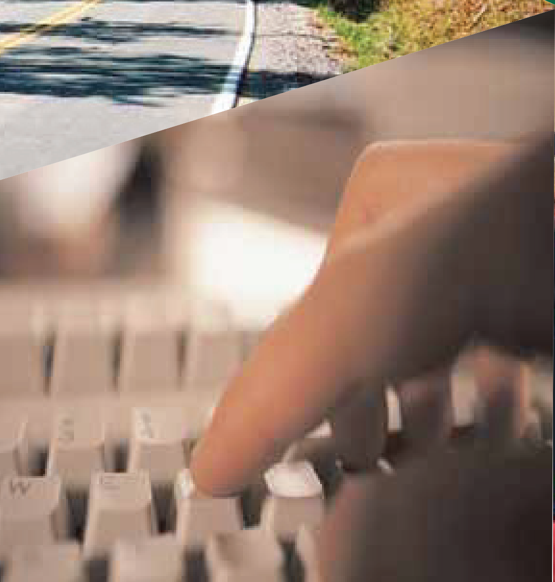
A POLICY ON

Geometric Design of Highways and Streets

2004

American Association of State Highway and Transportation Officials



A Policy on Geometric Design of Highways and Streets

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Information Handling

Drivers use many of their senses to gather information. Most information is received visually by drivers from their view of the roadway alignment, markings, and signs. However, drivers also detect changes in vehicle handling through instinct. They do so, for example, by feeling road surface texture through vibrations in the steering wheel and hearing emergency vehicle sirens.

Throughout the driving task, drivers perform several functions almost simultaneously. They look at information sources, make numerous decisions, and perform necessary control actions. Sources of information (some needed, others not) compete for their attention. Needed information should be in the driver's field of view, available when and where needed, available in a usable form, and capable of capturing the driver's attention.

Because drivers can only attend to one visual information source at a time, they integrate the various information inputs and maintain an awareness of the changing environment through an attention-sharing process. Drivers sample visual information obtained in short-duration glances, shifting their attention from one source to another. They make some decisions immediately, and delay others, through reliance on judgment, estimation, and prediction to fill in gaps in available information.

Reaction Time

Information takes time to process. Drivers' reaction times increase as a function of decision complexity and the amount of information to be processed. Furthermore, the longer the reaction time, the greater the chance for error. Johannson and Rumar (**8**) measured brake reaction time for expected and unexpected events. Their results show that when an event is expected, reaction time averages about 0.6 s, with a few drivers taking as long as 2 s. With unexpected events, reaction times increased by 35 percent. Thus, for a simple, unexpected decision and action, some drivers may take as long as 2.7 s to respond. A complex decision with several alternatives may take several seconds longer than a simple decision. Exhibit 2-26 shows this relationship for median-case drivers, whereas Exhibit 2-27 shows this relationship for 85th-percentile drivers. The figures quantify the amount of information to be processed in bits. Long processing times decrease the time available to attend to other tasks and increase the chance for error.

Highway designs should take reaction times into account. It should be recognized that drivers vary in their responses to particular events and take longer to respond when decisions are complex or events are unexpected. Clear sight lines and adequate decision sight distance provide a margin for error.

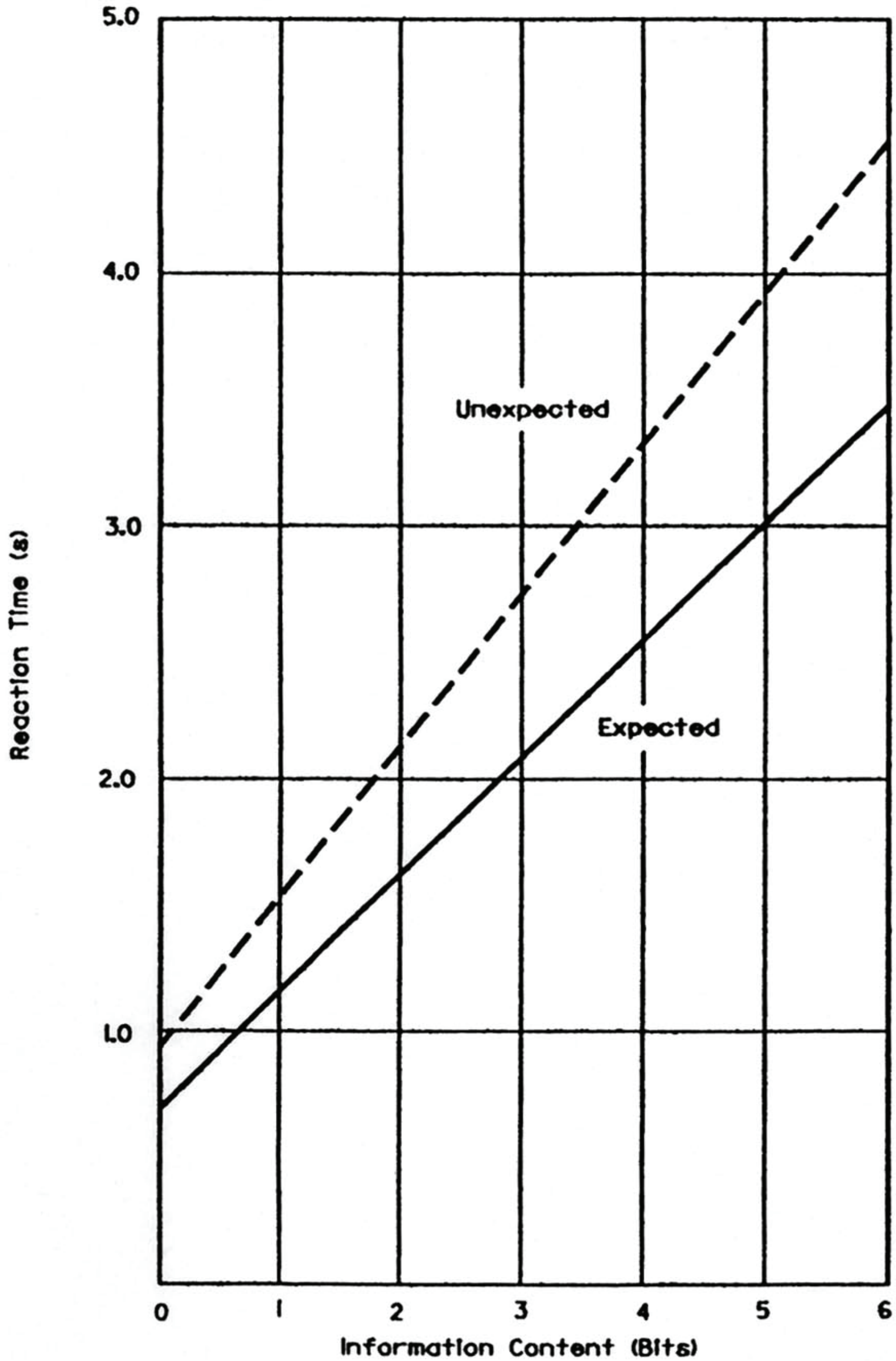

Exhibit 2-26. Median Driver Reaction Time to Expected and Unexpected Information

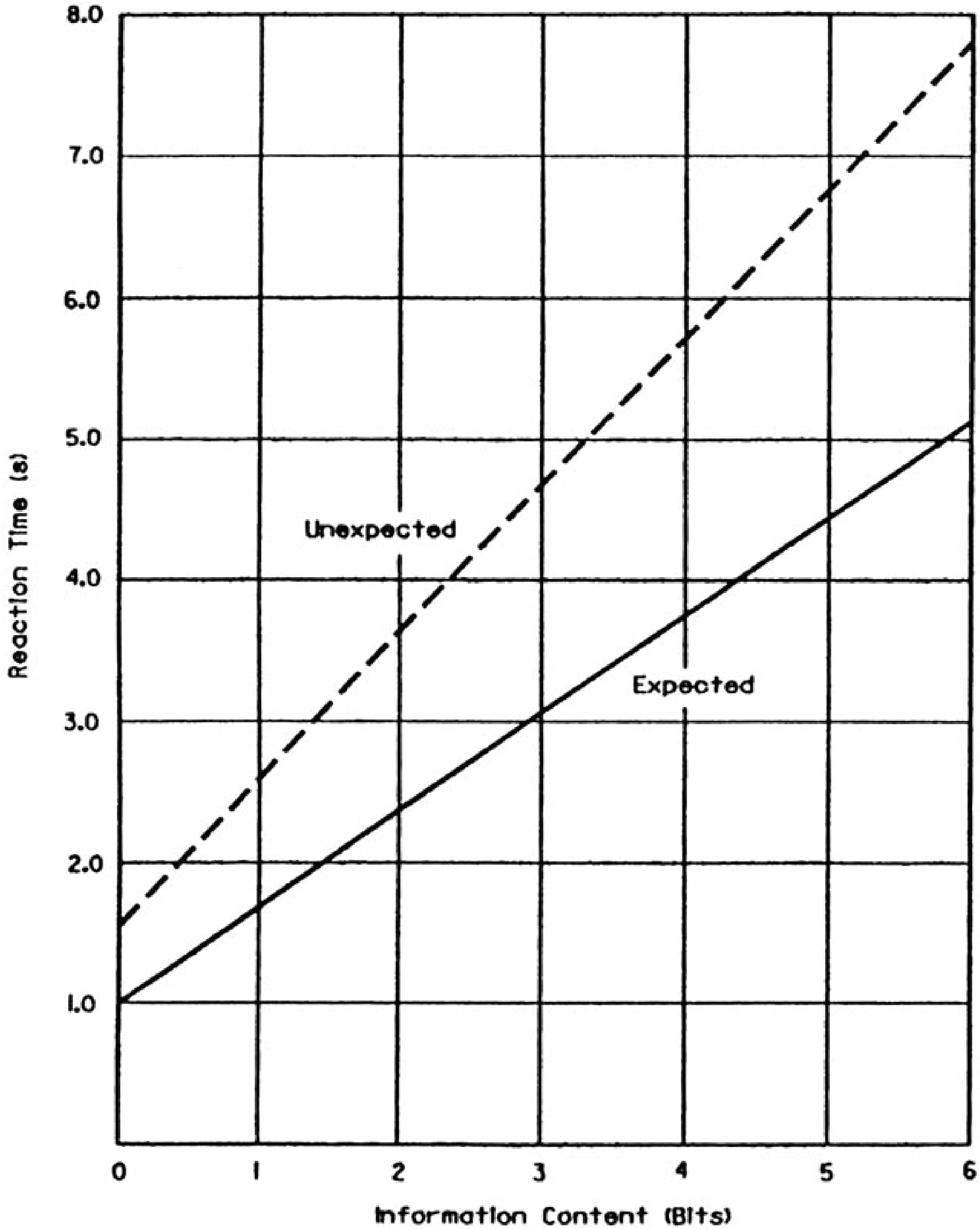

Exhibit 2-27. 85th-Percentile Driver Reaction Time to Expected and Unexpected Information

Primacy

Primacy relates the relative importance to safety of competing information. Control and guidance information is important because the related errors may contribute directly to crashes. Navigation information has a lower primacy because errors may lead to inefficient traffic flow, but are less likely to lead to crashes. Accordingly, the design should focus the drivers' attention on the safety-critical design elements and high-priority information sources. This goal may be achieved by providing clear sight lines and good visual quality.

Expectancy

Driver expectancies are formed by the experience and training of drivers. Situations that generally occur in the same way, and successful responses to these situations, are incorporated into each driver's store of knowledge. Expectancy relates to the likelihood that a driver will respond to common situations in predictable ways that the driver has found successful in the past. Expectancy affects how drivers perceive and handle information and modify the speed and nature of their responses.

Reinforced expectancies help drivers respond rapidly and correctly. Unusual, unique, or uncommon situations that violate driver expectancies may cause longer response times, inappropriate responses, or errors.

Most highway design features are sufficiently similar to create driver expectancies related to common geometric, operational, and route characteristics. For example, because most freeway interchanges have exits on the right side of the road, drivers generally expect to exit from the right. This aids performance by enabling rapid and correct responses when exits on the right are to be negotiated. There are, however, instances where expectancies are violated. For example, if an exit ramp is on the left, then the right-exit expectancy is incorrect, and response times may be lengthened or errors committed.

One of the most important ways to aid driver performance is to develop designs in accordance with prevalent driver expectancies. Unusual design features should be avoided, and design elements should be applied consistently throughout a highway segment. Care should also be taken to maintain consistency from one segment to another. When drivers obtain the information they expect from the highway and its traffic control devices, their performance tends to be error free. Where they do not get what they expect, or get what they do not expect, errors may result.

Driver Error

A common characteristic of many high-crash locations is that they place large or unusual demands on the information-processing capabilities of drivers. Inefficient operation and crashes usually occur where the driver's chances for information-handling errors are high. At locations where information-processing demands on the driver are high, the possibility of error and inappropriate driver performance increases.

Errors Due to Driver Deficiencies

Many driving errors are caused by deficiencies in a driver's capabilities or temporary states, which, in conjunction with inappropriate designs or difficult traffic situations, may produce a failure in judgment. For example, insufficient experience and training may contribute to a driver's inability to recover from a skid. Similarly, inappropriate risk taking may lead to errors in gap acceptance while passing (**9**). In addition, poor glare recovery may cause older drivers to miss information at night (**10**).

Adverse psychophysiological states also lead to driver failures. These include decreased performance caused by alcohol and drugs, for which a link to crashes has been clearly established. The effects of fatigue, caused by sleep deprivation from extended periods of driving without rest or prolonged exposure to monotonous environments, or both, also contribute to crashes (**11**).

It is not generally possible for a design or an operational procedure to reduce errors caused by innate driver deficiencies. However, designs should be as forgiving as practical to lessen the consequences of such failures. Errors committed by competent drivers can be reduced by proper design and operation. Most individuals possess the attributes and skills to drive properly and are neither drunk, drugged, nor fatigued at the start of their trips. When drivers overextend themselves, fail to take proper rest breaks, or drive for prolonged periods, they ultimately reach a less-than-competent state. Fatigued drivers represent a sizable portion of the long-trip driving population and should therefore be considered in freeway design.

Although opinions among experts are not unanimous, there is general agreement that advancing age has a deleterious effect on an individual's perceptual, mental, and motor skills. These skills are critical factors in vehicular operation. Therefore, it is important for the road designer to be aware of the needs of the older driver, and where appropriate, to consider these needs in the roadway design.

Some of the more important information and observations from recent research studies concerning older drivers is summarized below:

1. **Characteristics of the Older Driver**. In comparison to younger drivers, older drivers often exhibit the following operational deficiencies:

    - slower information processing
    - slower reaction times
    - slower decision making
    - visual deterioration
    - hearing deterioration
    - decline in ability to judge time, speed, and distance

- limited depth perception
- limited physical mobility
- side effects from prescription drugs

2. **Crash Frequency**. Older drivers are involved in a disproportionate number of crashes where there is a higher-than-average demand imposed on driving skills. The driving maneuvers that most often precipitate higher crash frequencies among older drivers include:

   - making left turns across traffic
   - merging with high-speed traffic
   - changing lanes on congested streets in order to make a turn
   - crossing a high-volume intersection
   - stopping quickly for queued traffic
   - parking

3. **Countermeasures**. The following countermeasures may help to alleviate the potential problems of the older driver:

   - assess all guidelines to consider the practicality of designing for the 95th- or 99th-percentile driver, as appropriate, to represent the performance abilities of an older driver
   - improve sight distance by modifying designs and removing obstructions, particularly at intersections and interchanges
   - assess sight triangles for adequacy of sight distance
   - provide decision sight distances
   - simplify and redesign intersections and interchanges that require multiple information reception and processing
   - consider alternate designs to reduce conflicts
   - increase use of protected left-turn signal phases
   - increase vehicular clearance times at signalized intersections
   - provide increased walk times for pedestrians
   - provide wider and brighter pavement markings
   - provide larger and brighter signs
   - reduce sign clutter
   - provide more redundant information such as advance guide signs for street name, indications of upcoming turn lanes, and right-angle arrows ahead of an intersection where a route turns or where directional information is needed
   - enforce speed limits
   - increase driver education

In roadway design, perhaps the most practical measure related to better accommodate older drivers is an increase in sight distance, which may be accomplished through increased use of decision sight distance. The gradual aging of the driver population suggests that increased use of decision sight distance may help to reduce future crash frequencies for older drivers. Where provision of decision sight distance is impractical, increased use of advance warning or guide signs may be appropriate.

Errors Due to Situation Demands

Drivers often commit errors when they have to perform several highly complex tasks simultaneously under extreme time pressure (**12**). Errors of this type usually occur at urban locations with closely spaced decision points, intensive land use, complex design features, and heavy traffic. Information-processing demands beyond the drivers' capabilities may cause information overload or confuse drivers, resulting in an inadequate understanding of the driving situation.

Other locations present the opposite situations and are associated with different types of driver errors. Typically these are rural locations where there may be widely spaced decision points, sparse land use, smooth alignment, and light traffic. Information demands are thus minimal, and rather than being overloaded with information, the lack of information and decision-making demands may result in inattentiveness by drivers. Driving errors may be caused by a state of decreased vigilance in which drivers fail to detect, recognize, or respond to new, infrequently encountered, or unexpected design elements or information sources.

Speed and Design

Speed reduces the visual field, restricts peripheral vision, and limits the time available for drivers to receive and process information. Highways built to accommodate high speeds help compensate for these limitations by simplifying control and guidance activities, by aiding drivers with appropriate information, by placing this information within the cone of clear vision, by eliminating much of the need for peripheral vision, and by simplifying the decisions required and spacing them farther apart to decrease information-processing demands.

Current freeway designs have nearly reached the goal of allowing drivers to operate at high speeds in comfort and safety. Control of access to the traveled way reduces the potential for conflicts by giving drivers a clear path. Clear roadsides have been provided by eliminating obstructions or designing them to be more forgiving. The modern freeway provides an alignment and profile that, together with other factors, encourages high operating speeds.

Although improved design has produced significant benefits, it has also created potential problems. For example, driving at night at high speeds may lead to reduced forward vision because of the inability of headlights to illuminate objects in the driver's path in sufficient time for some drivers to respond (**13**). In addition, the severity of crashes is generally greater with increased speed.

Finally, the very fact that freeways succeed in providing safe, efficient transportation can lead to difficulties. The Institute of Traffic Engineers (**14**) indicated that "Freeways encourage applicable design criteria are described later in this chapter. The special conditions related to sight distances at intersections are discussed in Chapter 9.

Stopping Sight Distance

Sight distance is the length of the roadway ahead that is visible to the driver. The available sight distance on a roadway should be sufficiently long to enable a vehicle traveling at or near the design speed to stop before reaching a stationary object in its path. Although greater lengths of visible roadway are desirable, the sight distance at every point along a roadway should be at least that needed for a below-average driver or vehicle to stop.

Stopping sight distance is the sum of two distances: (1) the distance traversed by the vehicle from the instant the driver sights an object necessitating a stop to the instant the brakes are applied; and (2) the distance needed to stop the vehicle from the instant brake application begins. These are referred to as brake reaction distance and braking distance, respectively.

Brake Reaction Time

Brake reaction time is the interval from the instant that the driver recognizes the existence of an obstacle on the roadway ahead that necessitates braking to the instant that the driver actually applies the brakes. Under certain conditions, such as emergency situations denoted by flares or flashing lights, drivers accomplish these tasks almost instantly. Under most other conditions, the driver must not only see the object but must also recognize it as a stationary or slowly moving object against the background of the roadway and other objects, such as walls, fences, trees, poles, or bridges. Such determinations take time, and the amount of time needed varies considerably with the distance to the object, the visual acuity of the driver, the natural rapidity with which the driver reacts, the atmospheric visibility, the type and the condition of the roadway, and nature of the obstacle. Vehicle speed and roadway environment probably also influence reaction time. Normally, a driver traveling at or near the design speed is more alert than one traveling at a lesser speed. A driver on an urban street confronted by innumerable potential conflicts with parked vehicles, driveways, and cross streets is also likely to be more alert than the same driver on a limited-access facility where such conditions should be almost nonexistent.

The study of reaction times by Johansson and Rumar (**1**) referred to in Chapter 2 was based on data from 321 drivers who expected to apply their brakes. The median reaction-time value for these drivers was 0.66 s, with 10 percent using 1.5 s or longer. These findings correlate with those of earlier studies in which alerted drivers were also evaluated. Another study (**2**) found 0.64 s as the average reaction time, while 5 percent of the drivers needed over 1 s. In a third study (**3**), the values of brake reaction time ranged from 0.4 to 1.7 s. In the Johansson and Rumar study (**1**), when the event that required application of the brakes was unexpected, the drivers' response times were found to increase by approximately 1 s or more; some reaction times were greater than 1.5 s. This increase in reaction time substantiated earlier laboratory and road tests in which the conclusion was drawn that a driver who needed 0.2 to 0.3 s of reaction time under alerted conditions would need 1.5 s of reaction time under normal conditions.

Minimum brake reaction times for drivers could thus be at least 1.64 s and 0.64 s for alerted drivers as well as 1 s for the unexpected event. Because the studies discussed above used simple prearranged signals, they represent the least complex of roadway conditions. Even under these simple conditions, it was found that some drivers took over 3.5 s to respond. Because actual conditions on the highway are generally more complex than those of the studies, and because there is wide variation in driver reaction times, it is evident that the criterion adopted for use should be greater than 1.64 s. The brake reaction time used in design should be large enough to include the reaction times needed by nearly all drivers under most highway conditions. Both recent research (**4**) and the studies documented in the literature (**1, 2, 3**) show that a 2.5-s brake reaction time for stopping sight situations encompasses the capabilities of most drivers, including those of older drivers. The recommended design criterion of 2.5 s for brake reaction time exceeds the 90th percentile of reaction time for all drivers and has been used in the development of Exhibit 3-1.

A brake reaction time 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. The need for greater reaction time in the most complex conditions encountered on the roadway, such as those found at multiphase at-grade intersections and at ramp terminals on through roadways, can be found later in this chapter in the section on "Decision Sight Distance."

Braking Distance

The approximate braking distance of a vehicle on a level roadway traveling at the design speed of the roadway may be determined from the following equation:

Metric	US Customary	
$d = 0.039 \frac{V^2}{a}$	$d = 1.075 \frac{V^2}{a}$	**(3-1)**
where: d = braking distance, m; V = design speed, km/h; a = deceleration rate, m/s^2	where: d = braking distance, ft; V = design speed, mph; a = deceleration rate, ft/s^2	

Studies documented in the literature (**4**) show that most drivers decelerate at a rate greater than 4.5 m/s^2 [14.8 ft/s^2] when confronted with the need to stop for an unexpected object in the roadway. Approximately 90 percent of all drivers decelerate at rates greater than 3.4 m/s^2 [11.2 ft/s^2]. Such decelerations are within the driver's capability to stay within his or her lane and maintain steering control during the braking maneuver on wet surfaces. Therefore, 3.4 m/s^2 [11.2 ft/s^2] (a comfortable deceleration for most drivers) is recommended as the deceleration