

Operational Definitions of Driving Performance Measures and Statistics

RATIONALE

A common and consistently defined vocabulary is a basic requirement for comparing evaluation procedures and their results for driving contexts, vehicles, and vehicle components. This is the reason for foundational documents such as SAE J1100 Motor Vehicle Dimensions (Society of Automotive Engineers, 2009) and related mobility documents (Steinfeld, Fong, Kaber, Lewis, Scholtz, and Goodrich, 2006). (See also National Research Council, 2011.) As shown by Savino (2009) and Green (2012), many terms used to describe driving performance are not consistently named, defined (if they are defined at all), or used in the automotive engineering and research literature. This inconsistency makes comparing studies, test procedures, and results difficult, which in turn can compromise safety and usability. To overcome the inconsistency problem, this document provides standard names and definitions of driving performance measures and statistics, as well as supporting information to encourage their use.

SAE J2944 has been reaffirmed to comply with the SAE Five-Year Review policy.

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1. SCOPE

This Recommended Practice, Operational Definitions of Driving Performance Measures and Statistics, provides functional definitions of and guidance for performance measures and statistics concerned with driving on roadways. As a consequence, measurements and statistics will be calculated and reported in a consistent manner in SAE and ISO standards, journal articles proceedings papers, technical reports, and presentations so that the procedures and results can be more readily compared. Only measures and statistics pertaining to driver/vehicle responses that affect the lateral and longitudinal positioning of a road vehicle are currently provided in this document. Measures and statistics covering other aspects of driving performance may be included in future editions. For eye glance-related measures and statistics, see SAE J2396 (Society of Automotive Engineers, 2007) and ISO 15007-1 (International Standards Organization, 2002).

1.1 Applicable Vehicles

This Recommended Practice applies to both left- and right-hand-drive wheeled vehicles having a steering control, accelerator pedal, and brake pedal. This document applies primarily to passenger vehicles, heavy trucks, and buses, including articulated vehicles and vehicles towing trailers, but may be useful for other types of vehicles. It applies to agricultural, construction, industrial, and military vehicles when those vehicles are driven on roadways, not off-road. Vehicles may be completely operated by a driver, automatically driven, or be operated by shared control.

This document does not apply to two-wheeled, three-wheeled, and tracked vehicles to avoid complicating the specification of lane-related measures and because of the unique steering controls they may have. Road vehicles operated only by hand controls and not foot controls, such as those driven by persons with physical disabilities, are also excluded to avoid complicating the specification the response time measures.

In addition, measures in section 7 concerning reaction, movement, and response time for foot pedals are not applicable for vehicles with a clutch pedal. These measures for vehicles with clutch pedals were not included in this edition of J2944 to avoid delaying its publication. However, measures in the rest of this document are applicable to vehicles with clutch pedals.

1.2 Applicable Contexts

This document is applicable to studies and tests of vehicles and drivers conducted on public and private traveled ways, on test tracks, or in driving simulators. All functional classes of highways and streets, as defined by the American Association of State Highway and Transportation Officials (AASHTO, 2011) Green Book, chapter 1 are included to support naturalistic driving studies.

1.3 Purpose

The measures and statistics defined in this document are used to describe the lateral and longitudinal control of road vehicles as part of safety and/or usability evaluations of (1) driver distraction caused by in-vehicle information systems (e.g., navigation systems, in-vehicle cell phones), (2) driver awareness and assistance systems (e.g., adaptive cruise control, lane keeping assistance, collision warning, crash avoidance braking), (3) fitness to drive/licensing, (4) drug and medication use by drivers, (5) autonomous driving, and (6) for other purposes. These measures and statistics appear in technical standards, journal articles, proceedings papers, technical reports, and presentations.

2. REFERENCES

2.1 Applicable Publications

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

Nakayama, O., Futami, T., Nakamura, T., And Boer, E.R. (1999). Development of a Steering Entropy Method for Evaluating Driver Workload (SAE paper 1999-01-0892), Warrendale, PA.

2.1.2 Related Publications

Several definitions included in this document have been taken verbatim or nearly verbatim from published articles listed in this section. The complete mathematical derivations of them, copied from the original articles, appear in the appendices so all relevant information appears in one document. Minor changes were made to improve clarity or to be consistent with SAE practice.

Boer, E.R., Rakauskas, M.E., Ward, N.J., and Goodrich, M.A. (2005). Steering Entropy Revisited, Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, 25-32, (http://drivingassessment.uiowa.edu/DA2005/PDF/05_Boerformat.pdf, retrieved June 7, 2011).

Brown, T. (2005). Adjusted Minimum Time-To-Collision (TTC): A Robust Approach to Evaluating Crash Scenarios, Proceedings of the Driving Simulation Conference North America, 40-48.

Markkula, G. and Engstrom, J. (2006). A Steering Wheel Reversal Rate Metric for Assessing Effects of Visual and Cognitive Secondary Task Load, paper presented at Proceedings of the 13th ITS World Congress, London, United Kingdom.

Minderhoud, M.M. and Bovy, P.H.L. (2000). Extended Time-to-Collision Measures for Road Traffic Safety Assessment, Accident Analysis and Prevention, 33(1), 89-97.

van der Horst, A.R.A. (1990). A Time-based Analysis of Road User Behaviour in Normal and Critical Encounters (Ph.D. thesis), Delft, Netherlands: Delft University of Technology, (http://repository.tudelft.nl/assets/uuid:8fb40be7-fae1-4481-bc3712a7411b85c7/emc_horst_19900424.PDF, retrieved February 15, 2015).

Van Winsum, W., Brookhuis, K.A., and De Waard, D. (2000). A Comparison of Different Ways to Approximate Time-to-Line Crossing (TLC) during Car Driving, Accident Analysis and Prevention, 32(1), 47-56.

NOTE: Most of the references cited in this document are in the Bibliography at the end of the Appendices.

3. CITING J2944 DEFINITIONS

REQUIREMENTS: The first time any terms defined in this Recommended Practice are used in a document, SAE J2944 shall be cited.

For terms for which there are parameters, for example a value greater than which data are excluded in a calculation, those parameter values shall be identified.

EXAMPLE: “The dependent statistic of interest was mean value of center of gravity (CG) distance separation, per SAE J2944. All values in excess of 120 m were omitted.”

For terms with multiple definitions (options), the option used shall be identified.

EXAMPLE: “The dependent statistic of interest was mean value of time-to-collision (TTC), option B per SAE J2944. All TTC values in excess of 10 s were excluded.”

4. INTRODUCTION

4.1 Background and Current Practice

Historically, there have been few comprehensive attempts to define terms used to describe driver performance, and only Savino (2009) examined common practice. As part of his master's thesis, Savino established a set of criteria for defining and naming standard terms. Savino's thesis was the motivation for this document. To determine names and terms that were used in the literature, Savino examined the driving performance literature from 2000-2005 including every article in *Human Factors*, *Ergonomics*, the *Driving Assessment and Human Factors and Ergonomics Society Conference Proceedings*, as well as Gawron's 2000 *Human Performance Measurements Handbook* and DOT (Department of Transportation) technical reports. Some 498 publications were examined, of which 111 were relevant. Based on this research, Savino identified the relative frequency with which various driving performance terms were used and the definitions for them. In brief, there were essentially no terms for which there was a single common name, and definitions for terms were rarely provided. In a more recent review, Green (2012) reached similar conclusions.

A few of the terms have also been defined in SAE and International Standards Organization (ISO) adaptive cruise control (ACC) standards (SAE J2399, ISO 15622, ISO 22179), and the SAE and ISO lane departure warning (LDW) standards (SAE J2808, ISO 17631). In addition, there is relevant information in the three most influential documents related to highway design:

1. AASHTO Green Book (AASHTO, 2011),
2. FHWA (Federal Highway Administration) *Highway Capacity Manual* (Transportation Research Board, 2010), and
3. MUTCD (*Manual on Uniform Traffic Control Devices*) (U.S. Department of Transportation, 2009).

The FHWA *Model Inventory of Road Elements* (MIRE) report (Lefler, Council, Harkey, Carter, McGee, and Daul, 2010) is derived from these and other documents and is often cited as a source for terms related to highway design.

A key source of definitions from the vehicle crash literature is:

ANSI D16.1-2007, ANSI accident classification manual (American National Standards Institute, 2007).

Derived from ANSI D16, and often cited as a source for terms related to crash investigation and analysis are:

1. *Model Minimum Uniform Crash Criteria* (MMUCC, U.S. Department of Transportation, 2012b) and
2. *Fatality Analysis Reporting System (FARS) Analytical User's Manual (1975-2012)* (U.S. Department of Transportation, 2013b).

For a single concise review that contains data relevant to many of the measures and statistics in this document, see Yekshatyan (2008) and Back, Jaeger, Skov, and Thomassen (2009). For background, additional measures, and related information, see Rupp (2010) and Campbell, Lichty, Brown, Richard, Graving, Graham, O'Laughlin, Torbic, and Harwood (2012).

Generally, terms relevant to driving performance measures and statistics are not consistently named and terms are not explicitly defined in publications, though there are cases where terms may be inferred from other definitions, figures, or their usage in a publication (e.g., *roadway* was not defined, but *roadway departure* was) (Savino, 2009; Green, 2012). Even when cited or provided, some of the definitions conflict with each other and others are not specific enough to allow for replication. Furthermore, definitions have not been created in a manner that produces a family of consistent names and allows for future expansion of that family of definitions as new relevant terms are needed (for example, time and distance measures of a characteristic).

4.2 Approach

The ultimate goal of this document is to encourage consistent use of a single name and definition for each driving performance measure and statistic. However, multiple definition options are provided for a term when there is a need to (1) reflect the potential multiple interpretations of that term, (2) be consistent with current standards and guidelines, (3) create a complete set of options, (4) support the variety of methods used in past and current studies, or likely to be used in future studies, and (5) accelerate the process of reaching agreement as to how that term is best defined. By including multiple options for defined terms, authors are more likely to find the definition they used, and are therefore more likely to cite this document, promoting its use.

Terms that represent states or processes, such as *lane departure*, *roadway departure*, and *lane change* can have multiple meanings. For example, does *lane departure* mean that a lane departure is predicted, is just starting, is in progress, or the vehicle has departed from the lane? For lane change, its initiation can be defined narrowly (when the vehicle crosses the lane boundary) or more broadly (when the driver is preparing to change lanes).

There will be instances where new alternative definitions of terms may be needed as technology advances (e.g., an additional option for what constitutes a lane departure), or new research identifies improved criteria for a definition (e.g., when braking is deemed to begin). Practitioners and researchers are encouraged to publish those improvements, reference SAE Recommended Practice J2944, and send new or revised definitions along with supporting evidence to the Driver Performance Operational Definition Subcommittee of the SAE Safety and Human Factors Steering Committee. Contact information is provided at the end of this document.

Guidance is provided to aid readers in applying the measures and statistics in this document. Typical values and frequency distributions for many of these measures and statistics from naturalistic and other driving studies have been provided to aid in understanding these definitions and to help users determine if their measurements are reasonable. Important references are provided to further understanding and encourage use of these definitions and this document. Again, the intent is to provide definitions for measures and statistics used in driving studies, encourage their use, and as a consequence, improve the quality of human factors evaluations of driving.

As users conduct evaluations using the measures and statistics in this document, they are encouraged to develop equations to predict differences between options. Further, they are encouraged to report results obtained for multiple options for the measures and statistics in the document, so that rules of thumb describing differences between options can be included in future versions of this document, enhancing its usefulness.

5. GENERAL MEASUREMENT AND REPORTING GUIDANCE AND REQUIREMENTS

Driving performance measures can be divided into at least three categories, (1) response time measures (for which means across trials are typically reported), (2) countable, discrete outcomes (such as lane and roadway departures), and (3) continuous performance measures such as steering wheel angle, lateral position, distance gap, time to collision) for which means, standard deviations, and other statistics are reported. Some of the guidance in this section applies to the measures and statistics in all three categories, whereas some apply to one or two categories. Countable outcomes can occur from a single trial (Did the vehicle depart the lane when the lead vehicle swerved?) or be aggregated over time (How many lane departures occurred in the fatigued condition?).

5.1 Good Measurement Practice

5.1.1 Specify a well-defined start point

The start point is a distinct, well-defined point indicating an event, task, or data collection has begun. Examples of event-related start points include:

1. illumination of a vehicle's brake lamps reaches a specified value,
2. illumination of a traffic signal reaches a specified value for some state or phase,
3. first word of a spoken warning begins or is completed, or an entire message is spoken,
4. lead vehicle decelerates above a specified threshold,
5. turn signal lamp flashes on, then off, and then starts to go on again, indicating a driver intends to change lanes,
6. front bumper of a vehicle on an intersecting path crossed a particular pavement marking for a pedestrian crossing, and
7. pedestrian begins to move a leg to walk in a particular direction.

In field experiments, video-based detection of events in the traffic environment is currently the most common method to determine the start point. Determination of start point is more challenging in the field than in a simulator, in part because there is less control over the initiating event, and because low resolution of the recorded video can sometimes make it difficult to perceive small objects/events far ahead of the subject vehicle.

For in-vehicle tasks, Angell, Cook, and Perez (2013) summarize discussions with human factors experts as to what constitutes the event start point, which for in-vehicle video display tasks requires identification of the first screen. That screen could be (1) the default start screen for the system function in question (the home screen, if there is one), (2) the screen used most often by the subject (often the radio menu), or (3) the screen on which the subject ended the previous task. Angell, Perez, and Garrott (2013) note that a task begins when the subject begins to interact with the device, which could be when the subject begins to move a hand to the device or when the subject first glances at the device, whichever occurs first.

For experiments that involve the driver states (e.g., fatigue), roadway, traffic, lighting, or weather conditions, the start point is generally a particular point on a roadway (e.g., a specified distance after an intersection or freeway entrance), but not immediately after the subject starts driving.

For identifying the start of foot movements, the shoe can be either on the floor, on a pedal, or suspended above the pedals. Use the lateral midpoint (x,y,z) of the shoe ball of foot to identify the initial shoe location if the shoe is not initially on a pedal. If the shoe starts on a pedal, report the geometric center of the pedal pad surface as the start point. See SAE J1100 (Society of Automotive Engineers, 2009) for pedal dimensions.

REQUIREMENTS: The start point of an event and a response shall be measurable and clearly defined when it is first used in a document. For the initial foot response, measure the position of the lateral midpoint of ball of the shoe or the geometric center of the pedal pad surface. The event and response start points shall also be reported.

5.1.2 Specify a well-defined end point

For event-initiated responses, the most significant problem in interpreting and comparing response time data is that the start point and/or end point of the response is often not clearly defined. Is the end point (1) when a specified movement of the accelerator pedal begins, or (2) when complete release of the accelerator pedal, touching the brake pedal, activating the stop lamp, full activation of the brake, or something else first occurs? Differences in the end point lead to substantial, practical differences in the values obtained.

The end point should be a distinct, well-defined point of the movement or utterance in response to the external event, not random variation in the accelerator movement that is directionally correct. The amount of movement, such as the angular rotation of the steering wheel (usually in degrees) or the movement of the accelerator (often in percentage displacement), and the time window over which the movement is detected shall be reported. Example end points could be: (1) when the foot is no longer in contact with the accelerator or (2) when the brake lamps illuminate in response to depressing the brake pedal.

For in-vehicle task-related measurements, the end point is when the subject has truly completed the task, which could be when the final manual input has occurred, or when the last glance has occurred. Determining the end point can be difficult in situations involving significant vehicle system delays (e.g., when the driver queries a web site and the vehicle system takes several seconds to retrieve and display the information to the driver). SAE J2364 (Society of Automotive Engineers, 2004) defines a system time-out period, most of which is excluded from the determination of total task time that the subject is engaged in the task. The disengagement is partial, with the subject making glances on the order of 1.0 - 1.5 s to the display every 5 - 10 s to determine if the task is completed and to obtain the desired information.

For experiments that involve the driver state (e.g., fatigue), roadway, traffic, lighting, or weather conditions, the end point is generally a particular point on a roadway determined in a manner similar to the start point.

REQUIREMENTS: The end point of a response shall be measurable and clearly defined when it is first used in a document. The amount of movement and the time window over which the movement is detected shall be reported.

5.1.3 Measure driver control movements accurately and precisely

Steering wheel and pedal movements are generally determined in one of four ways: (1) directly from the Controller Area Network (CAN¹) bus (which is becoming the most common method, available for all 1996 model year or newer cars), (2) from the OBD-II (On-Board Diagnostic) connector in U.S. vehicles or the EOBD (European On-Board Diagnostic) connector in European vehicles (present on gasoline engines since 2001 and diesel engines since 2004), (3) from displacement sensors installed on the accelerator and/or brake pedal to detect the onset of a driver pedal application or release; or (4) by manually or automatically coding the pedal response using frame-by-frame video analysis. For instances where the vehicle speed is controlled by the cruise control system, the beginning movement may be operating a switch to turn off the cruise control system or a foot movement towards the brake or accelerator.

Placing markers on the steering wheel rim (such as a ring of white adhesive tape) to make its angle more readily apparent facilitates video analysis. However, most steering measures require considerable accuracy (< 0.5 deg), a level that may be difficult to achieve visually (Johansson, Engstrom, Cherri, Nodari, Tofetti, Schindhelm, and Gelau, 2004).

The accuracy of movement timing depends upon the inverse of the frame rate of the video system. So, a system recording at 30 Hz is accurate to the nearest 33 ms, whereas a system recording at 5 Hz, as could be the case in a contemporary naturalistic driving study, is only accurate to the nearest 200 ms, which may be precise enough in many circumstances. In Europe and elsewhere, some video systems have frame rates of 50 Hz, in which case event times are accurate to the nearest 20 ms. Accordingly, measurement accuracy and precision shall be reported. A potential further complication is that to reduce processing requirements and minimize video storage requirements, the various cameras used may have different frame rates.

Of particular importance when sampling rates are low is the decision rule for identifying when movements appear to begin or end, (1) the frame in which there is clearly no movement, (2) the frame for which there is closest to no movement (indicated by minimal blur), or (3) some other rule. Often, the start and end points are determined manually by repeatedly replaying the frames around where the start/end point occurs to identify the key frame or frames. Whatever process and rules are used, they should be reported.

¹ CAN systems may not meet bandwidth requirements for connected or autonomous vehicles. Future systems may use Ethernet, FlexRay, LIN, or something else. See Schmid (2006), Talbot and Ren (2009), and Dello (2011) for a description of automotive serial buses.

Given concerns about the precision of video-based measurements when sampling rates are low, those measures may be complemented by displacement sensors that may also be paired with a load cell on the pedal itself to provide a better indication of the initial pedal contact time, as well as to measure the pedal forces applied by the driver. As described in 5.1.6, contemporary automated systems may independently apply the brakes, so the brake pressure may not always reflect driver actions. Obtaining CAN codes can be difficult for evaluators who do not work for manufacturers or suppliers. CAN codes are proprietary and often closely guarded by their developers. They are more widely available now than in the past and can sometimes be found online.

Another more binary method to determine when a brake is initially pressed as part of an emergency response is to place a microphone on or near the brake. The sound of the foot contacting the brake pedal provides accurate timing. This method is not often used and will be used less often in the future where brake-by-wire systems may provide the desired signal.

REQUIREMENTS: The accuracy and precision with which data were collected and the information used to determine such (e.g., video frame rates) shall be reported.

5.1.4 Eliminate sensor noise

Sensor noise can be intermittent or continuous. Intermittent noise includes shorts, disconnects, and failures that can be identified in plots of sensors outputs, where these failures are associated with outputs that are fixed ("flat lined", generally at zero or maximum values) for periods of time and may be caused by a sensor being disconnected, shorted, or failing for other reasons. Continuous noise includes AC electrical noise (50 or 60 Hz, depending on the recording system) and should be removed as it may result in signal values that appear to vary randomly when they are actually fixed. For example, when driving parallel to a lane marking, the distance to the lane marking over 100 m should only change by a few centimeters if the lane marking is straight. Plots of sensor output will reveal such problems. DC noise may result in upward or downward shifts of all values recorded for a sensor. When examining plots of data, the maneuver the driver is performing (e.g., car following on a straight section, driving through curves, braking in response to a traffic signal) needs to be considered.

In addition to electrical interference and sensor failures, there are other types of sensor noise that are inherent to the measures and groups of measures (GPS, vehicle speed, brake pressure, etc.) and how they are communicated to the data collection systems (dedicated digital or analog inputs, one of the CAN buses). Filtering is quite common for electrophysiological data (e.g., Healey and Picard, 2005; Mehler, Reimer, and Coughlin, 2012), but less so for driving performance data.

In addition to efforts to deal with specific errors, driving data are often filtered to eliminate random noise in the data. In filtering data consider the bandwidth of interest for each signal (e.g., for driver variables other than eye fixations, often less than 10 Hz for some tire characteristics, up to 100 Hz). The Nyquist folding frequency, which is double the frequency for which accurate measurement is desired, should be used to select filter cutoff frequencies. The most appropriate filter will depend on errors expected and the correction needed, with moving average, Kalman, Bessel, and Butterworth filters often being used. For examples, see Chen, Bas, and Bajpai (2009) and Chen, Shih, and Lin (2014).

REQUIREMENTS: Electronic noise from each sensor and out-of-range inputs shall be filtered out. Actions taken to deal with sensor noise shall be reported. When filters are used, the type of filter, whether the filter is low-, high- or band-pass, the cutoff frequency or frequencies, and any other relevant characteristics shall be reported.

5.1.5 Eliminate sensor and sensor integration lags

There are inherent time lags in on-board sensors, sensors added by experimenters, and systems associated with processing multiple sensors and integrating their output. In aggregate, lags can be quite large. For example, systems to determine foot movement may have mechanical and/or electronic sensor lags that can be as large as 300 ms (Lee, McGehee, Dingus, and Wilson, 1996).

More specifically, the delay that a driver experiences from the time of an input until the system responds is known as mechanical system lag time (Bullenger, Kern, & Braun, 1997). This lag is generally imperceptible to a driver, but in frame-by-frame analysis of video data, this lag becomes noticeable. However, detecting these lags may be difficult, depending on how the data are collected. U.S. video data is often recorded at 30 Hz, so a video record could lag an event by up to 33 ms. Furthermore, if multiple video streams are processed, multiplexing systems may wait until the last source is

complete (another 33 ms). There may be other delays associated with processing and storing frames. Krishnan, Gibb, Steinfeld, and Shladover (2001) estimate sensor delays are 100 ms.

For radar and LIDAR sensors, there may also be delays due to their scan times and reporting criteria. For example, the sensor may not report a target if it is detected on a single scan, but may require two successive scans or use some other rule such as two out of three successive scans. Delays can also occur when signals from multiple sensors are integrated.

REQUIREMENTS: Adjustments of response times to account for lags shall be reported because delays associated with lags can be a substantial fraction of response time.

5.1.6 Separate vehicle automated actions from driver actions

Automated functions include conventional and adaptive cruise control, lane keeping assistance systems, crash avoidance braking systems, and other systems that control some or all of the driving tasks.

When conventional cruise control and adaptive cruise control systems are actively controlling the throttle, the driver's foot does not have to be on the accelerator pedal. For adaptive cruise control there will be periods of time where changes in speed occur without any driver input. Lane-keeping and stability-control systems may apply the brakes to some or all of the wheels, and/or provide mild steering actions to maintain lane position or prevent unintended lane departure, partially overriding driver actions. Pre-crash braking systems and forward collision warning systems with braking capability intervene to help the driver avoid or reduce the severity of a collision. These systems may supplement or override driver actions, may pre-charge the brake, and cut off or reduce the throttle (Marshak, Cuderman, and Johnson, 2002; Forkenbrock, Snyder, and Jones, 2010). Consequently, there may be periods of time where changes in speed or lateral control may occur automatically without any driver input.

Other systems augment vehicle deceleration response to driver inputs. Pre-charging the brakes reduces the pedal displacement required for driver braking. Regenerative braking systems, or engine retarder systems in heavy trucks, may slow the vehicle without any change in brake pressure.

Keep separate of actions taken by automated functions and actions taken by the driver. This may require the foot pedal responses (and possibly steering responses) to be coded manually or automatically using frame-by-frame video analysis. The initial position of the foot (usually the right foot) should be taken from its position just before movement is initiated.

If automated functions are part of a steering or braking system, carefully examine the steering and brake pedal position data to ensure that the appropriate steering or braking start time is recorded. There are four cases to consider, (1) only the driver responded, (2) only the automated function responded, (3) the driver responded first but then the automated function took control, or (4) the automated function responded first but then the driver took control. Analysts have the option of (1) pooling trials in which either the driver or automated function responded, (2) analyzing the four cases separately, or (3) if there are only a few trials involving an automated response, ignoring the trials in which the automated function responded. To adequately assess the benefits of the automated function, analyze the four cases separately.

REQUIREMENTS: The automated systems (e.g., adaptive cruise control (ACC), lane keeping assistance (LKA)) installed in a test vehicle or in a driving simulator shall be reported as well as their state (off, standby, partially on, fully on, etc.) during each portion of an evaluation. Where automated functions take over from drivers or augment driver inputs, the conditions under which take over occurs (for example, the minimum operating speed for cruise control) shall be reported. Periods of automated or augmented control (e.g., cruise control is operating, regenerative braking is operating) shall be analyzed and reported separately from those of manual control.

5.1.7 Exclude preparatory movements from the accelerator or brake as well as random movements

Sometimes drivers will move their foot to be near or on a pedal anticipating a potential or developing threat. Such preparatory moves can be recorded but the primary response of interest is the driver response after the threat is perceived. However, if the driver rests a foot on the brake pedal, the brake sensor will indicate some displacement prior to a response event and even possibly activate a brake lamp. If this is the case, the brake position should be plotted in a time series to identify the point at which displacement of the brake pedal associated with the desired action occurs. When timing the driver's foot movements, use the first pedal movement (brake or accelerator) to determine when response time begins. If the foot rests lightly on the brake before the brake pedal is pressed in response to a threat, the movement of primary interest starts when the downward brake pedal motion is detected.

The brake pressure or other indicator of brake position will depend on the system. Normally, 0 % of maximum brake pressure (above nominal) indicates the foot is off the brake and 100 % is maximum pressure (and full pedal application), but that is not always the case. If a foot is resting on the brake pedal, the initial percentage of maximum brake pressure may not be 0 %. Hence, the indication of when braking has occurred may not be when brake pressure changes from 0 % of maximum brake pressure. To fully understand when meaningful braking has occurred and when a driver has responded by braking, the function relating brake pressure (or brake pedal position) to braking force is needed. Further, the analyst should work backwards from the maximum braking pressure to ensure that the initial braking response is accurately captured. A foot camera view of the accelerator and brake pedals is useful to validate initial accelerator pedal and brake pedal movements.

An alternative approach is to use regression to determine the relationship between brake pedal position or brake line pressure and time, and to find the point at which the regression line intercepts the time axis, where position or pressure is estimated to be zero. See Fitch, Blanco, Morgan, Rice, Wharton, Wierwille, and Hanowski (2010) for an example of this approach.

Another challenging sequence that is revealed by video occurs when the driver removes their foot from the accelerator pedal, is uncertain what to do and waves the foot above either or both pedals, and then depresses a pedal. Such indecision can only be detected from video recordings.

REQUIREMENTS: Instances when drivers do not have their foot or hand on a control at the beginning of a response sequence shall be reported. The location of the hand or foot at the movement beginning shall also be reported. These data shall be analyzed and reported separately from trials where the hand or foot rests on a control or pedal at the beginning of a response sequence.

5.2 Good Reporting Practice

5.2.1 Identify when drivers have both hands off of the steering device

Sometimes drivers will remove both hands from the steering device, possibly because they are distracted and performing another task (e.g., eating a sandwich with two hands), gesturing in conversation, or for some other reason. During those situations drivers may (1) steer using some means other than their hands (e.g., with a knee), (2) limit steering device movement (by resting their wrist on top of the steering device), or (3) provide no steering input at all. There may also be situations where a passenger steers.

RECOMMENDATIONS: Situations when both hands are off the steering device in any test condition should be analyzed separately from trials where drivers always have at least one hand on the steering device. Data can be pooled if no differences are found.

5.2.2 Identify when drivers use both feet to drive

For vehicles with clutch pedals, the driver uses two feet to manipulate the pedals. Driving with two feet is common for racecar drivers. As noted in 1.1, this document assumes the vehicle does not have a clutch pedal, an assumption made to simplify the development of response time measures and statistics related to foot pedals.

Some drivers, usually older drivers, rest their left foot on the brake pedal while they use their right foot to operate the accelerator pedal (Figure 1). At times they may even use both feet to operate the brake pedal (Figure 2). As noted in 5.1.7, the left foot resting on the brake pedal may lead to a non-zero brake pedal pressure, possibly enough to activate the brake lamps, so it cannot be taken as an indication that braking has begun. The brake pedal response to an event begins when the brake pedal moves downward and/or brake pressure increases beyond a resting or threshold value.



Figure 1 - Using both feet to drive

Source: Pettinato and Best (2012), personal communication



Figure 2 – Two-foot braking

Source: Pettinato and Best (2012), personal communication

In addition, for two-footed pedal operation, the release of the accelerator pedal may partially overlap with application of the brake pedal. In that case, the actions of the brake pedal are considered the defining action.

RECOMMENDATIONS: Instances when the left foot, the right foot, or both feet are used to brake should be analyzed and reported separately. Where automated functions for braking are provided, the four cases (in 5.1.6) should be analyzed and reported separately when assessing the benefits of the automated braking function. However, in lieu of a separate analysis, analysts may either (1) pool the trials in which either the driver or automated function responded, or (2) ignore the trials in which the automated function responded, if it rarely occurred.

5.2.3 Match the roadway segments for conditions being compared

When comparing conditions, such as a baseline with a test condition, select conditions that match for all important respects except for the difference of interest (though there may be exceptions when using Taguchi methods (Taguchi, Chowdhury, and Wu, 2004; Roy, 2010)). For experiments on real roadways, the ideal baseline condition is often taken on the same roadway just before or after the location where the test data were collected, or, if feasible, test conditions are interspersed between segments of the roadway. The baseline segments should match the test segments in terms of roadway geometry (e.g., curve radii, lane width, and speed limits) and traffic, though matching moment-to-moment changes in traffic is not easy. Ideally, each section should be of just one geometry type and one traffic condition. Usually, traffic changes between days or between roadways are often more pronounced than those within days and roadways. In a driving simulator, where roadway geometry and traffic can be specified, obtaining matching conditions is much easier.

Roadway sections where different test vehicle maneuvers occur should be analyzed separately (e.g., sections where drivers accelerate, decelerate, turn, change lanes, or back up). Walker, Alicandri, Sedney, and Roberts (1991) and Green, Williams, Hoekstra, George, and Wen (1993) are examples of studies where such separations were implemented.

RECOMMENDATIONS: When comparing conditions, such as a baseline with a test condition, users should select conditions that match as best as possible in terms of roadway geometry, signs, traffic signals, traffic (often measured by Level of Service), surface condition (using roadway roughness indices), visibility (using sight distance), vehicle mix, and drivers, and differ only in the treatment condition of interest.

5.2.4 Make the sample durations equal

Some statistics, such as the variability of a continuous measure (e.g., standard deviation of lane position), may depend on the sample duration. This can be a challenge when comparing activities that naturally have different durations, e.g., street address entry usually requires much more time to complete than dialing a phone number. To equalize duration, one can confine the analysis to the duration of the shortest task, and select samples from the longer tasks equal to that of the shortest duration (often, the first n seconds). Performance may not be stable over a longer task (e.g., destination entry), with drivers slowing down as the task progresses.

RECOMMENDATIONS AND REQUIREMENTS: The durations of tasks being compared should be approximately equal when measures of variability, skewness, or kurtosis are being determined. In all cases, the sample duration shall be reported.

5.2.5 Adjust for extreme responses

Many driving-related human performance measures are computed from censored distributions. For example, very long response times (e.g., beyond the four seconds) or situations where drivers fail to respond may reflect a response process that is different from when the response time is one or two seconds. Furthermore, for other measures, such as *distance gap* (8.1.1), *time to collision* (8.2.1) and *time to line crossing* (10.3.2), there is no practical difference in driving behavior when the response values are large versus very large. To be specific, whether a lead vehicle is 0.1 mile (0.16 km) or 1 mile (1.6 km) in front of a driver will have no substantial differential effect on how the following vehicle is driven, though the value does affect the computation of the mean gap. Furthermore, the sensors for some of these measures have range limitations. For example, current sensors for forward collision warning and adaptive cruise control have a range of about 120 m (almost 400 ft) under ideal conditions.

Censoring, ignoring values about some threshold, is one way to omit these values from the distribution of interest so as to focus the data analysis on the more relevant responses.

A much more complex alternative is to use survival analysis to make inferences about the underlying distributions, including the responses not observed (Cox and Oates, 1984; Ratliff, 1993; Ulrich and Miller, 1994; Palmer, Horowitz, Torralba, and Wolfe, 2011; Parmet, Avinoam, Oron-Gilad, Yael, and Lital, 2012).

A third alternative, most appropriate if all the data were generated by the same response process, is to examine the inverse of the response measure. In this alternative, responses that are inferred to take extremely long times or have extremely large values (essentially infinite) when inverted have values of zero, and the range of the inverse is from zero to one.

RECOMMENDATIONS AND REQUIREMENTS: When dealing with extreme or unusual responses, some method (e.g., censoring, identification of the number of missing responses, survival analysis, or inverses) should be used to adjust for the extreme responses. The method used shall be reported.

5.2.6 Percentiles are sometimes the most revealing statistic

Sometimes what may be of interest is only part of the range of a measure or a particular percentile. For example, when studying the effect of time or distance gap on crash risk or vehicle following performance, what matters is the fraction of time the gap is small, say a few car lengths (with the exact value depending on the speed driven). Thus, some percentile value of the distribution (say 5th or 10th) may be most important (or in this example, crash-relevant), but there is usually little theoretical justification for a particular percentile.

REQUIREMENTS: When what is important is a shift of some part of a distribution, analysts shall select a percentile relevant to that part of the distribution. The rationale for selecting that percentile shall be provided. That rationale may be consistency with prior publications (that are cited) or some other reason.

5.2.7 Report distribution parameters to aid modeling

As data from driving studies are now being used to build simulation models in addition to determining statistically significant differences, authors should not only report counts and means, but also report standard deviations, best fitting distributions, and distribution parameters for the measures and statistics in this document.

RECOMMENDATIONS: For the major dependent measures, their distribution type (e.g., normal, log-normal, double exponential) and the distribution parameters (e.g., mean, standard deviation, skewness, and kurtosis) should be reported. The rationale for the distribution type should be reported.

5.2.8 Select response measures and statistics appropriate for the question(s) posed

Prior to data collection, clearly define the specific questions to be investigated. From these questions, the analyst can determine the most suitable response measures. Most well designed experiments make specific quantitative predictions regarding the outcome. Mere directional predictions (A will be better than B) are insufficient.

For example, in an experiment to test the effectiveness of alternative brake lights, suppose the subject was instructed to (1) follow a lead vehicle and maintain a specific distance gap, a longitudinal control task, and (2) brake as rapidly as possible when the lead vehicle braked. For this experiment a specific hypothesis could be “as predicted by ... in the literature (or some human performance theory), the response time to design B will be 10% less than design A.” In that case, there is no need to examine lateral control measures, such as standard deviation of lane position, unless there was another hypothesis that brake lamp design would affect lateral control.

Furthermore, an insightful analyst would consider the entire sequence of actions in this case (initial release of the accelerator pedal, the point at which the accelerator pedal travel is zero, the point at which the brake pedal is first contacted, etc.) and make specific predictions about how each portion of the response sequence is expected to change.

For additional information about measuring real-world driver responses to various events, see Green (2000).

REQUIREMENTS: For each research question, analysts shall identify the measures and statistics used to answer that question.

5.3 Summary of General Measurement and Reporting Requirements

If available, the following items shall be reported for all measures and statistics:

1. The (a) start and (b) end points of the triggering event, if any, (e.g., when a warning sound begins and ends),
2. The (a) salience of the triggering event, (b) if it is expected, and (c) how often it has been seen before, (e.g., the luminance, area, and contrast ratio of a traffic signal),
3. The (a) alertness/fatigue of the driver, and (b) where the driver is looking,
4. The (a) start and (b) end points of the sampling period or response (the time window over which data are collected),

5. How the data were collected,
6. Quantification of the (a) lags and (b) noise in the data collection devices,
7. How drivers are using their (a) hands and (b) feet to drive, and (c) if there were any extraneous motions,
8. The roadway geometry, traffic, surface condition, and visibility for the data collection period,
9. The duration of the data collection period,
10. If the data were censored, and if so, how the censoring was done, and
11. The filter and its parameters, if used, to remove noise from the raw data.

Analysts should report the distribution type for each measure and statistic and the distribution parameters to aid modeling.

6. GENERAL DEFINITIONS

This section contains definitions of terms that are not performance measures or statistics, but are parts of vehicles or trafficways that are needed to define performance measures and statistics. For example, *leading and trailing surfaces*, defined in this section, are used in the operational definition for *gap* provided later. Other terms defined in this section, such as *response time*, are given more application-specific definitions in the operational definitions. For example, *response time until brake lights on* has an operational definition.

6.1 Vehicle Reference Surfaces

6.1.1 Leading surface

Part of the vehicle or anything mounted to or carried in/on a vehicle that is the most forward part of the vehicle, including accessories such as a snowplow or winch.

6.1.2 Trailing surface

Part of the vehicle or anything mounted to or carried in/on a vehicle that is the rearmost part of the vehicle, such as a trailer hitch, salt spreader, ladder, or lumber (Figure 3).

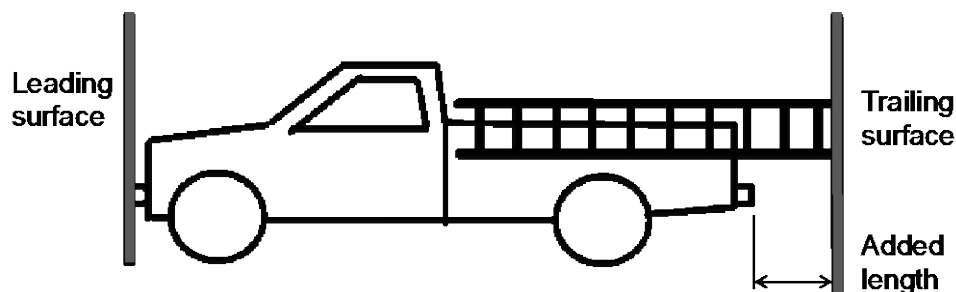


Figure 3 - Truck with a ladder that adds a trailing surface to its length

NOTE: In some situations, a vehicle may be sliding or in general may not be traveling approximately parallel to a lane boundary. In this case the most forward part may not be on the “front” of the vehicle, and the most rearward part may not be on the “rear” of the vehicle.

6.1.3 Surfaces beyond vehicle bumpers

REQUIREMENTS: If in the evaluated conditions a vehicle is fitted with accessories or cargo that add to the length of the vehicle, the added length of those accessories or cargo beyond the side view bumper prominence shall be reported as part of the evaluation vehicle description (Figure 3).

6.2 Trafficway Elements

In the literature there are many terms related to *trafficway* - such as *highway*, *roadway*, *road*, and *traveled way* - that can have conflicting or multiple meanings and often are confused with each other. To ensure consistent descriptions in technical reports, proceedings papers, and journal articles, this document (1) recommends use of terms such as *trafficway*, *traveled way*, and other terms described in this section, (2) defines the recommended terms, and (3) describes how they should be cited and used. Alternative definitions in current use are provided in the notes associated with some of these terms to aid in understanding how these terms have been defined and used elsewhere, and to encourage harmonization.

The two core documents for the definitions in 6.2 are (1) AASHTO's A Policy on Geometric Design of Highways and Streets (the Green Book, AASHTO, 2011 and Errata, 2012) and (2) ANSI D16.1-2007 (7th edition), a core standard for traffic safety. Definitions from these documents are in turn used in (1) the *Manual on Uniform Traffic Control Devices* (MUTCD, U. S. Department of Transportation, 2009), (2) the *Highway Capacity Manual* (HCM, Transportation Research Board, 2010), (3) Fatality Analysis Reporting Systems (FARS), www.fars.nhtsa.dot.gov/, (4) the Crashworthiness Data System (CDS),

[http://www.nhtsa.gov/Data/National+Automotive+Sampling+System+\(NASS\)/NASS+Crashworthiness+Data+System,](http://www.nhtsa.gov/Data/National+Automotive+Sampling+System+(NASS)/NASS+Crashworthiness+Data+System,) and (5) the General Estimates System (GES), [http://www.nhtsa.gov/Data/National+Automotive+Sampling+System+\(NASS\)/NASS+General+Estimates+System](http://www.nhtsa.gov/Data/National+Automotive+Sampling+System+(NASS)/NASS+General+Estimates+System).

For additional information on the definitions and explanations of trafficway elements, and the functional classifications of the roadway networks that should be used in publications, see the *Highway Performance Monitoring System Field Manual* (U.S. Department of Transportation, 2014).

GUIDANCE for Trafficway Elements: To provide for consistent descriptions in technical reports, proceedings papers, and journal articles, this document recommends use of the terms defined in 6.2, particularly the terms *trafficway*, *traveled way*, *roadway*, *shoulder*, *usable shoulder*, and *lane expansion*.

6.2.1 Trafficway

Any right-of-way open to the public as a matter of right or custom for moving persons or property from one place to another, including the entire width between property lines or other boundaries (Figure 4).

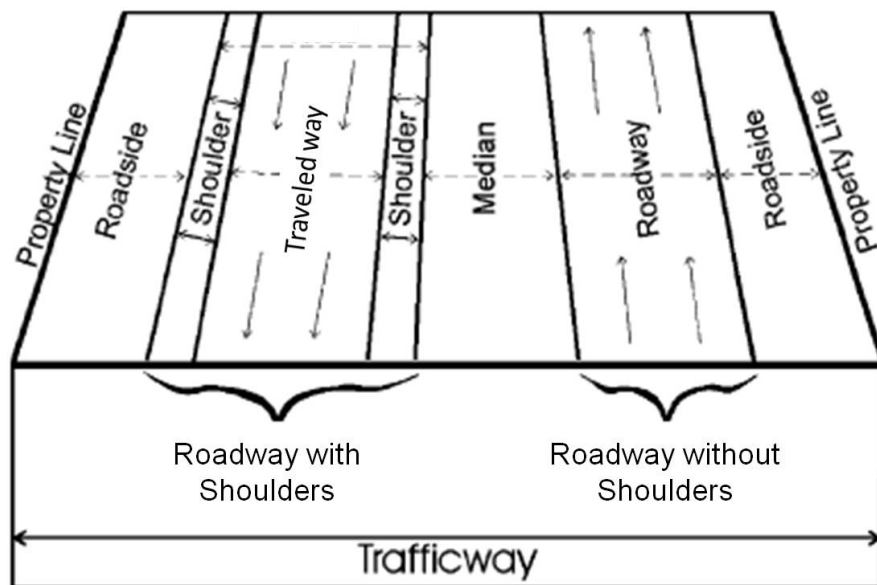


Figure 4 - Trafficway, traveled way, and roadway

Source: Modified from American National Standards Institute (2007), p. 3

NOTE 1: The *trafficway* includes not just the surface on which vehicles normally travel but also the shoulders, median, and roadsides.

NOTE 2: This definition is taken verbatim from the Glossary (Appendix B, p. 364) of *National Transportation Statistics* published by the Bureau of Transportation Statistics (U. S. Department of Transportation, 2013e, http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/appendix_b.html). The Bureau of Transportation Statistics definition lists *highway* as a synonym. The Bureau of Transportation Statistics definition is essentially the same as the ANSI D16.1-2007 definition 2.2.1 (American National Standards Institute, 2007).

NOTE 3: The MUTCD (U.S. Department of Transportation, 2009, p. 14) calls this the *highway* (definition 83). The AASHTO Green Book uses *highway*, *road* or *street* instead of *trafficway*. The *Highway Capacity Manual* (Transportation Research Board, 2010) does not define *trafficway* or *right-of-way*. However, on page 9-9, *highway* is defined as “a general term for denoting a public way for purposes of vehicular travel, including the entire area within the right-of-way.” This definition is equivalent to that for *trafficway* given here. Similarly, the Federal Highway Administration Planning Glossary (http://www.fhwa.dot.gov/planning/glossary/glossary_listing.cfm?TitleStart=H) states a *highway* “is any road, street, parkway, or freeway/expressway that includes rights-of-way, bridges, railroad-highway crossings, tunnels, drainage structures, signs, guardrail, and protective structures in connection with highways. The highway further includes that portion of any interstate or international bridge or tunnel and the approaches thereto (Title 23-United States Code, § 101a).”

NOTE 4: *Right-of-way* has both common usage and usage as a legal term. Right-of-way is determined by ownership (who owns the land) and by access (such as the easements of cable, electric, and phone companies).

6.2.1.1 Street

Trafficway in a city or town.

6.2.1.2 Highway

See trafficway (6.2.1).

Guidance for Trafficway: Use of the term *trafficway* is recommended because it is consistently defined wherever it is used. Terms such as *highway* and *street* may be used but they are not as consistently defined or are more often used in a way that means something different from trafficway. The term *road* is defined later and is not recommended to be used in lieu of trafficway because it has a variety of other meanings. The term *right-of-way* is sometimes used to mean trafficway, but such usage often includes legal implications that are beyond the scope of this document. Users should be careful when using the term *trafficway* because it sounds like *traveled way*, but has a very different meaning.

6.2.2 Traveled way

Portion of the *trafficway* for the movement of vehicles, exclusive of shoulders and bicycle lanes (Figures 4, 5).

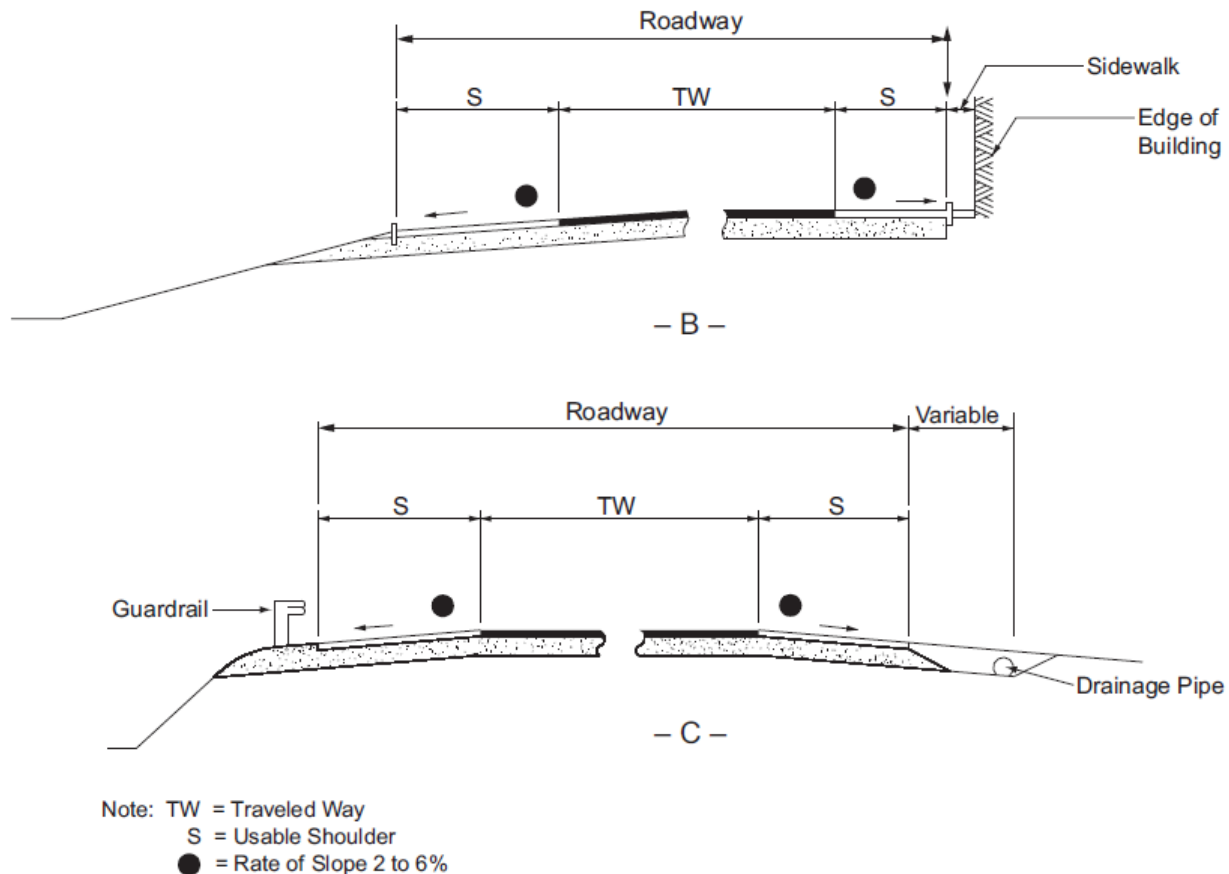


Figure 5 - Traveled way, roadway, and usable shoulder

Source: AASHTO (2012 errata)

NOTE 1: The definition in the AASHTO Green Book (2011, p. 4-1 and errata 2012) states the *traveled way* is the “portion of the trafficway for the movement of vehicles, exclusive of shoulders, and bicycle lanes.” The MUTCD (2009, p. 22) states the *traveled way* is “the portion of the roadway for the movement of vehicles, exclusive of the shoulders, berms, sidewalks, and parking lanes.” Figure 5 shows the traveled way using the corrected figure found in the 2012 Green Book errata. *Traveled way* is not defined in ANSI D16.1-2007 or in the *Highway Capacity Manual*.

NOTE 2: A traveled way includes the visually contiguous surface beyond the lane edge line. The *traveled way* is the portion of the trafficway that is designed to support the movement of motor vehicles on their intended path of travel. Vehicular traffic may be in the same or opposing directions. In Figure 6, the concrete surface from the lane to the paved asphalt shoulder is considered part of the traveled way. In Figure 7, the traveled way is paved with asphalt and the usable shoulder is paved with concrete. The concrete curb and gutter are part of the roadside.



Figure 6 - Example of visually contiguous paved traveled way, a paved shoulder, and a partially usable unpaved shoulder

Source: http://www.deldot.gov/information/community_programs_and_services/DSHSP/roadway_departure_crashes.shtml



Figure 7 - Example of a U.S. urban traveled way with a contiguous gutter and curb

Source: <http://collegetri.files.wordpress.com/2012/06/curb-of-a-road.jpg>

NOTE 3: The outside edge of the traveled way may be identified by a change in the color of the paving material, a seam, a control joint for expansion, a change in cross slope drainage, or a vertical drop off of more than one inch in the pavement edge (Figure 8).

When the pavement edge drop off exceeds one inch vertically, loss of control is more likely to occur because of a change in the aligning moment (Gillespie, 1992) and the probability of a safe return to the traveled way declines (Hallmark, Veneziano, MacDonald, Graham, Bauer, Patel, and Council, 2006; Transportation Research Board, 2009). The U.S. Federal Highway Administration (FHWA) suggests the angle of the pavement edge drop off should be 30 degrees to allow a safe return to the traveled way (Graham et al., 2011; see also <http://www.youtube.com/watch?v=asy33BGQwUw>). For additional information on shoulder design, shoulder drop offs, and loss-of-control crashes, see also Stoughton, Parks, Stoker and Nordin (1979), Gross, Jovanis, Eccles, and Chen (2009), Ivey, Johnson, Nordlin, and Zimmer (1984), Spainhour and Abhishek (2008), and Lord, Brewer, Fitzpatrick, Geedipally, and Peng (2011).

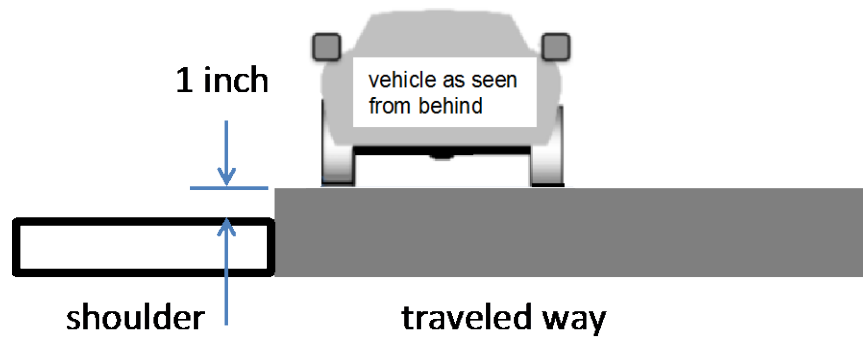


Figure 8 - Illustration of vertical drop off

NOTE 4: A traveled way consists of one or more vehicle lanes and may include part of the paved surface outside of the vehicle lane marking. For two-lane roads with no edge lines, the traveled way and vehicle lanes are the same.

6.2.3 Parking lane

Lane contiguous to a traveled way designed to provide temporary or emergency parking for motor vehicles (Figure 9).

NOTE 1: Parking lanes are considered part of the shoulder by AASHTO. They are not part of the traveled way but are considered part of the *roadway* by all agencies.

NOTE 2: Parking lanes are common on city streets, and parking may be parallel to or angled relative to the traveled way. Scenic outlooks along traveled ways can also provide parking lanes.



Figure 9 - Parking lanes

Source: http://www.denverinfill.com/images/blog/2007-08/2007-08-27_portland3.jpg

6.2.4 Bicycle lane

Lane that has been designated for preferential or exclusive use by bicyclists via pavement markings (and possibly by signs), and is either contiguous with (but marked off from) the traveled way (Figure 10 right), or physically separated from the traveled way (Figure 10 left).

NOTE: The definition used here is similar to that in the MUTCD (2009, p. 11) "a portion of a roadway that has been designated for preferential or exclusive use by bicyclists by pavement markings and, if used, signs" except that here reference is made to the traveled way because there are multiple options for the definition of *roadway* (6.2.5).



Figure 10 - Bicycle lanes separated by a barrier (left panel) and not separated (right panel) from the traveled way

Sources:

<http://www.bikexpert.com/bikepol/facil/images/9107N10R16Barrier%20bike%20lane.jpg> (left)

<http://rvelo.files.wordpress.com/2011/08/seattle-bike-lane.jpg?w=584&h=389> (right)

6.2.5 Roadway

Portion of a trafficway improved, designed, or ordinarily used for vehicular travel, which may or may not include the usable shoulder (or a part of it).

NOTE 1: The term *roadway* has a variety of meanings in common usage. One meaning, not used in this document, but often used in roadway construction and repair, broadens the above definition to include the entire trafficway - shoulders, drainage, and roadside.

NOTE 2: A divided trafficway has two or more roadways.

NOTE 3: There are four commonly used, well-entrenched, and conflicting sources of definitions of the term *roadway* – (A) AASHTO, (B) MUTCD/FARS/HCM, (C) ANSI, and (D) FHWA. The AASHTO definition (option A, 6.2.3.1) includes the usable shoulders. The MUTCD/FARS/*Highway Capacity Manual* definition (option B, 6.2.3.2) excludes the usable shoulder, except for parking lanes. The ANSI definition (option C, 6.2.3.3) excludes the usable shoulder, mirroring the *traveled way* definition. The distinction is important because it influences what is used to determine a roadway departure.

NOTE 4: The AASHTO Green Book (2011, p. 4-1) states the *roadway* is “the portion of a highway, including shoulders, for vehicular use.

NOTE 5: The MUTCD (2009, p. 19) states the *roadway* is “that portion of a highway improved, designed, or ordinarily used for vehicular travel and parking lanes, but exclusive of the sidewalk, berm, or shoulder even though such sidewalk, berm, or shoulder is used by persons riding bicycles or other human-powered vehicles. In the event a highway includes two or more separate roadways, the term *roadway* as used in this Manual shall refer to any such roadway separately, but not to all such roadways collectively.” The *Highway Capacity Manual* (2010, p. 9-16) uses verbatim the definition that appears in MUTCD. This definition includes the traveled way plus parking lanes. See 6.2.5.2.

NOTE 6: ANSI D16.1 (2007, p. 12, definition 2.2.28) defines the *roadway* as “that part of a trafficway designed, improved and ordinarily used for motor vehicle travel or, where various classes of motor vehicles are segregated, that part of a trafficway used by a particular class.” An associated figure shows exclusion of the shoulder from the roadway. The ANSI definition of *roadway* is identical to the AASHTO definition of *traveled way*.

NOTE 7: FHWA has at least three definitions for *roadway* depending on their application. First, the *Model Inventory of Roadway Elements* (MIRE) report (Lefler, Council, Harkey, Carter, McGee, and Daul, 2010) does not directly define what a *roadway* is. However, included among the roadway elements are the number of through lanes, left and right shoulder types, and left and right side slopes, which implies *roadway* is synonymous with their definition of highway and the definition of *trafficway* given here. Second, the FHWA *Highway Performance Monitoring System Field Manual* (U.S. Department of Transportation, 2014, p. B-3) defines roadway rather imprecisely as “the portion of a highway intended for vehicular use.” (See also <http://www.fhwa.dot.gov/ohim/hpmsmanl/chapt2.cfm>.) That definition is consistent with options A and B given here. Third, for roadway departures FHWA explicitly excludes shoulders and opposing lane(s) of vehicles, so crossing a lane centerline into an opposing lane of traffic is viewed as a roadway departure (option D, 6.2.5.4).

NOTE 8: The third FHWA definition suits FHWA’s needs for evaluating their trafficway safety improvement programs. In essence, it is the lane in which the driver is traveling as defined in 6.2.6, plus other contiguous lanes in the same direction of travel. FHWA decided to define *roadway departure* as they did to be consistent with FARS, to facilitate the evaluation of countermeasures (in particular shoulder and center rumble strips), and to be consistent with their prior practice and organizational structure. FHWA is continuing to review this and other terms related to roadway and lane departure, though FHWA is unlikely to revise their definition of *roadway departure* unless it contributes to improving road safety (Sutherland, 2012, personal communication). See 6.2.5.3.

NOTE 9: In the NHTSA *Model Minimum Uniform Crash Criteria* (MMUCC, U.S. Department of Transportation, 2012b, p. 6), *roadway* is defined by implication to exclude shoulders. Variable C8 (Location of First Harmful Event Relative to the Trafficway) has 10 attributes including “on roadway” and “shoulder.” FARS, whose users’ manual is based on the MMUCC, similarly defines variable C22 (Relation to Trafficway) as having nine attributes, including “on roadway” and “shoulder.” Though it is never stated in these crash databases, roadway is assumed to include parking lanes.

NOTE 10: Definitions of *roadway* in other publications either lack sufficient detail or are not consistent as a set. For example, SAE M105 (*Glossary of Automotive Terms*) defines *roadway* as, “the surface or plane which is supporting the vehicle, and on which it is moving” (Society of Automotive Engineers, 1992, p. 322). The glossary cites SAE J1451 as the source.

6.2.5.1 Roadway including usable shoulders (Option A)

Portion of a trafficway improved, designed, or ordinarily used for vehicular travel, including the usable shoulders (which can contain parking lanes and contiguous bicycle lanes).

NOTE 1: This definition is based on the definition of *roadway* in the AASHTO Green Book (AASHTO, 2011, p. 4-1), and the definition of *road* in ANSI D16.1 (2007). It consists of the traveled way plus the usable shoulder.

NOTE 2: This yields the widest roadway of the three roadway definition options.

NOTE 3: The AASHTO Green Book (2012), p 4-3 specifies the cross slope of the traveled way cannot differ from that of the usable shoulder by more than 8 %.

NOTE 4: The term *road* has many definitions. The definition in 6.2.5.1 is the most useful one for defining and applying terms such as *on-road* and *off-road*, terms that are often used in a vehicle or human factors context. Off-road includes areas beyond the road that can extend past any trafficway boundaries.

NOTE 5: SAE J2808, definition 3.1 defines *road* as “the surface that a vehicle would be expected to travel along in the absence of any obstruction” (Society of Automotive Engineers, 2007, p. 4). On that same page, further clarification comes from definition 3.2, *road boundary*, “the borderline of the road that is determined by incidental visible road features or other means such as GPS. This definition lacks sufficient detail.

6.2.5.2 Roadway including parking lanes (Option B)

Portion of a trafficway improved, designed, or ordinarily used for vehicular travel and parking lanes, but excluding the remainder of the usable shoulders.

NOTE: This definition is based on the definition of *roadway* in the MUTCD (*Manual on Uniform Traffic Control Devices*, 2009, p. 19). MUTCD specifically excludes bicycle lanes.

6.2.5.3 Roadway excluding usable shoulders (Option, C)

Same definition as *traveled way*.

NOTE: Use of the term *traveled way* is recommended.

6.2.5.4 Roadway excluding shoulders and opposing lanes (Option D)

Portion of a traveled way that excludes opposing lanes of traffic and is bounded by edge lines or a centerline/median separating opposing lanes of traffic.

NOTE: This definition is derived by implication from the FHWA definition of a roadway departure. FHWA defines *roadway departure* as, “A non-intersection crash in which a vehicle crosses an edge line, a centerline, or leaves the traveled way” (U.S. Department of Transportation, 2014, p. 3).

REQUIREMENTS: The first instance the term *roadway* is used in a document, the definition used (option A, B, C, or D) shall be reported.

Guidance for Roadway: How *roadway* is defined is important because it affects how roadway departures will be counted (10.5.2). Option D, the most restrictive definition of a *roadway*, is used in FARS and will identify the largest number of departures. Options C, B and then A successively include more paved surface area, and therefore using those definitions will decrease the number of departures counted. For all four definitions of *roadway*, all tires remain on a paved surface, so there is an opportunity to use the full handling capabilities of the vehicle to recover from a loss of control should that occur. However, as one moves farther from the traveled way (for option B and then A), the probability of encountering or crashing into objects to be avoided (e.g., pedestrians, bicyclists) increases. Further, parking lanes, bicycle lanes and shoulders, even though paved, may not be of the same surface quality as the traveled way.

Because the alternative definitions of roadway are so different, phrasing to reinforce the definition used (including usable shoulders, excluding shoulders, etc.) should be provided. For FHWA projects involving roadway departures, use of their definition (option D) is likely to be required and is consistent with existing practice. Where feasible, use of option A (traveled way plus usable shoulders) to count road departures is recommended in addition to option D. Including option B as well is less critical because option B is nearly synonymous with traveled way, and use of the term *traveled way* is preferred.

6.2.6 Paved roadway

Portion of a roadway, including usable shoulders and parking lanes, that is paved with asphalt or concrete or some other similarly rigid material (e.g., brick, cobblestone) for vehicular use.

NOTE 1: When a vehicle departs the traveled way, it may encounter (1) no usable shoulder, (2) gravel, shell, crushed rock, or bituminous shoulder surfaces, (3) usable shoulders that are partially paved, and (4) usable shoulders that are completely paved. As maneuvering is easier on a paved surface, knowing when a departure from a paved surface has occurred is important.

NOTE 2: The FHWA *Model Inventory of Road Elements* (MIRE) report refers to the “total paved surface width” (Lefler, Council, Harkey, Carter, McGee, and Daul, 2010, p. 26).

6.2.7 Shoulder

Paved or unpaved part of a trafficway that is contiguous with the traveled way for emergency use, for accommodation of stopped road vehicles, and for lateral support of the traveled way structure (Figures 7–9, 11).

NOTE 1: The AASHTO Green Book (2011, p. 4-8) defines the *shoulder* as “the portion of the roadway contiguous with the traveled way that accommodates stopped vehicles, emergency use, and lateral support of subbase, base, and surface courses. In some cases, the shoulder can accommodate bicyclists.” The Green Book also provides details on the side slope of shoulder and materials to surface them.

NOTE 2: The *Highway Capacity Manual* (2010, p. 9-17) defines the *shoulder* as that “portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles; emergency use; and lateral support of the subbase, base, and surface courses,” identical to the AASHTO definition, but without the comment on bicyclists (or bike lanes). ANSI D16-2007 (p. 13, definition 2.2.32) defines the shoulder as “that part of a trafficway contiguous with the roadway for emergency use, for accommodation of stopped road vehicles, and for lateral support of the roadway structure,” language very similar to that used in the *Highway Capacity Manual*.

NOTE 3: The shoulder usually varies in width from only 0.6 m (2 ft) on minor rural roadways to approximately 3.6 m (12 ft) on major roadways. For modern high-speed, high-volume roadways, the shoulder width is typically 3.0 m (10 ft) to enable a stopped vehicle to clear the edge of the traveled way by at least 0.3 m (1 ft), and preferably by 0.6 m (2 ft).

NOTE 4: On low-volume roadways, roadside barriers may be placed at the outer edge of the shoulder; in this case AASHTO (2011) recommends a minimum clearance of 1.2 m (4 ft) should be provided from the traveled way to the barrier.

NOTE 5: In the U.S., some traveled ways may have no shoulder at all. Also, sometimes there may be no visible indication of a shoulder if the entire shoulder is paved the same as the traveled way.

6.2.8 Usable shoulder

Portion of the shoulder, available for the driver to make an emergency stop or for parking.

NOTE 1: This definition is taken from AASHTO (2011, p. 4-8). See Figure 5.

NOTE 2: Parking lanes are part of roadway options A and B.

NOTE 3: The width of the usable shoulder is measured, usually in feet or meters, from the edge of traveled way to the point of intersection of the shoulder slope and mild slope (for example, 1:4 or flatter) or to the beginning of rounding to slopes steeper than 1:4. See the AASHTO Green Book (2011, p. 4-8) for details.

NOTE 4: FHWA recommends but does not require that usable shoulders be paved (U.S. Department of Transportation, 2007). A paved usable shoulder can have a cross slope of 2–6 %.

6.2.9 Vehicle Lane

Part of the traveled way intended for use by a single line of moving vehicles and usually delineated by pavement markings to guide drivers and reduce potential traffic conflicts.

NOTE: SAE 2808: 2007 and ISO 17361: 2007 define a *lane* as, “the area of roadway that a vehicle would be expected to travel along in the absence of any obstruction without the driver’s desire to change the path of travel” (Society of Automotive Engineers, 2007, p. 4; International Standards Organization, 2007, p. 1). SAE J2808 and ISO 17361 do not define the term *roadway*.

6.3 Trafficway Element Boundaries

Depending on the trafficway element and its design, a boundary could be identified by (1) a painted line, (2) objects abutting the road surface (drainage ditch, curb, gutter, gutter cover), (3) objects extending above the road surface (bridge abutment, tunnel or retaining wall, guardrail, fence, Jersey barrier), (4) a decrease in pavement elevation (drop off), change in cross slope, (5) a change in the traveled way surface material, or (6) other means.

The terms in 6.3 serve as the basis for determining when a departure from the lane, roadway, or roadway pavement has occurred.

6.3.1 Roadway boundary

Outermost edges of the roadway.

NOTE 1: Boundaries may be defined by edges of pavement markings, edge drop offs, changes in paving materials, or barriers such as curbs, gutters, guardrails, bridge abutments, or other roadside appurtenances.

NOTE 2: See 6.2.3.1, 6.2.3.2, and 6.2.3.3 for the three options to define the term *roadway*.

REQUIREMENTS: The first instance the term *roadway boundary* is used in a document, the option used to identify the roadway (A, B, C, or D) and the roadway boundary(s) shall be clearly defined.

6.3.2 Lane boundary

Physical or implied indicators on the traveled way that define the lateral edges within which vehicles move in a single file in the same direction except when passing, changing lanes, or exiting the traveled way.

NOTE 1: On paved traveled ways the lane boundaries are usually defined by pavement markings (single or double line, solid or dashed) or some other horizontal surface such as Botts dots. As noted in 10.2.1, the part of a lane marking that defines a departure (the inner edge, centerline, or outer edge) depends on the applicable definition for a lane departure.

NOTE 2: Unpaved traveled ways usually do not have an outside edge line marking or a centerline marking.

NOTE 3: For traveled ways intended to support two lanes of travel in opposing directions without a centerline marking, the boundary between the two lanes is the imaginary centerline between the pavement edges. If no outer edge markings are provided, the outer lane edge is the edge of the traveled way surface.

NOTE 4: For U.S. practice on pavement markings, see Chapter 3 (Markings) in the MUTCD (U.S. Department of Transportation, 2009).

NOTE 5: For European data on national road markings, see ISO 17361:2007, Annex A.

NOTE 6: SAE J2808, definition 3.4, using language from ISO 17361:2007 (also definition 3.4), defines a *lane boundary* as “the borderline of the lane that is determined by a visible lane marking and in the absence of a visible lane marking by incidental visible road features or other means such as GPS, electromagnetic nails, etc. In the case of a visible lane marking, the boundary shall be at the centre thereof” (Society of Automotive Engineers, 2007, p. 4; International Standards Organization, 2007, p. 2).

NOTE 7: Where vertical surfaces such as barriers (e.g., guard rails, Jersey barriers, bridge abutments, tunnel walls, etc.) restrict travel along the vehicle lane, the vertical surface closest to the lane center that actually restricts travel is the lane boundary.

REQUIREMENTS: The first instance the term *lane boundary* is used in a document, that boundary shall be clearly defined.

6.3.3 Lane expansion

Distance, in inches, centimeters, feet, or meters, computationally added to the lane width(s) for very narrow lanes of a traveled way in order to reduce the number of minor lane departures.

NOTE: For wide vehicles, such as heavy trucks and buses, sometimes their width is almost the legally specified width of a lane of the traveled way (Jahns, 2010, personal communication). In those cases, always maintaining vehicle travel within the specified lane boundary may not be possible. Therefore, in those cases, small departures from the lane boundaries may be accepted because they routinely occur and are likely not safety-relevant. Such departures can also occur for passenger cars if the lanes are very narrow (Dijkstra, Drolenga, and van Maarseveen, 2007; Dijkserthuis, Brookhuis, and de Waard, 2011).

REQUIREMENTS: The amount of lane expansion, if provided, shall be specified for at least four cases: (1) traveled way to an adjacent shoulder, (2) traveled way to adjacent bike lanes and parking lanes, (3) traffic lanes to traffic lanes in the same direction, and (4) traffic lanes into traffic lanes in the opposite direction.

GUIDANCE for Lane Expansion: Artificially increasing lane widths should only be done with great caution. The amount of lane expansion should not alter conclusions about the safety of driving on that traveled way. The amount of lane expansion that is routinely accepted is a matter of local convention. Expansion values are on the order of 5 % to 10 % of the width of the traveled way.

6.4 Terms Relating to Data Types

To be consistent with ISO nomenclature and provide clarity, only the terms *measure*, *measurement*, and *statistic* are used to refer to data and data collection. The term *metric* is not used because the term is not well defined or consistently used. At various times in the literature, the term *metric* has been used to represent a measurement, a measure, a statistic, or collections of those terms.

6.4.1 Measure

As a noun, a variable, either categorical, integer, or real, that represents the size, amount, or degree of a property of interest.

NOTE: Sometimes a *measure* is called a *channel*.

EXAMPLES: distance gap, time to collision, and lane departure

6.4.2 Measurement

As a verb, the process of collecting the values of a measure; as a noun, a single data point.

NOTE: The International Vocabulary of Metrology (JCGM 2000:2012, p. 16, definition 2.1) defines *measurement* as “the process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity.” Furthermore, the term *quantity value* is defined as “the value of a quantity” (definition 1.19, p. 12) and *quantity* is defined as “the property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference” (definition 1.1, p. 2).

6.4.3 Statistic

Attribute that characterizes one or more measurements, typically a single value representing or summarizing multiple measurements.

NOTE 1: Statistics include count, mean, minimum, maximum, sum, standard deviation, and so forth. Examples include mean distance gap, mean time to collision, and the number of lane departures.

NOTE 2: ISO 3534-1:1993, definition 2.45, defines a *statistic* less specifically as “a function of the sample random variables,” and notes that “a statistic, as a function of random variables, is also a random variable and as such it assumes different values from sample to sample.” The value of the statistic obtained by using the observed values in this function may be used in a statistical test or as an estimate of a population parameter, such as a mean or a standard deviation.

6.5 General Terms for Driver Reactions to Events and Movements

6.5.1 Event

Stimulus in the environment surrounding the driver that leads to a driver response involving steering, braking, or acceleration of the vehicle being driven.

EXAMPLES – An event could be the movement of other vehicles (e.g., braking, accelerating, or merging) or pedestrians, animals or other objects, a change in the state of a traffic signal, a change in environmental conditions (such as a crosswind, ice on the road, etc.), or the onset of a warning sound (or other stimulus).

NOTE: Sometimes a driver may fail to respond to an event.

REQUIREMENTS: The number of times drivers do not respond to each type of event shall be reported by event.

GUIDANCE for Event: Some consider no response to indicate an infinite response time, a value not compatible with computing the arithmetic mean time. However, an infinite time can be included in a computation of the mean if the analysis is done using the inverse time.

6.5.2 Reaction time (RT)

Time interval, usually measured in seconds or milliseconds, from onset of an initiating event to the first observable response to that event, such as a movement of the driver's hand (on the steering wheel) or foot (on a pedal or from the floor), or, the beginning or end of an utterance by the driver (for voice-activated controls).

NOTE 1: *Steering reaction time* (9.1.2) is a related term.

NOTE 2: The SAE Glossary of Automotive Terms (1992, p. 121) defines *driver reaction time* as "the time elapsed between the instant the driver perceives a demand for braking and the start of brake application." The Glossary refers to the now cancelled SAE J834a as the source. The Glossary definition is in conflict with the accepted scientific use of the term reaction time and the definition used in this document, which uses the first movement as the endpoint, not brake application. Usually, the foot would be initially resting on the accelerator, so the Glossary definition also includes the time for movement to the brake pedal.

NOTE 3: Although not often used, there may be instances where the reaction is an eye movement or a head movement.

NOTE 4: Reaction time values depend on the salience of the stimuli, the number of stimuli from which the driver is to choose, the probability of each stimulus, and other factors (Hick, 1952; Hyman, 1953; Teichner and Krebs, 1974).

REQUIREMENTS: The first instance the term *reaction time* is used in a document, the initiating event, the start and end points of the reaction shall be reported.

6.5.3 Movement time (MT)

Time interval, usually measured in seconds or milliseconds, for the responding foot or hand to move from one location to another.

NOTE 1: Foot movements can start and/or end with foot in contact with the accelerator pedal (option A), the brake pedal (option B), or on neither of these pedals, for example on a dead pedal, in the air, or on the floor (all option N).

NOTE 2: When moving the foot, a driver may unintentionally make contact with another pedal, e.g., accelerator pedal or brake pedal, prior to moving to and applying one of them. If a pedal misapplication occurs, this movement time is added into the total movement time.

NOTE 3: Movement time is determined by the movement distance travelled, the accuracy required at the end location, the extent to which vision is available to guide the movement, as well as other factors (Fitts, 1954; MacKenzie, 1992; Seow, 2005). Most foot movements are not visually guided; they are blind movements and often ballistic in nature.

NOTE 4: *Steering movement time* (9.1.2) is an analogous term involving hand movements of the steering wheel. Head or eye movement times, or vocal response times, are not covered in this document, nor are hand movements to controls.

GUIDANCE for Movement Time: Warshawsky-Livne and Shinar (2002) report movement times from the first movement of foot on the accelerator to contact with the brake pedal of 0.15 - 0.20 s for alerted subjects responding to brake lights in a simulator across repeated trials. In contrast, Engstrom, Aust, and Vistrom (2010) report mean movement times of 0.65 to 0.77 s, where that time was defined beginning when 2 % of full accelerator depression was reached during accelerator release and ending when the brake reached 2 % of maximum brake pressure. Their data was also collected in a driving simulator, but the scenario was the cut-in of a vehicle from an adjacent lane on a 4-lane traveled way.

REQUIREMENTS: The first instance the term *movement time* is used in a document, both the movement start and end points (options A, B, N) shall be reported. For example, the duration of a movement that starts on the accelerator pedal and ends on the brake pedal would be *movement time option AB*.

6.5.4 Response time (RspT)

Sum of reaction time and movement time, usually in seconds or milliseconds, from the event start point to the movement end point.

NOTE 1: A foot movement can start with the foot on either pedal or on the floor and end with the foot on the same or other pedal.

NOTE 2: *Steering response time* (9.1.1) is a related term.

NOTE 3: The abbreviation RspT was chosen to distinguish *response time* from *reaction time* (RT), the abbreviation more common in the psychological literature (e.g., Welford, 1980).

NOTE 4: When there is no movement, the reaction time and the response time are equal.

NOTE 5: When seeking a measure to more generally describe a subject response, the term response time is used. However, in the literature, some mistakenly use the term *reaction time* when the term *response time* should have been used, and vice versa.

REQUIREMENTS: The first instance the term *response time* is used in a document, the initiating event, and the start and end points of the movement shall be reported.

GUIDANCE for Response Time: When a pedal response time is reported but is not defined, the measure is usually brake response time, not accelerator response time, primarily because brake response time is easier to measure and braking is often the intended end response. However, accelerator response time provides a clearer indication of the type response that has occurred. For that reason, reporting the end point is essential.

6.5.5 Types of movement response end points

Movement responses can end in three different ways:

1. initial (at the earliest indication of a response),
2. intermediate (at a point between the initial and final), and
3. final (when the movement stops or reaches a maximum value).

In the common situation of maximum braking starting with the foot on the accelerator pedal, the initial response will be the initial movement to release the accelerator pedal. Intermediate response end points include when accelerator pedal is completely released, when the brake is contacted, and when the brake lights illuminate - this could be an initial movement, if foot was initially on the brake pedal. The final response is when maximum braking occurs. However, if the driver action, starting with the foot on the accelerator pedal, was only to coast down, the initial response would end with the first movement of the accelerator pedal, the final response would be end when the accelerator pedal is completely released, and there would be no intermediate response. These terms are explained in greater detail in the text that follows.

6.5.5.1 Initial driver response

Earliest reliable indication that a driver movement response has begun.

NOTE 1: This term is used to determine the end of driver reaction time and the start of the movement time.

NOTE 2: For pedal movements, the most common initial actions are (1) the foot begins to move off of the floor toward a pedal or (2) the foot is on a pedal and the pedal movement is greater than the normal variation to maintain speed (e.g., going from riding the brake to emergency braking).

6.5.5.2 Intermediate driver response

Reliable indication that a meaningful driver movement response is underway, past the movement start point but not to completion.

NOTE 1: This includes responses such as moving the foot from floor to pedal, or movement of a pedal away from its initial position. It indicates a response is in progress.

NOTE 2: Response times associated intermediate driver responses are collected because: (1) they are easier to collect than alternatives or (2) to provide a connection to other research. For example, determining the brake lamp is on by detecting an electrical signal may be easier than decoding the CAN bus signals that contain information concerning accelerator and brake pedal position.

6.5.5.3 Final driver response

Reliable indication that a pre-determined driver movement response is completed.

NOTE 1: The pre-determined end point is often a value such as maximal or x percent of maximum response. Maximum responses include fully depressing the accelerator or brake, or suddenly and completely releasing the accelerator or brake. Even though drivers may be instructed or intend to respond maximally, they often do not. So, for example, in emergency braking by a particular driver on a particular trial, only 75 % and not 100 % of maximum brake line pressure is often chosen as the movement endpoint. In some instances, the preferred method to identify a maximum response time may involve examining the maximum response of each subject for each trial.

NOTE 2: Whether a particular response is intermediate or final can depend on the context. For example, if the driver has their foot on the accelerator and engages in emergency braking, then foot contact with the brake pedal is an intermediate response. However, if the situation is less urgent, then merely contacting (or tapping) the brake could be the final response.

6.5.6 Perception-response time (PRT)

Time interval, usually measured in seconds or milliseconds, between when an initiating event (e.g., obstacle in the roadway) can be physically sensed and when braking begins.

NOTE 1: This term is often called perception-reaction time in the roadway design and accident reconstruction literature, even though it involves an intermediate movement to the brake, and is more than just reaction time as defined here. PRT includes the time needed to (1) see/perceive the roadway element or obstacle, (2) to complete relevant cognitive operations (e.g., recognize hazard, read sign, decide how to respond, etc.), and (3) initiate a maneuver (e.g., take foot off accelerator and step on brake pedal).

NOTE 2: A major ambiguity in this term is what is meant by “when braking begins.” It could mean (1) response time until brake pedal is contacted, option A (7.2.7), (2) response time until the brake lights illuminate, option A (7.2.8), or (3) when the brake line pressure reaches a point that the vehicle begins to decelerate or when a specified initial deceleration threshold is reached.

NOTE 3: The rationale for including the movement to the brake pedal in the PRT is that during the PRT period the vehicle generally maintains its current speed and trajectory. During the maneuver period the vehicle trajectory or speed changes. This makes PRT a useful measure for designing roadways or analyzing crashes. For example, roadway designers use PRT in their model of stopping sight distances ($SSD = PRT \text{ distance traveled} + \text{braking distance}$).

NOTE 4: The term PRT has most often been applied to vehicle braking responses. However, some authors have used the term PRT to describe non-braking responses. Campbell, Lichty, Brown, Richard, Graving, Graham, O’Laughlin, Torbic, and Harwood (2012) describe a number of these applications as does Lerner (1994).

REQUIREMENTS AND RECOMMENDATIONS: When the term *Perception-Response Time* (PRT) is used, the initiating event and associated test conditions, as well as the response endpoint shall be clearly defined and reported. Use of the term PRT should be restricted to situations involving an emergency braking response by the driver. Terms defined in section 7 involving brake response times may be used in lieu of PRT as they have more clearly defined response endpoints.

GUIDANCE for Perception-Response Time: The AASHTO Green Book (AASHTO, 2011, p. 111-113) recommends a perception-reaction time of 2.5 s. The Green Book cites research by Johansson and Rumar (1971), who found a mean PRT of 0.66 s when drivers were aware an event might occur (alerted), with 10 percent of drivers having PRT's of 1.5 s or longer (Figure 11). The distribution is roughly log-normal (Figure 11). If drivers were not alerted (such as when responding to an unexpected event), then their response times increased by approximately 1 s. Accordingly, the AASHTO Green Book concluded that the 90th percentile PRT for unexpected braking is approximately 2.5 s. They state that a PRT of "2.5 s is considered adequate for conditions that are more complex than the simple conditions used in laboratory and road tests, but it is not adequate for the most complex conditions encountered in actual driving, such as those found at multiphase at-grade intersections and at ramp terminals on through roadways."

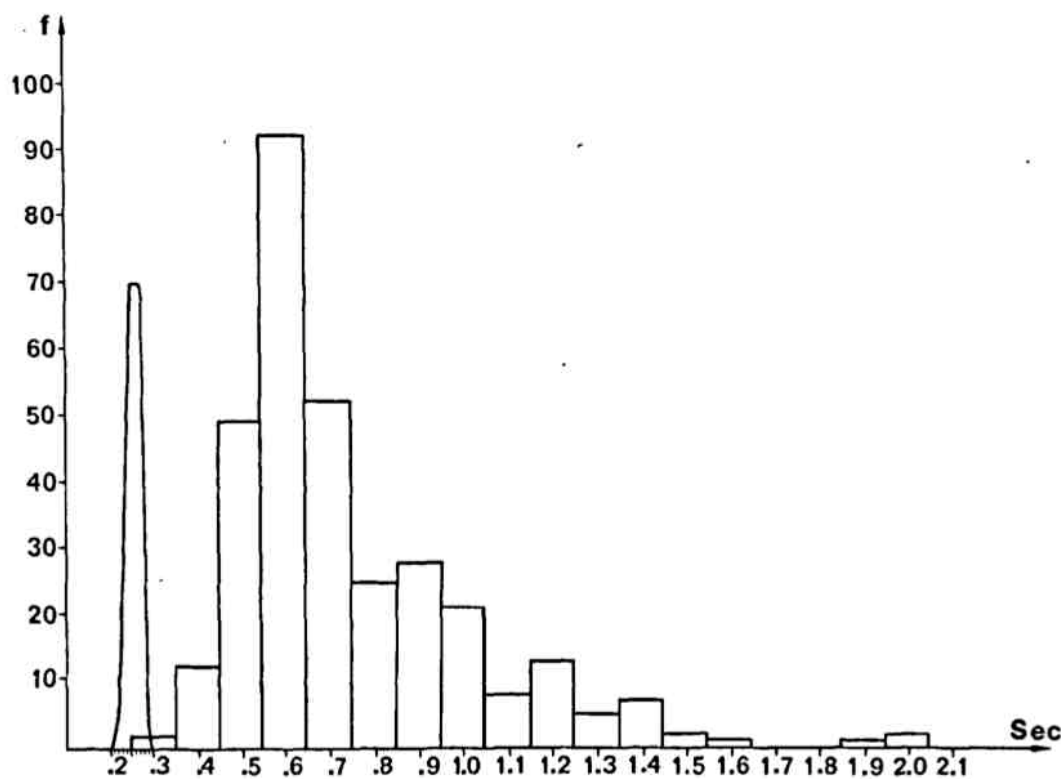


Figure 11 – Perception-response time distribution for 321 drivers

Source: Johansson and Rumar (1971), p. 26

In a study often quoted by accident reconstructionists, Olson and Sivak (1986) had young and older drivers brake in response to a foam block they unexpectedly encountered when cresting a hill. They estimated a median PRT of about 1.1 s to contact the brakes, with a 90th percentile value of about 1.6 s for both young and older drivers (Figure 12). Based on this data, accident reconstructionists often use 1.5 - 1.6 s as the perception-reaction time to an "unexpected" obstacle. The figures provided allow alternative percentiles to be selected.

For a web site on this topic that is regularly updated, see <http://www.visualexpert.com/Resources/realprt.html> (Let's Get Real about Perception-Reaction Time). See also Muttart (2003a, 2003b), Muttart, Messerschmidt, and Gillen (2005), and Krauss, Todd, and Heckman (2012) for a list of variables that affect PRT and for attempts to develop models to describe or predict PRT based on data from prior empirical studies.

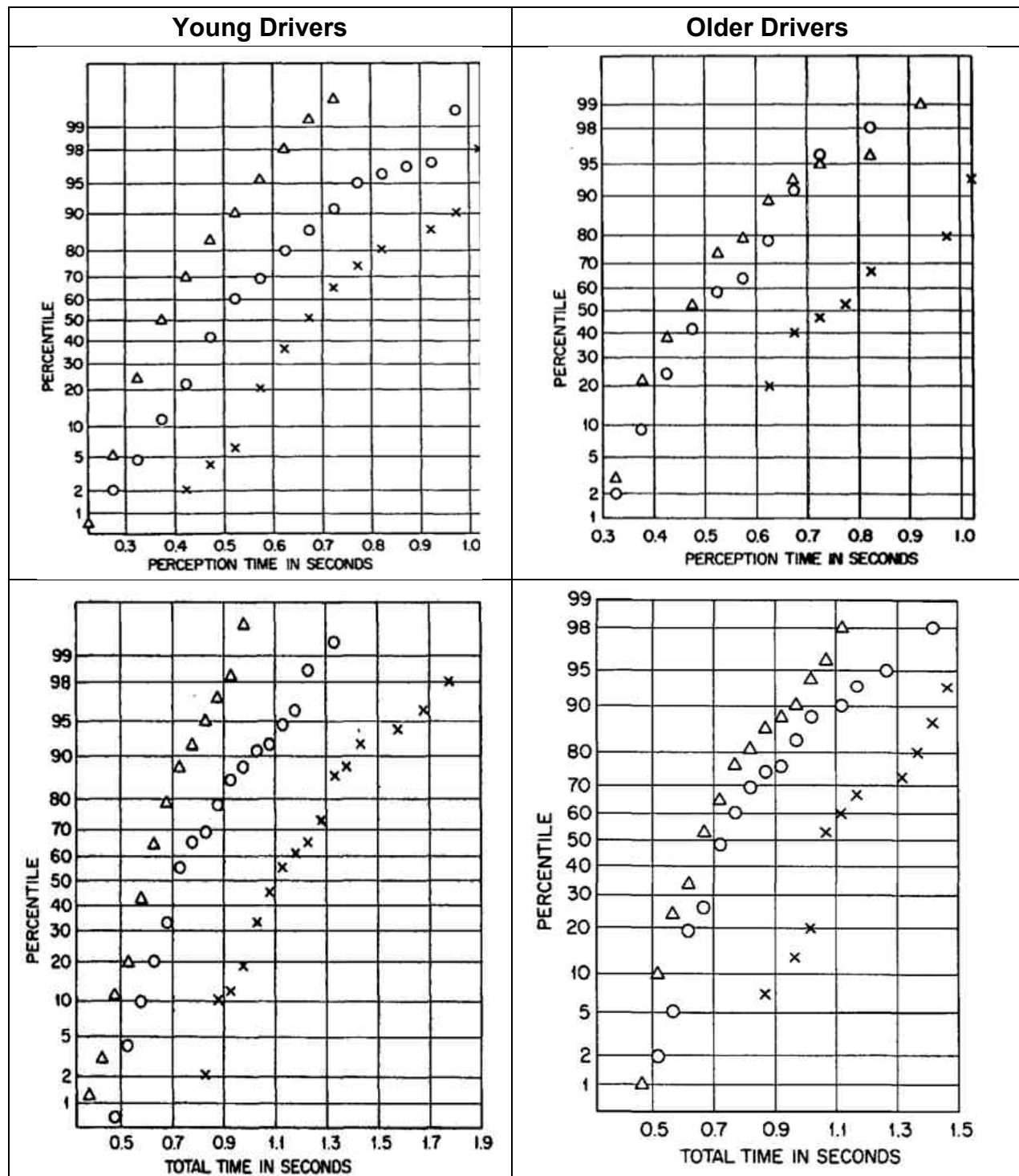


**Figure 12 – Normal probability plot for perception time (top row)
and PRT (bottom row) for younger and older drivers**

*X = surprise response to object on road, O = alerted response to object on road,
Triangle = brake in response to light on hood*

Source: Olson and Sivak (1986), p. 93-95

7. LONGITUDINAL CONTROL: OPERATIONAL DEFINITIONS FOR DRIVER'S PEDAL RESPONSES

7.1 Response Time Classification Scheme

7.1.1 Scheme overview

To eliminate ambiguity concerning the specification of pedal responses, this section provides a scheme to identify them. This scheme assumes the driver is responding using one foot, though the scheme can be applied to two-foot responses. Pedal responses are classified in 6.5.5 based on where the foot starts in the response sequence, the location where the foot ends the response sequence, and type of movement being examined (initial, intermediate, or final. It is important to determine the when response first began (the initial response), what response is most convenient to measure (generally intermediate response), and when the ultimate goal of the response has been achieved (the final response).

Pedal responses can start with the foot on the accelerator pedal (option A), on the brake pedal (option B), or in neither location (option N). Option N includes (1) on the floor (likely when a cruise control is engaged) or possibly even resting on a dead pedal (currently only provided for the left foot in left-hand drive cars), and (2) hovering over either the accelerator pedal or the brake pedal. Option N will become more common as vehicles become increasingly automated. See 5.1.1 for details about specifying the foot start point.

If the foot is releasing a pedal, the detectable actions include (1) the initial pedal movement, (2) for the brakes, the brake lights going off, and (3) pedal release. For pressing a pedal the detectable actions are (1) contact with the pedal, (2) for the brakes, the brake light illuminating, (3) some threshold or maximum pedal value being reached, either an accelerator or brake value, or (4) a vehicle acceleration (or jerk) value being reached.

The scheme that follows incorporates those actions into variable names in current use (e.g., response time until accelerator moved), supplemented by an option to indicate the initial location of the foot (A, B, or N) to provide a complete description the driver's response. The complete scheme appears on Table 1. Each of these terms is explicitly defined in the section that follows. It is important to emphasize the focus is on driver responses, either by themselves, or combined with automated functions. See 5.1.6 for guidance concerning automated functions.

At this point, the responses associated with partial release or application of the accelerator or brake are not formally defined because there is no consensus operational definition for those terms, though they are included in Table 1. Examples of such actions include easing up on the accelerator pedal after seeing a vehicle ahead slow down, and accelerating to cross the intersection before the yellow signal changes to red.

Table 1 - Response time measures classification scheme

Foot Position		Driver Response		
Initial action	Final action	Initial Response Time Until...	Intermediate Response Time Until...	Final Response Time Until...
on accelerator pedal (Option A)	depress accelerator pedal	Accelerator Moved (7.2.1)		75 % Throttle Value, option A (7.2.10) Maximum Jerk while Accelerating, option A (7.2.12) Maximum Accelerator Value, option A (7.2.14) Accelerator Completely Released (7.4)
	partial let up or depression of accelerator pedal			
	release accelerator pedal			
	move to brake pedal	Accelerator Moved (7.2.1)	Accelerator Completely Released (7.2.4)	75 % Brake Value, option A (7.2.11) Maximum Jerk while Braking, option A (7.2.13) Maximum Brake Value, option A (7.2.15)
	"maximal" brake		Brake Contacted, option N (7.2.7) Brake Lights On, option A (7.2.8)	
	move to not on any pedal	Accelerator Moved (7.2.1)	Accelerator Completely Released (7.2.4)	The final position may be in the air or on the floor; the exact final position is not important.
	7.1.1.1 vehicle coasts			
on brake pedal (Option B)	depress brake pedal	Brake Moved (7.2.2)		75 % Brake Value, option B (7.2.11) Maximum Jerk while Braking, option B (7.2.13) Maximum Brake Value, option B (7.2.15)
	partial let up or depression of accelerator			
	move to accelerator pedal	Brake Moved (7.2.2)	Brake Lights Off (7.2.8) Brake Completely Released (7.2.5)	75 % Accelerator Value, option B (7.2.10) Maximum Jerk while Accelerating, option B (7.2.12) Maximum Accelerator Value, option B (7.2.14)
	depress accelerator		Accelerator Contacted, option A (7.2.6)	
	move to not on any pedal	Brake Moved (7.2.2)	Brake Lights Off (7.2.9) Brake Completely Released (7.2.5)	The final position may be in the air or on the floor; the exact final position is not important.
	vehicle coasts			
not on any pedal (Option N)	move to accelerator pedal	Foot First Moved (7.2.3) As the initial position may be in the air or on the floor, the initial position is often difficult to determine.	Accelerator Contacted, option N (7.2.6)	75 % Accelerator Value, option N (7.2.10) Maximum Jerk while Accelerating, option N (7.2.12) Maximum Accelerator Value, option N (7.2.14)
	depress accelerator			
	move to brake pedal	Foot First Moved (7.2.3) As the initial position may be in the air or on the floor, the initial position is often difficult to determine.	Brake Contacted, option N (7.2.7) Brake Lights On, option N (7.2.8)	75 % Brake Value, option N (7.2.12) Maximum Jerk while Braking, option N (7.2.13) Maximum Brake Value, option N (7.2.15)
	panic brake			

7.1.2 The 1/5/75 rule to identify response movement start or end point

One of the challenges in analyzing response time data is to decide whether to visually analyze when certain pedal responses occurred on a trial-by-trial basis for each movement. Although this can provide a very accurate assessment as to what occurred, the time and cost required to obtain this information may be prohibitive. As an alternative, this section describes some rules of thumb concerning the percentage of maximum response to categorize initial or maximal movements of the destination pedal. A 1 % movement response of the destination pedal is used to define the initiation of destination pedal movement when the foot is not originally on the destination pedal. This also represents the end of the initial foot movement from its origin point, either the floor or another pedal. A 5 % movement response of the destination pedal is used to define the initiation of pedal movement when the foot is originally on the destination pedal. A 75 % movement response of the destination pedal is used to define a maximal movement or the end of the response. *Maximal* not *maximum* is used here, as the approximation does not guarantee it is the largest value, only that it is among the largest values – and a reasonable ending point for the pedal movement. This is called the 1/5/75 rule of thumb to aid in remembering the rule.

7.1.2.1 Initial movement when the foot is not on the destination pedal

The criterion that the destination pedal has moved is a 1 % change in either pedal travel, or some other relevant output signal such as throttle motion for the accelerator pedal or brake pressure for the brake pedal.

NOTE 1: There is not a one-to-one mapping between accelerator pedal travel and the throttle signal. Small initial movements of the pedal can map into large throttle changes to make a vehicle seems peppier. For accelerator travel near maximum, the opposite is true. Likewise for braking, there is not a one-to-one mapping between brake travel and brake pressure. For either pedal, the measure selected for analysis (e.g., accelerator travel or throttle percent) does not matter because the time differences between moving from pedal contact to 1 % of accelerator travel or 1 % of throttle signal are on the order of a few milliseconds, too small to matter.

NOTE 2: The 1 % change can be reliably detected with contemporary sensors and distinguished from signal noise.

NOTE 3: The initial pedal movement could be detected by a contact sensor or microphone, from the throttle signal or brake pressure signal, or by some other means.

7.1.2.2 Initial movement when the foot is on the destination pedal

When the foot is on the destination pedal, the criterion that the destination pedal has moved is a 5 % change in either pedal travel, or some other relevant output signal (e.g., throttle percent, change in brake pressure).

NOTE: The 5 % value was chosen because it allows for reliable separation of the moment-to-moment pedal movements from overt responses to an initiating event.

7.1.2.3 Final movement is maximal braking or acceleration

The criterion for a maximal response of the destination pedal is 75 % of maximum possible response for both the accelerator and the brake.

NOTE 1: For the accelerator, the 75 % can refer to either the percentage of maximum pedal travel or the percentage of maximum throttle signal.

NOTE 2: For the brake, the 75 % can refer to either the percentage of maximum pedal travel or the percentage of maximum brake pressure.

NOTE 3: Determining the threshold for a maximal response requires some consideration as drivers may not actually respond maximally when they need to do so. For example, even if the driver needs to accelerate by “flooring it” or use full braking authority, they may only use some of the vehicle capability. It is for that reason that brake assist systems (Fitch, Blanco, Morgan, Rice, Wharton, Wierwille, and Hanowski, 2010) have been developed. Complicating matters is that sometimes brake assist systems respond sooner than drivers do. Those instances should be treated separately in the data analysis.

Otherwise, the maximum response can be identified by using some value less than 100 % (here 75 %) or by determining the maximum response individually for each driver for each trial.

7.1.3 Final movement is maximum response of each driver

The criterion for a maximal response is the actual maximum response value produced by each driver for both the accelerator and the brake.

NOTE 1: For the accelerator, the measure can be the driver's maximum pedal travel or maximum throttle signal.

NOTE 2: For the brake, the measure can be the driver's maximum pedal travel or maximum brake line pressure.

NOTE 3: Rather than using a percentage of system maximum to identify a response endpoint, the response endpoint can be the actual maximum value produced by a driver. In this case the maximum response has to be uniquely determined on each trial, which is usually much more time consuming than the fixed percentage method.

NOTE 4: This method is most appropriate when the actual maximum pedal response of the driver is itself a measure desired by the experimenter.

7.2 Response Time Measures

7.2.1 Response time until accelerator moved

Time interval, usually measured in seconds or milliseconds, from an initiating event until the accelerator pedal (on which the foot is resting) is moved 5 %, if the movement is in response to that event.

NOTE: That 5 % can refer to either 5 % of maximum accelerator pedal travel or 5 % of maximum throttle signal.

GUIDANCE for Response Time until Accelerator Moved: Reported mean times for *response time until accelerator pedal movement* vary from 0.9 to 2.2 s (Brown, Lee, and McGehee, 2001; Perez, Doerzaph, and Neale, 2004, Wiese and Lee, 2004; Li and Milgram, 2005; McGehee and Carsten, 2011).

7.2.2 Response time until brake moved

Time interval, usually measured in seconds or milliseconds, from an initiating event until the brake pedal (on which the foot is resting) is moved 5 %, if the movement is in response to that event.

NOTE: That 5 % can refer to either 5 % of maximum brake pedal travel or 5 % of the range of the brake pressure.

7.2.3 Response time until foot first moved

Time interval, usually measured in seconds or milliseconds, from an initiating event until the foot (which was not on the brake or accelerator pedal) is moved towards the accelerator or brake pedal, if the movement is in response to that event.

NOTE: The foot could initially be resting on the floor, on a dead pedal or suspended above a pedal.

GUIDANCE for Response Time until Foot First Moved: Because the foot is not resting on a moveable pedal, the time when the foot is first moved will often be determined using video analysis. See 5.1.1 for details.

7.2.4 Response time until accelerator completely released

Time interval, usually measured in seconds or milliseconds, from an initiating event until the foot (initially on the accelerator pedal) is no longer in contact with the accelerator pedal or when the accelerator position signal reaches zero, if the movement is in response to that event.

NOTE 1: For some vehicles, even if the accelerator pedal is completely released, there may be some small residual throttle signal so that a stopped vehicle does not drift backwards excessively when starting to move again.

NOTE 2: Position or travel measurements should not be used to determine response time if the accelerator does not return to an un-depressed position when released. In this case, use video recording to determine the foot release point. Data analysts may have to work backward to determine when the final release occurred.

GUIDANCE for Response Time until Accelerator Completely Released: Accelerator pedal release is described in McGehee, Mazzae, and Baldwin (2000) and McGehee, Brown, Lee, and Wilson (2002). Initial accelerator pedal release times ranged from 0.96 to 1.26 s for data collected in a driving simulator and on a test track. See also Curry, Greenberg, and Kiefer (2005) and McGehee and Carsten (2010) for use of this measure.

Response time until accelerator pedal completely released is usually determined from the throttle signal on the CAN bus. That signal is also accessible from the OBD-II port.

7.2.5 Response time until brake completely released

Time interval, usually measured in seconds or milliseconds, from an initiating event until either the foot (initially resting on the brake pedal) is no longer in contact with the brake pedal, the brake position signal reaches zero, or the brake pressure signal reaches its resting (undepressed) value, if the pedal movement is in response to the initiating event.

NOTE 1: For most brake systems, the brake pressure is not zero when the brake pedal is not depressed.

NOTE 2: For some brake systems, even if the brake pedal is completely released, some time may be required for the brake pedal to move to the undepressed position. As with the accelerator (7.2.4), video analysis may be required.

NOTE 3: Figure 13 shows an example time history of a driver braking and then releasing the brake. A figure showing brake pressure versus time would be similar in shape although the y-axis would be shifted vertically slightly as the brake system may be slightly pressurized and never zero.

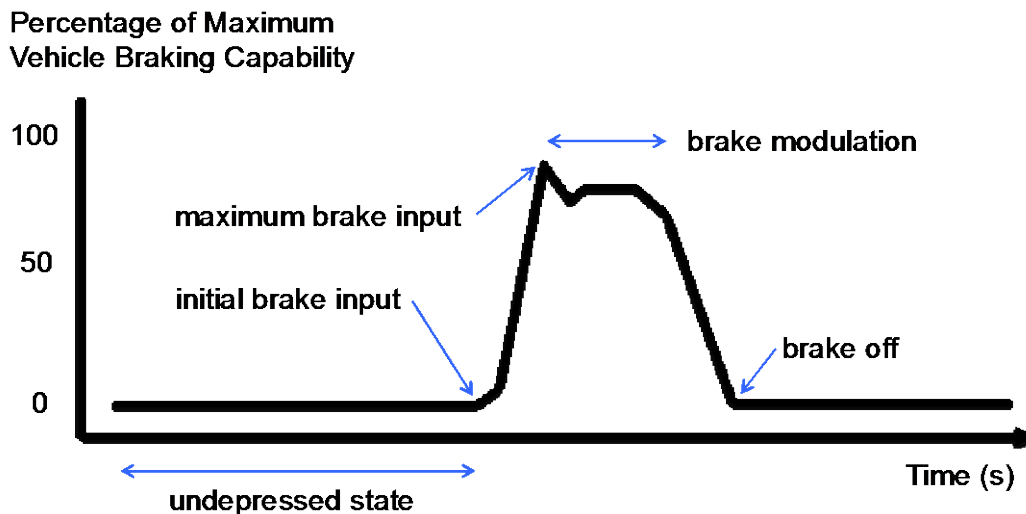


Figure 13 - Example of brake application and release

GUIDANCE for Response Time until Brake Completely Released: Response time until brake completely released is usually determined from the brake pressure signal.

7.2.6 Response time until accelerator contacted

Time interval, usually measured in seconds or milliseconds, from an initiating event until the accelerator pedal is contacted, if the movement is in response to that event.

NOTE: For option N, the foot can start on the floor or be hovering near the accelerator or brake pedal.

REQUIREMENTS: The first instance the term *response time until accelerator contacted* is used in a document, the foot start option (B (on the brake pedal) or N (neither on the brake or accelerator pedal)) shall be reported. See 5.1.1 for details. The data from the two options should be analyzed separately.

GUIDANCE for Response Time until Accelerator Contacted: For data on floor location start points, see McLaughlin and Serafin (1999). The response end point is often determined from the throttle signal on the CAN bus.

7.2.7 Response time until brake contacted

Time interval, usually measured in seconds or milliseconds, from an initiating event until the brake pedal is contacted, if the movement is in response to that event.

NOTE 1: For option N, the foot could be on the floor or hovering near the brake or accelerator pedal.

NOTE 2: Brake pedal contact point may be determined from a video recording, contact switch, brake pedal force sensor, brake line pressure, or by other means. In some cases, the indication of the first contact could be some small amount of displacement, with that amount being system specific.

NOTE 3: Of the various response time end points, this time is one of the most accurate, because contacts between objects can be readily detected.

NOTE 4: The term *brake response time* has been used in the literature to refer to a variety responses described in this document, though it is usually undefined. In the literature, the *brake response time* has meant *response time until brake contacted* (7.2.7), *response time until brake lights on* (7.2.8), *response time until maximum brake value* (7.2.15), or possibly something else. Furthermore, sometimes the term *perception-response time* or more often, *perception-reaction time* is used, especially in crash reconstruction (Triggs and Harris, 1982; Olson and Sivak, 1986; Olson, 2002). See 6.5.6.

REQUIREMENTS: The first instance the term *response time until brake contacted* is used in a document, the foot start option (A - on the accelerator pedal or N - neither on the accelerator pedal nor the brake pedal) shall be reported. See 5.1.1 for details.

GUIDANCE for Response Time until Brake Contacted: This measure may be particularly useful when maximum braking does not occur. For example, drivers may modulate their brake pedal if there is uncertainty in the collision threat (e.g., a lead car is spinning out of control and the driver does not know whether to brake, steer, or both) (Lee, McGehee, Brown, and Reyes, 2002).

As was noted previously, brake pedal contact can be determined acoustically, from video images, from a contact switch, from brake pressure data, or by other means. A typical hydraulic brake system has a maximum value of 1500 psi. To trigger the brake light switch, the pressure usually must reach 60 to 120 psi (414 to 826 kPa) or 4 to 8 % of maximum pressure, though it could be less.

The most extensive summary of brake response times is Young and Stanton (2007), who show mean brake response times ranging from 350 to 6300 ms and mean movement times of 170 to 180 ms. As examples, for responding to a center high-mounted stop lamp (CHMSL) in a driving simulator, Warshawsky-Livne and Shinar (2002) report brake response times of 0.39 s on average, with a movement time of about 0.17 s. For brake response times to a warning sound, Cheng, Hashimoto, and Suetomi (2002) report times ranging from 0.52 - 2.4 s with a mean of 1.08 s and a median of 0.96 s. The figure they provide suggests the distribution of response times is log normal. For additional data see Kiefer, LeBlanc, Palmer, Salinger, Deering, and Shulman (1999), Krishnan, Gibb, Steinfeld, and Shladover (2001), Najm and Lam (2003), Berndt, Wender, and Dietmayer (2007), Aust, Engstrom, Vistrom, Nabo, Bolling, Hjort, and Kallgren (2011), and Smith, Markkula, Benderius, Wolff, and Wahde (2012).

For related data on the braking performance of vehicles, information useful for predicting crash risk, see Marshek, Cuderman, and Johnson (2002a, b, c).

7.2.8 Response time until brake lights on

Time interval, usually measured in seconds or milliseconds, from an initiating event until the brake lights are illuminated, if the braking is in response to that event.

REQUIREMENTS: The first instance the term *response time until brake lights on* is used in a document, the foot-start option (A - on the accelerator pedal or N - neither on the accelerator pedal nor the brake pedal), the type of brake lamp, and the rise time to 90 % of steady state lamp luminance output shall be reported. See 5.1.1 for details.

GUIDANCE for Response Time until Brake Lights On: The time for a brake lamp to illuminate, and when it is detectable by a driver, depends on the type of lamp. For non-halogen incandescent brake lamps, no measurable light appears until about 50 ms after the voltage is applied, and it typically takes 250 ms for the lamp to reach 90 % of maximum output. For halogen incandescent bulbs, rise times are slightly faster but can still have measurable effects on overall human response times (Flannagan, 2014, personal communication). For all incandescent bulbs, the illumination vs. time function is an ogive. For LED lamps, the rise times to 90 % output are much less than 1 ms, a value too small to affect response time measurements (Flannagan, 2014, personal communication; Sivak, Flannagan, Sato, Traube, and Aoki, 1993).

7.2.9 Response time until brake lights off

Time interval, usually measured in seconds or milliseconds, from an initiating event until the brake lights are extinguished, if the foot is initially resting on the brake pedal and the movement is in response to that event.

REQUIREMENTS: The first instance the term *response time until brake lights off* is used in a document, the type of brake lamp and the fall time to 10 % of steady state incandescent lamp luminance output shall be reported.

GUIDANCE for Response Time until Brake Lights Off: LEDs extinguish very quickly, on the order of a millisecond, a value too small to affect response time measurements. However, incandescent lamps take time to extinguish, reaching 10 % of the illumination of the on state in about 100 ms. The decay is roughly exponential (Flannagan, 2014, personal communication).

7.2.10 Response time until 75 % accelerator value

Time interval, usually measured in seconds or milliseconds, from an initiating event until the accelerator response reaches 75 % of maximum, if the movement is in response to that event.

NOTE 1: See 7.1.3 for the rationale for the 75 % value.

NOTE 2: A common example of this response is when a traffic signal changes to yellow and a driver decides to accelerate through an intersection.

NOTE 3: The accelerator value could be the percentage of maximum accelerator pedal travel, the percentage of maximum throttle signal, or some other signal that describes the accelerator pedal use.

REQUIREMENTS: The first instance the term *response time until 75 % accelerator value* is used in a document, the foot start point (option A - on the accelerator pedal, B - on the brake pedal, or N - on neither the accelerator pedal nor the brake pedal) shall be reported. See 5.1.1 for details. The value that is used (e.g., percentage of maximum accelerator pedal travel, percentage of maximum throttle) shall be reported.

GUIDANCE for Response Time until 75 % Accelerator Value: Alternatives to this measure are *response time until maximum jerk while accelerating* and *response time until maximum accelerator value*. These two measures may provide a more accurate indication of a maximum accelerator pedal response, but are more difficult to determine.

7.2.11 Response time until 75 % brake value

Time interval, usually measured in seconds or milliseconds, from an initiating event until the brake response reaches 75 % of maximum, if the movement is in response to that event.

NOTE 1: See 7.1.3 for the rationale for the 75 % value.

NOTE 2: A common example of this response is when a closely followed vehicle suddenly brakes and the driver has to aggressively brake to avoid a crash.

NOTE 3: The brake value could be percent of maximum brake pedal travel, percent of maximum brake pressure signal, or some other signal that describes the brake pedal use.

REQUIREMENTS: The first instance the term *response time until 75 % brake value* is used in a document, the foot start point (option A - on the accelerator pedal, B - on the brake pedal, or N - on neither the accelerator pedal nor the brake pedal) shall be reported. See 5.1.1 for details. The value that is used (e.g., percentage of maximum brake pedal travel, percentage of maximum brake pressure) shall be reported.

GUIDANCE for Response Time Until 75 % Brake Value: Alternatives to this measure are *response time until maximum jerk while braking* and *response time until maximum brake value*. These two measures may provide a more accurate indication of a maximum brake pedal response, but are more difficult to determine.

7.2.12 Response time until maximum jerk while accelerating

Time interval, usually measured in seconds or milliseconds, from an initiating event until the maximum accelerator jerk, if the movement is in response to that event.

NOTE 1: Jerk is the time derivative of acceleration and is positive if the vehicle is accelerating, negative if decelerating. Specifically, ISO 2041 (2009) definition 1.5, defines jerk as “a vector that specifies the time-derivative of acceleration.”

NOTE 2: This value is determined for each subject for each trial.

NOTE 3: Previously, this measure and other measures related to jerk have not been collected very often (e.g., response time until maximum jerk while braking). However, as comfort issues related to adaptive cruise control and other automated systems supporting longitudinal control become increasingly common, so too will the use of jerk-related measures.

REQUIREMENTS: The first instance the term *response time until maximum jerk while accelerating* is used in a document, the foot start point (option A - on the accelerator pedal, B - on the brake pedal, or N – on neither the accelerator pedal nor the brake pedal) shall be reported. See 5.1.1 for details.

GUIDANCE for Response Time until Maximum Jerk while Accelerating: This measure is appropriate for situations where large changes in longitudinal acceleration can occur. Maximum jerk while accelerating for real vehicles can be determined directly from the speed and acceleration sensors, or more likely from data available on the CAN bus by differentiating the acceleration signal or by twice differentiating the speed signal. For driving simulators, vehicle speed is a default measure, and longitudinal acceleration may be available directly or be determined by differentiation of the speed signal.

Large jerk values increase riding discomfort. However, data on the magnitude of jerk values causing discomfort are limited (Rehnberg, 2008). For studies in which jerk is examined, see Nygard (1999), and Bagdadi and Varhelyi (2011, 2012).

7.2.13 Response time until maximum jerk while braking

Time interval, usually measured in seconds or milliseconds, from an initiating event until the maximum negative jerk, if the movement is in response to that event.

NOTE 1: This value is determined for each subject for each trial.

NOTE 2: See 7.2.12, *response time until maximum jerk while accelerating*, for related notes.

REQUIREMENTS: The first instance the term *response time until maximum individual jerk while braking* is used in a document, the foot start point (option A - on the accelerator pedal, B - on the brake pedal, or N - on neither the accelerator nor the brake pedal) shall be reported. See 5.1.1 for details.

GUIDANCE for Response Time until Maximum Jerk while Braking: This measure is appropriate for situations where large changes in longitudinal deceleration can occur. Maximum jerk while braking for real vehicles can be determined directly from the speed and acceleration sensors, or more likely from data available on the CAN bus by differentiating the acceleration signal or by twice differentiating the speed signal. For driving simulators, vehicle speed is a default measure, and longitudinal acceleration may be available directly or be determined by differentiation of the speed signal.

For studies in which jerk while braking is examined, see Nygard (1999), Bagdadi (2013), Bagdadi and Varhelyi (2011, 2013). For data on jerk while braking and accelerating, see Jensen, Wagner, and Alexander (2011).

7.2.14 Response time until maximum accelerator value

Time interval, usually measured in seconds or milliseconds, from an initiating event until the maximum individual accelerator value, if the movement is in response to that event.

NOTE 1: This value is determined for each subject for each trial.

NOTE 2: The maximum accelerator value could be the maximum accelerator pedal travel, the maximum throttle signal, or some other signal that describes the accelerator pedal use.

REQUIREMENTS: The first instance the term *response time until maximum accelerator value* is used in a document, the foot start point (option A - on the accelerator pedal, B - on the brake pedal, or N - on neither the accelerator pedal nor the brake pedal) shall be reported. See 5.1.1 for details.

GUIDANCE for Response Time until Maximum Accelerator Value: Because this measure is time consuming to determine (potentially requiring visual inspection of each trial of interest to identify local maxima), *response time to 75 % throttle* may be preferred.

7.2.15 Response time until maximum brake value

Time interval, usually measured in seconds or milliseconds, from an initiating event until the maximum individual brake value, if the movement is in response to that event.

NOTE 1: This value is determined independently for each subject for each trial.

NOTE 2: In fixed-base driving simulators (but not motion-based simulators), people tend to accelerate and brake more aggressively than in real driving, so the maximum acceleration values and maximum braking values are greater (McGehee, 2014, personal communication).

NOTE 3: The brake value could be the maximum brake pedal travel, the maximum brake pressure, or some other signal that describes the brake pedal use.

REQUIREMENTS: The first instance the term *response time until maximum brake value* is used in a document, the foot start point (option A - on the accelerator pedal, B - on the brake pedal, or N - on neither the accelerator nor the brake pedal) shall be reported. See 5.1.1 for details.

GUIDANCE for Response Time until Maximum Brake Value: Because this measure is time consuming to determine (potentially requiring visual inspection of each trial of interest to identify local maxima), *response time to 75 % brake value* may be preferred.

7.3 Guidance for Use of Accelerator Pedal and Brake Pedal Measures

Response times are generally reported in seconds (usually to nearest 0.01) or milliseconds, often reflecting the accuracy to which response time is measured. When response time is obtained using video data, accuracy is no greater than the inverse frame rate. See 5.1.3.

When selecting response measures, initial response measures (the earliest indication of a response) and final response measures (the desired pedal movement has occurred) are preferred over intermediate responses because of their safety consequences. However, for practical reasons, *response time until brake contact* or *response time until brake light on* are often used because those terms (1) communicate information to other drivers, (2) are easy to measure in a real vehicle, and (3) are useful in roadway design and crash litigation. Simulators and advanced instrumented vehicles may have more sophisticated methods to measure pedal deflection to determine the time of initial pedal contact.

Olson (1986) or Olson (2002), as well as Green (2000) and Johansson and Rumar (1971) provide additional information on brake response time. For a more recent study comparing stationary (parked) and while driving response times, see Makishita. and Matsunaga (2008). For a study simultaneously examining multiple measures of pedal responses, see Lerner, Jenness, Robinson, Brown, Baldwin and Llaneras (2011).

8. LONGITUDINAL CONTROL: OPERATIONAL DEFINITIONS OF VEHICLE-BASED MEASURES

In analyzing and reporting longitudinal distance measures, values above a user-specified maximum are sometimes excluded from the data set, such as when the lead vehicle is so far away that it has no practical effect on the driving behavior of the following vehicle. See 8.1.10 for details.

8.1 Vehicle Longitudinal State Measures

The arithmetic mean is the statistical measure most often reported for the state measures in 8.1.1 - 8.1.8. These means are not explicitly defined, but guidance for each mean is reported with the state measures. Standard deviations of those measures are often of interest, but only limited guidance is provided in this version. Additional guidance will appear in the next version.

For applications of these measures, see NCAP *Forward Crash and Lane Departure Warning System 2010 Test Procedures* (U.S. Department of Transportation, 2010a, b) and Alliance of Automobile Manufacturers *Driver Focus Guidelines* (Alliance of Automobile Manufacturers, 2006).

8.1.1 Distance gap

Longitudinal distance along a traveled way, usually measured in feet or meters, between one vehicle's leading surface and another vehicle's trailing surface.

NOTE 1: This definition was expanded from the *Highway Capacity Manual* (2010, p. 9-8).

NOTE 2: The distance along the traveled way is not always a straight-line distance. See Figure 23 for an illustration of the difference between distance gap and range.

NOTE 3: The two vehicles are usually the subject vehicle and a vehicle immediately ahead in the same lane traveling in the same direction (Figure 14). Often in the literature, but especially for forward crash warning studies, the term *headway* is used when the context indicates *gap* should have been used.

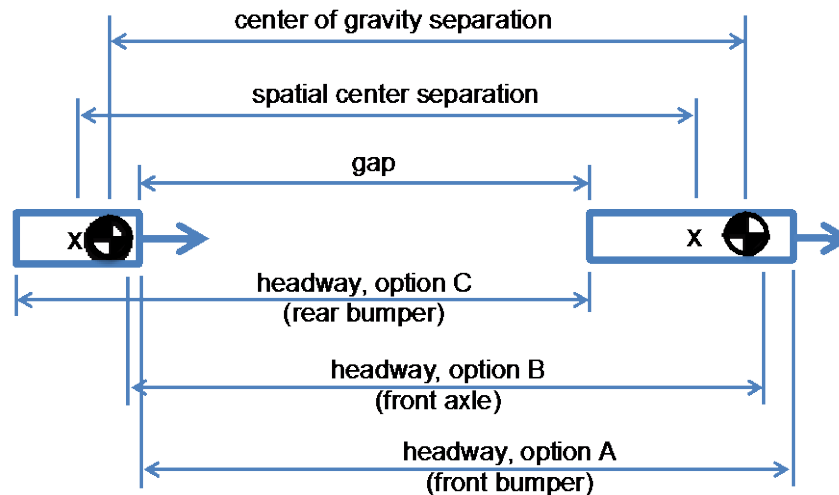


Figure 14 - Longitudinal distance or time measures

- NOTE 4: When the gap between vehicles is the straight-line distance (not the distance along a curved section of the traveled way), the term range (8.1.7) can be used.
- NOTE 5: Although these measures are intended to apply to vehicle-to-vehicle separation, they could also be applied to vehicle-to-pedestrian and pedestrian-to-pedestrian separation.
- NOTE 6: *Distance gap* is called *clearance* in SAE J2399: 2003. The time equivalent of distance gap is time gap, defined in 8.1.2.
- NOTE 7: The gap measure that is reported (e.g., distance gap (8.1.1), time gap (8.1.2) or range (8.1.9)) will likely depend on how the gap was determined (ground-based sensors or on-board sensors) and the curvature of the road. For straight roads, distance gap and range are identical.
- NOTE 8: When the gaps refer to vehicles immediately ahead of and behind the subject vehicle, the terms front and rear gap are used (Figure 15), though the term following gap has often been used instead of front gap. See Hidas (2005) for use of front and rear gap.
- NOTE 9: For multi-lane traveled ways, *gap* can refer to (1) the distance between the subject vehicle and a leading or trailing vehicle in the same lane (called the front and rear gaps), (2) the distance between the subject vehicle and a leading or trailing vehicle in another lane (called the *lead* and *lag* gaps), or (3) the distance gap between two vehicles in a lane adjacent to the subject vehicle, called the *adjacent lane gap* (Figure 15). The gap between the two vehicles in the adjacent lane (adjacent lane gap) is important if the subject wants to change into that lane.

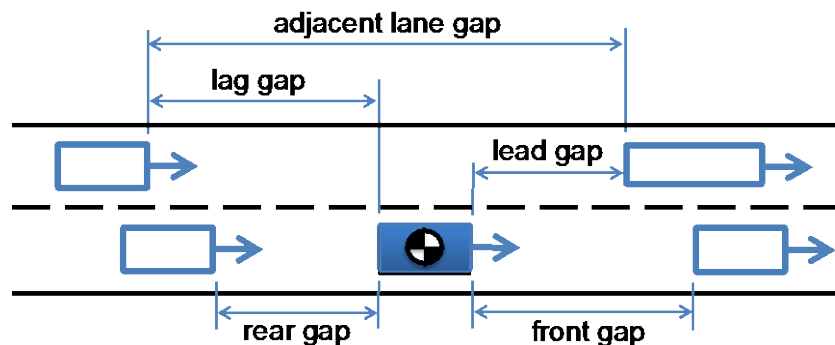


Figure 15 - Gap alternatives in a multi-lane traveled way

NOTE 10: Figure 16 shows the subject vehicle merging onto a multi-lane traveled way, where the driver has to judge the gap between other vehicles and their relative position in order to merge safely (Lee, 2004).

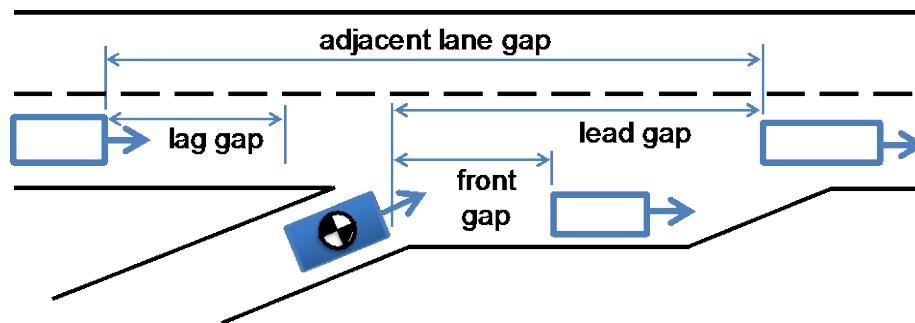


Figure 16 - Merging onto a multi-lane traveled way

NOTE 11: Figure 17 shows the gaps a driver would need to consider when passing a lead vehicle on a two-lane traveled way (Farah, Bekhor, Polus, and Toledo, 2012). When the subject vehicle is in the passing lane, then the gap for merging between the two vehicles in the original lane is the return lane gap.

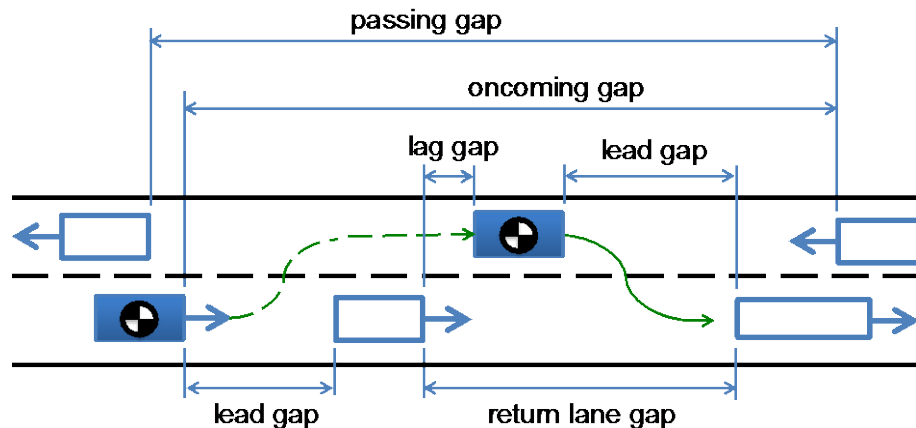


Figure 17 - Passing maneuver on a two-lane traveled way

NOTE 12: The term *gap* can also refer to the distance between the subject vehicle and approaching vehicles in intersecting lanes of travel (Figures 18 and 19). In this scenario, the gap is measured between the lead surface of the through vehicle and nearest side the crossing vehicle. When deciding to cross intersecting lanes of traffic, drivers have to consider the gaps in the crossing traffic relative to the subject vehicle and the speed(s) of the approaching vehicle(s). The scenarios shown in Figures 18 and 19 can also be applied for the case of a pedestrian at a crosswalk.

Figure 20 shows an example of a left turning vehicle, where the driver of the subject vehicle is deciding if it's safe to turn left in front of an oncoming vehicle. Oncoming gap has sometimes been referred to as "lag" in the literature (Alexander, Barham, and Black, 2002). For additional information on the use of intersection gap measures, see, Brilion, Koenig, and Troutbeck (1999), Alexander, Barham and Black (2002), Cody, Nowakowski, and Bougler, (2007), and Yan, Radwan, and Guo, (2007).

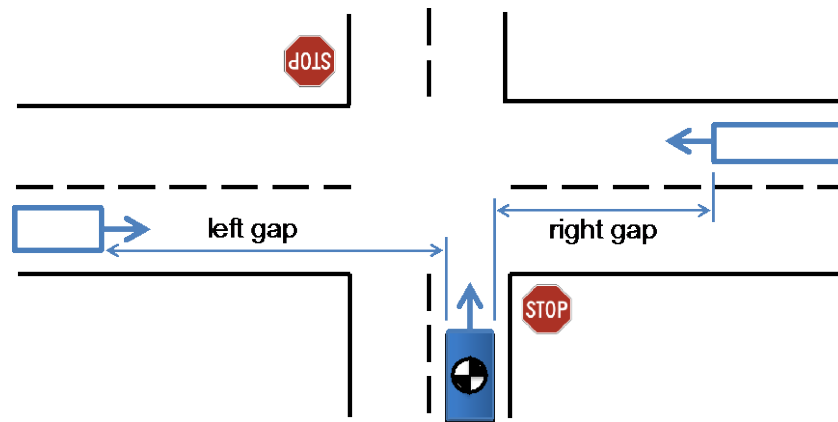


Figure 18 – Gaps when proceeding from stop to cross a right-angle intersection

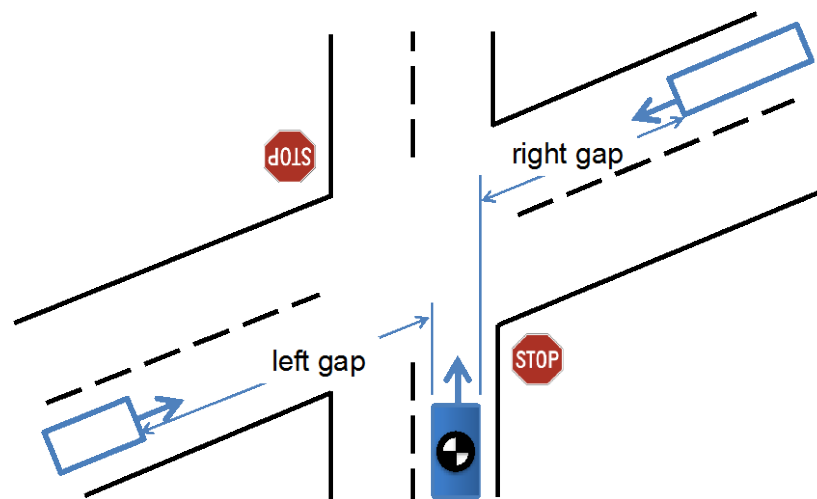


Figure 19 - Gaps when proceeding from stop to cross an angled intersection

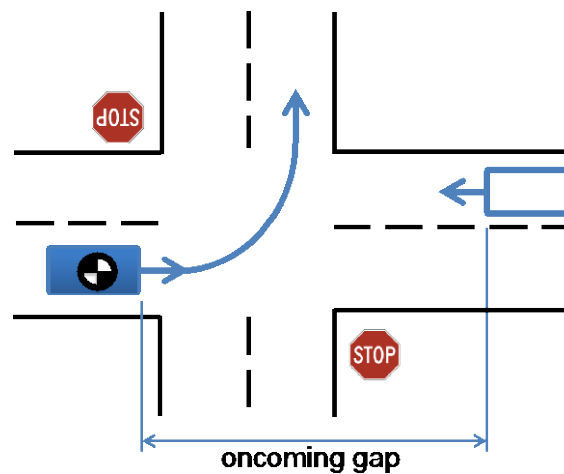


Figure 20 - Gap for left turn across path

REQUIREMENTS: The first instance the term *distance gap* is used in a document, the two vehicles in the gap measurement and the value above which distance gap is ignored, if any, shall be reported. Separate analyses and records of distance gaps shall be kept for each lane location

GUIDANCE for Distance Gap: The distance gap represents the clearance between two vehicles in the same lane and is used in safety assessments to indicate safe following distance. This includes making decisions about passing a lead vehicle (and the space between the lead vehicle and the vehicle ahead of it), and at intersections when merging into or crossing in front of vehicles traveling perpendicular to the subject's direction of travel (gap acceptance studies) (Gibbs, 1965; Farber and Silver, 1967; McLean, chapter 8, 1989; Cooper and Zheng, 2002; U.S. Department of Transportation, 2010a; Rossi, Gastaldi, Gecchele, and Meneguzzo, 2014). For additional information on gaps in lane changes, see 10.5.1.

Table 2 shows the “average spacing” between vehicles as a function the Level of Service, a categorical indication of the volume of traffic, per Wikipedia. The original source for these data is the 2000 *Highway Capacity Manual*. Level of Service A corresponds to free flow. Level F corresponds to a lack of free flow, and levels B - E correspond to intermediate amounts of traffic flow. For additional information on the definition of Level of Service, see the *Highway Capacity Manual* (Transportation Research Board, 2010) and the AASHTO Green Book (AASHTO, 2011). Furthermore, using the service volume data in the *Highway Capacity Manual* along with assumptions about the relative fractions of car and truck traffic, and the mean lengths of each vehicle type, the mean gap can be estimated as a function of road type (e.g., expressway, urban), number of lanes, and level of service. For information on the factors that influence the distance and time gaps drivers select when following a vehicle, see Kitajima, Marumo, Hiraoka and Itoh (2008) and Wada, Doi, Tsuru, Isaj, and Kaneko (2012).

Table 2 - “Average spacing” (distance gap) between vehicles for highways

Source: modified from http://en.wikipedia.org/wiki/Level_of_service, retrieved May 22, 2012

Level of Service (LOS)	Average Spacing (ft, m)
A	550, 168
B	330, 101
C	220, 67
D	160, 49
E	130, 40
F	highly variable

8.1.2 Time gap

Time interval, usually measured in seconds, for a following vehicle's leading surface to reach the current location of the trailing surface of a vehicle ahead.

NOTE 1: This definition was expanded from the *Highway Capacity Manual* (2010, p. 9-8) and modified to be consistent with the wording for distance gap.

NOTE 2: To determine the time gap, the following vehicle speed is assumed fixed at the current value, so acceleration is not a factor. If the lead vehicle is braking, then time to collision is a more appropriate measure.

NOTE 3: Time gap is equal to distance gap divided by the speed of the following vehicle, assuming following vehicle speed is constant.

NOTE 4: Time gap can be measured for the scenarios defined in Figures 14-20.

NOTE 5: Consistent with the definition specified herein, SAE J2399:2003, 3.17, defines *time gap* as “time interval for traveling a distance equal to the clearance ‘c’ to the immediately forward vehicle, given the current vehicle speed.” Time gap is represented by the symbol τ .

REQUIREMENTS: The first instance the term *time gap* is used in a document, the two vehicles in the measurement and the value above which time gap is ignored, if any, shall be reported. Separate analyses and records of time gaps shall be kept for each lane.

GUIDANCE for Time Gap: There is a considerable body of literature that refers to time headway and related measures (e.g., Mitra and Utsav, 2011). However, if it is measured using radar or LIDAR mounted on the subject vehicle and reflected by the rear of the lead vehicle, what is identified in publications as time headway is actually time gap (if the traveled way is straight).

Some of the most extensive data on time gap appears in Ervin, Sayer, LeBlanc, Bogard, Mefford, Hagan, Bareket, and Winkler, (2005). See Figure 21. Across all of the on-road conditions they examined (speeds greater than 25 mi/hr (40 km/hr)), they reported time gaps ranging from about 0.3-3.0 s with a median of 1.4 s and a mode of about 1.0 s. The distribution of time gaps appears to be log normal. They also provide data that show the effect of driver age and other factors. Michael, Leeming, and Dwyer (2000) show time gaps for urban driving to be between 1.4 and 2.2 s. Mitra and Utsav (2011) show the effects of fog on time gap. For the effect of lane driven, see Ayres, Li, Schleuning and Young (2001). For time gaps in work zones, see Wang, Benekohal Ramezani, Nassiri, Medina, and Hajbabaie (2011).

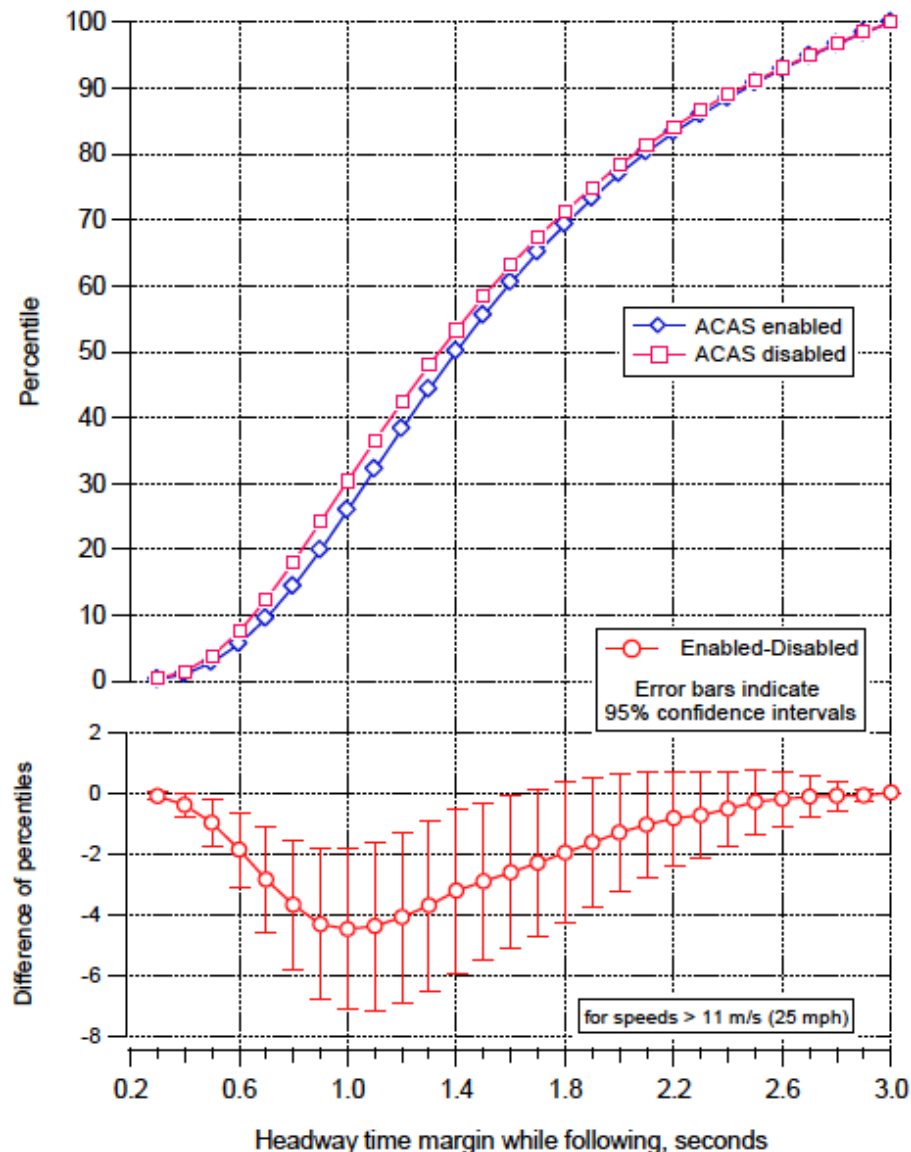


Figure 21 - Time gap distribution

(Ervin et al (2005) refer to time gap as headway.)

Source: Ervin, Sayer, LeBlanc, Bogard, Mefford, Hagan, Bareket, and Winkler (2005), p. 7-6

Of importance is the description of the distribution of time gaps. Hoogendoorn and Bovy (1998) state that the distribution of “headway” (what they refer to as “empty zone”, but which appears to be mean time gap) is fitted by a Pearson-III, mixed-vehicle-type Generalized Queuing Model (GQM). For that distribution, they provide distribution parameters (alpha, beta, d, gamma, theta) as a function of vehicle type (car, truck, articulated truck) and as a function of time of day

(morning, noon, evening). For the use of time gap to estimate crash avoidance, see Yang and Peng (2010) and Zhang, Shladover, and Zhang, (2007).

The most common statistic based on time gap is mean time gap. Mitra and Utsav (2011) suggest only considering time gaps of 6.0 s or less to deal with the problem posed by very large time gaps when computing a mean value. Another option is to focus on the median time gap. Either option is acceptable.

For data on gaps when driving on real (not simulated) traveled ways, see Brackstone and McDonald (1999), Brackstone, Sultan, and McDonald (2002), Lee and Peng (2004), Brackstone and McDonald (2007), Brackstone, Waterson, and McDonald (2009), and Fancher, Bareket, and Ervin (2001).

8.1.3 Distance headway

Longitudinal distance along a traveled way, usually measured in feet or meters, between two vehicles measured from the same common external feature of both vehicles (Figure 14).

NOTE 1: The two vehicles are a subject vehicle and a vehicle immediately ahead in the same lane (Figure 15).

NOTE 2: The three options for the external feature are: (1) the front bumper (option A), (2) the front axle or tires (option B), or the rear bumper (option C).

NOTE 3: The definition presented here is similar to the definition used in the *Highway Capacity Manual* with the added qualification that the common feature is on the outside of the vehicles.

NOTE 4: *Distance gap* and *distance headway* often differ by one “vehicle” length. For option A (front bumper), the difference is the length of the lead vehicle. For option C (rear bumper), the difference is the length of the following vehicle. However, for option B (front axle), the difference is some combination of both vehicle lengths.

NOTE 5: As noted in 8.1.1, the term headway is often erroneously used when gap is the correct term. See Figure 14 and 8.1.10 for the distinction between them.

REQUIREMENTS: The first instance the term *distance headway* is used in a document, the two vehicles in the distance headway measurement, the common external feature (option A, B, or C), and the value above which distance headway is ignored, if any, shall be reported. The method for sensing the distance headway shall also be reported.

GUIDANCE for Headway: The common external feature (option A, B, or C) used for the measurement is usually determined by which sensors are readily available.

Klein, Mills, and Gibson (2006) describe several ways for detecting vehicles passing a particular point. The methods that they and others describe for sensing external features (e.g., video image processing, active and passive infrared beams) can provide accuracy sufficient for human factors studies. Other methods that do not rely on those features (e.g., inductive loops, magnetometers, road tubes, etc.) primarily have value for counting traffic and assessing traffic flow.

There are particular concerns about the accuracy of inductive loops (Nihan, Zhang, and Wang (2002). There are also concerns about the accuracy of magnetometers and road tubes for human factors studies. When road tubes are used, the distance will be measured from front axle to front axle. When light beams are used, the distance will usually be measured from front bumper to front bumper, but it could be from rear bumper to rear bumper.