

Bounds on Permissible Automated Vehicle Behavior on Virginia Freeways

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Abstract

Automation of the driving task will profoundly impact the safety and capacity of roadways. Because driving behavior will be encoded in software, automated vehicle developers require clear guidance regarding which driving behaviors are permissible on public roads. This article identifies potential restrictions on automated vehicle following distance, lateral movement, and platooning on Virginia freeways based on a review of the legal literature, model legislation, and Title 46.2 of the Code of Virginia on motor vehicles. The reasonable and prudent standard used to regulate following distance may vary in practice based on one's selected guidance (e.g. legal concepts such as the Assured Clear Distance Ahead doctrine, industry standards, recommended driver training distances) and assumptions regarding braking abilities of leading vehicles. Several statutes have relevance to lateral movement, both position within a lane and lane selection. No regulations were found that expressly prohibit platooning.

Keywords: Vehicle automation, regulation, capacity

Introduction

Automation of the driving task continues to progress rapidly, with significant investment from industry. Because vehicles are controlled by computer software, they will require that driving behaviors such as speed and lane selection be encoded in a vehicle's programming. For a vehicle to drive in a safe manner in adherence with all laws, motor vehicle codes must be translated into computer code with relevance to a range of potentially applicable situations. This is complicated by competing interpretations of statutes as well as supplemental case law.

The objective of this study was to identify the relevant legal and regulatory issues that may affect the behavior of automated vehicles on freeways in Virginia. The studied behaviors were allowable following distances, lateral movement (both within a lane and lane selection), and the formation of closely-spaced platoons. Implications for roadway capacity were discussed, as these issues might be relevant for transportation modelers seeking to understand the impact of automated vehicles on a network. Finally the status of the definition of "driver" in the Code of Virginia was also discussed, as this definition seems

contingent on the enforceability of any statute that refers to a vehicle's driver.

This analysis was not performed by an attorney and does not represent any official legal interpretation by the Commonwealth of Virginia or any of its agencies. The Office of the Attorney General has not yet issued any interpretations of many of these issues. The list of legal and regulatory issues identified in this report is neither comprehensive nor exhaustive.

Methods

To determine potential restrictions on driving behavior relevant to automated vehicles, a review of the relevant literature, model legislation, and Title 46.2 of the Code of Virginia on motor vehicles was conducted. Several aspects of automated vehicle behavior were considered, such as allowable following distance, visibility and stopping sight distance standards, restrictions on lateral movement, and barriers to the formation of vehicle platoons.

In addition to the Code of Virginia, this task relied on the following documents: a legal audit of fifteen states (including Virginia) regarding vehicle automation prepared as part of the National Cooperative Highway Research Program (NCHRP) (1), an analysis of automated vehicle freeway capacity considering the Assured Clear Distance Ahead doctrine (2), an early assessment of the legality of automated vehicles in the United States (3), and an NCHRP report on dedicating lanes for automated vehicles (4). Other literature was found from forward and reverse citations from these articles, as well as searches using the terms car-following, capacity, behavior, automated vehicle, and autonomous vehicles in various combinations. Searches were performed in Google Scholar and the Transport Research International Documentation database (5), an integrated database of the Transportation Research Board's Transportation Research Information Services (TRIS) database and OECD's Joint Transport Research Centre's International Transport Research Documentation (ITRD) database.

Definition of Driver

A recent legal audit of state motor vehicle codes for automated vehicles noted that following distance laws in most states, including Virginia (§ 46.2-816), refer to the "driver" of a motor vehicle. If the term "driver" is interpreted as referring only to a natural person, then following distance restrictions may not apply to AVs:

"Following distance requirements generally apply to the 'driver' of a vehicle. But recall that the term 'driver' is ambiguous and can thus have a range of meanings, which includes the possibility that trucks with an ADS properly engaged have no 'driver' and hence are not bound by any following distance requirement at all" (1).

The authors of the study recommend that policymakers consider the possibility that their existing vehicle codes might be interpreted to regulate only "drivers" who are human, exempting highly automated vehicles (where automated driving systems are effectively the "drivers") from most regulation.

Following Distance

The vehicle behavior with the most significant impact on freeway capacity is the distance headway or time headway at which it follows the vehicle directly ahead. The spacing between vehicles can be expressed in units of distance or time. Spacing can be converted between distance and time using the equation:

$$d = vt$$

In this equation, d is the distance, t is the time, and v is the speed of the vehicle.

Additionally, there are two standard definitions of vehicle spacing: gap and headway. Gap refers to the separation between the rear of the lead vehicle and the front of the following vehicle. Headway refers to the separation between the front of the lead vehicle and the front of the following vehicle. Figure 1 demonstrates these differences.

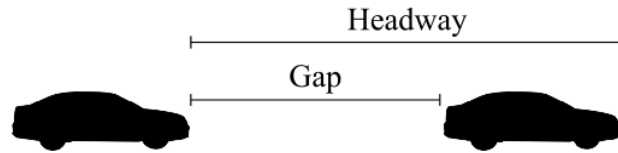


Figure 1. Gap and headway between two vehicles

The gap can be converted to headway using the equations:

$$d_{headway} = d_{gap} + x_l$$

$$t_{headway} = t_{gap} + \frac{x_l}{v}$$

In these equations, $d_{headway}$ is the distance headway, d_{gap} is the distance gap, $t_{headway}$ is the time headway, t_{gap} is the time gap, x_l is the length of the lead vehicle, and v is the vehicle speed.

Driver's Education Training

Many state departments of motor vehicles, in their driving training courses, recommend headways of two to four seconds (2). Virginia DMV (6) recommends a varying headway of between two and four seconds depending on the speed of the vehicle, as shown in Table 1.

Table 1. Virginia DMV recommended time headways in dry conditions (6)

Vehicle Speed	Recommended Headway
Under 35 mi/hr	2 seconds
35 – 45 mi/hr	3 seconds
46 – 70 mi/hr	4 seconds

These headways are directly related to capacity, as two-second headways yield 1,800 veh/ln/hr, three-second headways yield 1,200 veh/ln/hr, and four-second headways yield 900 veh/ln/hr. Observed and theoretical capacities are higher than those suggested by DMV following distances. The Highway Capacity Manual assumes a theoretical maximum capacity of a freeway under ideal conditions of 2,250 to 2,400 passenger cars per hour per lane depending on free-flow speed (7). These equate to headways of 1.5 to 1.6 seconds. Capacities of 2800 veh/ln/hr have been observed in the field (8), from average headways of 1.3 seconds.

Automated vehicles may also follow at shorter than recommended time headways. The adaptive cruise control feature in a 2017 Audi Q7 can be set to the following time gap of one second (9), and Virginia recently hosted a truck platoon demonstration with gaps of 0.6 seconds at speeds of 55 mi/hr (10). In research demonstrations, automated vehicles have driven with gaps as short as 13 feet and 0.18 seconds when using vehicle-to-vehicle communications (11).

Statutory guidance

The Virginia Driver’s Manual is an informational tool. Therefore, these recommendations do not supersede “the Code of Virginia, Virginia Administrative Code, or any other statute” (6). The Code of Virginia is less specific than DMV guidance regarding following distance. Va. Code § 46.2-816 states, “The driver of a motor vehicle shall not follow another vehicle, trailer, or semitrailer more closely than is reasonable and prudent, having due regard to the speed of both vehicles and the traffic on, and conditions of, the highway at the time.” Violation of this restriction can constitute negligence per se (3), and the overall effect of this law on capacity depends on the interpretation of the qualitative terms “reasonable and prudent.”

Assured clear distance ahead doctrine

One attempt to define a reasonable following distance is the Assured Clear Distance Ahead (ACDA) doctrine. This refers to a common law manifestation of defensive driving concepts where a vehicle operator is responsible for maintaining a sufficient gap so that the vehicle can be stopped for an object within his or her path. Pearson (12) defines ACDA as requiring a driver to “regulate his speed so that he can stop within the range of his vision.” Most jurisdictions follow this standard, presuming negligence on the part of the following driver in a rear-end collision regardless of whether the leading vehicle was moving or stopped (13).

An exception to the ACDA doctrine is the Sudden Emergency doctrine, which excuses a driver from negligence in a collision with a vehicle, person, or object that moves unexpectedly into the lane, either laterally or vertically, e.g., a falling tree branch. Buchwalter et al. (13) provides an example: “A motorist driving at a reasonable speed and obeying the rules of the road is generally not liable for injuries to a child who darts in front of the vehicle so suddenly that the motorist cannot avoid injuring the child, as where a child darts out from behind other vehicles that were stopped in traffic, directly into the path of the vehicle, and there is no evidence that [the] driver was driving too fast.” A vehicle abruptly changing lanes into the path of another vehicle may also qualify under the Sudden Emergency doctrine (14), while physical features of the roadway may not (15).

Le Vine et al. (2) note that ACDA generally requires drivers to avoid striking both the vehicle ahead as well as stationary objects. Avoiding only the vehicle ahead is referred to as the “weak” interpretation and allows closer following distances. Avoiding stationary objects as well is referred to as the “strong” interpretation, as it requires that a driver maintain sufficient space to stop not only for the vehicle ahead but for debris that may appear within the driver’s range of vision only after the leading vehicle has passed over it. Consider a tractor-trailer that may drive over a moderately-sized box with which a smaller following car might collide; the driver of the following vehicle would need to maintain a following distance adequate to come to a complete stop. Disregarding reaction time, a vehicle traveling at 55 mi/hr and capable of decelerating at a rate of 16.4 ft/s² (2) must maintain a time gap of 2.46 seconds to the leading vehicle to avoid striking the box, a distance greater than minimum settings on some ACC systems (9) as well as following distances observed in the field.

Le Vine et al. (2) calculate minimum allowable headway as:

$$H_{min} = t_{lag\ f} + \frac{v}{2a_f} - \frac{x_{veh} - \frac{v^2}{2a_l}}{v}$$

Where:

H_{min}	minimum allowable time headway
$t_{lag\ f}$	reaction time of following vehicle f , set as 0.4 seconds unless otherwise noted
a_f	maximum deceleration of following vehicle f
a_l	assumed maximum deceleration of leading vehicle l
v	free-flow speed
x_{veh}	length (units of distance) of leading vehicle l , set to 19 feet unless otherwise noted

The derivation of the minimum headway equation can be found in Appendix B of Levine et al. (2).

Based on a vehicle’s braking ability, the applied interpretation of ACDA, assumptions regarding the

leading vehicle's braking ability, and vehicle speeds, there several ways that adherence to ACDA may impact minimum following headways and freeway capacity. Le Vine et al. (2) identify 11 scenarios, shown in Table 2.

Table 2. Automated vehicle following scenarios with different ACDA interpretations and assumptions (2)

Name	a_l (ft/s ²)	a_f (ft/s ²)	Min Allowable Headway (s)			Notes
			55 mi/hr	65 mi/hr	75 mi/hr	
Baseline Weak	28.3	16.4	1.7	1.8	2.0	Must stop for vehicle ahead only
Baseline Strong	Inf	28.3	2.1	2.3	2.5	Must stop for debris as well
Scenario 1	21.3	16.4	1.2	1.3	1.3	Wet pavement
Scenario 2	41.6	16.4	2.1	2.4	2.6	Assumes lead vehicle is high performance
Scenario 3	N/A	a_l	0.6	0.6	0.6	Assumes can brake at same rate as lead vehicle
Scenario 4	41.6	28.3	1.1	1.1	1.2	Following vehicle can brake at maximum rate
Scenario 5	30.38	26.21	0.8	0.8	0.9	a_l and a_f brake at 99.9 th and 0.1 th percentile of typical passenger car hard brake, respectively
Scenario 6	28.3	1.8	21.6	25.4	29.2	a_f same as high-speed rail
Scenario 7	28.3	26.0	0.8	0.7	0.7	a_f set so that local maximum capacity attained at $v = 75$ mi/hr
Scenario 8	28.3	16.4	1.3	1.4	1.6	Instant reaction time using CV technologies (0.4 s all other scenarios)
Scenario 9	28.3	16.4	1.7	1.8	2.0	25 percent longer lead vehicle length

Note: a_l denotes the leading vehicle and a_f denotes the following vehicle.

In many scenarios, the following vehicle is expected to brake at 16.4 ft/s², which represents both the upper limit of adaptive cruise control braking standards and the lower limit of forward collision mitigation systems standards. The leading vehicle is expected to brake at various, often higher rates of deceleration, forcing the following vehicle to leave adequate spacing. Headways varied from 0.6 seconds when the following vehicle was assumed to be capable of braking at the same rate as the lead vehicle, to 29.2 seconds for the following vehicle that can decelerate no faster than is permitted on high-speed rail. In most scenarios, however, time headways at 75 mi/hr range from 0.9 to 2.6 seconds.

Human drivers routinely violate ACDA requirements. In low-light conditions, drivers adhering to ACDA would be limited to speeds of 20 mi/hr to avoid striking a “dark-clad pedestrian” (16). Violations are also observed in daylight conditions. Videos of vehicles on a California freeway were recorded and analyzed as part of the Next Generation Simulation (NGSIM) study (17). Assuming that following vehicles could brake at maximum rates with negligible reaction time, drivers in the NGSIM study violated ACDA 0.2%

of the time (2). Under more realistic assumptions of reaction times between 0.5 and 1.75 seconds, vehicles were observed to violate ACDA requirements between 1.5% and 49% of the time (2).

Industry standards

Adaptive cruise control systems on production vehicles generally adhere to the ISO 15622 standard (18). Under this standard, vehicles are limited to following time gaps of 0.8 seconds or higher, and at least one selectable time gap setting should be within the range of 1.5 to 2.2 seconds. When the ACC system is initiated and has not retained the previous time gap setting selected by the driver, then the time gap must be set to a “predefined default value equal of 1.5 s or greater” (18).

Summary of standards

Table 3 lists several of the time headways discussed in this section. All represent vehicles with various levels of automation except the DMV headway. All but one of the Le Vine et al. (2) settings (Scenario 8) represent unconnected vehicles that cannot communicate wirelessly with the lead vehicle but instead must rely on their sensors to detect closing speed.

Table 3. Examples of car-following headways

Citation	Headway at 65 mi/hr	Notes^a
Le Vine et al. (2)	0.6 – 2.6 s	Requires adherence to Assured Clear Distance Ahead doctrine. See citation and Table 2 for parameters and assumptions.
ISO (18)	1.0 s	Minimum allowable headway for the ACC system.
	1.7 s	Minimum default headway for the ACC system.
	2.4 s	Maximum default headway for the ACC system.
Audi (9)	1.2 s	Minimum headway setting for 2017 Audi Q7’s ACC system.
	2 s	Recommended headway setting for 2017 Audi Q7’s ACC.
DMV (6)	4 s	Recommended headway, not specified in the Code of Virginia.

^a Time gaps have been converted to headways by adding 0.2 seconds, i.e., the time required for a vehicle to travel 19 feet (the length of a vehicle) at 65 mi/hr.

Lateral Movement

Several guidance documents and statutes address the lateral position of a vehicle on Virginia freeways, both in terms of lane selection and position within a lane. The Virginia DMV recommends but does not require driving in the middle of the lane, especially when driving through work zones (6). Table 4 is a non-comprehensive list of statutes with potential relevancy for automated vehicle operations on freeways.

Table 4. Sample of Virginia statutes regarding lane selection relevant to AVs on freeways

Code of Virginia Statute	Relevant Language
§ 46.2-838. Passing when overtaking a vehicle	The driver of any vehicle overtaking another vehicle proceeding in the same direction shall pass at least two feet to the left of the overtaken vehicle and shall not again drive to the right side of the highway until safely clear of such overtaken vehicle, except as otherwise provided in this article.
§ 46.2-804. Special regulations applicable on highways laned for traffic; penalty.	Any vehicle proceeding at less than the normal speed of traffic at the time and place and under the conditions existing shall be driven in the lane nearest the right edge or right curb of the highway when such lane is available for travel except when overtaking and passing another vehicle or in preparation for a left turn or where right lanes are reserved for slow-moving traffic as permitted in this section;
§ 46.2-842.1. Drivers to give way to certain overtaking vehicles on divided highways.	It shall be unlawful to fail to give way to overtaking traffic when driving a motor vehicle to the left and abreast of another motor vehicle on a divided highway. On audible or light signal, the driver of the overtaken vehicle shall move to the right to allow the overtaking vehicle to pass as soon as the overtaken vehicle can safely do so. A violation of this section shall not be construed as negligence per se in any civil action.
§ 46.2-921.1. Drivers to yield right-of-way or reduce speed when approaching stationary emergency vehicles or public utility vehicles on highways; penalties	The driver of any motor vehicle, upon approaching a stationary vehicle that is displaying a flashing, blinking, or alternating blue, red, or amber light or lights as provided in § 46.2-1022, 46.2-1023, or 46.2-1024, subdivision A 1 or 2 of § 46.2-1025, or subsection B of § 46.2-1026 shall (i) on a highway having at least four lanes, at least two of which are intended for traffic proceeding as the approaching vehicle, proceed with caution and, if reasonable, with due regard for safety and traffic conditions, yield the right-of-way by making a lane change into a lane not adjacent to the stationary vehicle or (ii) if changing lanes would be unreasonable or unsafe, proceed with due caution and maintain a safe speed for highway conditions. The provisions of this section shall not apply in highway work zones as defined in § 46.2-878.1.

The statutes in Table 4 may affect capacity in several ways. For example, § 46.2-842.1 requires drivers traveling “to the left and abreast of another motor vehicle on a divided highway” to move to the right as soon as they can safely do so when signaled either by “audible or light signal” by an overtaking driver. Microscopic simulation models may wish to incorporate this behavior into lane-changing models, especially if automated vehicle developers choose to implement audible or light signals when overtaking in order to leverage this statute.

Capacity may decrease if automated vehicles strictly adhere to § 46.2-921.1. Often referred to as the “move over law,” this statute requires drivers encountering stationary vehicles with activated blue, red or amber lights “on a highway having at least four lanes, at least two of which are intended for traffic proceeding as the approaching vehicle” to move into the lane not adjacent to the stationary vehicle. If changing lanes is “unreasonable or unsafe,” the vehicle should “proceed with due caution and maintain a safe speed for highway conditions.” This may decrease capacity as vehicles switch lanes. This may also decrease capacity if automated vehicle developers determine that the “safe speed for highway conditions” is significantly lower than free-flow speed.

Platooning

For this section, platoons refer to two or more vehicles that operate on roadways in a close formation using automated driving technologies on some, but not necessarily all, vehicles. To achieve small headways of one second or less—and the resulting reductions in wind resistance and fuel usage—wireless connectivity among the vehicles is often used. Early deployments of platooning in the United States are expected to involve the trucking industry, as it enables long-distance shipment of goods with lower fuel costs, improved safety, and fewer paid drivers. Platoons do not require high levels of automation, as the lead vehicle in the platoon may be driven by a human who is responsible for slowing for traffic and avoiding incidents. The remaining vehicles may merely follow the vehicle ahead, provided they can safely move to the shoulder in the event of a hardware or software failure.

Virginia uses the “reasonable and prudent” standard for regulating following distances (§ 46.2-816):

“The driver of a motor vehicle shall not follow another vehicle, trailer, or semitrailer more closely than is reasonable and prudent, having due regard to the speed of both vehicles and the traffic on, and conditions of, the highway at the time.”

According to a recent NCHRP report auditing state laws on vehicle automation, states like Virginia that use only the “reasonable and prudent” standard may not need to modify their legislation to permit closely-spaced platoons:

“However, in states that currently apply Approach #1, the due care or “reasonable and prudent”- type standard that allows for safe distances between vehicles to vary based “the speed of such vehicles and the traffic upon and the condition of the highway” would arguably allow for safe distances to vary based on the [connected and automated driving system] features that enable truck platooning” (1).

Scribner (19), in a report from the Competitive Enterprise Institute (CEI), concurs with the NCHRP finding but recommends adding language to § 46.2-816 explicitly exempting connected and automated vehicle applications.

A recent audit of state motor vehicle law found that, while state DMVs and DOTs generally treat platoons as groups of individual trucks, there are other terms in state statutes that might be interpreted to cover platoons:

“To take one example, in the UVC and many of the state codes in our sample, there is a repeated reference to a “combination of vehicles,” a term that is rarely defined. While there appears to be a strong consensus that the term does not cover platoons, the law itself is somewhat ambiguous on this point” (1).

In Virginia, the term “combination of vehicles” appears in 29 statutes¹ but is not defined. The authors of the legal audit recommend that policymakers should consider providing guidance or introduce new legislation to provide a clearer definition of truck platoons. If platoons were classified under the term “combination of vehicles,” the authors argue, truck platoons would probably violate most length and weight restrictions (1). In Virginia, vehicle lengths are covered under § 46.2-1112, and in most circumstances, limit combinations of vehicles to 65 feet. Gross weight for a combination of vehicles on Interstate highways is generally limited to 80,000 lbs. (84,000 lbs. with a fee) under § 46.2-1127, § 46.2-1126, and § 46.2-1128.

¹ § 46.2-1117.1. Commercial delivery of towaway trailers; § 46.2-697. Fees for vehicles not designed or used for transportation of passengers; § 46.2-1110. Height of vehicles; damage to overhead obstruction; penalty; § 46.2-1104. Reduction of limits by Commissioner of Highways and local authorities; penalties; § 46.2-644.01. Lien of keeper of garage, § 46.2-1112. Length of vehicles, generally; special permits; vehicle combinations, etc., operating on certain highways; penalty; § 46.2-613.1. Civil penalty for violation of license, registration, and tax requirements and vehicle size limitations; § 3.2-5812. Capacity of scales not to be exceeded; determining gross or tare weight of vehicle or combination of vehicles; § 46.2-701. Combinations of tractor trucks and semitrailers; five-year registration of certain trailer fleets; § 46.2-1116. Vehicles having more than one trailer, etc., attached thereto; exceptions; § 46.2-1117.1. Commercial delivery of towaway trailers; § 46.2-113. Violations of this title; penalties; § 46.2-1083. Rear fenders, flaps, or guards required for certain motor vehicles; § 46.2-1127. Weight limits for vehicles using interstate highways; § 46.2-1018. Marker lights on vehicles or loads exceeding thirty-five feet; § 46.2-872. Maximum speed limits for vehicles operating under special permits; § 46.2-100. Definitions; § 46.2-341.4. Definitions; § 46.2-2000. Definitions; § 46.2-341.16. Vehicle classifications, restrictions, and endorsements; § 46.2-704. Prohibited operations; checking on weights; penalties; § 46.2-1138.2. Town ordinances concerning weight limits on certain roads; § 46.2-1067. Within what distances brakes should stop vehicle; § 46.2-1138.1. City ordinances fixing weight limits on certain roads; § 46.2-657. When registration by nonresident not required; § 46.2-843. Limitations on overtaking and passing; § 46.2-870. Maximum speed limits generally; § 46.2-1231.1. Immunity from liability for certain towing; § 46.2-1068. Emergency or parking brakes.

Conclusions

This study investigated possible legal and regulatory restriction on automated vehicle behavior when operating on freeways in Virginia. The findings have relevance for automated vehicle developers attempting to program safe and legal vehicles, as well for modelers seeking to measure capacity impacts of automated vehicles on Virginia freeways.

The desired following distance selected by automated vehicles may vary based on a vehicle's braking ability, assumptions about other vehicles' braking behaviors, interpretations of legal concepts such as the Assured Clear Distance Ahead doctrine, industry standards, consumer preference, recommended driver training distances, or a range of other factors.

Virginia statutes do not explicitly prohibit platooning at close following distances. Virginia does not specify any following distance or cut-in requirements for vehicles, relying instead on the “reasonable and prudent” standard, and is, therefore, a permissive regulatory environment for most platooning applications.

Virginia should consider the possibility that the interpretation of “driver” in state statutes might apply only to humans and not exempt a highly automated vehicle—where the automated driving system might be considered the “driver”—from regulation. Virginia should also consider the possibility that a truck platoon is interpreted to be a “combination of vehicles” and therefore subject to weight and length restrictions that make the operation of multi-vehicle platoons impractical.

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References

1. National Academies of Sciences, Engineering, and Medicine. (2018). *Implications of connected and automated driving systems, vol. 2: State legal and regulatory audit*, Washington DC: The National Academies Press. <https://doi.org/10.17226/25296>.
2. Le Vine, S., Y. Kong, X. Liu, and J. Polak. (2017). Vehicle automation and freeway ‘pipeline’ capacity in the context of legal standards of care, *Transportation*, vol. 46 no. 4, pp. 1215–1244. <https://doi.org/10.1007/s11116-017-9825-8>.
3. Smith, B. W. (2014). Automated vehicles are probably legal in the United States, *Texas A&M Law Review*, vol. 1, pp. 411–521. <https://doi.org/10.2139/ssrn.2303904>.
4. National Academies of Sciences, Engineering, and Medicine. (2018). *Dedicating lanes for priority or exclusive use by connected and automated vehicles*, Washington DC: The National Academies Press. <https://doi.org/10.17226/25366>.

5. Transportation Research Board. Transport Research International Documentation - TRID. <https://trid.trb.org/>. Accessed Jun. 10, 2019.
6. Virginia Department of Motor Vehicles. *Virginia driver's manual*. <https://www.dmv.virginia.gov/webdoc/pdf/dmv39.pdf>. Accessed Jun. 10, 2019.
7. Transportation Research Board. (2016). *Highway capacity manual: A guide for multimodal mobility analysis*, Washington DC: Transportation Research Board.
8. Dong, S., A. Mostafizi, H. Wang, and J. Li. (2018). A stochastic analysis of highway capacity: empirical evidence and implications, *Journal of Intelligent Transportation Systems*, vol. 22, no. 4, pp. 338–352. <https://doi.org/10.1080/15472450.2017.1396898>.
9. Audi AG. (2016). *Owner's manual, 2017 Q7*. Publication 4M0012721BC. Ingolstadt, Germany: Audi AG.
10. Reiskin, J. S. (2017). FHWA demonstrates 3-truck platoon in Virginia, *Transport Topics*. <https://www.ttnews.com/articles/fhwa-demonstrates-3-truck-platoon-virginia>.
11. Tsugawa, S. (2013). An overview on an automated truck platoon within the Energy ITS Project, *IFAC Proceedings Volumes*, vol. 46, no. 21, pp. 41–46. <https://doi.org/10.3182/20130904-4-JP-2042.00110>.
12. Pearson, J. O. (2005). Automobiles: sudden emergency as exception to rule requiring motorist to maintain ability to stop within assured clear distance ahead, in *American Law Reports* 75, p. 333.
13. Buchwalter, J. D., W. H. Danne, J. J. Dvorske, L. H. Dietz, R. P. Eclaves, E. K. Esping, S. Larsen, J. K. Levin, W. Lindsley, T. Muskus, and E. C. Sutette. (1962). *American Jurisprudence 2d: Automobiles and Highway Traffic*, Jurisprudence Publishers, Inc.
14. Decker v. Wofford. (1960). NW2d, 104, p. 760.
15. Coppola v. Jameson. (1972). NW2d, 200, p. 877.
16. Leibowitz, H. W., D. A. Owens, and R. A. Tyrrell. (1998). The assured clear distance ahead rule: Implications for nighttime traffic safety and the law, *Accident Analysis & Prevention*, vol. 30, no. 1, pp. 93–99. [https://doi.org/10.1016/S0001-4575\(97\)00067-5](https://doi.org/10.1016/S0001-4575(97)00067-5).
17. FHWA. (2007). *NGSIM fact sheet: US Highway 101 dataset*, Publication FHWA-HRT-07-030. Washington DC: Federal Highway Administration.
18. ISO. (2010). *ISO 15622:2010(En), Intelligent transport systems — adaptive cruise control systems — performance requirements and test procedures*, Publication ISO 15622:2010, Geneva:International Organization for Standardization.
19. Scribner, M. (2018). *Authorizing automated vehicle platooning: A guide for state legislators*, Washington DC: Competitive Enterprise Institute.