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Jessica M. Hutton, Karin M. Bauer, Chris A. Fees, Alison Smiley. *Evaluation of left-turn lane offset using the naturalistic driving study data*. Pages 5.e1-15.

The Strategic Highway Research Program 2 (SHRP 2) Naturalistic Driving Study (NDS) data were used to evaluate gap acceptance behavior of drivers at left-turn lanes with negative, zero, or positive offsets ranging from − 29 ft to + 6 ft. The objectives of the study were to develop guidance for the design of offset left-turn lanes used as a safety countermeasure, and to provide insight regarding the use of the NDS data to future users. **Method:** The study included 3350 gaps in opposing traffic evaluated by 145 NDS volunteer drivers and 275 non-NDS drivers at 14 two-way stop-controlled intersections and 44 signalized opposing left-turn pairs. Logistic regression was used to model the critical gap length for drivers as a function of offset, under conditions when their view was either blocked or not by an opposing left-turning driver. **Results:** The analysis found that the critical gap was longer at left-turn lanes with negative offsets than at those with zero or positive offsets, and was also longer when sight distance was blocked by an opposing left-turning vehicle. Sight distance was much more likely to be restricted by an opposing left-turning vehicle at negative-offset and drivers at those intersections were less likely to accept a gap when an opposing left-turn driver was present. **Conclusions:** Longer gap lengths could potentially result in decreased operational efficiency of an intersection. In addition, drivers making left-turns at negative-offset left-turn lanes are, on average, more likely to leave the shortest amount of time between their turn and the arrival of the next opposing through-vehicle, which may present a potential safety concern. **Practical applications:** The findings provide guidance for highway designers considering using offset left-turn lanes as a crash countermeasure. This research also highlights the benefits and limitations of using the SHRP 2 NDS data to answer similar research questions.

- **Keywords:** Critical gap; Accepted gap length; Rejected gap length; Safety surrogates; Offset left-turn lanes; Logistic regression

Shauna L. Hallmark, Samantha Tyner, Nicole Oneyear, Cher Carney, Dan McGehee. *Evaluation of driving behavior on rural 2-lane curves using the SHRP 2 naturalistic driving study data*. Pages 17.e1-27.

Over half of motor vehicle fatalities are roadway departures, with rural horizontal curves being of particular interest because they make up only a small share of the system mileage but have a crash rate that is significantly higher than tangent sections. However

the interaction between the driver and roadway environment is not well understood, and, as a result, it is difficult to select appropriate countermeasures. **Method:** In order to address this knowledge gap, data from the SHRP 2 naturalistic driving study were used to develop relationships between driver, roadway, and environmental characteristics and risk of a road departure on rural curves. The SHRP 2 NDS collected data from over 3,000 male and female volunteer passenger vehicle drivers, ages 16–98, during a three year period, with most drivers participating between one to two years. A Roadway Information Database was collected in parallel and contains detailed roadway data collected on more than 12,500 centerline miles of highways in and around the study sites. **Results:** Roadway data were reduced for rural 2-lane curves and included factors such as geometry, shoulder type, presence of rumble strips, etc. Environmental and traffic characteristics, such as time of day, ambient conditions, or whether the subject vehicle was following another vehicle, were reduced from the forward roadway video view. Driver characteristics, such as glance location and distraction were reduced from the driver and over the shoulder videos. **Conclusions:** Logistic regression models were developed to assess the probability (odds) of a given type of encroachment based on driver, roadway, and environmental characteristics. At the point this study was undertaken, crashes and near crashes were not yet available and only around 1/3 of the full SHRP NDS dataset could be queried. As a result, the likelihood of crossing the right or left lane line (encroachments) and speeding were used as dependent variables.

- **Keywords:** Roadway encroachment; Rural curves; Speed; Roadway countermeasures; Naturalistic driving study

Justin M. Owens, Linda Angell, Jonathan M. Hankey, James Foley, Kazutoshi Ebe. *Creation of the Naturalistic Engagement in Secondary Tasks (NEST) distracted driving dataset*. Pages 33.e29-36.

Distracted driving has become a topic of critical importance to driving safety research over the past several decades. Naturalistic driving data offer a unique opportunity to study how drivers engage with secondary tasks in real-world driving; however, the complexities involved with identifying and coding relevant epochs of naturalistic data have limited its accessibility to the general research community. **Method:** This project was developed to help address this problem by creating an accessible dataset of driver behavior and situational factors observed during distraction-related safety-critical events and baseline driving epochs, using the Strategic Highway Research Program 2 (SHRP2) naturalistic dataset. The new NEST (Naturalistic Engagement in Secondary Tasks) dataset was created using crashes and near-crashes from the SHRP2 dataset that were identified as including secondary task engagement as a potential contributing factor. Data coding included frame-by-frame video analysis of secondary task and hands-on-wheel activity, as well as summary event information. In addition, information about each secondary task engagement within the trip prior to the crash/near-crash was coded at a higher level. Data were also coded for four baseline epochs and trips per safety-critical event. **Results:** 1,180 events and baseline epochs were coded, and a dataset was constructed. The project team is currently working to determine the most useful way to allow broad public access to the dataset. **Discussion:** We anticipate that the NEST dataset will be extraordinarily useful in allowing qualified researchers access to timely, real-world data concerning how drivers interact with secondary tasks during safety-critical events and baseline driving. **Practical applications:** The coded dataset developed for this project will allow future researchers to have access to detailed data on driver secondary task engagement in the real world. It will be useful for standalone research, as well as for integration with additional SHRP2 data to enable the conduct of more complex research.

- **Keywords:** Naturalistic driving; Distraction; Secondary task engagement; Dataset; Driver behavior

Bruce G. Simons-Morton, Sheila G. Klauer, Marie Claude Ouimet, Feng Guo, Paul S. Albert, Suzanne E. Lee, Johnathon P. Ehsani, Anuj K. Pradhan, Thomas A. Dingus. *Naturalistic teenage driving study : findings and lessons learned*. 41.e29-44.

This paper summarizes the findings on novice teenage driving outcomes (e.g., crashes and risky driving behaviors) from the Naturalistic Teenage Driving Study. **Method:** Survey and driving data from a data acquisition system (global positioning system, accelerometers, cameras) were collected from 42 newly licensed teenage drivers and their parents during the first 18 months of teenage licensure; stress responsivity was also measured in teenagers. **Results:** Overall teenage crash and near-crash (CNC) rates declined over time, but were > 4 times higher among teenagers than adults. Contributing factors to teenage CNC rates included secondary task engagement (e.g., distraction), kinematic risky driving, low stress responsivity, and risky social norms. **Conclusions:** The data support the contention that the high novice teenage CNC risk is due both to inexperience and risky driving behavior, particularly kinematic risky driving and secondary task engagement. **Practical Applications:** Graduated driver licensing policy and other prevention efforts should focus on kinematic risky driving, secondary task engagement, and risky social norms.

- **Keywords:** Adolescence; Risk taking; Accidents; Speeding; Kinematic; Expertise

Feng Guo, Youjia Fang, Jonathan F. Antin. *Older driver fitness-to-drive evaluation using naturalistic driving data*. Pages 49.e29-54.

As our driving population continues to age, it is becoming increasingly important to find a small set of easily administered fitness metrics that can meaningfully and reliably identify at-risk seniors requiring more in-depth evaluation of their driving skills and weaknesses. **Method:** Sixty driver assessment metrics related to fitness-to-drive were examined for 20 seniors who were followed for a year using the naturalistic driving paradigm. Principal component analysis and negative binomial regression modeling approaches were used to develop parsimonious models relating the most highly predictive of the driver assessment metrics to the safety-related outcomes observed in the naturalistic driving data. **Results:** This study provides important confirmation using naturalistic driving methods of the relationship between contrast sensitivity and crash-related events. **Practical applications:** The results of this study provide crucial information on the continuing journey to identify metrics and protocols that could be applied to determine seniors' fitness to drive.

- **Keywords:** Fitness to drive; Older driver; Naturalistic driving study; Driving risk; Contrast sensitivity

Jonny Kuo, Sjaan Koppel, Judith L. Charlton, Christina M. Rudin-Brown. *Evaluation of a video-based measure of driver heart rate*. Pages 55.e29-59.

Internal driver events such as emotional arousal do not consistently elicit observable behaviors. However, heart rate (HR) offers promise as a surrogate measure for predicting these states in drivers. Imaging photoplethysmography (IPPG) can measure HR from face video recorded in static, indoor settings, but has yet to be examined in an in-vehicle driving environment. **Methods:** Participants (N = 10) completed an on-road driving task whilst wearing a commercial, chest-strap style heart rate monitor ("baseline"). IPPG was applied to driver face video to estimate HR and the two measures of HR were compared. **Results:** For 4 of 10 participants, IPPG produced a valid HR signal (± 5 BPM of baseline) between 48 and 75% of trip duration. For the remaining participants, IPPG accuracy was poor (< 20%). **Conclusions:** In-vehicle IPPG is

achievable, but significant challenges remain. **Practical applications:** The relationship between IPPG accuracy and various confounding factors was quantified for future refinement.

- **Keywords:** Cognitive distraction; Cognitive workload; Photoplethysmography; Computer vision; Heart rate

Zhenlong Li, Xue Jin, Xiaohua Zhao. *Drunk driving detection based on classification of multivariate time series*. Pages 61.e29-64.

This paper addresses the problem of detecting drunk driving based on classification of multivariate time series. **Methods:** First, driving performance measures were collected from a test in a driving simulator located in the Traffic Research Center, Beijing University of Technology. Lateral position and steering angle were used to detect drunk driving. Second, multivariate time series analysis was performed to extract the features. A piecewise linear representation was used to represent multivariate time series. A bottom-up algorithm was then employed to separate multivariate time series. The slope and time interval of each segment were extracted as the features for classification. Third, a support vector machine classifier was used to classify driver's state into two classes (normal or drunk) according to the extracted features. **Results:** The proposed approach achieved an accuracy of 80.0%. **Conclusions and practical applications:** Drunk driving detection based on the analysis of multivariate time series is feasible and effective. The approach has implications for drunk driving detection.

- **Keywords:** Drunk driving detection; Multivariate time series; Bottom-up segmentation; Support vector machine

Shan Bao, Huimin Xiong, Mary Lynn Buonarosa, James R. Sayer. *Using naturalistic driving data to examine drivers' seatbelt use behavior : comparison between teens and adults*. Pages 69.e29-73.

Teens and young drivers are often reported as one driver group that has significantly lower seatbelt use rates than other age groups. **Objective:** This study was designed to address the questions of whether and how seatbelt-use behavior of novice teen drivers is different from young adult drivers and other adult drivers when driving on real roads. **Method:** Driving data from 148 drivers who participated in two previous naturalistic driving studies were further analyzed. The combined dataset represents 313,500 miles, 37,695 valid trips, and about 9500 h of driving. Drivers did not wear their seatbelts at all during 1284 trips. Two dependent variables were calculated, whether and when drivers used seatbelts during a trip, and analyzed using logistic regression models. **Results:** Results of this study found significant differences in the likelihood of seatbelt use between novice teen drivers and each of the three adult groups. Novice teen drivers who recently received their driver's licenses were the most likely to use a seatbelt, followed by older drivers, middle-aged drivers, and young drivers. Young drivers were the least likely to use a seatbelt. Older drivers were also more likely to use seatbelts than the other two adult groups. The results also showed that novice teen drivers were more likely to fasten their seatbelts at the beginning of a trip when compared to the other three adult groups. **Summary:** Novice teen drivers who were still in the first year after obtaining their driver's license were the most conservative seatbelt users, when compared to adult drivers. **Practical application:** Findings from this study have practical application insights in both developing training programs for novice teen drivers and designing seatbelt reminder and interlock systems to promote seatbelt use in certain driver groups.

- **Keywords:** Seatbelt use; Naturalistic driving data; Novice teen drivers; Young drivers; Old drivers

Janet I. Creaser, Christopher J. Edwards, Nichole L. Morris, Max Donath. Are cellular phone blocking applications effective for novice teen drivers? Pages 75.e29-78.

Distracted driving is a significant concern for novice teen drivers. Although cellular phone bans are applied in many jurisdictions to restrict cellular phone use, teen drivers often report making calls and texts while driving. **Method:** The Minnesota Teen Driver Study incorporated cellular phone blocking functions via a software application for 182 novice teen drivers in two treatment conditions. The first condition included 92 teens who ran a driver support application on a smartphone that also blocked phone usage. The second condition included 90 teens who ran the same application with phone blocking but which also reported back to parents about monitored risky behaviors (e.g., speeding). A third control group consisting of 92 novice teen drivers had the application and phone-based software installed on the phones to record cellular phone (but not block it) use while driving. **Results:** The two treatment groups made significantly fewer calls and texts per mile driven compared to the control group. The control group data also demonstrated a higher propensity to text while driving rather than making calls. **Discussion:** Software that blocks cellular phone use (except 911) while driving can be effective at mitigating calling and texting for novice teen drivers. However, subjective data indicates that some teens were motivated to find ways around the software, as well as to use another teen's phone while driving when they were unable to use theirs. **Practical applications:** Cellular phone bans for calling and texting are the first step to changing behaviors associated with texting and driving, particularly among novice teen drivers. Blocking software has the additional potential to reduce impulsive calling and texting while driving among novice teen drivers who might logically know the risks, but for whom it is difficult to ignore calling or texting while driving.

- **Keywords:** Novice drivers; Teenagers; Distracted driving; Cellular phones; Technology

Johnathon P. Ehsani, Kaigang Li, Bruce G. Simons-Morton, Cheyenne Fox Tree-McGrath, Jessamyn G. Perlus, Fearghal O'Brien, Sheila G. Klauer. *Conscientious personality and young drivers' crash risk*. Pages 83.e29-87.

Introduction: Personality characteristics are associated with many risk behaviors. However, the relationship between personality traits, risky driving behavior, and crash risk is poorly understood. The purpose of this study was to examine the association between personality, risky driving behavior, and crashes and near-crashes, using naturalistic driving research methods. **Method:** Participants' driving exposure, kinematic risky driving (KRD), high-risk secondary task engagement, and the frequency of crashes and near-crashes (CNC) were assessed over the first 18 months of licensure using naturalistic driving methods. A personality survey (NEO-Five Factor Inventory) was administered at baseline. The association between personality characteristics, KRD rate, secondary task engagement rate, and CNC rate was estimated using a linear regression model. Mediation analysis was conducted to examine if participants' KRD rate or secondary task engagement rate mediated the relationship between personality and CNC. Data were collected as part of the Naturalistic Teen Driving Study. **Results:** Conscientiousness was marginally negatively associated with CNC (path $c = -0.034$, $p = .09$) and both potential mediators KRD (path $a = -0.040$, $p = .09$) and secondary task engagement while driving (path $a = -0.053$, $p = .03$). KRD, but not secondary task engagement, was found to mediate (path $b = 0.376$, $p = .02$) the relationship between conscientiousness and CNC (path $c' = -0.025$, $p = .20$). **Conclusions:** Using objective measures of driving behavior and a widely used personality construct, these findings present a causal pathway through which personality and risky driving are associated with CNC. Specifically, more conscientious teenage drivers engaged in fewer risky driving maneuvers, and suffered fewer CNC. **Practical Applications:** Part of the variability in crash risk observed among newly licensed teenage drivers can be explained by

personality. Parents and driving instructors may take teenage drivers' personality into account when providing guidance, and establishing norms and expectations about driving.

- **Keywords:** Crashes; Teenage drivers; Personality

Huimin Xiong, Shan Bao, James Sayer, Kazuma Kato. *Examination of drivers' cell phone use behavior at intersections by using naturalistic driving data*. Pages 89.e29-93.

Many driving simulator studies have shown that cell phone use while driving greatly degraded driving performance. In terms of safety analysis, many factors including drivers, vehicles, and driving situations need to be considered. Controlled or simulated studies cannot always account for the full effects of these factors, especially situational factors such as road condition, traffic density, and weather and lighting conditions. Naturalistic driving by its nature provides a natural and realistic way to examine drivers' behaviors and associated factors for cell phone use while driving. **Method:** In this study, driving speed while using a cell phone (conversation or visual/manual tasks) was compared to two baselines (baseline 1: normal driving condition, which only excludes driving while using a cell phone, baseline 2: driving-only condition, which excludes all types of secondary tasks) when traversing an intersection. **Results:** The outcomes showed that drivers drove slower when using a cell for both conversation and visual/manual (VM) tasks compared to baseline conditions. With regard to cell phone conversations, drivers were more likely to drive faster during the day time compared to night time driving and drive slower under moderate traffic compared to under sparse traffic situations. With regard to VM tasks, there was a significant interaction between traffic and cell phone use conditions. The maximum speed with VM tasks was significantly lower than that with baseline conditions under sparse traffic conditions. In contrast, the maximum speed with VM tasks was slightly higher than that with baseline driving under dense traffic situations. **Practical applications:** This suggests that drivers might self-regulate their behavior based on the driving situations and demand for secondary tasks, which could provide insights on driver distraction guidelines. With the rapid development of in-vehicle technology, the findings in this research could lead the improvement of human-machine interface (HMI) design as well.

- **Keywords:** Driver distraction; Naturalistic driving; Drivers' cell phone use; Driver behavior; Driving safety

Kristofer D. Kusano, Rong Chen, Jade Montgomery, Hampton C. Gabler. *Population distributions of time to collision at brake application during car following from naturalistic driving data*. Pages 95.e29-104.

Forward collision warning (FCW) systems are designed to mitigate the effects of rear-end collisions. Driver acceptance of these systems is crucial to their success, as perceived "nuisance" alarms may cause drivers to disable the systems. In order to make customizable FCW thresholds, system designers need to quantify the variation in braking behavior in the driving population. The objective of this study was to quantify the time to collision (TTC) that drivers applied the brakes during car following scenarios from a large scale naturalistic driving study (NDS). **Methods:** Because of the large amount of data generated by NDS, an automated algorithm was developed to identify lead vehicles using radar data recorded as part of the study. Using the search algorithm, all trips from 64 drivers from the 100-Car NDS were analyzed. A comparison of the algorithm to 7135 brake applications where the presence of a lead vehicle was manually identified found that the algorithm agreed with the human review 90.6% of the time. **Results:** This study examined 72,123 trips that resulted in 2.6 million brake applications. Population distributions of the minimum, 1st, and 10th percentiles were computed for each driver in speed ranges between 3 and 60 mph in 10 mph increments. As speed increased, so did

the minimum TTC experience by drivers as well as variance in TTC. Younger drivers (18–30) had lower TTC at brake application compared to older drivers (30–51 +), especially at speeds between 40 mph and 60 mph. **Discussion:** This is one of the first studies to use large scale NDS data to quantify braking behavior during car following. The results of this study can be used to design and evaluate FCW systems and calibrate traffic simulation models.

- **Keywords:** Forward collision warning; Naturalistic driving study; Driver behavior; Time to collision

Gregory M. Fitch, Paul R. Bartholomew, Richard J. Hanowski, Miguel A. Perez. *Drivers' visual behavior when using handheld and hands-free cell phones*. Pages 105.e29-108.

This study investigated driver distraction and how the use of handheld (HH), portable hands-free (PHF), and integrated hands-free (IHF) cell phones affected the visual behavior of motor vehicle drivers. **Method:** A naturalistic driving study recorded 204 participating drivers using video cameras and vehicle sensors for an average of 31 days. A total of 1564 cell phone calls made and 844 text messages sent while driving were sampled and underwent a video review. Baselines were established by recording epochs prior to the cell phone interactions. Total eyes-off-road time (TEORT) was examined to assess the visual demands of cell phone subtasks while driving. Percent TEORT was reported and compared against the baseline. **Results:** Visual-manual subtasks performed on HH, PHF, and IHF cell phones were found to significantly increase drivers' mean percent TEORT. In contrast, conversing on an HH cell phone was found to significantly decrease drivers' mean percent TEORT, indicating that drivers looked at the forward roadway more often. No significant differences in percent TEORT were found for drivers conversing using PHF or IHF cell phones. The mean TEORT durations for visual-manual subtasks performed on an HH cell phone were significantly longer than the mean TEORT durations on either IHF or PHF cell phones. **Practical applications:** This research helps to further reinforce the distinction made between handheld and hands-free cell phone use in transportation distraction policy.

- **Keywords:** Naturalistic driving study; Visual attention; Portable aftermarket devices; Driver distraction; Integrated cell phones

Zifan Liu, Andrej Ivanco, Zoran Filipi. *Naturalistic drive cycle synthesis for pickup trucks*. Pages 109.e29-115.

Future pick-up trucks are meeting much stricter fuel economy and exhaust emission standards. Design tradeoffs will have to be carefully evaluated to satisfy consumer expectations within the regulatory and cost constraints. Boundary conditions will obviously be critical for decision making: thus, the understanding of how customers are driving in naturalistic settings is indispensable. Federal driving schedules, while critical for certification, do not capture the richness of naturalistic cycles, particularly the aggressive maneuvers that often shape consumer perception of performance. While there are databases with large number of drive cycles, applying all of them directly in the design process is impractical. Therefore, representative drive cycles that capture the essence of the naturalistic driving should be synthesized from naturalistic driving data. **Method:** Naturalistic drive cycles are firstly categorized by investigating their micro-trip components, defined as driving activities between successive stops. Micro-trips are expected to characterize underlying local traffic conditions, and separate different driving patterns. Next, the transitions from one vehicle state to another vehicle state in each cycle category are captured with Transition Probability Matrix (TPM). Candidate drive cycles can subsequently be synthesized using Markov Chain based on TPMs for each category. Finally, representative synthetic drive cycles are selected through assessment of significant cycle metrics to identify the ones with smallest errors. **Summary:** This

paper provides a framework for synthesis of representative drive cycles from naturalistic driving data, which can subsequently be used for efficient optimization of design or control of pick-up truck powertrains. **Impact on industry:** Manufacturers will benefit from representative drive cycles in several aspects, including quick assessments of vehicle performance and energy consumption in simulations, component sizing and design, optimization of control strategies, and vehicle testing under real-world conditions. This is in contrast to using federal certification test cycles, which were never intended to capture pickup truck segment.

- **Keywords:** Pickup trucks; Naturalistic drive cycle; Real-world driving; K-means clustering; Transition Probability Matrix (TPM); Markov chain; Representative drive cycle