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L. RAY BUCKENDALE LECTURE

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The Naturalistic Study of Distracted Driving: Moving from Research to Practice

Richard Joseph Hanowski
Virginia Tech Transportation Institute

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L. Ray Buckendale Lecture

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Established in 1953, this lecture commemorates the contributions of L. Ray Buckendale, 1946 SAE President. L. Ray Buckendale, by his character and work, endeared himself to all who were associated with him. Foremost among his many interests was the desire to develop the potential abilities in young people. As he was an authority in the theory and practice of gearing, particularly as applied to automotive vehicles, it was in this field that he was best able to accomplish his purpose. To perpetuate his memory, SAE established this lecture to provide practical and useful technical information to young people involved in vehicle engineering.

The individual presenting the Buckendale Lecture will receive an honorarium and a framed certificate. All those in attendance at the lecture received an electronic copy of the lecture, and attended a sponsored reception which immediately followed the lecture.



2011 Lecturer

Richard Joseph Hanowski
Virginia Tech Transportation Institute

Dr. Richard Hanowski is the Director of the Center for Truck and Bus Safety at the Virginia Tech Transportation Institute (VTTI) where he oversees a team of 25 researchers. Since joining VTTI in 1996, he has served several roles with the Institute including Research Scientist for the Safety and Human Factors Engineering Group and Leader for the Truck and Bus Safety Group before being appointed Director for the Center of Truck and Bus Safety in 2005. Dr. Hanowski has served as Principal Investigator or Co-PI on over 70 projects, managing \$30M in contract research. He has successfully assembled, led and managed multi-disciplinary and multi-organizational research teams.

Dr. Hanowski has authored over 180 publications including journal articles, conference papers, book chapters, and technical reports including several that are specifically directed at "Driver Distraction" (the topic of his L. Ray Buckendale lecture). In April of 2010, he was selected by the U.S. Department of Transportation to serve as one of six international experts to provide insight on the topic of Driver Distraction for an ongoing Federally-funded US-EU joint effort. His research on Driver Distraction has been nationally and internationally recognized and has had an impact on transportation policy. Dr. Hanowski's research has been featured many times in the media including stories in the NY Times, the Washington Post, and on CNN.

Dr. Hanowski serves as the Driver Fatigue Subject Matter Expert for the National Surface Transportation Safety Center for Excellence and is the Vice Chair of the ITS America Safety Forum Committee. He has received numerous research awards including the 2008 SAE Arch T. Colwell Merit Award for outstanding paper, the 2008 SAE Lloyd L. Withrow Distinguished Speaker Award, and was a 2009-2010 Virginia Governor's Award Program nominee. He earned his Ph.D. in Industrial & Systems Engineering from Virginia Tech in 2000.

56TH ANNUAL L. RAY BUCKENDALE LECTURE

The Naturalistic Study of Distracted Driving: Moving from Research to Practice

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Virginia Tech Transportation Institute
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This SAE technical paper presents the 56th Annual L. Ray Buckendale Lecture, which was presented during the SAE Commercial Vehicle Engineering Congress on September 13, 2011 in Rosemont, Illinois, USA.

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ABSTRACT

Driver distraction has become an important topic in society and the research community. A telltale sign of how driver distraction has impacted society is evidenced by the designation of the term “distracted driving” as Webster's New World® College Dictionary 2009 Word of the Year. Since the release of a key study directed at commercial vehicle drivers [Olson, Hanowski, Hickman and Bocanegra, 2009], there have been two U.S. Department of Transportation summits to address the topic, in addition to legislation banning texting-while-driving in commercial motor vehicles. Given that “driver distraction” is a construct without a consensus definition, many studies on driver distraction have focused on its fundamental and theoretical underpinning, which is a critical first step in understanding the phenomenon. However, few studies have been conducted to elicit information that can directly be applied to addressing the driver distraction problem through system design, education, or policy recommendations.

The concept of Research-to-Practice (r2p) was first introduced by the National Institute for Occupational Safety and Health (NIOSH) as an approach to transfer knowledge gained from research into effective practices. Fundamentally, the r2p philosophy is the antithesis of “research for research's sake” by focusing on the pragmatic application of research; that is, research for the purpose of impacting change. Despite the attention that driver distraction has garnered, there have been few studies in this domain that clearly fit the r2p model.

This paper highlights two naturalistic driving studies that fit the r2p paradigm and provide data that have informed driver education, shaped U.S. national transportation policy, and are relevant to system design aimed at reducing driver distraction. It was noteworthy that some of the findings from

these naturalistic studies are inconsistent with previous research; thus, this paper provides insight into the potential reasons for these discrepancies. In addition, the paper outlines a hierarchical model of research approaches that can facilitate the pragmatic application of research findings.

INTRODUCTION

As described on the website of the National Institute for Occupational Safety and Health (NIOSH), the Research to Practice (r2p) initiative aims to develop and improve workplace practices and products using knowledge gained from research (website ref: www.cdc.gov/niosh/r2p). The r2p paradigm focuses on pragmatic research and the conduct of goal-oriented studies by translating research findings into practice so as to improve worker health and safety.

Driver distraction (which, for this paper, is synonymous with “distracted driving,” although some researchers [Hancock, Mouloua and Senders, 2009] have distinguished between the two terms) has been an important topic from a societal and research perspective. In the United States, the release of a naturalistic driving study aimed at commercial motor vehicle (CMV) truck drivers [Olson, Hanowski, Hickman and Bocanegra, 2009], and the subsequent reporting of the study in the New York Times [Richtel, 2009], was a catalyst for bringing the topic to the forefront of the general population. So much so that the term “distracted driving” was designated as Webster's New World® College Dictionary 2009 Word of the Year. The Olson et al. [2009] study also served as a catalyst for policy makers and within weeks of the study's release there was: (i) an Executive (U.S. Presidential) Order banning texting-while-driving for government workers in government vehicles, (ii) a federal regulation banning texting-while-driving for CMV drivers, and (iii) the call for a U.S. Department of Transportation Summit to address the driver distraction phenomenon.

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Though the [Olson et al. \[2009\]](#) study is one of the most recent studies to investigate distraction in CMV operations, there have been previous research efforts aimed at assessing in-vehicle distractions encountered by this driver group. For example, [Ranney, Mazzae, Garrott and Goodman \[2000\]](#) outlined the National Highway Traffic Safety Administration's (NHTSA) driver distraction research program in which research with truck drivers was a main focus. For example, a study by [Tijerina \[1996\]](#) looked at workload assessment for CMV drivers while [Tijerina, Kiger, Rockwell and Tornow \[1995\]](#) focused on the distraction of in-cab text message systems and cellular phones. A key take-away from the previous research was that a quantitative model to predict crashes based on driver workload (i.e., distraction) was not feasible because of the complexity associated with crash causation. A second important take-away from these earlier studies was that visual allocation measures and the measurement of visual demand associated with task engagement, along with lane-keeping measures, were important measures to assess distraction and workload. As will be described in the study examples outlined later, the importance of visual measures and vehicle control (e.g., lane keeping) has continued to be considered a key component of driver distraction research, including naturalistic driving research.

DEFINING DRIVER DISTRACTION

Despite the attention that driver distraction has received from both the public and the research community, the construct is not without disagreement. For example, researchers differ with respect to what the term “driver distraction” means. A cursory examination of the literature finds that there are many different definitions. The term is poorly and inconsistently defined, which is problematic for a number of reasons, including the inability to make inter-study comparisons [\[Regan, Lee and Young, 2009\]](#). Given this fundamental problem of a lack of a common definition, it is important that researchers focus on developing a common definition and a better understanding of the theoretical underpinning and nuances of the term. Nonetheless, research should also be directed at addressing the implications of driver distraction, which can be considered as “the diversion of attention from activities critical for safe driving to a competing activity” [\[US-EU Bilateral ITS Technical Task Force, in press\]](#). Although the nuances of the term may not be agreed upon, there is sufficient agreement on the basic meaning of driver distraction so as to direct research aimed at addressing its deleterious effects.

One of the most comprehensive and pragmatic definitions of driver distraction defines the construct in terms of both the *driver behavioral components* and the *driving performance components* [\[Pettitt, Burnett and Stevens, 2005\]](#). As described later in the naturalistic driving research highlighted in this paper, this particular definition guided the identification of

safety-critical events (e.g., crashes and near-crashes) involving driver distraction using video recordings. In accounting for four key components of driver distraction, [Pettitt, Burnett and Stevens \[2005, p. 11\]](#) note that distraction occurs:

- When a driver is delayed in the recognition of information necessary to safely maintain the lateral and longitudinal control of the vehicle (the driving task) (*Impact*)
- Due to some event, activity, object or person, within or outside the vehicle (*Agent*)
- That compels or tends to induce the driver's shifting attention away from fundamental driving tasks (*Mechanism*)
- By compromising the driver's auditory, biomechanical, cognitive or visual faculties, or combinations thereof (*Type*).

From a practical standpoint, this definition provides researchers with a clear protocol for identifying driver distraction as a contributing factor in safety-critical events. Although this definition was developed and tested using crash report data, an outstanding and unanswered question was whether this definition could be applied to naturalistically collected data.

A study by [Hanowski, Perez and Dingus \[2005\]](#) was one of the first to identify driver distraction using naturalistic driving data. As part of that study, a taxonomy of secondary and tertiary tasks (terms defined below) was developed by analyzing naturalistic safety-critical event data ([Table 1](#)). To accomplish this, video of safety-critical events collected during a naturalistic CMV study were reviewed to determine what behaviors the driver engaged in prior to the occurrence of a safety-critical event. These behaviors reflect the *Agents* and underlying *Mechanisms*, as described in [Pettitt, Burnett and Stevens \[2005\]](#), that can distract a driver and lead to a safety-critical event (or *Impact*). It is important to note that the individual distractions listed in [Table 1](#) do not constitute *all* possible driver distractions. Rather, this set of task/behaviors represents what was observed in the recorded video from this particular study [\[Hanowski, Perez and Dingus, 2005\]](#).

There were two key take-aways from the [Hanowski, Perez and Dingus \[2005\]](#) study. First, naturalistic driving data provide researchers with an “instant replay” of safety-critical events, thereby providing new insight into tasks and behaviors that distract a driver. Second, the video of the driver allows researchers to investigate driver distraction at the *sub-component* task level rather than the higher level or *overall* task level. For example, “using a cell phone” should be considered a multi-action or multi-component process (e.g., plugging in, dialing, talking, etc.) where the risks associated with each sub-component are not assumed to be equal. This highlights an issue with studies that assess cell phone use at the *overall task level*; when rolled up into the

overall task, it is impossible to disentangle the sub-components to determine which specific sub-component may be contributing to an increase in risk (e.g., is the risk primarily associated with dialing or talking, or are the risks equal?).

In the naturalistic driving studies presented later, safety-critical events (*Impact*) and baseline epochs (normative driving) were filtered from continuous driving data collected from CMVs and reviewed for the presence of potential distractions (*Agents*). As the data set included video of the driver, biomechanical and visual distraction was the *Type* of distraction evaluated. There was no audio associated with the video recording; thus, auditory distraction could not be investigated. Furthermore, although it may be possible to investigate cognitive distraction with video review, it was not the focus in the current research.

Understanding Task Types and the Impact of Driver Distraction

In a previous section, the terms “secondary tasks” and “tertiary tasks” were used and require further explanation before moving forward. There are three terms relevant to the driver's task that must be defined in order to understand driver distraction. As noted in [Ablassmeier, Poitschke, Wallhoff, Bengler, and Rigoll \[2007\]](#), the taxonomy of driving tasks includes (i) primary tasks, (ii) secondary tasks, and (iii) tertiary tasks. Primary tasks are those that include direct control operations to safely control the vehicle. As noted by [Pettitt, Burnett and Stevens \[2005\]](#), under distraction *Impact*, those specific tasks that occur during vehicle operation include steering and accelerating/braking. The safe control of the vehicle occurs with the effective or, at least, “satisficing” [\[Hancock, Mouloua, and Senders, 2009\]](#), execution of the driver's primary tasks. All other tasks that drivers engage in while driving are considered secondary or tertiary to the primary task.

Secondary tasks are driving operations, but ones which are not necessary for keeping the vehicle on course. For example, using the turn signal, honking the horn, and checking the speedometer are common secondary driving tasks. Tertiary tasks are those tasks that drivers perform that do not concern actual driving. Adjusting the radio, eating, or interacting with a mobile device are examples of common tertiary tasks. As a driver, it is his/her responsibility to safely maintain control of the vehicle and the driver's focus must be on successfully executing the primary task. Distraction occurs when the driver's focus shifts to secondary or tertiary tasks at the expense of the successful execution of the primary task.

Failure to execute the primary task of safely operating the vehicle can result in lateral and/or longitudinal driving performance errors (i.e., errors related to steering and/or accelerator/brake control). For example, a lateral error would

include the driver unintentionally moving (drifting) into an adjacent lane (i.e., “lateral deviation of through vehicle” [\[Hanowski, Hickman, Wierwille and Keisler, 2007\]](#)). A lateral error resulting in the unintentional drifting of a vehicle into an adjacent lane may result in a “sideswipe” crash (e.g., if the striking and struck vehicles are traveling in the same direction) or a “head-on” crash (e.g., if the striking and struck vehicles are traveling in opposing directions). A longitudinal error would include the driver failing to maintain proper speed and/or adequate headway to a lead vehicle, which may result in “late braking for stopped/stopping traffic” [\[Hanowski, Hickman, Wierwille and Keisler, 2007\]](#). Delayed recognition of stopped/stopping vehicles and subsequent failure to brake would result in a rear-end crash (absent of a steering maneuver). [Figure 1](#) shows diagrams of a lateral error and a longitudinal error.

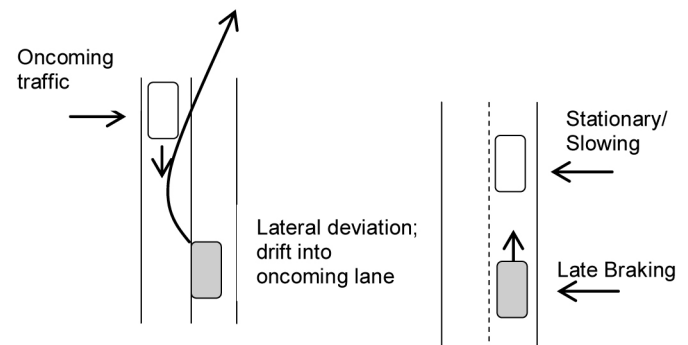


Figure 1. Diagrams of (L) lateral and (R) longitudinal driving performance errors (based on [Hanowski, Hickman, Wierwille and Keisler, \[2007\]](#)).

The scenarios shown in [Figure 1](#) highlight examples of the *Impact*, noted by [Pettitt, Burnett and Stevens \[2005\]](#) that can occur as a result of driver distraction. Secondary and tertiary tasks represent the *Agents* and the associated *Mechanisms*, respectively, (as noted by [Pettitt, Burnett and Stevens \[2005\]](#)) that distract the driver, resulting in a negative impact on the safe control of the vehicle. The *Type* of distraction characterizes the secondary and tertiary tasks in terms of the specific driver faculties that are impacted [\[Pettitt, Burnett and Stevens, 2005\]](#).

THE SCIENCE OF DRIVER DISTRACTION

This paper focuses on the implementation of research findings aimed at addressing the impacts of driver distraction. The paper continues with describing what naturalistic driving research is, and considers this approach within the context of other transportation safety research methods, including empirical and epidemiological approaches. Two naturalistic driving studies that were integral in formulating U.S. national driver distraction policy in CMV operations are highlighted. Although the results from these studies had an impact on

Table 1. Taxonomy developed in Hanowski, Perez and Dingus [2005].

Distraction	Definition
Talking on CB	Driver is holding CB to mouth and talking; usually looking forward; one hand off the wheel
Adjusting CB	Driver is adjusting knobs, with right arm extended up, on CB receiver located on ceiling at the front and center of cab; glancing at CB periodically; one hand off the wheel
Looking at CB	Driver is looking up at CB receiver located on ceiling at the front and center of cab; both hands on the wheel
Adjusting radio	Driver is reaching to the music radio, on center console of cab, adjusting station or volume; glancing at radio periodically; one hand off the wheel
Looking at radio	Driver is looking at the music radio, down and to the right, on center console of cab; both hands on the wheel
Dialing cell phone	Driver is looking down at cell phone in hand, dialing number; one hand off the wheel
Plugging in cell phone	Driver is plugging in battery charger to bottom of cell phone; usually looking at the phone; one hand off the wheel
Talking on cell phone	Driver is holding cell phone up to ear and talking on it; usually looking forward; one hand off the wheel
Answering ringing cell phone/Looking at cell phone display	Driver is answering ringing cell phone; reaches to middle console, picks up phone, looks down at phone several times, but never puts it to ear; one hand off the wheel
Phone Call/Hanging up cell phone	Driver makes phone call and is hanging up cell phone; reaches down to floor to put phone back; usually looks down; one hand off the wheel
Lighting cigarette	Driver is lighting a cigarette; often looking at cigarette; one or both hands off the wheel
Getting cigarette	Driver is removing a cigarette from rest of pack; often looking at pack; one hand off the wheel
Blowing smoke	Driver has head turned, blowing smoke out the window; usually holding cigarette with one hand off the wheel
Drinking	Driver is drinking out of a soda bottle or mug; usually looking forward; one hand off the wheel
Getting Food	Driver is getting food out of a bag in his/her lap; often looking at bag/food; one or both hands off the wheel
Eating/Talking	Driver is eating food and looking at passenger; one hand off the wheel
Talking to passenger	Driver is talking to another person in the cab; sometimes looking to the right at passenger; both hands on the wheel
Reaching in pocket	Driver is reaching for something in either front shirt pocket or back pant pocket; usually looking forward but moving around in seat; one hand off the wheel
Reaching to floor	Driver is reaching for something either on the floor of the cab (down and to the right) or somewhere in the cab; usually looking forward; takes one hand off the wheel

Table 1. Taxonomy developed in Hanowski, Perez and Dingus [2005] (Continued).

Distraction	Definition
Looking at paperwork	Driver is holding paperwork on steering wheel and is looking down at it; one or both hands off the wheel
Looking at floor	Driver is looking at/for something on the floor (down and to the right); both hands on the wheel
Looking at Instrument Panel	Driver is looking down, through steering wheel, at instrument panel containing speedometer and gauges; both hands on the wheel
Looking down	Driver is looking down; either in lap at something unknown, or at hands; may have one or both hands off the wheel
Looking up	Driver is looking up at the visor; both hands on the wheel
Toothpick/Visor mirror	Driver is looking up in the visor mirror, while picking teeth with a toothpick; one hand off the wheel
Looking right - outside	Driver has head turned to the right, either looking in passenger side mirror, or out passenger window; usually both hands are on the wheel
Looking left - outside	Driver has head turned to the left, either looking in driver-side mirror, or out driver window; usually, both hands are on the wheel
Looking outside	Driver is looking at a road sign, something along side of the road, or another car, but is still looking out front window; both hands on the wheel
Adjusting in seat	Driver is adjusting himself/herself in driver seat; usually looking forward; both hands on the wheel
Taking off jacket	Driver is taking off jacket; usually looking forward; one hand off the wheel
Letting go of wheel	Driver is looking forward but does not have either hand on wheel while dancing in seat; is not holding anything
Wiping dash	Driver is wiping off dash of cab with a cloth; usually looking at dash; one hand off the wheel
Rubbing face	Driver is wiping face off or rubbing eyes; usually looking forward but eyes may close for a few moments; one hand off the wheel
Brushing hair	Driver is using a hairbrush to brush hair; looking forward; one hand off the wheel
Coughing	Driver is coughing; usually closes eyes for a short period of time; both hands on the wheel
Yawning	Driver is yawning; usually closes eyes for a short period of time; both hands on the wheel

transportation policy, some of the findings were inconsistent with previous research. A discussion of these differences and potential explanations are explored. In addition, a description of the tangential characteristics of naturalistic driving studies that make them suitable in the r2p initiative is provided. Also, the pragmatic implications of the results from these studies are highlighted and include information to inform education, policy, and driver-vehicle interface design. Finally, a Hierarchical Research Paradigm is introduced that provides

researchers, designers, and policy makers with a heuristic model for characterizing and structuring driving safety research that may support pragmatic research initiatives.

WHAT IS NATURALISTIC DRIVING RESEARCH?

Naturalistic driving research is a method for studying driver behavior and driving performance as it occurs in the real world. In contrast to driving simulator studies that capture

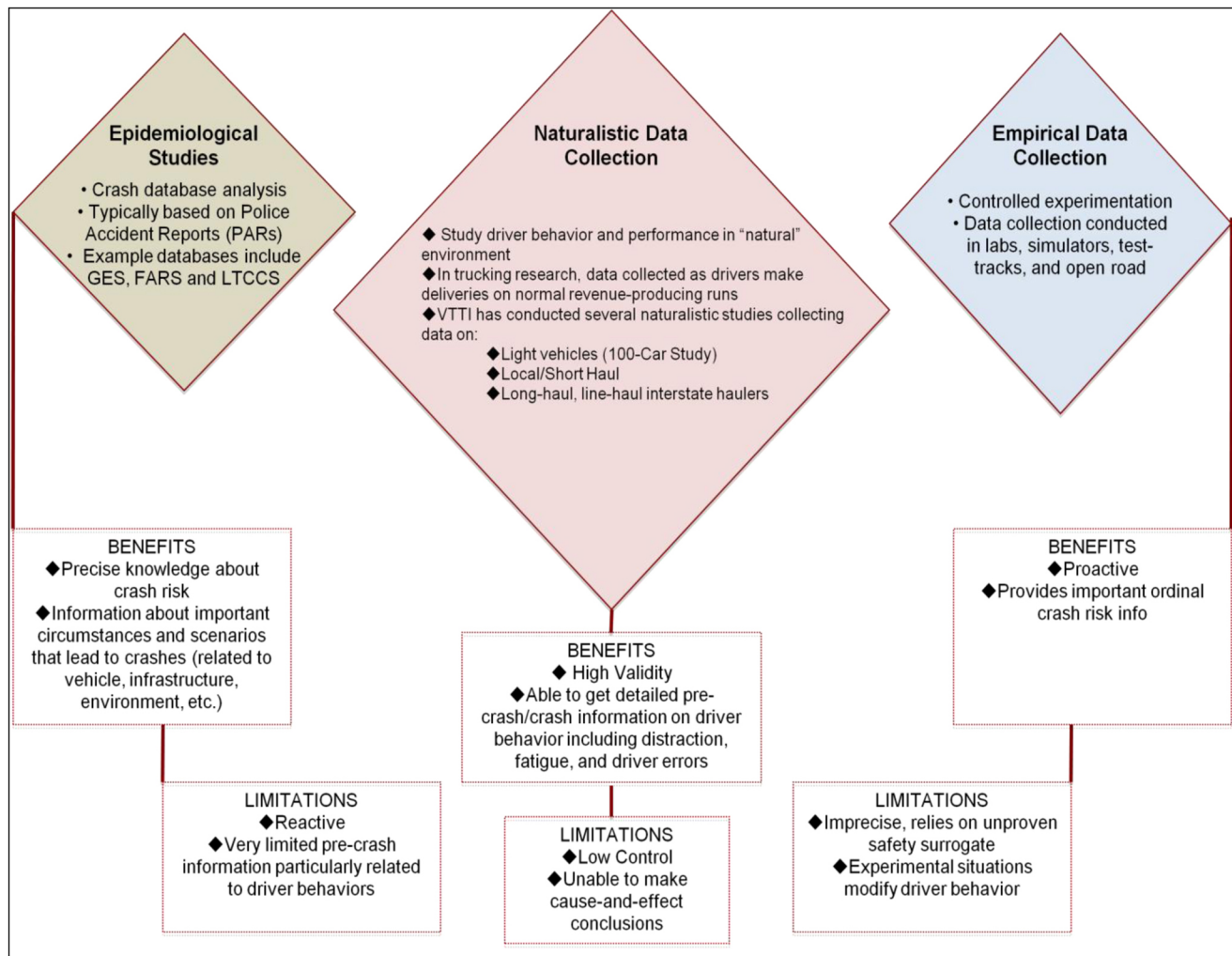


Figure 2. Highlights, benefits and limitations of three data collection approaches used to evaluate driver behavior and performance. Adapted from Dingus [2003].

simulated driving behavior and performance, naturalistic driving research captures actual driving, under real-world conditions and stresses, for extended periods of time. This method has been used with CMVs [Hanowski, Wierwille and Dingus, 2003; Dingus et al., 2002; Hanowski et al., 2008; Blanco et al., in press], light vehicles [e.g., Dingus et al., 2006; Sayer, Devonshire and Flannagan, 2007] and motorcycles [McLaughlin, Doerzaph and Cannon, 2011]. For research involving truck drivers, naturalistic driving involves collecting data as drivers operate fleet vehicles during revenue-producing delivery runs. As such, the vehicle and driving environment becomes the laboratory setting in which normal, day-to-day driving data are collected.

Naturalistic Driving: Bridging Epidemiology and Empirical Research

A unique aspect of naturalistic driving studies is that they combine features from epidemiological and empirical data collection to capture information that may not be entirely

available from either approach alone. Adapted from Dingus [2003], Figure 2 shows the relationship between epidemiological, empirical, and naturalistic data collection. As shown, various research methods used to assess driver behavior have their own strengths and limitations though each can provide important information regarding traffic safety. Note that the strengths and limitations listed for each method in Figure 2 are presented in a general sense, and different studies using a given approach will not be identical in this regard. A key point from Figure 2 is that naturalistic driving research is synergistic with other, more commonly used, approaches and can address some of the limitations inherent in other methods.

Epidemiology is a reactive research approach whereby crash databases, for example, are analyzed to investigate crash characteristics. This approach is particularly effective in assessing the non-behavioral components in the crash, including environmental (e.g., weather), infrastructure (e.g., number of road lanes), and vehicle (e.g., brake failure)

conditions. Three key areas pertaining to crashes that are highlighted in the landmark “Indiana Tri-Level Study” [Treat, 1980], environmental, infrastructure, and vehicle conditions can be well-studied using epidemiological methods. However, the “human factor” associated with crashes, which is the most critical aspect in most crashes, is more difficult to assess using an epidemiological approach. Why is this the case? Crash databases used in epidemiological research are populated by Police Crash Reports (often called police accident reports, PARs), which make it difficult (if not impossible) to determine driver behavior immediately preceding the crash. For example, questions such as “where was the driver looking immediately before the crash onset?” cannot be ascertained through a PAR (and if that information was included on the PAR, how reliable would it be?). In addition, the reporting officer must report what was observed and be prepared to testify to those observations in a judicial setting. This can be particularly problematic for driver behavior assessment, including drowsiness and distraction, given that these conditions may be difficult to ascertain after the crash has occurred. Therefore, given the circumstances under which PAR data are collected, it is difficult to confidently determine driver behaviors that may have contributed to the crash. As such, determining cause-and-effect relationships are not possible through the epidemiological approach. Rather, epidemiological analyses tend to focus on assessing the increase in risk given certain circumstances; for example, determining that not wearing a safety belt significantly increases the likelihood of a fatality in a crash.

To be able to make cause-and-effect statements on driver behavior and driving performance, empirical research is the most appropriate method. Because of the ability to carefully control conditions, laboratories, driving simulators, test tracks, and the open road are often used in empirical driving studies. Typically, participants engage in test scenarios where behavior and performance are measured. For example, empirical studies using the Virginia Smart Road test track have used naive truck drivers to test and evaluate systems that reduce blind spots on tractor-trailers [Wierwille, Schaudt, Fitch and Hanowski, 2008]. Empirical studies such as this provide important data to examine the benefits and unintended consequences of safety technologies by studying driver behavior and performance while drivers interact with these systems.

Past and Present Naturalistic Driving Studies

Naturalistic driving research has been conducted for the past several decades. Early notable studies with CMV drivers were conducted by the United States Department of Transportation (USDOT) in the early 1970s. For example, Harris and Mackie [1972] and Mackie and Miller [1978] investigated driver alertness as a function of driving time, while Mackie, O'Hanlon and McAuley [1974] focused on

internal cab factors of heat, noise, and vibration and their impact on driver alertness. In addition, a landmark study on driver fatigue was conducted by Wylie, Shultz, Miller, Mitler and Mackie [1996] that involved 80 truck drivers on revenue-producing runs. The focus of the Wylie et al. [1996] study was on driver fatigue and alertness and the research included on-road data collection (e.g., steering wheel movement, speed) and video recording of the driver's face and forward roadway, which served as a precursor to the naturalistic driving studies conducted today.

Over the past 10 years or so, the naturalistic driving method has become more sophisticated and feasible with the miniaturization of hardware and the development of on-road data collection/analysis tools and software. With these technological breakthroughs, collecting reliable data in the field for extended periods of time is possible. Naturalistic driving can be thought of as somewhat of a hybrid between epidemiological and empirical methods. Naturalistic driving research utilizes sensors and video cameras installed in vehicles and drivers use these “instrumented vehicles” for an extended period of time that can include weeks [e.g., Blanco et al., in press], months [Hanowski et al., 2008], or a year or more [Dingus et al., 2006]. Robust and high-capacity hard drives allow for continuously collected data whereby the data are recorded at all times the vehicle is on and in motion.

The continuous data collection approach means that the vast majority of data is normative (normal, non-event) driving. That is, safety-critical events, including crashes, are rare and most of the data collected in naturalistic driving studies is made up of non-event driving. In addition, although crashes are analyzed, events based on “driver errors” and near-crashes are studied. There is a theoretical underpinning for this approach that stems from research in industrial applications called “Heinrich's Triangle” [Heinrich, 1931].

HEINRICH'S TRIANGLE AND THE RELATIONSHIP BETWEEN CRASHES AND ERRORS

Using crash surrogates to study underlying safety issues has a long history in transportation safety research. One approach, called the Traffic Conflict Technique, uses traffic conflicts and near-misses as indirect measures of safety (Perkins and Harris, 1968, as cited in Archer, 2001). Predating the Traffic Conflict Technique is Heinrich's Triangle. Developed by Herbert William Heinrich [1931], Heinrich's ideas were formed by studying industrial accident data. The general concept of Heinrich's Triangle is that there is a relationship between very serious accidents and less serious accidents. Therefore, to study the underlying issues associated with severe accidents, researchers need not be reactive by waiting for an accident to occur. As Chapanis [1959] points out, the severity of an accident is largely fortuitous. He cites an

example in which one investigator found that out of 330 accidents of a particular type, 300 resulted in no injury, 29 resulted in minor injuries, and one resulted in a fatal injury. This suggests that it is the situation and contextual factors related to the accident coupled with the underlying behavior - not the severity of the accident - that is most important.

Figure 3 shows a model from Dingus et al. [1995] regarding the frequency of safety-critical events in the transportation safety domain. Dingus et al. [1995] estimated that “Error, Hazard Present” incidents occur 100,000 times for every fatality. For “Error, No Hazard Present,” the estimate is 1,000,000 times for every fatality.



Figure 3. Example of Heinrich's Triangle concept modified by Dingus et al. [1995].

Mollenhauer [1998] (also see, Dingus, Hetrick, and Mollenhauer [1999]) followed up on the Dingus et al. [1995] estimates using data collected in a light-vehicle naturalistic study. Mollenhauer applied Heinrich's Triangle to the data, supplemented by data retrieved from an accident database, and came up with the severity relationship shown in Figure 4.

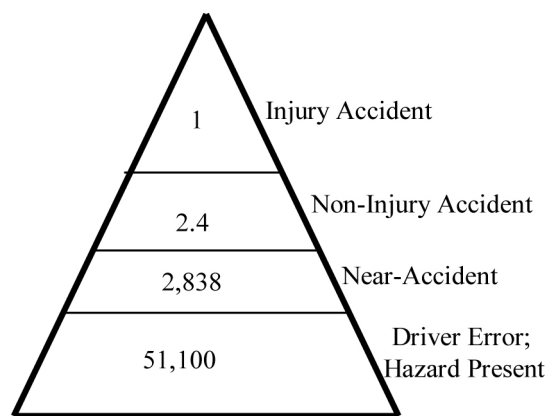


Figure 4. Modified version of Heinrich's Triangle using light-vehicle driver error data from Mollenhauer [1998].

Though Mollenhauer's [1998] study used light-vehicle data, the relationship between crashes and near-crashes has been investigated in CMV operations as well. Perhaps the first such study was conducted by McFarland and Moseley [1954] who studied the types of near-crashes that occur in long-haul trucking, their frequency, and the conditions under which they take place. The data were collected by a trained observer who rode with 17 different drivers on 20 trips totaling 5,000 miles. The observer watched for safety-critical incidents that could have led to crashes. For each incident, the observer diagrammed the characteristics of the incident, and noted the time of day, the weather conditions, visibility, the type of road, the elapsed time since the start of the trip, and the estimated speed of the vehicle(s) involved. Across the 5000 miles, 48 near-accidents were recorded (approximately one near-accident for every 100 miles). Table 2 shows the errors and the frequency with which they occurred.

Table 2. Errors observed in the near-accidents [McFarland and Moseley, 1954].

Errors Resulting in Near-Accidents	Frequency
Dangerous Assumptions	13
Errors in Passing	7
Operator Unprepared	5
Operator Taking Complete Defensive Action	5
Gross Negligence	4
Operator Inattention	3
Operator Indecision	3
Highway Maintenance	3
Operator Taking Partial Defensive Action	2
Failure to Observe Posted "Danger" Signs	1
Failure to Help Other Operator	1
Situations Deliberately Caused by Drivers	1
Total	48

In a review of the McFarland and Moseley [1954] study, Chapanis [1959] notes that in addition to several interesting findings, the method of examining near-accident data proved to be an efficient data collection technique. The disadvantages of the study, Chapanis indicates, are twofold. First, the definition of a near-accident depends upon the judgment of an observer. Second, the presence of a trained observer riding inside the vehicle with the driver may have impacted the driver's behavior. Since the 1950s (when these data were collected), major technological innovations have occurred that address these two disadvantages as described by Chapanis. For example, computers and sensors equipped inside the vehicle, coupled with specialized software (in