content can be analyzed by using cluster analysis. The results can be analyzed across time and offer a way to conduct surveillance by using drivers as sensors.

Twitter Data

Lee informed workshop participants that another way to use drivers as sensors to collect data is by looking at Twitter text to

identify hot trends and compare Twitter data across place and time. A University of Wisconsin-Madison computer science research team used its socio-scope approach to extract the spatio-temporal signal from Twitter and create spatial-temporal maps to target pre-defined target phenomenon. Some issues to be aware of when using this type of data are population bias, imprecise location of phenomena, and low counts of events. The research team demonstrated this surveillance method through Twitter to evaluate the intensity of road-kill events across the continental United States.¹¹

The proof of concept can be extended into different areas by using proper filters and text classifiers. This type of data can be obtained at a low cost. Workshop participants noted several interesting possibilities for Twitter data for future consideration. These could target the following areas:

- Patterns of distracted driving.
- Road infrastructure problems.
- Early warning of vehicle automation issues.

Conclusion

In conclusion, Lee informed workshop participants that triangulation of data sources provides several research opportunities; however, the following challenges still remain:

- Harmonizing data structures, data resolution, and variable definitions.
- Harmonizing representative sampling and synthesis of drivers and contexts.

10. Ghazizadeh, M., & Lee, J. D. (2012). Consumer complaints and traffic fatalities: Insights from the NHTSA vehicle owner's complaint database. *Proceedings of the Human Factors and Ergonomics Society 56th Annual Meeting* (pp. 2256-2260). Boston, MA.

11. Xu, J-M., et al. (2012). Socioscope: Spatio-temporal signal recovery from social media. *Proceedings of the European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases* (pp. 644-659). Bristol, UK.

- Recognizing complementary methods—there is no gold standard for measuring driver behavior.
- Reducing the expense of triangulation.
- Performing driver modeling to clarify, combine, and accumulate findings.

Discussion

During the discussion following the presentation, Lee informed participants that the project results will be published soon. The discussion also raised several points relating to using Twitter data as a new surveillance method for driver-vehicle research. When asked about the general cost of a Twitter data-collection effort, such as the effort to look at road kill across the United States, Lee noted that the cost is in the range of tens of thousands of dollars.

Lee also told participants that computer technology is increasingly more powerful and less expensive, and therefore practical for research. Lee explained that the example that used Twitter data regarding species, time, and place of road kill was intended to be a proof of concept to illustrate the technique because the ground truth is known. In contrast, less is known about the characteristics of teenagers who tweet, and Twitter analyses may have potential to illuminate this issue. In response to a question regarding whether a generative model of curve negotiation is an example of modeling helping with triangulation, Lee noted that it explains why people behave differently with different simulators. In addition, the parameters that are estimated from the model can help researchers understand how to take into account on-road data.

Driver-Vehicle Data for Human Factors Research

Dr. Linda Ng Boyle

University of Washington

Introduction

During this presentation, Dr. Linda Ng Boyle recommended integrating methodologies rather than choosing a single methodology for human factors research on driver and vehicle data. Boyle informed workshop participants that there is immense value in considering different research and analytical tools. Multiple data sources can offer different but complimentary perspectives and can provide greater insights for a common research topic. Boyle showed workshop participants examples of how to complement data sources, looking specifically at in-vehicle driver support systems. The proposed framework integrates different data sources to understand driving behavior and safety outcomes, using the adaptive cruise control (ACC) in-vehicle driver support system as an example.

Adaptive Cruise Control

In-vehicle driver support systems provide traffic and other information to users with the purpose of improving traffic flow and enhancing driver comfort and safety. These systems are integrated into vehicles today and also exist as cloud-based systems that can be used with smart mobile devices.

ACC is an example of an embedded in-vehicle driver support system, where a driver can set the desired speed and distance from a lead vehicle.

Boyle noted, although ACC has been available in the United States since 2001, its safety benefits have not been fully assessed. Depending on the vehicle make and model, ACC may not necessarily work in stop-and-go traffic, and has limited ability to recognize a vehicle that has stopped directly in front or on a sharp, curvy road.

User Survey Data

To understand consumer's perceptions and actual use of ACC, Boyle's research team conducted a survey in Washington state between 2010 and 2011. In this study, ACC owners were asked about ACC's functional limitations. Of the surveys sent, 584 surveys were returned, and 118 were from actual ACC users. Many ACC users reported that the ACC system was helpful in stop-and-go traffic, on curved roads, and for recognizing stopped vehicles. Some users reported that they did not know whether or not ACC was successful in assisting them under these conditions. A similar survey was conducted in Iowa between 2008 and 2009, with 514 surveys returned and 132 of the surveys from actual ACC owners. Across both surveys, over 50 percent of drivers were not aware of the limitations of ACC, as indicated by the percent responding "Yes" or "Don't Know."

During the presentation, Boyle highlighted that survey data can provide some insights

on drivers' motivation, attitudes, and previous experiences; however, there are many other factors that can impact the overall safety of the driver, which need to be gathered from other data sources. Mediating factors are based on more subjective traits but may actually have a greater influence on the driver's behavior. These factors emerge from long-term exposure to a system, in conjunction with their other driving experiences, motivational factors, and driver limitations.

Initiating factors come from the direct interaction with the system, and the feedback that the driver receives at the moment the system is in use for any given road, traffic, and environmental situation. Both the mediating and initiating factors need to be considered to understand the safety implications of ACC and the impact this system has on the driver. Boyle noted that driver response can be observed in a naturalistic environment and

tested in various conditions in a simulated environment. The system is a closed loop, as illustrated in figure 17, and changes in the initiating and mediating factors will impact the drivers' response for the next response or action that is taken by the driver.

Complementing Survey Data with Field Data

The data from the closed-loop system in figure 17 comes from a myriad of data sources to assess the overall safety impacts of the driver-ACC system interactions. Boyle reminded workshop participants that many mediating factors can be obtained through surveys; however, on-road or field data is better for capturing initiating factors.

Field Data

Boyle told workshop participants that the University of Michigan Transportation Research Institute (UMTRI) conducted a field operational test for novice ACC system

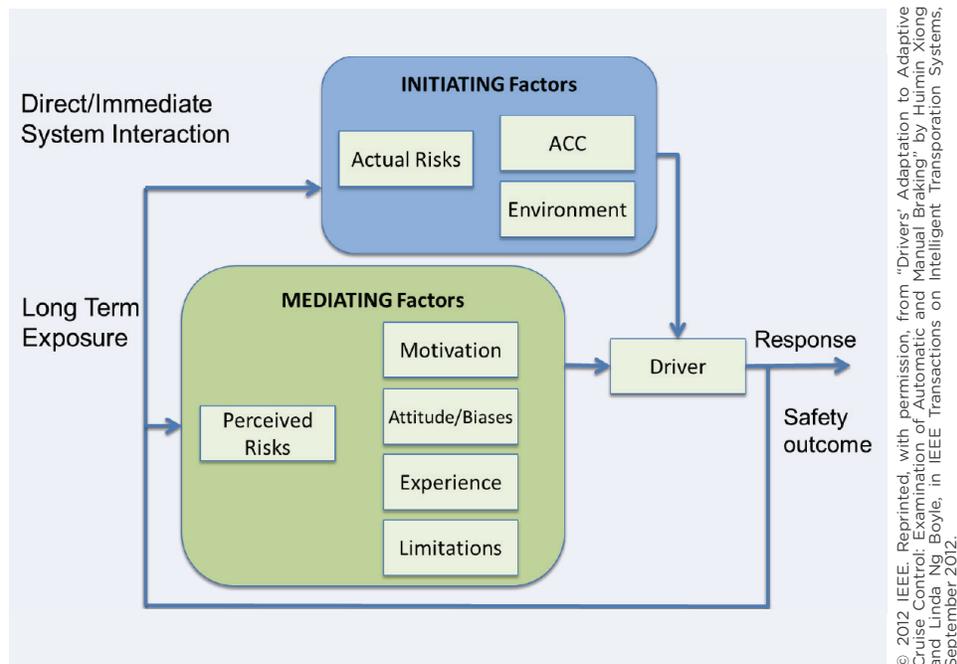


Figure 17. Impacts on driver response when using adaptive cruise control.

users. The purpose of this study was to observe drivers using ACC in the real world. In accordance, investigators looked at three closing events with lead vehicle braking. A closing event lasts from the moment that the ACC's automatic braking control is activated until any braking (or deceleration) stops. The three categories included low risk, conflict, and near crash. The likelihood that a driver will intervene when ACC is on differed by age. More specifically, middle-aged drivers were more likely to intervene when compared with older drivers. Boyle noted that user settings were also related to the likelihood of intervention. Users that preferred long gap settings were less likely to intervene compared with those drivers that preferred short settings. The likelihood of driver interventions was also related to the roadway environment—drivers were less likely to intervene during highway driving.

Complementing Field Data with Simulation Data

Although the associations between driving behavior and ACC can be observed by using field data, Boyle suggested simulation data should also be considered to gain insights on situations not observed in the real world. Simulators can be used to focus on the relationships identified from the field data that may have the greatest safety impact. They make it possible to examine “what if” scenarios, as well as to more closely examine various driver characteristics in a variety of scenarios that may not be encountered by all ACC users. Boyle told workshop participants that the benefit of establishing a relationship between the outcomes from field data and simulation lies in the ability to identify factors that impact safety while using ACC.

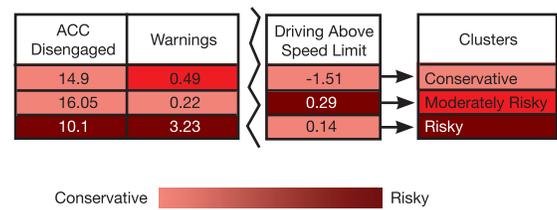


Figure 18. Cluster analysis using simulation data.
Note: ACC = adaptive cruise control.

Simulation Data

Driving simulators allow one to examine the use of ACC in controlled settings and for various driving scenarios that could be of safety concern to drivers. It can also be used to examine differences in novice and experienced users. In a simulation study conducted at NADS using cluster analysis, researchers tested measurements previously identified in the field data in a motion-based simulator. The research questions included:

- How often do drivers disengage ACC?
- How many warnings did drivers get from ACC?
- What are drivers' ACC gap settings?
- How fast did the drivers drive?

Figure 18 shows the outcomes of the cluster analysis, which grouped drivers into three categories: conservative, moderately risky, and risky drivers. The simulator data can make it possible to identify causal relationships among ACC owners and to help identify the different types of risk-seeking behavior by using the same driving performance measures in the same drive scenarios. On one hand, those who drove conservatively, for example, disengaged the ACC system quite often and drove below the speed limit. On the other hand, risky drivers received more warnings, disengaged the ACC system less often, and drove above the speed limit.

Complementing Simulation Data with Survey Data

Boyle told workshop participants that simulation data may not be sufficient to explain all of the drivers' behavior. Survey methods can be used in conjunction with the simulator data to understand why some drivers had more risk propensity. Surveys can capture information on drivers' perception of ACC, willingness to use ACC, and drivers' understanding of ACC. Perceived risks, motivation, attitude or biases, experience, and limitations are all mediating factors that can be obtained from survey data.

Through the analysis of survey data, driving behavior can be classified according to risk propensity. For example, survey results showed that risky drivers tended to feel too comfortable trusting ACC and were easily distracted. Moderately risky drivers have the lowest level of trust in ACC and are confident with their driving skills. Finally, conservative drivers demonstrated the highest level of overall trust in the system and resembled cautious driving styles. Boyle noted that these findings demonstrate the value of using survey data to complement simulation data. Although simulation can be used to quantify the objective performance associated with risky behavior, surveys can extend the analysis by categorizing driving behavior according to the driver's confidence and trust in the ACC system.

Integration of Data Sources

During the presentation, Boyle showed that driving behavior can be measured by using field, simulation, and survey data. Field data measures actual behavior on the road. Behaviors identified in the field can then be manipulated in a simulated environment to observe and identify the factors that would influence a response. Survey data was used to understand drivers' motivations, perceptions, and preferences for ACC use. When the

different perspectives are considered, the complete picture of safety outcomes is obtained; however, to understand how this information comes together, it is important to recognize that exposure to this technology will change driving behavior. An FOT methodology can provide insights on initial exposure, but drivers will behave differently after becoming accustomed to an ACC system. Similarly, Boyle noted that if an ACC system is embedded in a driver's personal vehicle for several years, a different driving behavior profile will result because of adaptation.

Adaptation and Road Safety

Boyle told workshop participants that a driver's behavior may differ given the length of time the driver is exposed to an ACC system. Using an ACC system for the first time is accompanied by a novelty effect that results in high performance. Over time, drivers' attitudes, expectations, and perceptions of the ACC system may change, which can impact the drivers' longer term use of ACC systems. Drivers can also experience positive and negative transitions when they switch to vehicles without ACC capabilities. Boyle suggested that behavioral adaptation may explain some of the variation among users and the differences in driving behavior among conservative and risky drivers.

Conclusion

Boyle discussed the importance of considering multiple sources to conduct human factors research in this presentation. As technology evolves, different systems are studied, and the need to find associations and causality persists. Different research methods can complement each other to understand outcomes. A research framework with a driver model delegates different information to different data sources. This type of framework enhances the value of each dataset, without ignoring the limitations of each method. When

identifying differences, not only between tools but also within methods, it is possible to understand complementary aspects of data sources. For instance, there may be different results using the same tool in different labs. Different simulators produced different outcomes because of geographic variations; however, it is necessary to compare these outcome variations to validate findings and to identify individual differences. Finally, Boyle noted that triangulating data is crucial to obtain the complete picture of safety outcomes when using ACC systems or other in-vehicle systems.

Discussion

The workshop participants discussed several topics following the presentation. These are summarized below:

- Each data source provides causality and association of driving behavior according to its capabilities and therefore can be used collectively. Causality identifies factors present in a particular incident under a scenario that results in certain behaviors. Simulation can repeat and reproduce these conditions, however, associations in terms of risk can be established when using naturalistic data.
- Driver models provide an expected trajectory when conducting an experiment. They embody the causal factors and give the distribution of parameters in experimental design. The formulation of hypotheses can help select which method to use. The challenge is to fit driver models together and to build a comprehensive research framework.
- The main purpose in performing human factors research is crash prevention. There are several viewpoints that underpin this endeavor. One method analyzes the distribution of parameters in terms of descriptive statistics (e.g., mean and standard deviation) and the other considers crashes as rare events. There is uncertainty as to how to incorporate relationships between safety and crash outcomes while putting together the basis to compare multiple data sources as an approach to identify their strengths.
- The characteristics of fatalities in crashes are not representative of the rest of the driver population, and using crash data alone may constrain research.
- Investigating the implications of in-vehicle systems with respect to actual use may not provide the intended outcomes. For example, in one system examined, time to collision did not appear to be incorporated in the ACC algorithm. There is a benefit when researchers work with the technology after it is deployed into the market and may have to work backward (reverse engineer) to determine how the system engages given the preferred gap and speed settings.
- Researchers find it very beneficial to share data, and they can use data repositories to identify issues.
- Surveys conducted at different locations may give similar and different results because of duration of exposure to the new elements. There are a surprising number of ACC system users who are not familiar with its limitations, although the feature has been on the market for a decade.

Acknowledgments

The work described in this presentation summary was supported by funding from the National Science Foundation (NSF, IIS Grant No. 1027609), National Highway Traffic Safety Administration (Contract No. DTNH 22-06-D-00043, Task Order 0005), with data collected at UMTRI for an FOT project on intelligent cruise control, and the University of Iowa National Advanced Driving Simulator (NADS). Graduate students David Dickie, Huimin Xiong, Jarrett Bato, and Yuqing Wu assisted with data collection and analysis. Any opinions, findings, and conclusions or recommendations expressed in this report are those of the presenter (L. Boyle) and do not necessarily reflect the views of NSF, USDOT, UMTRI, or the University of Iowa.

Additional Resources

Papers

- Manser, M., Creaser, J., & Boyle, L.N. (2013). Behavioral adaptation issues. In Rudin-Brown, M., & Jamson, S. (Eds.), *Behavioural Adaptation and Road Safety: Theory, Evidence and Action* (pp. 389–358). Boca Raton, FL: CRC Press.
- Xiong, H., & Boyle, L.N. (2012). Driver's adaptation to adaptive cruise control: Examination of automatic and manual breaking. *IEEE Transactions on Intelligent Transportation Systems*, 13(3), 1468–1473.
- Xiong, H., Boyle, L.N., Moeckli, J., Dow, B., & Brown, T. (2012). Use patterns among early adopters of adaptive cruise control. *Human Factors*, 54(5), 722–733.

Day Two: Discussion and Summary

Following the presentations, the second day of the workshop used expert panel and small group discussion to identify research gaps and recommendations.

Expert Panel Discussion

Moderated by Dr. Donald Fisher

University of Massachusetts Amherst

Day two began with an expert panel discussion session, in which the seven presenters served as panelists. The discussion focused on three examples of where researchers need to take advantage of the information provided by multiple datasets. The panel moderator stated that the goal is to link risk, prevalence, and ecology of behaviors to crashes, an effort that may require resolving contradictions (contradictory datasets), creating linkages among the datasets (complementary datasets), and generating entirely new datasets (comprehensive datasets). These datasets are outlined below.

Contradictory Datasets

In some cases, different datasets lead to different conclusions, for example, the information available on the increase in crash risks caused by cell phones. Simulator studies of cell phone records lead to one conclusion, naturalistic studies to another conclusion, and retrospective studies to contradictory conclusions. The moderator asked the panelists to provide examples of contradictory datasets and methods one might undertake to resolve the controversies.

Complementary Datasets

In some cases, information is available on driver and other road-user behaviors in different datasets that appears to be complementary but that is not formally linked. These complementary datasets can

radically expand the ability to understand increases in risk tied to particular behaviors in a given scenario, the likelihood of those behaviors in the selected scenarios, and the prevalence of the scenarios. For example, information can be gathered on advanced yield markings at marked midblock crosswalks from the glance and yielding behaviors of drivers on the simulator. In addition, information can be gathered in the field using semi-controlled studies and naturalistic studies, and also from field observational studies.

Panelists noted simulator studies are well-suited for providing information on the increase in risky behaviors in particular scenarios but not the likelihood of such behaviors in these scenarios, or the prevalence of the scenarios. Naturalistic studies can also provide information on the prevalence of particular scenarios but cannot be so easily used to identify the increase in risk in the scenarios that can be attributed to particular behaviors. With the rapid increase over the last decade in multiple complementary datasets, it is now possible to provide information on the increase in risk that a particular behavior creates in a given scenario, the likelihood that the driver engages in the behavior, and the prevalence of the scenario.

The moderator asked panelists to identify which datasets are best suited to providing

information about the risk of particular behaviors, the likelihood that drivers engage in those behaviors in particular scenarios, and the prevalence of the scenarios.

Comprehensive Datasets

Panelists noted an ever-increasing ability to predict the incidence of crashes and near-crashes from knowledge gained about the risk and prevalence of driver behaviors. A comprehensive dataset contains information on behaviors and crashes at a particular location; however, although such datasets do not yet exist, they could in the near future. This could include a dataset at a busy intersection that could provide information on a range of risky driver behaviors, the prevalence of those behaviors, and the frequency of crashes. An overarching model of driver behavior is required that is sensitive to factors, such as driver state and the roadway environment. This model would not only predict when drivers engage in risky behaviors but also predict the likelihood of a crash or near-crash when the driver is engaging in a particular behavior. The datasets will need to include where actual crashes are recorded, and panelists were asked how they might go about creating such datasets.

In summary, the moderator asked panelists to discuss what sorts of issues they were studying that required the use of contradictory, complementary, or comprehensive datasets. Panelists gave several examples of these issues encountered in their research, as outlined below.

Contradictory Datasets—Examples from Panelists

The moderator highlighted the following examples of contradictory datasets:

- Effects of driver interaction with warning signs in cooperative intersections in the field often contradict data from simulated experiments.
- Roadway departures at night with one person in the car are practically impossible to replicate in the simulator.
- Research that studies driver behavior with pavement markings and delineator posts in roadway curves can lead to contradictory datasets. In particular, brighter road markers lead to over compensation in one setting but not the other.
- Two major NHTSA crash databases, the National Automotive Sampling System General Estimates System and the Fatality Analysis Reporting System, often yield apparently contradictory data and different results depending on the context of the crash.

The panellists noted several reasons for these contradictions:

- Exposure—Relatively frequent in the simulator and relatively infrequent on the open road.
- Feedback loops—Drivers change their behavior based on feedback from the environment.
- Abstract reality—Scenarios are abstractions of reality and do not allow for real-world interactions.
- Sampling bias—Bias in the sampling of laboratory studies (often college-age students) can produce different effects depending on the driving population.

Complementary Datasets—Examples from Panelists

The moderator highlighted the following examples of complementary datasets:

- Different datasets can sometimes be combined to produce better estimates

of high-risk periods. For example, the number of bicycle crashes reported is highest for noon and midnight; however, bringing crash reports and exposure data together shows that the real risk of bicycle crashes is highest very early in the morning.

- Different datasets may need to be kept separate to understand different aspects of a problem. For example, understanding the cause of a crash can frequently come from naturalistic data, but finding the pattern of where crashes occur may come from crash data.
- Contradictory datasets can become complementary if the methods used to collect the data are changed in ways that potentially account for the contradiction. For example, roadway departure studies conducted in the field complement simulator studies in that drivers will depart from the simulated roadway if the drive is long enough.
- When the issues are multifaceted, the best combination of complementary methods and datasets for any given set of issues can be identified by using the table of methods and issues shown in figure 15.

Comprehensive Datasets—Examples from Panelists

The moderator highlighted the following examples of comprehensive datasets:

- Single bicycle crashes—Datasets do not capture many of the potential causes of these crashes; thus, comprehensive datasets are still a long way off.
- Pedestrian and vehicle crashes—Police crash databases in Japan are not useful for understanding causation

but can still be used to generate possible countermeasures; however, comprehensive datasets are not a near-term possibility.

The panelists noted that researchers need to understand when data are corrupted, for example, a top-down approach can help when the bottom-up approach is in error.

General Discussion

Following the panelist session, the group discussed the following topics:

Current Datasets

- *Need for theory:* Researchers require a theory of behavior to inform data mining, serve as a framework, and make different types of data coherent.
- *Need for careful problem identification:* Problem identification, by using data to identify that there is a problem, can lead to the wrong conclusion if the research community is not careful in choosing the database or methodology used.
- *Need for understanding limitations:* Data can be easily misinterpreted, not only in analysis but also in collection. For example, SHRP 2 data were collected for a specific purpose, and researchers need to recognize that there are limitations to these data.

Future Datasets

- *Standardization:* There is a strong need for standardization. Human factor researchers and traffic engineers use terminology differently: The former define headway as front bumper to front bumper, but the latter define headway as rear bumper to rear bumper. Another

example is crash reports, which differ across different municipalities. Missing data can create a gray area for researchers.

- *Broad goals:* To take full advantage of the data that are collected in the future, researchers should remember that their research questions are not the only questions that need to be answered in regard to the data collected.

In summary, the panelists noted that there are two different ways of viewing how best to deal with multiple, contradictory datasets as follows:

- Bottom up—It is possible to take various known instances in which there are contradictions across datasets and identify why these inconsistencies arise and what can be done to avoid them in the future.
- Top down—A study across multiple sites would allow for the collection of various different types of data. It would then be possible to look for inconsistencies across sites in the same dataset and inconsistencies within sites across datasets.

Recommendations

In conclusion, the panel members considered what type of study would be needed to (1) understand how to resolve long-standing contradictions among different datasets; (2) allow for the use of complementary datasets to generate information on the risk of different behaviors, their likelihood, and the prevalence of the scenarios in which they occur; and (3) generate a comprehensive dataset that links behaviors and crashes. Panelists were unanimous in recommending that there should be an attempt to understand how to use the different types of data in a study, which includes the following components:

- Multiple sites (e.g., locations, geometries, traffic density, and environment).
- Multiple types of data gathered at each site (e.g., survey, simulator, and field).
- Multiple users (e.g., bicyclists, pedestrians, motorists, and drivers).
- Multiple methods of analysis (e.g., descriptive and inferential statistics, and quantitative behavioral models).

The panelists suggested intersections, road departures, and connected vehicles as possible areas of focus for the study. They noted that intersections have many characteristics suitable to the study, are one of the best places to study V2V communications, and perhaps are one of the only places to study vehicle-to-pedestrian communications. Moreover, the three major issues surrounding multiple datasets can be studied at intersections. In particular, the data from naturalistic and simulator studies, which often lead to different estimates of risk, can easily be compared at intersections to determine why the various contradictions among datasets exist. Information on both the risk of a particular behavior (e.g., the risk that failing to take a secondary glance has on crashing, given that a vehicle materializes when the driver fails to take the glance), the likelihood of a particular behavior in a given scenario (e.g., the likelihood of taking a secondary glance), and the prevalence of the scenario (e.g., the prevalence of situations in which the driver fails to take a secondary look and a vehicle materializes) can be used to create complementary datasets. Finally, given the high incidence of crashes at selected intersections, the behavioral data can be combined with the crash and near-crash data to generate comprehensive datasets.

Group Session Summary

Overview

For the final session of the workshop, participants gathered into groups to discuss three key topics relating to data needs for human factors research: (1) driver-driver and other road user data, (2) driver-vehicle data, and (3) driver-infrastructure and roadway data. Following extensive group discussion, involving multidisciplinary experts from government, academia, and industry, the participants reconvened, summarized their findings, and made recommendations. This section presents the overall findings of the breakout groups.

Driver-Driver and Other Road Users' Data for Human Factors Research

Need for Pedestrian and Bicyclist Exposure Data

- Researchers do not have ways to measure the exposure of pedestrians and bicyclists. For example, although there are automatic counting systems for vehicles at intersections, there is no analogous system to record the numbers of cyclists and pedestrians passing through.
- The lack of exposure data makes it impossible to calculate a risk ratio for pedestrians or bicyclists, although the numbers of fatalities are known. For this reason, it is impossible to compare the United States' pedestrian and bicyclist fatalities with the risks to pedestrians and bicyclists in other countries.
- Technology is becoming more available to gather pedestrian and bicyclist data.

For example, in Gothenburg, Sweden, researchers installed several boxes with sensor equipment that can detect and record the number of bicyclists that pass each of these boxes. This current technology is rudimentary, for example, it is not able to distinguish between a bicycle or a stroller and is subject to erroneous input because of people intruding in bike lanes where they should not be.

Normative Variations in Pedestrian Behavior

- Participants noted that pedestrian behavior varies depending on culture and education. For example, in Australia, pedestrians do not have the right of way, resulting in more cautious pedestrian behavior. In Sweden, pedestrians do not jay walk, unlike places such as Boston or Washington, DC, where jaywalking is a huge problem resulting in many pedestrian-vehicle strikes.
- Participants also discussed who is at fault for incidents in which pedestrians are struck, injured, or killed and referred to the largest study of fault attribution conducted to date in the United States. This showed that blame fell equally on pedestrians and motorists. The assignment of fault is different in Japan where drivers are found to be at fault 90 percent of the time, and 10 percent of the fault falls to the pedestrians.
- Pedestrians in the vision-impaired community had specific concerns with the practice of permitting right turns on red. Although FHWA has looked into

this issue, the subset of data is small, and police reports detailing these incidents lack sufficient detail and consistency to permit a fuller understanding of the risks of this type of vehicle behavior. Other issues affecting pedestrian and bicyclist safety include visibility and distraction at intersections.

Hazards and Solutions in Roadway Design and Setup

- Participants noted that many intersections lack sufficient visibility for pedestrians and bicyclists because intersections were designed to give vehicles a good line of sight, rather than to give all road users that good line of sight. For example, the High-intensity Activated crossWalk (HAWK) signal provides a protected pedestrian crossing as a way to increase safety. It is used only for pedestrian crossings and does not control traffic on side streets. The HAWK signal for pedestrians at larger crossings on a multilane-divided highway may pose risks to pedestrians—drivers, once they come to a stop, may be cleared to go but cannot see the pedestrian.
- Improved reflectivity for pedestrians and bicyclists was another suggestion made to improve roadway safety for pedestrians and bicyclists. Pedestrians and bicyclists need to be more visible and could employ ways to emit more reflectivity. At present, bicycles must have one reflector but pedestrians have no obligation to emit reflectivity. It was recommended that pedestrians be encouraged to wear clothing with at least one reflective element to increase their visibility for drivers.

- Infrastructure could be changed to separate cars and bicycles so that cars and bicycles do not cross paths.
- Participants agreed that if the roadway was set up so that speed was controlled, and if that speed was slower at intersections, then this would reduce many incidents. The group showed participants an example of a traffic-calming roadway setup in Japan, where intersections are compact so a driver cannot increase his or her speed. The participants suggested that future studies investigate ones that make vehicles or bicycles speed up or slow down, especially in roundabouts, which are not considered safe for pedestrians or bicyclists.

Technology for Pedestrian and Bicyclist Safety

There are potential ITS technologies that can improve pedestrian and bicycle safety. DSRC devices that transmit information through mobile devices may be an option in the future to improve pedestrian and bicyclist safety. At present, the ITS Joint Program Office's Connected Vehicle program is exploring the feasibility of introducing pedestrian DSRC by using a smartphone. In addition, Volvo has recently introduced a pedestrian detection system, and bicycle manufacturers are starting to introduce auto brakes for bicycles, in addition to external airbags.

Driver-Vehicle Data for Human Factors Research

Participants in this group illustrated how to sequence methodologies to conduct research, by using multiple data sources. The process to address driver-vehicle research is detailed as follows:

Naturalistic Scenario Sampling and Problem Definition

There are many methods that can be used to monitor interactions among road users, such as TMC, traffic cameras, and social media. Traffic cameras can be used because of their availability; they can reveal possible navigation issues, traffic movements and conflicts; and they can recognize trends in traffic. Participants also suggested social media offers an alternate source of naturalistic data, for example, applications such as Twitter and Waze can also provide traffic and road information.

Simulation

Simulation is useful to examine an issue in detail and to explore conflict situations not readily detected from observation. With simulation, it is possible to vary the frequency of the driver's exposure to an intervention and to analyze the resultant driving behavior. For example, simulation is useful to study gap acceptance. Because of a disproportionate number of fatal accidents at rural intersections, Wisconsin DOT used simulation as an initial tool to test whether different types of signage would affect gap rejection and to encourage the acceptance of safer gaps, prior to using the more expensive on-road testing of alternative signage.

There are other issues in which the utility of simulation is constrained because of the lack of exposure. For example, roadway departure crashes account for about half of all vehicular fatalities but these scenarios are challenging to replicate in

simulation.¹² It is very difficult to replicate the contributing factors, such as fatigue, to roadway departure. Simulation gives useful null results, but it is not possible to get a good understanding of roadway departure because it is impossible to replicate the scenarios, and the simulation process lacks sufficient exposure data.

Intervention Development and Evaluation

By using response data obtained from simulators and information culled from naturalistic data, it is possible to design and develop interventions to modify behavior and to meet safety needs. Although the simulator results in Wisconsin on gap acceptance were not definitive, they did provide trend information, which became the basis for subsequent road testing of signage most likely to foster acceptance of safer gaps.

Field Operational Test Data: Data from the field can provide complementary information about the effects of a new or modified intervention on drivers and vehicles.

Model-Based Benefit Estimation: Societal benefits can be estimated based on the effectiveness of interventions evaluated in experiments. Short-term benefits provided by treatments that have a significant impact (e.g., crash worthiness) can be identified and measured after implementation. Long-term benefits will change and evolve as the population of users adapt to the intervention.

Policy Design: Transportation policies are outlined based on evaluation of interventions, in addition to societal benefits.

Bayesian and Model-Based Surveillance: Model-based analysis provides a measurement to evaluate scenarios after an intervention

12. Federal Highway Administration Safety Program. Retrieved June 13, 2014, from http://safety.fhwa.dot.gov/roadway_dept/.

has been implemented. Continuous surveillance can serve as a method to simultaneously collect new naturalistic data for a newly identified problem. In this case, this step will provide feedback to the procedure for a new strategy.

Driver-Infrastructure and Roadway Data for Human Factors Research

Connected Vehicle Technology and Driver Behavior

One of the key topics that participants raised during discussion was the importance of researching how connected-vehicle technology will impact driver behavior. For example, connected-vehicle technology has the ability to warn following vehicles if they are not slowing down in response to a slowing lead vehicle, even if the lead vehicle is several vehicles ahead. It is important to understand whether drivers believe that the warning is specific to them, because they will be more likely to acknowledge it. There is also an issue of whether the warning should be placed in the infrastructure or in the vehicle and how the alternative venues might affect compliance. Finally, there is also a need to explore connected-vehicle signage options, in terms of alternative methods of presentation and where the signage should reside in the infrastructure.

Operation and Safety

Participants identified several areas where operation and safety are linked. The operational simulation models, which

include car following and lane modeling, raise human factors issues. It is important to calibrate these models correctly in the simulator to obtain the surrogate measurements to be applied to the real-world behaviors.

Research Priorities

Participants identified the following areas of priority concerning safety: roadway departure, urban intersections, vehicle and pedestrian to bicyclist interaction, and data analysis. Participants suggested a good synthesis project for roadway departures could ask a basic question such as, “When does the driver begin reacting to the curve?” There is also a need to evaluate the effectiveness of current signage used on roadways. Specifically, researchers want to know if and how current signs affect driving behavior, for example, when approaching a curve or in urban intersections, where all types of roadway users meet, and in left-turn conflicts. It was noted that there is difficulty running scenarios, such as speed perception, in simulators because of the inability to measure lateral acceleration in these settings.

Data Sources

There are existing data sources that can be mined at low cost to provide insight, such as TMC data. Researchers need to look into how to combine different data sources to gain more powerful insights than can any one dataset provide. Simulation was suggested as a good tool for identifying issues.

Workshop Recommendations

Participants identified many areas of priority for human factors research, which could make use of the expanding datasets now available and soon to be available. These include modeling, safety, roadway departure, urban intersections, vehicle, pedestrian and bicyclist interaction, and data analysis. Several items were suggested for further research, as follows:

- Evaluation of the effectiveness of current signage used on roadways.
- Research on speed perception.
- Solutions to improve roadway safety for pedestrians and bicyclists.
- Evaluation of current ITS technologies for pedestrian and bicycle safety.
- Developing a methodology to conduct research that uses multiple data sources.
- Methods to measure exposure of pedestrians and bicyclists.

To advance understanding and use of multiple data types, the participants recommended a study, possibly focused at intersections, that includes multiple sites, multiple data types gathered at each site, multiple user types, and multiple methods of analysis. This study could provide critical information on how to resolve contradictions among datasets, how to put together complementary datasets that describe risky behaviors, and how to generate comprehensive datasets that link behaviors and crashes.

Appendices

Appendix A: Agenda

UTILIZING VARIOUS DATA SOURCES FOR SURFACE TRANSPORTATION HUMAN FACTORS RESEARCH

Turner-Fairbank Highway Research Center, McLean, VA

Wednesday, November 6, 2013

10–11:15 a.m.	Pre-Workshop Event <i>Tour of research tools at the Federal Highway Administration’s Human Factors Laboratory</i>
11:15 a.m.–1 p.m.	Lunch
1–1:15 p.m.	Introduction and Welcome
1:15–1:30 p.m.	Overview of the Federal Highway Administration’s Exploratory Advanced Research Program
1:30–1:45 p.m.	Workshop Objectives and Expected Outcomes
1:45–2:45 p.m.	Presentation Set 1 <i>“Driver-Driver and Other Road Users’ Data for Human Factors Research”</i> Presenters: Dr. Marco Dozza, <i>Chalmers University of Technology, Sweden</i> Dr. Toru Hagiwara, <i>Hokkaido University, Japan</i> Dr. Hidekatsu Hamaoka, <i>Akita University, Japan</i>
2:45–3 p.m.	Break
3–4 p.m.	Presentation Set 2 <i>“Driver-Infrastructure and Roadway Data for Human Factors Research”</i> Presenters: Dr. Michael Manser, <i>University of Minnesota</i> Dr. Susan Chrysler, <i>University of Iowa</i>
4–5 p.m.	Presentation Set 3 <i>“Driver-Vehicle Data for Human Factors Research”</i> Presenters: Dr. John D. Lee, <i>University of Wisconsin–Madison</i> Dr. Linda Boyle, <i>University of Washington</i>
5 p.m.	Day 1 Adjournment

Thursday, November 7, 2013

8-8:15 a.m.	Recap of Day 1
8:15-9:30 a.m.	Expert Panel Discussion and Q&A Moderator: Dr. Donald Fisher, <i>University of Massachusetts Amherst</i>
9:30-9:45 a.m.	<i>Break</i>
9:45-10:45 a.m.	Small Group Discussion and Recommendations from Group Discussion
10:45-11:45 a.m.	Conclusions and Recommendations from Group Discussion
11:45 a.m.-12 p.m.	Workshop Wrap-Up
12 p.m.	Day 2 Adjournment

Appendix B: About the Presenters

Marco Dozza is an assistant professor at Chalmers University of Technology in the Department of Applied Mechanics. Since 2010, Dozza has been part of the Accident Prevention Group at Chalmers. His research interests focus mainly on naturalistic field operational test analysis (including bicycle safety) and methodology and active safety. Dozza is currently working on several national and international projects related to field operational tests, such as the second Strategic Highway Research Program (SHRP 2), as well as his own grants mainly related to cycling safety. Dozza is skilled in research framing, design, analysis, and interpretation and presentation of research results. He is the author of more than 40 scientific articles and peer-reviewed contributions to conferences.

Toru Hagiwara is a professor at Hokkaido University, Japan, in the Department of Civil Engineering. His research interests include on-road human factors and accident analysis in Japan. Hagiwara is currently working on several projects related to analyzing conflicts between drivers and pedestrians at intersections. This work includes (1) evaluating driver behavior to avoid conflicts with pedestrians, (2) evaluating pedestrian behavior to avoid conflicts with right/left-turning vehicles, and (3) evaluating a dedicated short-range communication system to avoid conflicts between drivers and pedestrians. His work is mainly conducted on test tracks.

Hidekatsu Hamaoka is an associate professor at Akita University, Japan. Hamaoka's research field is traffic safety analysis, with a focus on human factors. His work includes design to decrease the number of right-turn accidents (left-turn accidents in the United States) with pedestrians at major intersections, arterial-local intersection design for bicycle safety, and proposals to reprogram traffic signals to avoid rear-end collisions. Hamaoka has worked with Hagiwara to conduct test track experiments for nearly a decade.

Michael Manser's work focuses on designing and evaluating novel technology-based transportation systems intended to support driver performance and safety. Manser's work includes (1) designing and evaluating an infrastructure-based collision avoidance system intended to facilitate driver decisionmaking at high-risk rural intersections; (2) evaluating driver performance, workload, and usability associated with the use of a novel vehicle-based haptic collision avoidance system; and (3) evaluating driver mental and behavioral adaptation to the introduction and continued use of infrastructure-based driver support systems. His work is conducted in simulation and on-road testing environments.

Susan Chrysler joined the University of Iowa as the Director of Research at the National Advanced Driving Simulator in 2011. Chrysler's areas of expertise include human factors, driving simulation, driver behavior, visual attention, traffic operations, visibility, and photometry. Chrysler has served as principal investigator (PI), or task leader, for projects on traffic-sign design and comprehension, pavement-marking effectiveness, visibility, and traffic operations. She recently completed the FHWA guide to evaluation methods for traffic control devices intended to aid practitioners who request experimentation in the MUTCD process.

John D. Lee is the Emerson Electric professor in the Department of Industrial and Systems Engineering at the University of Wisconsin–Madison and director of the Cognitive Systems Laboratory. Lee's research seeks to better integrate people and technology in complex systems, such as cars, semi-autonomous systems, and telemedicine. He has served on the National Academy of Sciences committees on human system integration, electronic vehicle controls and unintended acceleration, and autonomy in civil aviation. He has also served as an editor for many publications related to this field.

Linda Ng Boyle is an associate professor in the College of Engineering at the University of Washington. She received her Ph.D. in Civil and Environmental Engineering from the University of Washington in 1998. Boyle is an associate editor for the journal *Accident Analysis Prevention* and chairs the Transportation Research Board committee on Statistical Methods (ABJ80). She has been the PI, or co-PI, on several SHRP 2 and USDOT projects that involve on-road and simulator data for examining driver distraction, crash risk, and road-user safety. Boyle is the recipient of the National Science Foundation Career Award and is a member of the Human Factors and Ergonomics Society, American Statistical Association, and Institute of Industrial Engineers.

Donald Fisher heads the Department of Mechanical and Industrial Engineering at the University of Massachusetts Amherst. He is also the director of the Arbella Insurance Human Performance Laboratory and serves as a Faculty Fellow at the Volpe National Transportation Systems Center in Cambridge, MA. Fisher's research focuses on efforts to understand the behaviors of novice, older, and distracted drivers that increase their risk of crashes and developing and evaluating training programs to reduce their risk. Fisher has served as an investigator on projects designed to identify the characteristics of warning systems inside the vehicle, along with signs, signals, and pavement markings outside the vehicle that are most likely to lead to behaviors that decrease the risk of injuries and crashes.

About the EAR Program

Federal legislation establishes an Exploratory Advanced Research (EAR) Program for transportation to address longer term, higher risk, breakthrough research with the potential for dramatic long-term improvements to transportation systems, improvements in planning, building, renewing, and operating safe, congestion-free, and environmentally sound transportation facilities. The Federal Highway Administration's (FHWA) EAR Program secures broad scientific participation and extensive coverage of advanced ideas and new technologies through stakeholder engagement, topic identification, and sponsored research.

The uncertainties in the research approach and outcomes challenge organizations and researchers to be innovative problem-solvers, which can lead to new research techniques, instruments, and processes that can be applied to future high-risk and applied research projects.

For more information, please visit the program Web site at <http://www.fhwa.dot.gov/advancedresearch/>.

Office of Safety Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

Publication No. FHWA-HRT-14-077
HRTM-30/07/14(1M)E