Observations of Driver Behavior During Overtaking of Bicycles on Rural Roads

Jeremy R. Chapman and David A. Noyce

The interaction between motorized and nonmotorized road users has been an issue of contention for many years. Drivers complain that bicyclist behavior ranges from annoying to dangerous to illegal. Bicyclists complain that driver behavior ranges from annoying to dangerous to illegal. Many studies have observed these interactions on urban roads. However, only anecdotal evidence existed for the interactions on rural roads. When looking at driver and bicyclist behavior, specifically during interactions on rural roads, researchers have not had independent data to review. The study underlying this paper collected real-time interaction data between bicycles and motorized vehicles on rural roads, with Dane County, Wisconsin, as a field laboratory. Researchers collected video and sensor data for 1,151 interactions between bicycles and motorized vehicles. This paper provides initial observations drawn from these interactions. This study found that drivers, in fact, operated in a technically unsafe manner by frequently performing passing maneuvers outside designated areas. This study also found that despite the frequent comment from bicyclists that drivers passed too closely, these actions were actually quite rare and accounted for only 0.5% of all the observed interactions (six of 1,151). Drivers were far more likely to give bicyclists more room than required and risked a centerline violation, even when conditions were not safe to do so. Bicycle lanes (paved shoulders) directly affected the likelihood of a driver committing a moving violation, with violation rates four to six times lower when a paved shoulder was available.

The interaction between motorized and nonmotorized road users has been an issue of contention for many years. Drivers complain that bicyclist behavior ranges from annoying to dangerous to illegal. Bicyclists complain that driver behavior ranges from annoying to dangerous to illegal. When looking at driver and bicyclist behavior, specifically during interactions on rural roads, researchers have been left with only anecdotal reports, and have not had independent data to review.

As a research tool, the crash report is frequently used to identify problem locations where roadway geometry or other correctable issues may exist. Crash reports may also be relied on to determine actual behavior of those involved. Because crash reports are based on observations and statements collected after an incident has already occurred, there is an inherent bias when only those involved are available to give information. Individuals involved in a collision will provide their opinion of what occurred, which intentionally, or otherwise, is frequently skewed to put them in a better light. When third parties are present, additional observations (presented as fact) are available to the responding officer. Only through a comparison of all of these statements can an actual set of events be inferred, which may not be very useful to researchers.

What becomes readily apparent is that the underlying bias makes it difficult to ascertain exactly what happened during a crash. Researchers may be forced to combine collected statement and after-crash site analysis to infer the most likely scenario for the crash. Without a way to collect data of the interactions in real time, there is no reliable means to study what actually occurred during the interactions. These interaction data (for bicycles and pedestrians) have been on the research wish list (*1*).

LITERATURE REVIEW

Two areas of literature are of interest with this research. The first area focuses on the behavior of drivers while passing other motorized vehicles, and the second area is the behavior of drivers when passing bicycles. In 1968, Gordon and Mast published their seminal study of driver decisions in the overtaking and passing of other motorized vehicles (*2*). Their work first looked at a literature review published by Farber and Silver in 1967 (*3*). The main conclusion of this literature review was that "the actual number of studies reported is small and in any given area, very little definitive work has been done. Much of the research has been of a distinctly exploratory nature and many more problems have been raised than solved."

In reviewing the literature, Gordon and Mast also noted several previous studies. Some of the earliest studies date back to the late 1930s and early 1940s. A 1938 study by Matson et al. and a 1941 study by Prisk looked at the distances needed to perform two types of pass: one in which the overtaking vehicle starts at the same speed as the overtaken vehicle (accelerative pass) and one in which the overtaking vehicle is traveling faster than the overtaken vehicle (flying pass) (*4, 5*). The other area these studies looked at was the return-to-lane maneuver, with distinctions noted for a normal (or unhurried) return, and for when the driver must complete the maneuver more sharply (forced return because of an oncoming vehicle).

In 1963, Crawford conducted the first study of driver behavior as it related to overtaking and passing. This study used controlled experiments in which measurements were made of "accepted gap distance, overtaking, and safety distances" (*6*).

Crawford's findings, as shown in Figure 1, indicated that far shorter passing distances were necessary across all speeds than later studies showed. Gordon and Mast speculated that this was primarily because of the use of trained drivers instead of observations of natural behavior.

J. R. Chapman, B245 Engineering Hall, and D. A. Noyce, 1204 Engineering Hall, Traffic Operations and Safety Laboratory, Department of Civil and Environmental Engineering, University of Wisconsin–Madison, 1415 Engineering Drive, Madison, WI 53706. Corresponding author: J. R. Chapman, jrchapman@wisc.edu.

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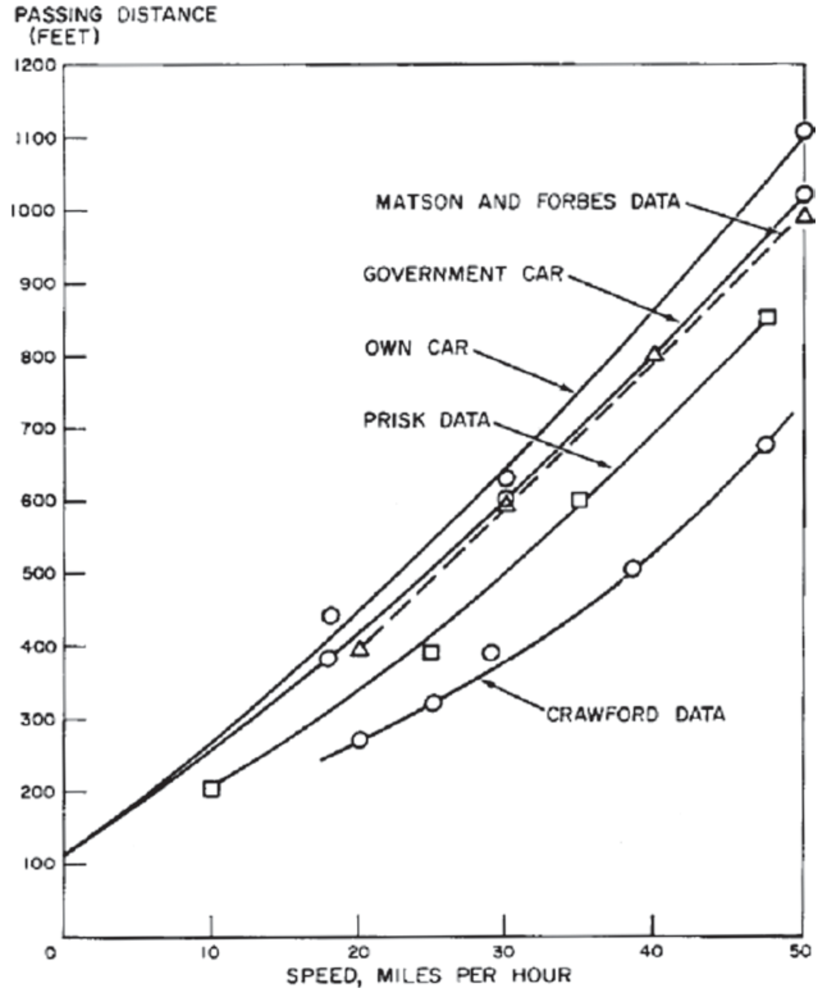


FIGURE 1 Overtaking and passing distances for various studies (*2*).

Crawford validated his findings by making observations about vehicle overtaking on the basis of a van driving on a highway. A 1966 study conducted by Silver and Bloom found that drivers were incapable of making accurate judgments of the speed of oncoming vehicles and therefore misjudged available passing distances (*7*). The study further noted that when drivers were provided with the speed of the oncoming vehicles, their estimation of available passing distance and time statistically improved.

In a similar study, Jones and Heimstra noted the necessity of focusing on both the gap time and distance separating the vehicles and also the time and distance required to actually perform the overtaking maneuver (*8*). In this study, drivers were asked to identify "the last moment they could safely pass a lead car and avoid hitting an oncoming car." Although this study found that 88 of 190 judgments were unsafe, no conclusions were drawn about the cause of these driver errors.

Gordon and Mast's study also looked at the ability of drivers to judge the distance required for overtaking and passing. They simplified the procedure by "terminating the maneuver at a fixed point on the road rather than by the passing of an oncoming car." This simplification minimized the situational assessment errors (drivers misjudging available time and distance to pass). The drivers also used their own vehicles, rather than test vehicles, to minimize the effects of drivers being unfamiliar with the vehicle. To understand the effects of unfamiliarity, the researchers also evaluated drivers using a single test vehicle.

The overtaking and passing distance data from the studies noted by Gordon and Mast are plotted in Figure 1.

Gordon and Mast found that when drivers are in their own vehicle, there is a significantly larger variance in passing distance than when drivers all used the same vehicle. They also noted that drivers were unable to estimate the overtaking and passing distances necessary to perform these maneuvers safely, especially at high speed, and should be provided guidance through the following suggested driving aids:

1. Passing areas and "No Passing" signs (traditionally used);
2. Speed limits and other speed regulations, especially in passing zones;
3. Driver education on not passing at high speeds and on cooperating with the overtaking driver;
4. Road design modifications, such as wide shoulders and addition of lanes;
5. Traffic planning to minimize the use of two-lane rural roads; and
6. Electronic devices that inform the driver when it is safe to pass.

The second area of research has received little coverage across the available literature, with no identifiable research looking at motor vehicle and bicycle interactions occurring before 1977. As a result, the Gordon and Mast research and the present literature review represent the foundation for research on overtaking and passing. The fundamental aspects of driver behavior, such as the mechanics of lane positioning and the ability to judge the necessary distance to safely pass, do not change according to what is being overtaken. When the focus shifted to motor vehicles overtaking bicycles, few publications on the actual on-the-road interactions could be located (*9, 10*). Research was identified that used staged situations to obtain observations of motor vehicle and bicycle interactions to judge the effects of bike lanes on behavior (*11*).

A 1977 study by Kroll and Ramey looked at the effects of bicycle lanes on driver and bicyclist behavior (*11*). The authors stated that they were the first ever to study "the extent to which driver and bicyclist behavior is affected by a bicycle lane." The research consisted of photographically capturing interactions between bicyclists and other road users. The camera was placed as inconspicuously as possible, "either in the parking lane between parked cars or close to the roadway edge, often behind bushes or telephone poles." Most observations were obtained at locations at which there were few bicyclists. Therefore, the authors used "a confederate cyclist who rode in a predetermined place on the road and was photographed the moment he was passed by an auto" rather than sampling real bicyclists interacting with passing autos. Twenty sites, 10 with a bicycle lane and 10 without a bicycle lane, were selected in the greater Sacramento, California, area. Six additional sites in Davis, California, allowed for sampling with real bicyclists. The film of each interaction allowed the authors to measure (by scaling off of the rear bike wheel height or measured lane width) the following:

1. Separation distance, distance between bike and car (at rear wheel of bike), and the car's position defined by a line on the roadway drawn between right front and right rear tires;
2. Bike and car positioning, distance of both bicycle and car from bike lane where applicable, or from the centerline or roadway edge; and
3. Incidence of cars crossing the centerline while passing bike.

The study found that on streets with bicycle lanes:

1. Drivers, when passing bicyclists, exhibited decreased variability in the deflection distance from their traveled path, but these results are only conclusive for roads with speeds of 35 mph or less.
2. There was no change in the mean separation distance between bicycles and motor vehicles.
3. Auto displacement decreased (drivers maintained a smaller separation distance).
4. Lateral dispersion of bicycles and motor vehicles traveling alone was narrowed.

The authors also emphasized the need to reduce centerline violations. Findings 2 and 3 showed that "[t]he high-separation drivers will drive closer to the bike and the low-separation drivers will driver further away," which leaves the average separation distance unchanged. This calming effect on the amplitude of the separation distance means fewer drivers will cross the centerline.

The second study identified through this research was by Walker in 2006 (*9*). No relevant research between 1977 and 2006 could be identified through an extensive literature review. Walker studied, from a psychological perspective, the responses of drivers on the basis of perceptions of the bicyclist being overtaken. He looked at the effects of bicyclist position along the edge of the roadway, helmet use by the bicyclist, type of vehicle overtaking, and apparent gender of the bicyclist. Walker personally performed the field data collection using a Trek hybrid bicycle equipped with panniers (bags mounted to a rack over the rear wheel). He dressed in everyday clothes to appear as much like a typical bicycle commuter as possible. To simulate the apparent gender, Walker wore a "long feminine wig." The bike was equipped with various data collection devices, with a laptop computer and ultrasonic distance sensor stored in the panniers.

In the course of this research, Walker was twice struck by motor vehicles, sustaining only a slight injury from one collision and unscathed from the other. He was wearing a helmet at the time of each. Walker found that the overtaking distance between the bicyclist and the motor vehicle was lower when

- The bicyclist wore a helmet,
- The bicyclist rode away from the edge of the road,
- The bicyclist was male, and
- The motorist was operating a bus or truck.

From other studies of drivers' perception of bicyclists, Walker concluded "that many of these effects are the result of motorists making assumptions about bicyclists' behaviors based on a brief visual assessment of their likely experience levels." A caveat is offered, indicating that the likelihood of these results predicting collisions is minimal.

The third study identified was a preliminary exploration of the data collection methodology used for this evaluation (*10*). Chapman and Noyce undertook the development and testing of a low-cost, portable, on-bicycle data collection system for use on rural roads. This system was designed to minimize the influence on overtaking driver behavior by using a standard road bicycle and equipment that was inconspicuous. Preliminary results have shown that at the higher speeds on rural roads, driver behavior is unaffected by the presence of the on-bicycle data collection system (no noticeable slowing or other change in driving behavior is observable in video or sensor logs). There are some general similarities to the system used by Walker (forward/rearward video, ultrasonic side-fire sensor), but the different evaluation environment (rural roads in Wisconsin instead of suburban roads outside London) required some significant alterations (road bike rather than hybrid bike; much smaller, custom-built sensor; and no saddlebags to hold equipment).

DATA COLLECTION SETUP

Figure 2 shows the data collection bicycle in profile. Circled are the forward-facing camera and rear-facing camera, as well as the lateral distance sensor and container holding the data logging computer. The data collection methodology used was initially detailed by Chapman and Noyce in 2010 (*10*). The equipment used follows:

- Specialized Allez Comp (steel frame) road bicycle,
- Two Oregon Scientific ATC2K helmet cameras,
- Hewlett-Packard Mini netbook model 2140,
- Garmin Forerunner 201 Global Positioning System unit, and
- Maxbotix LV-EZ1 ultrasonic range finder in custom housing wired to netbook.

FIGURE 2 Data collection bicycle.

DATA COLLECTION FINDINGS

More than 1,300 passing maneuvers were observed in approximately 80 h of video recorded during data collection. Of these passing maneuvers, 1,151 interactions had complete data (video from front and rear cameras, as well as sensor log data) and were coded. The remaining passing maneuvers were either missing one of the camera views or the sensor log as a result of equipment issues (most commonly a dead battery). The recordings were all performed in southwestern Dane County (in South Central Wisconsin) along state and county trunk highways and local rural roads (as shown in Figure 3).

For each of the 1,151 interactions, the following data were recorded:

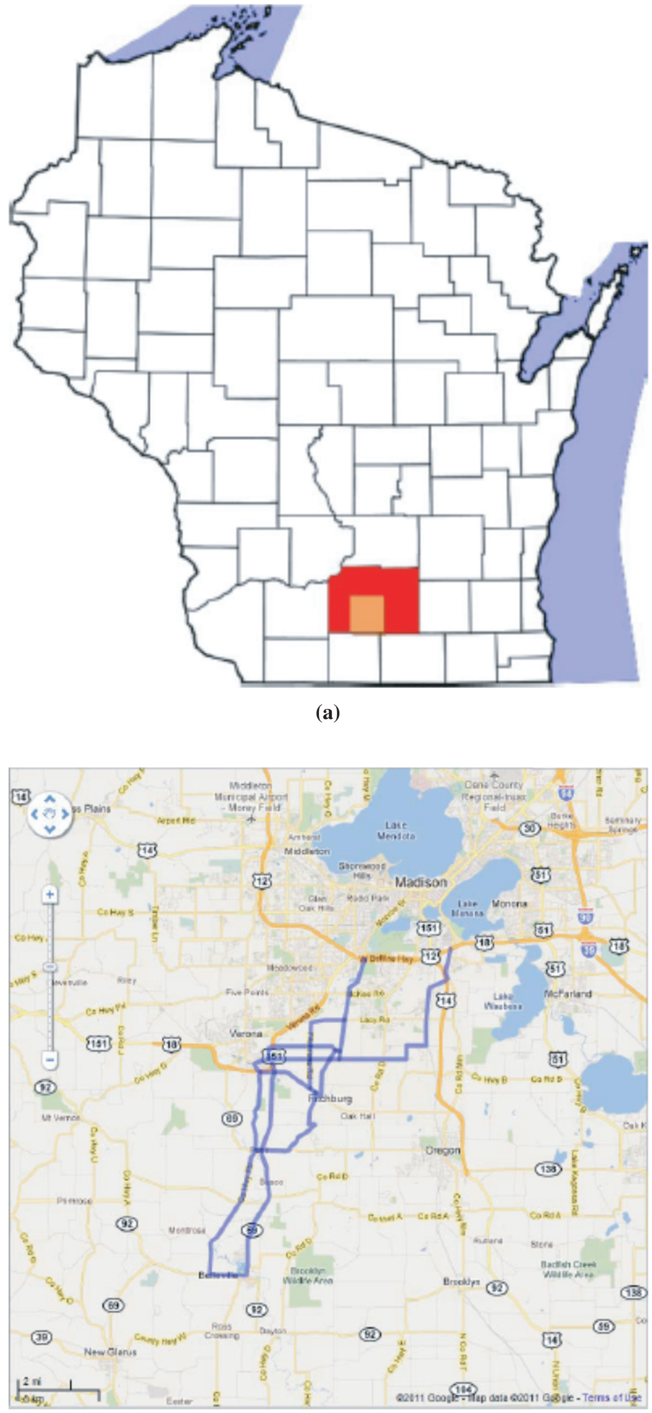
- Location (road name) and direction of travel;
- Road conditions and signing and marking;
- Road shoulder (when present) conditions (a paved shoulder was considered to be a bicycle lane);
- Bicycle speed and position;
- Vehicle make, model, estimated speed, and lane position;
- Lateral clearance between bicycle and vehicle;
- Moving violations, hazardous situations, and collisions (if any);
- Weather conditions; and
- Presence of oncoming vehicle.

Of 1,151 observations coded and analyzed, 46.3% of the vehicles were cars, 26.1% were sport utility vehicles, 13.5% were pickup trucks, and 8.5% were minivans. The remaining vehicles were trucks (UPS, U-Haul panel truck), vans, vehicles with trailers, semitrucks, school buses, and motorcycles. The complete breakdown of vehicle types is presented in Table 1.

Of the 1,151 observations, 789 (68.5%) occurred on roads with a bike lane or paved shoulder (Figure 4*a*), and the remaining 362 (31.5%) occurred on roads with no bike lane or paved shoulder (Figure 4*b*).

The average distances observed between the overtaking vehicle and the bicycle were nearly constant, regardless of whether a bike lane was present. The average with a bike lane was 6.4 ft, and the average without a bike lane was 6.3 ft, a difference of 0.1 ft (or approximately 1 in.). It is worth noting that Wisconsin observes the "3-ft rule," which requires drivers to provide at least 3 ft of lateral clearance to any overtaken bicyclist. This study found only six instances in which this rule was violated. Of these, five of the six occurred where there was no bike lane present, and the lateral clearance distance for all six ranged from 2.0 to 2.9 ft. Table 2 presents the vehicle type, lateral clearance distance, bike lane presence, road grade, and oncoming vehicle presence for all six of these observations. In all six cases, there were visible pavement markings for both the centerline and edgelines, and the width of the traveled way was approximately 20 ft. Figure 5 shows the average, minimum, and maximum lateral clearance distances for each vehicle type when a bike lane was available or not available.

A closer examination of the average lateral clearance distance afforded by drivers indicated that they crossed the centerline of the



(a)

(b)

FIGURE 3 Map of Wisconsin highlighting study area and collection routes.

TABLE 1 Vehicle Types Observed

Vehicle Type	Count	%
Car	533	46.3
SUV	300	26.1
Pickup	155	13.5
Minivan	98	8.5
Truck	24	2.1
Van	18	1.6
Vehicle with trailer	13	1.1
Semi	6	0.5
School bus	3	0.3
Motorcycle	1	0.1
Total	1,151	100.0

TABLE 2 Lateral Clearance Violations

Vehicle Type	Lateral Clearance (ft)	Bike Lane?	Road Grade	Opposing Vehicle?
Car	2.42	Yes	Level	No
Vehicle with trailer	2.75	No	Level	No
SUV	2.67	No	Uphill	No
Car	2.17	No	Downhill	Yes
Car	2	No	Uphill	No
SUV	2.92	No	Level	Yes

roadway with some frequency. When the centerline is a normal broken yellow line, the passing maneuver occurs solely on the basis of driver judgment. When the centerline is solid (or double-solid) yellow, a driver is, by law, prohibited from crossing. Because passing and no-passing zones are commonly determined by available sight distance, drivers committed moving violations to accomplish at least some of the observed passing maneuvers, and may have created hazardous situations with the potential for collisions with oncoming vehicles. Table 3 presents the violation totals by vehicle type, percentage of total violations, and the percentage of violations within each vehicle type. Although cars represented the highest number of violations, less than one-fourth of all cars committed a violation. Nearly half of all vehicles with trailers, and more than 30% of pickup trucks and semitrucks committed a violation.

The comparison of vehicles observed (by percentage of total) versus violations by vehicle type (as a percentage of total violations) showed that for nearly all vehicle types, the violation rate was approximately the same, or lower, than the total observations for that vehicle type. The two vehicle types with an increased violation rate were vehicles with trailers (up 1.0%) and pickup trucks (up 2.9%).

The most common violation was crossing a solid (or double) yellow centerline. Drivers crossed a solid yellow centerline 53.6% of the time when there was no paved shoulder (194/362). When there was a paved shoulder, the violation rate dropped to 11.0% (87/789). In all instances, there was sufficient space within the lane for both the bicycle and a vehicle to safely overtake (while staying on or inside the center lane line and observing the 3-ft rule). The average clearance distance observed was 6.3 to 6.4 ft. This distance resulted in drivers crossing a solid yellow centerline whenever the lane was shared with a bicycle.

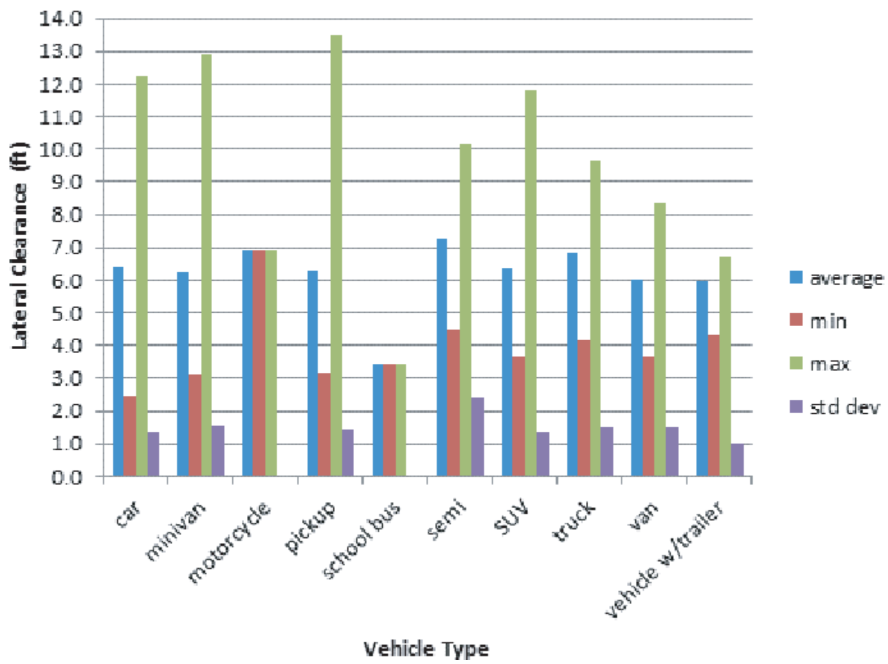
Of greater concern than just the overall violation rate is the roadway geometrics on which the violations occurred, specifically the vertical profile. When no bike lane was present, drivers heading down a grade were observed crossing a solid (or double) yellow centerline 42.9% of the time (12/28). For level grades with a solid (or double) yellow centerline, the violation rate was 37.9% (89/235). On uphill roadway segments, the violation rate was 93.9% (93/99). Downhill and level segments designated as no-passing zones are typically horizontal curves where sight distance may be limited by the interior of the curve, but there is likely sufficient visibility. Uphill segments are vertical crest curves where sight distance is blocked by the ground and roadway itself. Table 4 shows the complete breakdown for roadway grade by presence or absence of a paved shoulder.

Of the 1,151 observed passing maneuvers, 107 were designated as hazardous situations within the data (9.3%). For this study, a hazardous situation was defined as a vehicle crossing a solid (or double) yellow line to pass on a blind uphill segment or with oncoming traffic on a level or downhill segment. No collisions were observed during the data collection for this study; however, two observations showed

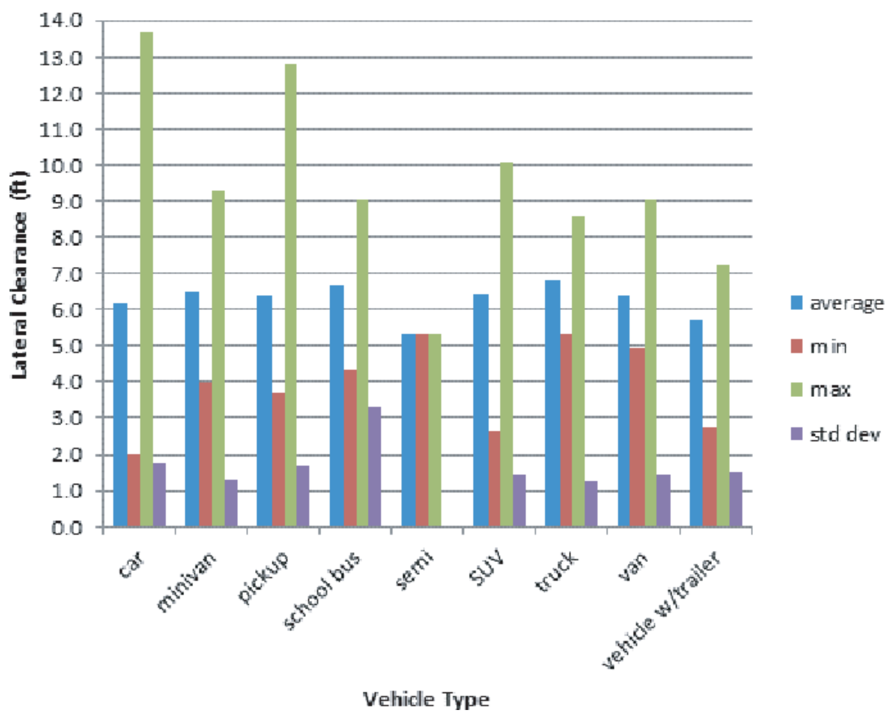
(a)

(b)

FIGURE 4 Examples of roadways (*a*) with and (*b*) without paved shoulder.



(a)



(b)

FIGURE 5 Lateral clearance distances by vehicle type: (*a*) bike lane and (*b*) no bike lane (min = minimum, max = maximum, std dev = standard deviation).

an oncoming vehicle being forced at least partially to leave the roadway to avoid a head-on collision. Figures 6 and 7 illustrate one of these observations.

Figure 6 provides three sequential images from the forward camera. In Figure 6*a,* the oncoming vehicle is first visible coming over a blind crest curve, just past the front of the white car. In Figure 6*b,* the white car has moved back to the center of its lane, but the red car is significantly across the double yellow centerline. In Figure 6*c,* the oncoming vehicle has been forced to drive onto the unpaved shoulder to avoid the red car, which is still more than 1 ft across the double yellow centerline.

Figure 7 provides three sequential images from the rearview camera. In Figure 7*a*, the red car is shown as it overtakes the data collection bicycle. In Figure 7*b*, the oncoming car is first visible in

TABLE 3 Violations by Vehicle Type

Vehicle Type	Count	% of Violations	% of Violations Within Vehicle Type
Car	129	45.9	24.2
SUV	66	23.5	22.0
Pickup	49	17.4	31.6
Minivan	19	6.8	19.4
Truck	7	2.5	29.2
Van	3	1.1	16.7
Vehicle with trailer	6	2.1	46.2
Semi	2	0.7	33.3
School bus	0	0.0	0.0
Motorcycle	0	0.0	0.0
Total	281	100.0	

the rearview camera and is still driving with passenger side tires completely on the unpaved shoulder. In Figure 7*c,* a full view of the oncoming vehicle is visible, and it is still driving on the shoulder. The elapsed time over this entire sequence was approximately 1 s.

CONCLUSIONS

Drivers and bicyclists have, seemingly, been complaining about each other's actions since they started sharing the roadways. Drivers have been quick to blame bicyclists for problems, and bicyclists have been quick to blame drivers for the same problems. Although studies have shown how these interactions occur on urban roads, only anecdotal evidence has existed for rural road

TABLE 4 Violations by Roadway Grade and Bike Lane Presence

Variable	Count	% of Subtotal	% of Category
No Paved Shoulder			
Downhill	28	7.7	
No violation	16		57.1
Violation	12		42.9
Level	235	64.9	
No violation	146		62.1
Violation	89		37.9
Uphill	99	27.3	
No violation	6		6.1
Violation	93		93.9
Subtotal	362		
Paved Shoulder			
Downhill	96	12.2	
No violation	90		93.8
Violation	6		6.3
Level	498	63.1	
No violation	445		89.4
Violation	53		10.6
Uphill	195	24.7	
No violation	167		85.6
Violation	28		14.4
Subtotal	789		
Grand total	1,151		

(a) (b) (c)

FIGURE 6 Head-on collision avoidance, front camera view.

(a)

(b)

(c)

FIGURE 7 Head-on collision avoidance, rear camera view.

interactions. This study found that drivers do, in fact, operate in a technically unsafe manner by frequently performing passing maneuvers outside of designated areas. This study also found that despite the frequent comment from bicyclists that drivers pass too closely, these actions are actually quite rare, at least for rural roads in the area around Madison, Wisconsin (at a minimum), accounting for only 0.5% of all the observed interactions (6 of 1,151). Drivers were far more likely to give bicyclists more room than required, risking a centerline violation, even when conditions were not safe to do so.

The study also found that as a group, the percentage of vehicle type and the percentage in violation for that vehicle type were approximately equal. Only pickup truck drivers were disproportionately likely to commit a moving violation. Finally, the bicycle lanes (paved shoulders) directly affected the likelihood that a driver would commit a moving violation, with violation rates four to six times lower when a paved shoulder was available.

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The Vehicle User Characteristics Committee peer-reviewed this paper.