STANDARDIZED NAMES AND DEFINITIONS FOR DRIVING PERFORMANCE MEASURES

A thesis
submitted by

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Abstract

Historically, driving performance measures have been undefined or vaguely defined, and if defined, inconsistently used. Consequently, driving studies are difficult to compare and challenging to replicate, undermining the professional credibility of researchers and the field of automotive human factors.

This study developed names and definitions for 12 common lateral and longitudinal driving performance measures relating to: driving within and between lanes (lane departure, lane change, lateral lane position); steering wheel reversal; headway and gap (distance gap, time gap, distance headway, time headway); pedals (accelerator release time, accelerator to brake transition time, brake reaction time); and time to collision)

Human factors and lexicographical criteria were developed for defining driving performance operational definitions. Based on the criteria and literature, standard measure names and definitions were developed. It is intended that human factors engineers and researchers will use these definitions for research and design, consequently providing a more consistent and comparable evaluation processes.
Acknowledgements

I would like to thank my advisers Paul Green, Dan McGehee, and Anil Saigal for their advice and expertise. I thank the Society of Automotive Engineers for their enthusiasm and patience and the staff of UMTRI Human Factors Department, especially Jim Sayer, for providing me with the resources necessary to complete this work. The incredible practical and emotional support provided by Tina Sayer and Emily Nodine was invaluable. Finally, I want to thank my parents for being my cheerleaders, and for helping me to think positively, even when work seemed overwhelming.
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Definitions for Terms Used in This Work

In a thesis that concerns definition, it is particularly important that all terms be properly defined. Accordingly, the following definitions were obtained from Webster’s 3rd Edition New World Dictionary (Gove, 1968).

- **Definition:**
  
  “A word or phrase expressing the essential nature of a person or thing or a class of persons or a class of things” (p. 592).

- **Measuring:**
  
  “To ascertain the quantity, mass, extent, or degree of in terms of a standard unit or fixed amount usually by means or an instrument or container marked off in the units” (p. 1400).

- **Measure:**
  
  “A standard of measurement” (p. 1424)

- **Name**
  
  “A word or sound or a combination of words or sounds by which an individual or a class of individuals (as persons or things) is regularly known or designated” (p. 1501).
• Nomenclature:

“A system or set of terms, designations, used in a particular science, discipline, or art and formally adopted or sanctioned by the usage of its practitioners” (p. 1534).

• Term:

“A word or expression that has a precisely limited meaning in some uses or is peculiar to a science, art, profession, trade, or special subject (p. 2358)”.
Notes

- To introduce measures and statistics and to distinguish them from surrounding text, they may appear in italics. For example, “As an example of nomenclature inconsistency, the driving performance measure distance headway has been named in a variety of manners. Some examples include the terms following distance (e.g., Strayer & Drews, 2004), space headway (e.g., Koziol et al., 1999) and headway distance (e.g., Wood, & Hurwitz, 2005).”

- Stressed words and phrases are underlined. For example, “Definitions include the distance from the rear bumper of a vehicle to the front bumper of the vehicle it is following (e.g., Zador, Krawchuk, & Voas, 2000); the distance between the front bumper of a vehicle to the front bumper of the vehicle it is following (e.g., Koziol et al., 1999); and the distance between the front bumper of a vehicle to the rear bumper of the vehicle it is following (e.g., Strayer & Drews, 2004).”

- Figures are not drawn to scale
Introduction

There has been considerable interest over the last 20 years in assessing driving performance due to a marked increase of in-vehicle telematics devices that affect driving, such as satellite navigation, cell phones, adaptive cruise control, lane departure, and collision warning systems (Jamson et al., 2004; Tsimhoni & Green, 2001; Richardson & Green, 2000). Much research has been conducted to understand the effects of the distracted driver (Dingus et al., 2006; LeBlanc et al., 2006; Irvin, 2005). This research (and many others) report measurements and statistical summaries of driver performance, information that is used to make decisions about what is safe for drivers to do.

Measurement is often considered the backbone of science. For example, Director of the National Institute of Standards and Technology (NIST), William Jeffrey, testified the following to the Committee on Commerce, Science, and Transportation Subcommittee on Technology, Innovation, and Competitiveness of the United States Senate (2006):

The ability…to be technologically innovative both drives and is driven by our ability to observe and to measure. If you cannot measure something – you will not be able to control it. And if you can not control it – you will not be able to reliably manufacture it.

(p. 2)

Jeffrey also noted the importance of standardization (2006):
In 1901, there were as many as eight different standard gallons; Brooklyn, NY recognized four different legal measures of the foot, and about 50 percent of tested food scales were wrong, usually favoring the grocer. Today, American consumers and businesses can be confident in the quantity of product being purchased – making transactions more reliable and cost effective. (p. 3)

There are many tools to capture driver performance—different types of simulators, vehicles, and assessment instrumentation such as eye trackers, each with its own measurement process, many of which are unique. As a consequence, driving performance measures are often not collected in a consistent manner. In part, this is because driving performance measures and statistics are often undefined or vague. Where they are defined, definitions are inconsistent, though there are notable exceptions, such as AIDE (Adaptive Integrated Driver-vehicle Interface); HASTE (Human Machine Interface and the Safety of Traffic in Europe); and the 100-Car Study (naturalistic driving study sponsored by the National Highway Traffic Safety Administration, Virginia Tech Transportation Institute, and others).

As an example of definition inconsistency, the driving performance measure *distance headway* has been defined several ways. Distance headway has been called: *following distance* (Strayer & Drews, 2004), *space headway* (Koziol et al., 1999) and *headway distance* (Wood, & Hurwitz, 2005). Definitions include the distance from the rear bumper of a
vehicle to the front bumper of the vehicle it is following (Zador, Krawchuk, & Voas, 2000); the distance between the front bumper of a vehicle to the front bumper of the vehicle it is following (Koziol et al. 1999); and the distance between the front bumper of a vehicle to the rear bumper of the vehicle it is following (Strayer & Drews, 2004). Thus, depending on which definition is used, the value reported can vary about 17 feet, the length of a passenger car.

In many cases, definitions are vague, which also occurs for definitions of distance headway. Schindhelm et al. (2005) defines the measure as the “bumper to bumper” distance between two vehicles, without specifying which bumpers are referenced, and leaving the definition open to multiple interpretations. If the two vehicles in question are of different lengths (e.g., a heavy truck followed by a car), then the distance from the front of the lead vehicle to the front of the following vehicle is not the same as the rear of the lead vehicle to the rear of the following vehicle. However, the most common situation is that publications do not define the driving performance measures at all.

There are three main consequences of undeveloped definition standards. First, many studies cannot be reliably repeated. Second, it is very difficult to compare the results between studies. Finally, the credibility of the field of human factors and driving is undermined because the research appears ad hoc.
A previous publication (Gawron, 2000) catalogued measures of human performance, and serves as a foundation for the standardization of driving performance measures. However, to date, there has not been any comprehensive study (1) investigating how driving performance measures have been named and defined in human factors research; (2) investigating the process of naming and defining driving performance operational definitions; and (3) proposing a set standardized terms and operational definitions. This thesis addresses these three points.

Procedure

The procedure was divided into five main steps:

1. Identify key human factors literature to review and establish a systematic investigation process;

2. Select most commonly cited and used driving performance measurement terms and definitions;

3. Determine collection and cataloguing techniques; collect driving performance measurement terms and definitions;

4. Determine analysis techniques; analyze driving performance measurement terms and definitions;

5. Propose standardized driving performance measurement terms and definition.
1. **Identify key human factors literature to review and establish a systematic investigation process**

The goal of the review was to examine high quality publications on human factors and driving for the last few years. To keep the effort reasonable and focus on topical material, only publications from roughly the previous six years (2000 – 2005, 2006 if available) were examined. It was understood, however, that human factors and driving research literature extends well before 2000. In general, most of the literature examined had undergone some peer review (scholarly journals, proceedings papers, industry standards, and some technical reports), which helps assure some level of quality.

Table 1 summarizes all publications and corresponding years examined in this study. The level of effort was considerable: almost 500 articles of which examined and more than 100 were relevant.
Table 1. Examined Literature

<table>
<thead>
<tr>
<th>Publication</th>
<th>Dates examined</th>
<th>Number of articles examined</th>
<th>Number of relevant articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Factors 2000 – 2005</td>
<td></td>
<td>35</td>
<td>18</td>
</tr>
<tr>
<td>Ergonomics 2000 – 2005</td>
<td></td>
<td>31</td>
<td>11</td>
</tr>
<tr>
<td>Department of Transportation (DOT), National Traffic Highway Safety Association (NHTSA), and other funded studies relating to driver performance 2000 -2006</td>
<td></td>
<td>49</td>
<td>14</td>
</tr>
<tr>
<td><strong>Total number of examined literature</strong></td>
<td></td>
<td><strong>498</strong></td>
<td><strong>111</strong></td>
</tr>
</tbody>
</table>

The primary source used for accessing publications was the University of Michigan Transportation Research Institute (UMTRI) Library located in Ann Arbor, Michigan. The UMTRI Library houses one of the world's most extensive collections of literature on traffic safety, with a
collection that includes more than 110,000 items and more than 210 periodical titles.

An effort was made to ensure that all countries involved in driving research in human factors were represented. The thesis advisors assisted with contacting eminent human factors researchers and the author spoke with colleagues at Toyota Technical Center in Ann Arbor, Michigan for recommendations of databases and publications meeting literature criteria. Suggestions for international publications to consider were also obtained through the SAE Safety and Human Factors Committee. Research from North America, Europe, Asia, and Australia were collected, but research from South America and Africa were not considered in this research.

2. Select most commonly cited and used driving performance measurement terms and definitions

Driving performance measures were limited to those pertaining to lateral and longitudinal control, the most common and core measures of driving performance. Measures of event detection, visual performance, occlusion, physiological response, secondary task performance, subjective assessment, and situational awareness, although important, were not considered to keep the scope reasonable. Measures that have already been defined by physics, such as velocity, acceleration, and deceleration, were also not included.
Research regarding on-road driving on public and private roads, test tracks and courses, and in driving simulators was considered. Eligible vehicles types in the investigated research were any four- (or greater) wheeled road vehicles, such as passenger vehicles, trucks, and buses. Studies concerning agricultural, construction, industrial, and military vehicles were not examined because their performance is primarily assessed off-road and the definitions being developed were for on-road applications. Two-wheeled vehicles (e.g. motorcycles) and tracked vehicles were excluded because they added unwanted complications to this initial effort, but should be included in future efforts.

3. **Determine collection and cataloguing techniques; collect driving performance measurement terms and definitions**

To assure accuracy, definitions drawn from the literature are presented here verbatim from the original sources. In many cases, text surrounding the definition was also included in the recording to provide context for the definition. In the few rare cases where definitions were in the form of tables or figures, they are presented. Where a measurement was listed but not defined, the text surrounding the measurement name was quoted to show lack of definition. Complete citations for all collected quotations were gathered for documentation and future reference (Appendix A – K).
For each term examined in this thesis, two tables are provided. An abbreviated data table (Table 2) identified the source of definitions for measures of interest.

### Table 2. Example of Abbreviated Data Collection Table

<table>
<thead>
<tr>
<th>Date of article</th>
<th>Measure</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HF2 brake/accelerator pedal position</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HF3 time-to-collision (TTC)</td>
<td></td>
</tr>
</tbody>
</table>

A detailed data table (Table 3) was used to provide additional information, in particular the verbatim definition.

### Table 3. Example of Detailed Data Collection Table

<table>
<thead>
<tr>
<th>#, Author, journal, date, region</th>
<th>Measure name (code)</th>
<th>Defn: yes no?</th>
<th>Definition</th>
<th>Page # of defn</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Llaneras. et al., Human Factors, Spring 2005</td>
<td>HF1 brake reaction time (RT)</td>
<td>Y</td>
<td>&quot;For back-up warning systems, the first driver behavior parameter is driver brake reaction time (RT; i.e., the time between crash alert onset and the driver triggering the brake switch...)&quot;</td>
<td>201</td>
</tr>
<tr>
<td>2 North America, Spring 2005</td>
<td>HF2 time-to-collision (TTC)</td>
<td>N</td>
<td>&quot;The primary dependent measure for the altered backing trials was the subjective rating of warning timing appropriateness provided by drivers. The alerted backing trials also provided an opportunity to gather additional vehicle dynamics data to characterize driver backing performance (average, minimal and maximum braking speeds; deceleration rates, TTC, brake and accelerator pedal position, etc.)&quot;</td>
<td>204</td>
</tr>
</tbody>
</table>
Next, all collected measures from the literature were sorted into general, high-level categories. The categories were determined based on the driving performance measures collected. As shown below in Table 4, eleven primary measures were identified.

<table>
<thead>
<tr>
<th>Investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lane departure</td>
</tr>
<tr>
<td>2. Lane change</td>
</tr>
<tr>
<td>3. Lateral lane position</td>
</tr>
<tr>
<td>4. Time-to-line crossing</td>
</tr>
<tr>
<td>5. Steering wheel reversal</td>
</tr>
<tr>
<td>6. Time headway</td>
</tr>
<tr>
<td>7. Distance headway</td>
</tr>
<tr>
<td>8. Accelerator pedal release time</td>
</tr>
<tr>
<td>9. Accelerator to brake transition time</td>
</tr>
<tr>
<td>10. Brake reaction time</td>
</tr>
<tr>
<td>11. Time to collision</td>
</tr>
</tbody>
</table>

4. **Determine analysis techniques; analyze driving performance measurement terms and definitions**

The analysis consisted of three parts: First, a general background description of the driving performance measure was provided to clarify the general meaning and use of the measure. Second, each term was evaluated using lexicographical (Landau, 2001) and human factors-related criteria. Lexicography, which focuses on the design, compilation, use, and evaluation of general dictionary definitions and provides a theoretical framework and practical recommendations for analyzing terms and
definitions, is of obvious importance here. Third, each measurement
definition was likewise evaluated.

**Lexicographical criteria.** Historical linguist and lexicographer
Ladislav Zgusta (Landau, 2001) describes the following four principles of
definitions:

1. All words within a definition must be explained;
2. The lexical definition should not contain words more “more
difficult to understand” than the word defined;
3. The defined word may not be used in its definition, nor may
derivations or combinations of the defined word unless they are
separately defined;
4. The definition must correspond to the part-of-speech of the word
defined.

Landau (2001) also describes seven basic principles for creating
definitions:

1. Avoid circularity. There are two forms of circularity. One
defines A in terms of B and B in terms of A, and the other
defines A in terms of A. The first kind is illustrated by these
definitions:

<table>
<thead>
<tr>
<th>LEXICAL UNIT</th>
<th>DEFINITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Beauty</td>
<td>The state of being beautiful</td>
</tr>
<tr>
<td>B Beautiful</td>
<td>Full of beauty</td>
</tr>
<tr>
<td>A Bobcat</td>
<td>Lynx</td>
</tr>
<tr>
<td>B Lynx</td>
<td>Bobcat</td>
</tr>
</tbody>
</table>

The second kind of circularity is illustrated by this definition:
LEXICAL UNIT | DEFINITION
---|---
Fear | The state of being fearful

Fearful is nowhere defined in the dictionary and is perhaps run on as a derivative to the article for fear.

The rule may be stated thus: No word can be defined by itself, and no word can be defined from its own family of words unless the related word is separately defined independent of it. Therefore, if fearful were defined separately without reference to fear, the definition quoted above would not be circular.

Better definition:

<table>
<thead>
<tr>
<th>LEXICAL UNIT</th>
<th>DEFINITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Lynx</td>
<td>Any of several wildcats of Europe and North America, with a short tail, tufted ears, and long limbs; a bobcat</td>
</tr>
<tr>
<td>B Bobcat</td>
<td>The American lynx</td>
</tr>
</tbody>
</table>

There is no circularity, because the meaning of lynx does not depend on the inclusion of bobcat in its definition.

2. Define every word used in a definition. When using a monolingual, general dictionary, readers have a right to expect that if they do not know the meaning of a word used in a definition, they can look that word up and find it defined.

3. Define the entry word (Landau, 2001). The definition must define and not just talk about the word or its usage. It must answer the question, “what is it?” directly and immediately.

4. Priority of essence (Landau, 2001). The most essential elements of meaning come first, the more incidental elements...
5. Simplicity (Landau, 2001). Avoid including difficult words in definitions of simpler words’ is a traditional rule that seems to make sense, but like so many lexicographic rules it is often impossible to apply.

6. Brevity (Landau, 2001). Dictionary definitions should not waste words. The art of defining depends not only on the ability to analyze and understand what the words mean, but equally on the ability to express such meanings succinctly.

7. Avoidance of ambiguity (Landau, 2001). Words in definitions must be used unambiguously in the context of the definition. If a word used in a definition has more than one meaning, the particular sense in which it is intended must be made clear by the rest of the definition.

Independently from Landau and Zgusta, a list of criteria for well-defined driving performance measures and definitions specific to human factors and driving research was also developed by the authors with assistance from his advisors. In some cases, the developed criteria were unique to driving performance definitions, but in other cases the criteria resonated with lexicographic theory. A summary of all criteria is presented in Table 5 below, followed by detailed explanations of each criterion.
Table 5. Human Factors Criteria for Driving Performance Measurement

Terms & Definitions

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Suggests a single and complete measurement procedure</td>
</tr>
<tr>
<td>2.</td>
<td>Easy to measure</td>
</tr>
<tr>
<td>3.</td>
<td>Measurement is repeatable</td>
</tr>
<tr>
<td>4.</td>
<td>Can be used in simulator testing as well as field testing</td>
</tr>
<tr>
<td>5.</td>
<td>Has single interpretation</td>
</tr>
<tr>
<td>6.</td>
<td>Can be easily represented graphically</td>
</tr>
<tr>
<td>7.</td>
<td>Applicable to engineering procedures and calculations</td>
</tr>
<tr>
<td>8.</td>
<td>Applicable to international driving conditions, driving infrastructure and vehicles</td>
</tr>
<tr>
<td>9.</td>
<td>Frequency of use</td>
</tr>
<tr>
<td>10.</td>
<td>Consistency within a set</td>
</tr>
<tr>
<td>11.</td>
<td>Written in simple, clear, concise English</td>
</tr>
<tr>
<td>12.</td>
<td>Uses SI units where appropriate</td>
</tr>
</tbody>
</table>

1. **Suggests single and complete measurement procedure:** The definition must completely explain all aspects of the measurement procedure, from the time measurement begins until measurement is concluded. For example, Blanco, Hankey, & Chestnut (2005) defined lane departure "as the time from when the tire came into contact with the lane marker until the tire was no longer in contact with the lane marker and the vehicle was in the correct lane". This definition offers a single and complete measurement procedure from measurement beginning (“tire came into contact with the lane marker”) until measurement end (“until the tire was no longer in contact with the lane marker and the vehicle was in the correct lane”). Conversely, the following lane departure definition, also from Blanco, Hankey, & Chestnut (2005), does not offer a complete...
measurement procedure: “Defined as when the vehicle’s tire came into contact with the lane marker.” Although the definition offers a clear point at which to begin measurement (“when the vehicle’s tire came into contact with the lane marker”), the definition does not state any point at which measurement is to end.

2. *Easy to Measure:* Practically speaking, ease of measurement is one of the most important criteria for a good driving performance definition. If a definition is not easy to measure, it will see limited use to researchers. Ease of measurement considers current, comprehensive measurement tools, such as video cameras, and on-board sensors frequently found on contemporary driving simulators and instrumented vehicles. Measurement ease also considers convenience for researchers: For example, if a researcher is measuring a lane departure, it might be more convenient to reference the departure in terms of tire contacting lane striping compared to vehicle body contacting the plane of the lane striping because the tire/striping contact is a directly visible intersection, as opposed to an indirect contact, such as a wing mirror over the lane striping.

3. *Measurement is Repeatable:* Repeatability means that the findings are consistent if measurement were repeated. If the measurement were not repeatable, then there is potential that different experimenters may interpret the definition differently, therefore
producing differing results. As an example of a repeatable definition, SAE J1761 3.155 defines headway as the “time between which the leading surfaces of two consecutive vehicles pass the same location along a roadway.” It is clear from the definition that headway is always measured from the leading surface of two consecutive vehicles traveling on the same roadway. The leading surface of vehicles is a point that will remain consistent and has only one interpretation. Conversely, the following definition for time headway is open to numerous interpretations: “Time headway - defined as the distance expressed in time between two vehicles” (Hakan 2000). No specific measurement reference points on the vehicles are specified in this definition, which leaves this definition open to many different interpretations.

4. **Can be used in simulator testing as well as in field-testing:** The more versatile the measurement procedure, the more useful it will be to any study. Human factors specialists conduct testing in both driving simulators and on the road in instrumented test vehicles. Because these two types of testing are popular, one definition that could be applied to both contexts would be ideal. For example, the location of the center of gravity is readily determined on a simulated vehicle but requires much more effort for a real vehicle.
5. **Has single interpretation:** Measure name clearly describes phenomenon in question. There is no ambiguity describing any driving performance measure.

6. **Can be easily represented pictorially(graphically):** One advantage to summarizing data pictorially or graphically is that data can often be concisely summarized. Measures with definitions convenient for graphing have the potential to assist researchers. A second advantage is that pictures and graphs generally transcend language, providing readily accessible data to individuals whose native language is different from the language used in the research.

7. **Applicable to engineering procedures and calculations:** Proposed measurement definitions must be useful for carrying out engineering procedures and conducting calculations.

8. **Applicable to international driving conditions, driving infrastructure and vehicles:** Needing consideration are left versus right-hand drive, differences in lane widths and shoulders, differences in lane markings (line width, solid versus dashed) and their regulatory implications, other differences due to traffic rules, customs and other characteristics.

9. **Frequency of use:** Defined as measurement term being used at least three times in selected literature.

10. **Consistency within a set:** In order to create commonality between measurement terms across all measure categories, it is preferred to
use common terminology. For example, the measure name “lane change” is consistent with the measure name, “lane departure,” because both share the common term “lane.”

11. **Written in plain English:** Measurement terms must be easy to understand, by both experts in human factors research and non-experts alike. Therefore, jargon that may be human factors-specific should be avoided to promote universal understanding. Measurement terms should not be too long as to promote more concise communication and should be easily spelled.

12. **Uses SI/metric units:** The International System of Units (abbreviated SI from the French *Système international d'unités*) is the modern form of the measurement system. It is the world's most widely used system of units, both in everyday commerce and in science. Since human factors research is scientific in nature, all measures should be expressed in SI units.

The developed and published criteria were compiled into a unified list shown in Table 6. Lexicographical theory was combined with human factors criteria for “good definitions” to form final criteria by which to judge collected measure terms and definitions. Note that final criteria were divided into four main groupings: measurement process, application, consistency, and language.
Table 6. Summary of Final Criteria Applied to Judge Robustness of Each Measure Name and Definition

<table>
<thead>
<tr>
<th>Final criteria</th>
<th>Measurement process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Suggests a single and complete measurement procedure</td>
</tr>
<tr>
<td>2.</td>
<td>Easy to measure</td>
</tr>
<tr>
<td>3.</td>
<td>Measurement is repeatable</td>
</tr>
<tr>
<td>4.</td>
<td>Can be used in simulator testing as well as field testing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.</td>
</tr>
<tr>
<td>6.</td>
</tr>
<tr>
<td>7.</td>
</tr>
<tr>
<td>8.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consistency</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.</td>
</tr>
<tr>
<td>10.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.</td>
</tr>
<tr>
<td>12.</td>
</tr>
<tr>
<td>13.</td>
</tr>
<tr>
<td>14.</td>
</tr>
<tr>
<td>15.</td>
</tr>
<tr>
<td>16.</td>
</tr>
</tbody>
</table>

*Other notes related to data analysis.* Only the root of the overall measure was analyzed (and defined). Statistical terms – such as number, mean, median, and standard deviation – were not considered. For example, mean steering entropy and standard deviation steering wheel entropy were treated as the same base term, steering entropy. Only measures with definitions with at least three data points (i.e., at least three different terms or three different definitions) were eligible for evaluation.
Once driver performance name and definition measurements were analyzed, standardized terms and definitions were proposed. In some cases, multiple terms and definitions were proposed for the same measure, in consideration for alternating ways researchers may use to collect measures. To avoid confusion, a researcher should identify how each term was defined when used (e.g., lane departure-definition A).

Table 7 below summarizes two key questions this research attempts to investigate and answer.

Table 7. Key Questions to Investigate through Measure Analysis

| 1. To what extent were measurement terms and definitions consistent across all literature? | Consistent driving performance measurement terms and definitions are key to the success of human factors driving-related research. If definitions are inconsistent, then effort must be conducted to standardize measurement terms and definitions. |
| 2. What percentage of measures was defined versus undefined? | If the percentage of defined measures is low, further work, such as standardizing measurement terms and definitions, must be conducted to promote greater frequency of definition use. |

5. Propose standardized driving performance measurement terms and definitions

Once each driving performance measurement term and definition is analyzed using the criteria above, a term name, and definition is proposed. Multiple definitions may be proposed in consideration for varying measurement practices and techniques and to avoid a forced consensus where it is not needed.
Results

The results below were divided into eleven sections, one per driving performance measure. Each contains:

A general description of the concept and background of the measure

- Name result
- Definition results
- The full list of verbatim definitions is found in Appendices A – K

Lane Departure

Background. Lane departure describes the condition of a vehicle straying from its intended lane either off the road, onto the shoulder, or into an adjacent lane. Lane departure is generally considered an unintended action and differs from lane change, which is an intentional action taken by the driver to switch from the current driving lane.

Conducting secondary tasks (e.g. operating a navigation system or talking on a mobile phone) while driving has led to an increase in lane departures (Tsimhoni & Green, 2001; Nowakowski, Friedman, & Green, 2002). Lane departure is a precursor to a potential crash, either into a vehicle in an adjacent lane, a curb, a Jersey barrier, a guardrail, pedestrian, parked vehicle, or other object. Figure 1 is a plan view representation of a vehicle departing its lane, and Figure 2 shows a rear elevation of this phenomenon.
Figure 1. Plan view image of a vehicle departing its current driving lane
Which terms have been used? Table 8 shows the most frequent measure name found from literature was lane deviation, observed five instances, followed by the measure names out of lane (four), and lane departure (three).
Table 8. Terms Used for Lane Departure in the Literature

<table>
<thead>
<tr>
<th>Measure name</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane deviation</td>
<td>5</td>
</tr>
<tr>
<td>out of lane</td>
<td>4</td>
</tr>
<tr>
<td>lane departure</td>
<td>3</td>
</tr>
<tr>
<td>lane exceedence</td>
<td>2</td>
</tr>
<tr>
<td>lane keeping</td>
<td>1</td>
</tr>
<tr>
<td>lane violations</td>
<td>1</td>
</tr>
<tr>
<td>crossing white sidelines</td>
<td>1</td>
</tr>
<tr>
<td>major lane deviations</td>
<td>1</td>
</tr>
</tbody>
</table>

Several measurement terms can be misleading. For example, *lane deviation* does not clearly explain whether a vehicle is deviating from a straight path within the lane (standard deviation of lane position) or whether a vehicle is deviating from the current driving lane to an adjacent lane (or off the road).

Lane keeping describes the phenomenon of remaining in the current driving lane. Since human factors researchers (and the driving population at large) may find the condition of departing the current lane or road more important than staying within the current lane, the name *lane keeping* does not match the driving performance area of interest.

*Out of lane* describes a state condition (physically being out of the current driving lane) without explaining the process to achieve the result (i.e. departing the current driving lane). There is no action component associated with this name, such as departing or exceeding the lane. A vehicle may be out of a lane for a variety of reasons, such as deliberately changing lanes, or deliberately pulling off the road, but this does not
correspond to the measure of interest, which is unintentionally drifting out of the current driving lane.

The term \textit{lane violations} does not precisely convey the experience of a vehicle departing (or exceeding, or deviating from) the current lane and could suggest entering another lane (but not being on the shoulder). \textit{Lane violations} may conjure images of traffic malfeasance, which is not related to lane departure.

\textit{Crossing white sidelines} is a misleading measure name. Since white sidelines are used to delineate parking spaces as well as lanes, the name crossing white sidelines is not specific enough. Further, not all lane markings are white – they can be yellow, white, or red. Specifically, the Michigan Manual of Uniform Traffic Control Devices states, "Longitudinal pavement markings shall conform to the following basic concepts: 1. Yellow lines delineate the separation of traffic flows in opposing directions or mark the left edge of the pavement of a divided highway or one-way roads. 2. White lines delineate the separation of traffic flows in the same direction or mark the right edge of the pavement. 3. Red markings delineate roadways that shall not be entered or used by the viewer of those markings" (Nowak, 1994). Lane markings are not universally called "sidelines." Sometimes sidelines refer only to the lines painted near the outside edges of the road.

The name \textit{lane departure} has only one, clear meaning: departing the lane. The name \textit{exceedence} has only one, clear meaning:
exceeding the lane. Lane departure is not to be confused with road
departure, which could mean either departure from the travel lane or
departure from the travel lanes and shoulders.

The measurement term *lane deviation, lane departure, lane
keeping, and lane violations* are clear, concise, and easy to spell.
According to Merriam-Webster 3rd Edition Dictionary, “exceedence” has
two spellings, “exceedence” and “exceedance,” which has the potential to
cause confusion and defy standardization (Gore, 1968). The
measurement terms *out of lane* and *crossing white sidelines* use common,
non-technical wording, but a phrase consisting of three words is
cumbersome communicate, as compared with other measurement terms
that use fewer words to describe the same concept.

All collected measurement terms include the word *lane*, which
requires further definition. Specifically of interest is whether lane width
includes or excludes the width of the lane boundary lines (also called
longitudinal lane markings by civil engineers).

**How should lane departure be defined?** Eight unique definitions
(Appendix A) for lane departure were observed in the examined literature.
Please see Appendix A for verbatim definitions.

Most lane departure definitions in the literature did not include a
complete measurement procedure. Five specified a point at which
measurement began but did not identify how or when the lane departure
ended. For example, Jenness et al. (2002) states a lane departure begins
when “the automobile crossed the white sidelines on the roadway,” whereas Blanco, Hankey, & Chestnut (2005) defined the beginning "when the vehicle’s tire came into contact with the lane marker.”

Three definitions are good examples of a complete measurement procedure. Blanco, Hankey, & Chestnut (2005) specified measurement begins from "the time from when the tire came into contact with the lane marker," and measurement ends when "the tire was no longer in contact with the lane marker and the vehicle was in the correct lane.” Harder, Bloomfield, & Chihak (2001) stated that measurement began "the time from the beginning of the lane departure," and measurement ended "the moment that the vehicle was completely back in lane."

None of the lane departure definitions had a single interpretation. For example, Blanco, Hankey, & Chestnut (2005) indicated that lane departure occurred “when the vehicle’s tire came into contact with the lane marker.” There was no indication which part of the tire must come into contact with the lane marker (right tire edge, left tire edge, or some other tire part). Likewise, there was no indication of which part of the lane marker was defined as the contact point (right edge of lane marker, left edge of lane marker, or some other lane marker part). See Figure 3 for a rear elevation representation.
Figure 3. Six different interpretations of lane departure measurement (rear elevation)
Blanco, Hankey, & Chestnut (2005) stated that lane departure was defined as the “time from when the tire came into contact with the lane marker until the tire was no longer in contact with the lane marker and the vehicle was in the correct lane.” This definition does not address what happened when tire was no longer in contact with the lane marker but was in the incorrect lane (i.e. a deliberate lane change is satisfied by this definition of lane departure).

Johansson et al. (2005) defined lane departure as the proportion of a time “any part of the vehicle is outside the lane boundary.” This definition is ambiguous because the reader or researcher may have different interpretations for “part of the vehicle.” Normally the width of a vehicle is defined as the side view edge to side view mirror edge, but some may consider width in terms of the vehicle proper, namely the outermost point of the body or tires. For example, the outer tire is still well within the current driving lane by the time the wing mirror crosses the lane boundary as shown in Figure 4 below.
Figure 4. Wing mirror lane departure compared to tire crossing: tire remains in vehicle’s intended lane, while wing mirror crosses into adjacent lane (rear elevation).

**Lane Change**

**Background.** Lane change describes the condition of a vehicle moving from its current lane to an intended adjacent lane (Figure 7). Lane change is an intended action and differs from lane deviation, which is the unintended action of veering out of the current driving lane.

Lane change is an important measure to study because, as Lee, Olsen, & Wierwille reported (2004), “transportation researchers estimate that lane change crashes account for 4 to 10% of all crashes (Barr & Najm, 2001; Eberhard et al., 1994; Wang & Knipling, 1994; Young, Eberhard & Moffa, 1995).” Extensive research has been conducted to characterize lane change behavior (Dingus et al., 2006; Lee et al. 2004;
Which terms have been used? Lane change is the only name in the selected literature used to describe the incident of a vehicle intentionally departing its current lane. The name lane change clearly indicates that a vehicle is changing from one lane to another lane. Lane change is a clear and concise measure name that is easy to spell.

How should lane change be defined? Three definitions were observed in the collected literature, however two of these definitions were exactly the same (Lee et al., 2004; Olsen, Lee, & Wierwille 2002). The third lane change definition referred only to lane changes involving crashes. Complete verbatim lane change definitions are found in Appendix B.
The definitions from Lee et al., 2004 and Olsen, Lee, & Wierwille, 2002 suggested a single and complete measurement procedure. Measurement began “the point the vehicle first moved laterally,” and lane change ended “when the vehicle was centered in destination lane.” These endpoints are not easy to determine because there is always some amount of lateral position variation as a vehicle travels down a road.

The definition provided by Sen, Najm, & Smith (2003) also specified when measurement began: when “one vehicle encroaches into the travel lane of another vehicle that is initially traveling in the same direction, and on a parallel path.” However, this definition did not specify when a lane change ended.

All three definitions did not have single interpretations. For example, “centered in the destination lane” is not specifically defined (Lee et al., 2004; Olsen, Lee, & Wierwille 2002). The definition does not make clear the exact position of the vehicle when it is centered in the destination lane. For example, the vehicle could be off-centered in the destination lane even though the lane change is completed. Some may interpret “settled” as a speed-related condition (speed is becomes constant after the lane change), while others may associate “settled” as lateral distance-related. For the definition provided by Sen, Najm, & Smith, there is no clear definition of exactly when the “encroaching” into the other lane begins.
There is evidence that some of the name change definitions suggested a single and complete measurement procedure. However, none of the three definitions had single interpretations, meaning that repeatability is impossible. Interestingly, no definition specified lane change beginning when the driver checked the blind spot or when a turn signal was initially switched on.

**Tim- to-Line Crossing (TLC)**

**Background.** “Time-to-line crossing,” or TLC for short, is the time it would take for a vehicle to cross a lane boundary if the instantaneous speed and steering wheel position (and in some cases, acceleration) were frozen in time. Time-to-line crossing is an important measure because it assesses the possibility of a lateral crash or driving off the road. According to Godthelp et al. (1984), TLC represents the time available for a driver until the moment at which any part of the vehicle reaches one of the lane boundaries. Van Winsum, Brookhuis, and De Waard (2000) originally worked with TLC, demonstrating important applications of this measure definition in regard to severe impairment caused by driver drowsiness.

**Which terms have been used?** No variations of the name *time-to-line crossing* were found in the selected literature. Although *time-to-line crossing* relates to the lane, the name does not use the term *lane*. One might expect the measure name to be *time-to-lane crossing* for consistency. Time-to-line crossing is written in a clear, concise, and non-technical manner.
How should time-to-line crossing be defined? There were five unique definitions for time-to-line crossing. Please see Appendix C for all definitions.

A commonality observed from all five definitions is that measurement repeatability was impossible because the definitions did not have single interpretations. Some defined line crossing as when the vehicle reached the edge of the driving lane, while other definitions stated that line crossing occurred when the wheel or tire crossed the lane boundary.

According to Reymond et al., (2001), "TLC is defined as the time necessary for the vehicle to reach either edge of the driving lane." Gawron (2000) stated that "TLC equals the time for the vehicle to reach either edge of the driving lane." It was impossible to tell from either of these two definitions what part of the vehicle must reach the edge of the driving lane for line crossing to occur. Just as with lane departure, the calculated time-to-line crossing would be different if one researcher chose the wing mirror, another researcher chose the outside edge of the tire and a third researcher chose the inside edge of the tire.

Paul et al. (2005) stated "TLC is the time required for a vehicle to run off the road boundary (road shoulder or oncoming traffic lane)." This definition did not clarify the meaning of “run off the road boundary” because the part of the vehicle that ran off the road boundary was not specified.
Lateral Lane Position

Background. Lateral lane position describes a vehicle’s horizontal position in a lane, with respect to a specified point on the vehicle and a specified point on the road. This measure is useful to assess a driver’s ability to keep the vehicle on a straight path within the driving lane. There is evidence that lateral lane position is affected by secondary tasks, such as conversations held with other passengers (Sayer, Devonshire, & Flanagan, 2005).

Which terms have been used? As shown in Table 9, Lane position was referenced twenty-four times in the selected literature, and lateral position was referenced eighteen times. The frequency of all other observed terms was negligible.

Table 9. Terms Used for Lateral Lane Position in the Literature

<table>
<thead>
<tr>
<th>Measure name</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>lane position</td>
<td>24</td>
</tr>
<tr>
<td>lateral position</td>
<td>18</td>
</tr>
<tr>
<td>lateral lane position</td>
<td>2</td>
</tr>
<tr>
<td>lane position and movement in lane</td>
<td>1</td>
</tr>
<tr>
<td>lateral placement</td>
<td>1</td>
</tr>
<tr>
<td>lateral control</td>
<td>1</td>
</tr>
<tr>
<td>lateral offset</td>
<td>1</td>
</tr>
<tr>
<td>lane variability</td>
<td>1</td>
</tr>
<tr>
<td>road position (tracking)</td>
<td>1</td>
</tr>
<tr>
<td>lateral deviation</td>
<td>1</td>
</tr>
<tr>
<td>lateral displacement</td>
<td>1</td>
</tr>
<tr>
<td>lane keeping</td>
<td>1</td>
</tr>
</tbody>
</table>

Lane position and lateral position both have unclear terms. Lane position is unclear because the name does not specify whether it refers to
lateral position or longitudinal position. *Lateral position* is also unclear because there is no indication of whether lateral position refers to a position on the road or lane or other position. Of all the other measure terms, the only name that suggests a clear indication of meaning is *lateral lane position*, an amalgam of *lane position* and *lateral position*.

**How should lateral lane position be defined?** Ten unique definitions for lateral lane position were observed from the literature. Refer to Appendix D for all definitions. The measurement procedures observed in lateral lane position definitions varied widely. Most measurement procedures were not single and complete. For completeness, a measure must reference a specific point on the vehicle and a specific point on the road, as shown in Figures 6 (plan view) and 7 (front elevation).

![Diagram of reference points for lateral lane position](image)

Figure 6. Reference points for lateral lane position (plan view).
When these two points are aligned at a specified lateral distance, the vehicle is “ideally” located in the driving lane. When the vehicle moves in its current driving lane to the right or to the left of the specified position, then lateral deviation is measured.

A common omission of many observed lateral lane position measures is the lack of specificity in identifying the reference points on the vehicle and on the road or lane marking. For example, Definition 4 states: "the mean lane position is defined as the mean distance between a reference point on the vehicle and an arbitrary position in the lane (normally one of the lane boundaries or the lane centre)" (Johansson et al., 2005). Neither the “reference point on the vehicle” nor the “arbitrary position in the lane” is specified. Definition 6 also offers vague a measurement procedure: "Lane position was determined by measuring
the absolute deviation of the vehicle relative to the vehicle’s lane, reflected by both mean and standard deviations" (Zheng, McConkie, & Tai, 2003).

Many lateral lane position definitions do offer a complete measurement procedure, but there is a lack of agreement on which parts of the vehicle and the road or lane marking to use for reference points.

For example, definitions 1, 8 and 9 reference the center of the road to the center of the vehicle as measurement reference points. Definition 8 states: "road position (tracking), measured as the deviation in percentile of the centre of the vehicle from the centre of the right hand lane. The extreme edge of the left lane position was demarcated as 100%, and extreme right lane position was 0%. Thus, ideal road position for the given task of maintaining the vehicle in the centre of the right lane was 25%." (Moller et al., 2005). Definition 9 defines lane position "as distance (m) from lane center (positive is right of center)" (Najm et al., 2006). Finally, 'definition 1 determines lane position "by measuring the absolute deviation of the vehicle (in meters) relative to the center of the vehicle's lane" (Horrey & Wickens, 2004).

Definition 2 references the front left wheel of the vehicle and the white line by the left edge of the road: "lateral position was defined as the distance from the front left wheel of the car to the left white line by the edge of the road (driving in the UK)" (Blana & Golias, 2002). Definition 3 references the front right wheel of the vehicle but does not specify which edge of the road pavement is referenced. Further, in the case of a multi-
lane road, measuring to the edge of the road pavement may span across one or more lanes from the current driving lane. "Lateral position = the distance between the right hand wheel and the edge of the road pavement" (Steyvers & deWaard, 2000). Definition 5 references the front right wheel of the vehicle and the white line by the right edge of the road: "Lateral position is usually defined as the distance between the right hand part of the front right wheel to the left part of the right hand lane marking. When the line crosses the lateral position it becomes negative" (Roskam et al., 2002).

Note, however, that Definition 5 was the only lateral lane position definition to specify in detail which part of the tire "right hand part of the front right wheel" and which part of the lane marking “left part of the right hand lane marking” were measurement reference points. For a measure to be consistently repeatable, this level of detail is a requirement.

**Steering Wheel Reversal**

**Background.** Steering wheel reversal describes changing the direction of movement of the steering wheel from a counterclockwise direction to a clockwise direction, or visa versa. Such changes in steering wheel direction are sometimes informally called *corrections*. The frequency and magnitude of steering wheel corrections are often noticed when a driver is performing a secondary task (with the primary task being driving the vehicle). Some examples of secondary tasks while driving are operating switches on the instrument panel, changing a CD, talking on a
mobile phone, and eating (Dingus et al., 2006). Steering wheel reversal is a valuable measure to gain an understanding of how many steering wheel corrections a driver needs to make in order to drive the vehicle within a specified driving area, which is typically a driving lane on the road.

Which terms have been used? Referenced five times, steering wheel reversal is the most common name observed from the sampled literature. See Table 10 for a list of all terms collected from literature.

Table 10. Terms Used for Steering Wheel Reversal in the Literature

<table>
<thead>
<tr>
<th>Measure name</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>steering wheel reversal</td>
<td>5</td>
</tr>
<tr>
<td>rate of steering wheel reversals</td>
<td>3</td>
</tr>
<tr>
<td>steering wheel rate</td>
<td>2</td>
</tr>
<tr>
<td>steering wheel reversal rate</td>
<td>2</td>
</tr>
<tr>
<td>changes in steering wheel rotational direction</td>
<td>1</td>
</tr>
</tbody>
</table>

Webster’s 3rd Edition New World Dictionary (Gove, 1968) defines reversal as “to turn or move in the opposite direction.” The name “steering wheel reversal” describes moving the steering wheel in the opposite direction from the current direction of movement, which is a clear indication of the meaning. Other terms, such as “rate of steering wheel reversals,” “steering wheel rate,” and “steering wheel reversal rate” are misleading because all three measurement terms use the term “rate.” Not all steering wheel reversals are defined by rate – some steering wheel reversals are measured in degrees. Measurement terms such as “rate of steering wheel reversals,” “steering wheel reversal rate,” and changes in
steering wheel rotational direction (reversal rate)” are a bit long and cumbersome.

**How should steering wheel reversal be defined?** Five definitions were observed for steering wheel reversal but only three unique definitions existed of the total number of definitions collected. Definitions 1 and 2 were identical, as were Definitions 4 and 5.

Definitions 1 and 2 suggested a single and complete measurement procedure: "For each of the selected sections, the mean steering wheel rate reversals (SRR) per participant were determined. This measure was derived from steering wheel movements analyzed in terms of number of reversals per second (e.g., Verwey & Veltman, 1996). A movement was defined as a change from the negative (clockwise movement) to a positive (counterclockwise) rotational velocity when the positive rotational velocity exceeded 3.0 degrees per second" (Fisher et al., 2002). Measurement begins when: "the steering velocity left a zero-velocity dead band," and measurement ends when: "the steering velocity entered a zero-velocity dead band such that the magnitude of the reversal was 2 degrees or greater." See 8 below for a representation of steering wheel reversal.
Definitions 4 and 5 also suggest a single and complete measurement procedure: "For each of the selected sections, the mean steering wheel rate reversals (SSR) per participant were determined. This measure was derived from steering wheel movements analyzed by number of reversals per second (e.g., Verwey & Veltman, 1996). A movement was defined as a change from the negative (clockwise movement) to a positive (counterclockwise) rotational velocity when the positive rotational velocity exceeded 3.0 degrees per second" (Theeuwes, Alferdinck, & Perel, 2002). The definition did specify when measurement begins and ends: "change from the negative (clockwise movement) to a positive (counterclockwise) rotational velocity when the positive rotational velocity exceeded 3.0 degrees per second."

While Definition 3 specified when measurement begins: "the steering wheel is reversed by a magnitude larger than a specific angle, or gap," it did not specify when measurement ends: "SSR is one of the most commonly used driving performance measures. The measure represents
the number of times that the steering wheel is reversed by a magnitude larger than a specific angle. The angle magnitude reported in the literature varies between 0.5-10 degrees (Johansson et al., 2005).

Incidentally, Definition 3 violates a lexicographical guideline – the term “reversed” is used to define the measure “steering wheel reversal.”

For Definitions 1 and 2 measurements are not repeatable. For example, a reversal is defined as a movement from 0 degrees to -2 and back to 0 degrees. It can also be defined as 0 degrees to -2 degrees to -4 degrees, meaning the steering wheel has not changed direction. Definition 3 is not repeatable because “gap size” is not specified. Definitions 4 and 5 are repeatable because the measurement procedure is clearly defined.

All measure definitions collected define a steering wheel reversal by degrees from a zero velocity dead band. Definition 5 is the same definition as Definition #6. Both definitions refer to steering wheel movement as negative (clockwise movement) and positive (counterclockwise movement). Whereas Definitions 1 and 2 require the reversal magnitude to be greater than 2 degrees, Definitions 5 and 6 require the reversal magnitude to be greater than 3 degrees per second. Definitions 5 and 6 express reversal in terms of rate whereas definitions 1, 2, and 3 express reversal in terms of degrees.
All steering wheel reversal definitions were written in clear American English, but Definitions 1 and 2 use the term “zero-velocity dead band,” which may be too technical for some readers and researchers.

McGehee et al. (2004) define steering wheel reversal as: "A deflection of the steering wheel away from a central or neutral position (i.e., where the wheels are completely straight) followed by a reversal of the steering wheel back to the neutral position. Steering wheel reversals do not include steering movements associated with an intentional vehicle turning maneuver, such as a curve negotiation.

Headway/Gap

Background. Headway determines how much space (expressed in distance or time to travel it) exists between two vehicles. Classically, the field of civil engineering considers headway as the distance between the front bumper of a lead vehicle and the front bumper of the following vehicle since their focus is on highway capacity (vehicles/lane/hour). In this sense, headway may be considered the arrival time, the time it takes for a following vehicle to pass through the same specific location as the lead vehicle.

For the field of human factors, on the other hand, it is often useful to define headway in terms of the space (or gap) between rear bumper of the lead vehicle and the front bumper of the lead vehicle since the focus is on maneuvering space and collision avoidance. Practical uses for gap
include: distance until a crash, space for a lane change, and settings for adaptive cruise control.

Key elements of headway include:

1. Vehicles must travel in the same lane;
2. Vehicles must be consecutive along a path;
3. Only the longitudinal component of distance is calculated between the two vehicles on a straight road (on curvy roads, measurement becomes more complicated)

There are two main classifications for headway, distance headway and time headway. **Distance headway** is calculated by measuring the longitudinal distance between one point on the lead vehicle and a second point on the following vehicle. As was noted earlier, things become complicated when the two vehicles of interest are of different lengths (e.g., a car following a heavy truck), so the difference between distance headway and gap depends on the length of the lead vehicle.

**Time headway** is distance headway divided by the velocity of the following vehicle. Time headway can also be calculated as the time for a common point on two vehicles (e.g. front bumper) to pass through a stationary point outside of the two vehicles (e.g. a road sign). Sometimes it is helpful to think of time headway as the time it would take for a following vehicle to collide into a lead vehicle if the lead vehicle were to instantaneously stop (Roskam et al., 2002).
Time headway is a measure of longitudinal risk. The closer and faster a subject travels behind a lead vehicle, the lesser the chance the following vehicle can avoid a collision if the lead vehicle reduces speed (Strayer & Drews, 2004; Roskam et al., 2002; Taieb-Maimon & Shinar, 2001). Headway is a valuable measure used to understand whether or not a following vehicle is traveling too close to a lead vehicle compared with a recommended safe following distance (Roskam et al., 2002).

**Which terms have been used?** As shown in Table 11, the measurement term *distance headway* is the most popular in the sample literature.

<table>
<thead>
<tr>
<th>Measure name</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>distance headway</td>
<td>6</td>
</tr>
<tr>
<td>following distance</td>
<td>3</td>
</tr>
<tr>
<td>space headway</td>
<td>1</td>
</tr>
<tr>
<td>vehicle headway</td>
<td>1</td>
</tr>
<tr>
<td>gap</td>
<td>1</td>
</tr>
<tr>
<td>gap distance</td>
<td>1</td>
</tr>
<tr>
<td>minimum following distance</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 12 shows that the measure name *time headway* is overwhelmingly used compared with other measure terms collected from literature.
Table 12. Terms Used for Time Gap in the Literature

<table>
<thead>
<tr>
<th>Measure name</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>time headway</td>
<td>20</td>
</tr>
<tr>
<td>time in closing states</td>
<td>4</td>
</tr>
<tr>
<td>temporal headway</td>
<td>3</td>
</tr>
<tr>
<td>headway time</td>
<td>1</td>
</tr>
<tr>
<td>vehicle time-headway</td>
<td>1</td>
</tr>
<tr>
<td>space headway</td>
<td>1</td>
</tr>
<tr>
<td>gap</td>
<td>1</td>
</tr>
<tr>
<td>time gap</td>
<td>1</td>
</tr>
<tr>
<td>time in closing states</td>
<td>1</td>
</tr>
<tr>
<td>time in closing close sub-state</td>
<td>1</td>
</tr>
</tbody>
</table>

*How should headway/gap be defined?* Ten distance headway definitions and 18 time headway definitions were collected from literature. One definition was common to both distance headway and time headway, resulting in 27 unique headway definitions.

Of the three key components to headway specified above, none of the distance or time headway definitions collected from the literature specified that the two vehicles must travel in the same lane. None of the distance headway and two of the time headway definitions specified that the two vehicles must be consecutive within the lane. None of the distance or time headway definitions specified that only the longitudinal component of distance is calculated between the two vehicles.

An example of a definition specifying consecutiveness was time headway Definition 13 from the Society of Automotive Engineers (SAE),
which defined time headway as the “time between which the leading surfaces of two consecutive vehicles pass the same location along a roadway” (SAE J1761 3.155).

Most of the definitions for distance headway and time headway indicated that headway was measured between two vehicles, but specific points on each vehicle were not offered. For example, time headway Definition 7 expressed following distance as “the distance between the pace car and the participant's car” (Strayer, Drews & Crouch, 2003).

Approximately half of the definitions indicated that headway is measured between the bumpers of two vehicles. Of this half, there was not agreement to which bumpers to use for reference. The bumper choice (front versus rear) does not matter practically, as long as there is consistency within the field of human factors (and the vehicles are of equal length).

Some definitions specified that distance headway was measured from the rear bumper of the lead vehicle to the front bumper of the following vehicle. For example, distance headway Definition 2 defined following distance as “the distance between the rear bumper of the pace car and the front bumper of the participant's car” (Strayer & Drews 2004). Definition 10 provides another example, identifying gap as “the distance between the front bumper of a vehicle and the back bumper of the vehicle it is following” (Koziol et al., 1999).
Other definitions measured distance headway from front bumper of the lead vehicle to the front bumper of the following vehicle. For example, Definition 9 identifies distance headway as “the distance between the front bumper of a vehicle and the front bumper of the vehicle it is following (Koziol et al., 1999).

Many definitions for time headway reference the front bumpers of the lead and following vehicles. In some cases, time headway was defined as the time it took for the lead and following vehicles to pass through a stationary point along the roadway (SAE J1761 3.155; Lee et al., 2004).

One definition (distance headway Definition 8) measured distance headway from the rear bumper of the following vehicle to the front bumper of the lead vehicle (Zador, Krawchuk, & Voas, 2000).

Finally, many definitions specified that distance headway was measured from the bumpers of two vehicles, but the bumpers (front or rear) were not specified. Distance headway Definition 1 illustrates this example: “the distance headway is the bumper-to-bumper gap between the lead vehicle and the following” (Taieb-Maimon & Shinar, 2001).

Another example was distance headway Definition 3: “distance headway is defined as the average distance to the lead vehicle (from bumper to bumper)” (Johansson et al., 2005).

It is important to note that some have stressed subtle but important differences between headway definitions, such as gap versus headway.
and following distance versus headway. For example, Koziol et al. (1999) makes it clear in the same paper that distance headway is the “distance between the front bumper of a vehicle and the front bumper of the vehicle it is following,” whereas gap is the “distance between the front bumper of a vehicle and the back bumper of the vehicle it is following.” Likewise, Lerner & Singer (2005) defined vehicle headway as “the latency from the front of a lead vehicle to the front of a following vehicle,” making sure to add, “note that this [vehicle headway] is not the same as following distance (distance from rear of lead vehicle to front of target vehicle) or following headway (time from arrival of rear of lead vehicle to front of target vehicle), although the measures are highly related.”

While a standardized definition for the term headway would be beneficial to defining distance headway and time headway, repeatability would still be a problem. For example, if distance headway were defined as the distance between the front bumper of a lead vehicle and the front bumper on the following vehicle, it is still not clear which point on the bumpers is referenced. Of 27 unique distance and time headway definitions, only one definition attempts to define this point: Definition 13 that defined time headway as the “time between which the leading surfaces of two consecutive vehicles pass the same location along a roadway” (SAE J1761 3.155). Leading surfaces is still ambiguous because a leading surface can be a width, height or a length of a vehicle.
**Accelerator Release Time**

*Background.* Accelerator release time measures how quickly a driver releases the accelerator pedal when presented with a stimulus that requires braking, such as the onset of a lead vehicle’s brake lamp illumination (Wiese & Lee, 2004; Li & Milgram, 2004), or the onset of an amber phase of a traffic signal (Perez, Doerzaph, & Neale, 2004).

Accelerator release reaction time is useful for understanding brake reaction behavior to visual stimuli (Li & Milgram, 2004) or auditory stimuli (Wiese & Lee, 2004). It is important to note the industry trend of “selective braking,” in which electronics brake the vehicle and do not necessarily illuminate the tail lamps. Traction control (which involves braking of individual wheels) and adaptive cruise control (which can involve throttle adjustments and/or braking of all wheels) are examples of selective braking.

*Which terms have been used?* As shown in Table 13, there is not any particular name for accelerator release reaction time that was particularly favored in the sampled literature.

<table>
<thead>
<tr>
<th>Measurement term</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>accelerator release reaction time</td>
<td>2</td>
</tr>
<tr>
<td>time to accelerator release</td>
<td>2</td>
</tr>
<tr>
<td>accelerator release time</td>
<td>1</td>
</tr>
<tr>
<td>time of taking foot off gas pedal</td>
<td>1</td>
</tr>
<tr>
<td>accelerator release</td>
<td>1</td>
</tr>
<tr>
<td>throttle reaction time</td>
<td>1</td>
</tr>
</tbody>
</table>
All measurement terms for accelerator release reaction time were clear except for *accelerator release* and *throttle reaction time*. *Accelerator release* does not indicate any *time* component in its name (i.e. reaction time), and *throttle reaction time* does not indicate any *release* component in its name.

**How should accelerator release time be defined?** Six unique definitions for accelerator release reaction time were observed in the selected literature.

A complete measurement procedure for accelerator release reaction time identifies an initial stimulus and specifically defines when and how the accelerator pedal is released.

Three definitions did not offer a complete measurement procedure. For example, Definition 2 specified an initial stimulus but did not define how or when the accelerator pedal was released: "the accelerator release reaction time is the reaction time of onset of the lead vehicle braking, measured from the moment the lead vehicle applies the brakes, which coincided with the illumination of the brake lights of the lead vehicle" (Wiese & Lee, 2004). Conversely, Definition 6 defined when the accelerator pedal was released: "the time it took for a participant to remove his/her foot from the throttle pedal," but did not define the initial stimulus (Neurauter, 2005).

Definitions 3, 4, and 5 offered a complete measurement procedure. For example, Definition 5 indicated the initial stimulus was "when the lead
vehicle began to brake," and measurement concluded when "the driver released the accelerator." However, the point at which measurement ended was still too vague because there was no indication when and how the accelerator pedal was released.

Perez, Doerzaph, & Neale (2004) indicated the initial stimulus was "the onset of the amber phase," and measurement concluded at "the initial release of the accelerator pedal (operationally defined as the first decrease in accelerator position, after amber onset, of more than 2.5 percent in 0.1 sec)," which offers enough specificity to repeat (Definition 3).

**Accelerator to Brake Transition Time**

**Background.** Accelerator-to-brake transition time measures the time it takes a driver to release the accelerator pedal and apply the brake pedal. This measure is important when measuring reaction time to a specific stimulus, such as the brake lamp illumination of a lead vehicle. In some cases, accelerator-to-brake transition time is part of a decomposed brake reaction time, which consists of accelerator release time, accelerator-to-brake transition time, and brake-to-maximum-brake time (Wiese & Lee, 2004; Lee et al., 2002; Wiese & Lee, 2001; Lee, McGehee, & Brown, 2000).

**Which terms have been used?** “Accelerator to brake transition time” is one of two terms found in the selected literature used to describe
this phenomenon. The other name used was “initial accelerator release to initial brake press,” as shown in

Table 14.

Table 14. Terms Used for Accelerator to Brake Transition Time in the Literature

<table>
<thead>
<tr>
<th>Measure name</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>accelerator-to-brake transition time</td>
<td>3</td>
</tr>
<tr>
<td>initial accelerator release to initial brake press</td>
<td>1</td>
</tr>
</tbody>
</table>

**How should accelerator to brake transition time be defined?**

Only two definitions for accelerator-to-brake transition time were observed in the literature, one from Wiese and Lee (2004) and one from Lee (2002). Definition 1 stated: "the accelerator to brake transition time is the time from accelerator release to brake application" (Wiese & Lee, 2004).

Definition 2 was very similar to Definition 1, with some minor rephrasing: "accelerator-to-brake transition time specifies the time between driver release of the accelerator and application of the brakes" (Lee et al., 2002).

Both definitions had a complete measurement procedure, for which measurement began when the driver releases the accelerator pedal and ended when the driver applied the brake pedal.

While both definitions offer a complete measurement procedure, they do not provide enough detail to reliably reproduce. More specific information is required to show *how* and *when* accelerator pedal is released and brake pedal is applied. Some examples of more information
could be: the moment the foot leaves accelerator pedal or touches brake pedal; when pedals reach a certain position (in degrees); when a certain force is removed or applied from the pedals.

**Brake Reaction Time**

**Background.** Similar in concept to accelerator release time, brake reaction time measures how quickly a driver engages the brake pedal when presented with a stimulus that requires braking, such as onset of a lead vehicle braking (Seppelt, Lees, & Lee, 2005; Levy, Pashler, & Boer, 2004; Strayer, Drews, & Crouch, 2003). Brake reaction time can be a good indicator of reaction time to various stimuli, such as rear end crash scenarios (Kiefer et al., 2005); forward collision warnings (Curry, Greenberg, & Kiefer, 2005; Smith, Najm, & Lam, 2003); or back-up warning systems (Llaneras, 2005).

**Which terms have been used?** The name *brake reaction time* was referenced most frequently (eight times) to describe the phenomenon of a driver’s brake reaction time to a particular stimulus. Table 15 shows a complete list of measurement terms from the sampled literature.

Table 15. Terms Used for Accelerator to Brake Reaction Time in the Literature

<table>
<thead>
<tr>
<th>Measurement term</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>brake reaction time</td>
<td>8</td>
</tr>
<tr>
<td>time to brake</td>
<td>2</td>
</tr>
<tr>
<td>brake-onset time</td>
<td>2</td>
</tr>
<tr>
<td>braking reaction time</td>
<td>1</td>
</tr>
<tr>
<td>time to initial brake</td>
<td>1</td>
</tr>
<tr>
<td>braking time</td>
<td>1</td>
</tr>
<tr>
<td>time of first pressing brake pedal (TPB)</td>
<td>1</td>
</tr>
</tbody>
</table>
All terms collected for the measure brake reaction time clearly indicate their meaning except for *braking time*. This name does not connote brake *reaction* time, and therefore may be misleading to the measure of interest. All measurement terms are written with clear, concise English except for the measure name *time of first pressing brake pedal*, which is too verbose.

**How should brake reaction time be defined?** Eleven unique definitions were observed for brake reaction time. As with accelerator release reaction time, a complete measurement procedure for brake reaction time requires a stimulus from which to begin measurement and a defined moment when measurement is completed.

All definitions collected defined an initial stimulus to begin measurement and defined when to conclude measurement, except for Definition 10, which did not indicate a point of conclusion: "brake onset time is the time interval between the onset of the participants' braking response" (Strayer & Drews, 2004).

While most brake reaction time definitions indicated a complete measurement procedure, in many cases the measurement procedure was not very clear, which compromised repeatability. For example, Definition 8 stated: "brake-onset time is the time interval between the onset of the pace car's brake lights and the onset of the participant's braking response" (Strayer, Drews & Crouch, 2003). While there is a clear point at which
measurement *begins* (the onset of the pace car’s brake lights), there is no clear point at which measurement *ends*. “Onset of the participant’s braking response” can be interpreted in many ways, such as pedal movement (in degrees), pedal force, or initial contact from the driver’s shoe.

Definition 7 was a good example of a clear and complete measurement procedure: "time-to-Brake (TB) was measured from the onset of the amber phase to the onset of brake application (operationally defined as a change of brake position of more than 5 percent in 0.1 sec)" (Perez, Doerzaph, & Neale, 2004). There was a clear point at which measurement begins (onset of amber phase) and when measurement ended (change of brake position of more than 5 percent in 0.1 sec).

Definition 9 was another good example of a clear and complete measurement procedure, defining brake reaction time as "the time difference between initial braking of the lead car and braking of the following driver (defined as achieving a deceleration of greater than 1 m/s²)" (Jamson, et al., 2004). Like Definition 7, there was a clear point at which measurement begins (initial braking of the lead car) and when measurement ends (deceleration of greater than 1 m/s²).

Note, however, that Definitions 7 and 9 defined response measures differently. Definition 7 defined response in terms of brake pedal movement over time: “the onset of brake application (operationally defined as a change of brake position of more than 5 percent in 0.1 sec)."
Definition 9 defined response in relation to overall vehicle braking:

“deceleration of greater than 1 m/s².”

A third way of defining response was the moment brake pedal was initially contacted, which was specified in Definition 2: "The brake RT was defined as the interval from when the lead car’s brake light illuminated until the initial depression on the brake pedal" (Levy, Pashler, & Boer, 2004).

*Time to Collision (TTC)*

**Background.** Time to collision is the time it would take a vehicle to collide with a lead vehicle if the velocities and accelerations of both vehicles were frozen in time. The time in time to collision is mathematically defined as the distance between following and lead vehicles divided by the difference in velocity between the two vehicles.

As Jamson et al. reported (2004), “TTC reflects the time safety margin adopted by drivers for taking action if the lead car brakes suddenly; the less TTC, the less safety margin.”

Similar to *headway*, the following are key elements of TTC:

Vehicles must be consecutive along a path;

Only the longitudinal component of distance is calculated between the two vehicles (on curvy roads, measurement becomes more complicated);

**Which terms have been used?** Overwhelmingly the most popular measure name from all sampled literature, *time to collision* is referenced
thirty-three times. Table 16 below shows that the next most popular measure name is “forward time-to-collision, which is referenced three times. *Forward time to collision* and *rear time to collision* are sub-classifications of *time to collision*. *TTC to a lead vehicle* is a redundant name because time to collision is always in relation to a lead vehicle.

<table>
<thead>
<tr>
<th>Measurement Term</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>time to collision (TTC)</td>
<td>33</td>
</tr>
<tr>
<td>forward time-to-collision</td>
<td>3</td>
</tr>
<tr>
<td>rear time-to-collision</td>
<td>2</td>
</tr>
<tr>
<td>TTC to a lead vehicle</td>
<td>1</td>
</tr>
</tbody>
</table>

**How should time-to-collision be defined?** The examined literature provided fourteen unique definitions for TTC.

Except for Definitions 6 and 8, none of the definitions from the sampled literature specify that the two vehicles referenced in measuring time to collision must be *following* one another (Appendix K). For example, Definition 1 defines time to collision as “the time it would take for one vehicle to collide with another vehicle if no action is taken to prevent the collision” (Hakan, 2000). This definition would encompass lateral collision (e.g., lane change crash). If lateral collision were included in time to collision, then the lateral distance (and lateral velocity and acceleration) between the two vehicles must be specified. For example, lateral distance could be the distance between the vehicles’ wing mirrors or the distance between specific points on each vehicle’s side body panels.
Time to collision measures the time for a following vehicle to crash into a lead vehicle, with two assumptions:

Following and lead vehicles are consecutive and have the same trajectory (i.e., driving in the same lane)

The velocity and acceleration of the two vehicles is fixed.

Definition 6 is a good example of a complete measurement: "the TTC-Case 1 measure was defined as the time it would take the following and lead vehicle to collide assuming the prevailing following vehicle speed and lead vehicle speed. This is mathematically defined as the gap between the two vehicles divided by the difference in speeds between these two vehicles, or gap/ΔV. Note that with this measure the lead vehicle and following vehicle speeds are assumed to remain constant throughout the maneuver" (Kiefer et al., 2003).

Definition 4 supplements the measurement procedure with an example of how to calculate time to collision: "the TTC is calculated as the range between the two vehicles divided by their range-rate or relative velocity (ΔV). Take the case of two vehicles that are 100 feet apart. If the front vehicle is moving at 100 feet/second and the following vehicle is moving at 120 feet/second, the range-rate would be 100 feet/second minus 120 feet/second, or 20 feet/second. To calculate the TTC, 100 feet is divided by 20 feet/second. Therefore, the TTC is 5.0 s. In other words, it would take 5.0 s for the following vehicle to collide with the lead vehicle if velocity was constant. However, the TTC parameter assumes constant
speed and does not account for vehicle acceleration (Smith, Najm, & Glassco, 2002)” (Lee et al., 2004).

While Definition 6 offers a complete measurement process, it is not repeatable because they do not define how to measure range (gap) between the following and lead vehicles. Gap is equivalent to one interpretation of distance headway, or the distance between the front bumper of the following vehicle with the rear bumper of the lead vehicle.

Definition 13 attempts to clarify how to measure the distance between the following and lead vehicles “TTC to a lead vehicle is formally defined as the distance to the vehicle (bumper to bumper), divided by the speed of the vehicle” (Johansson et al., 2005). This measurement procedure is not specific enough because it does not specify which bumpers (front or rear) on the following and lead vehicles are used to measure the distance.

Discussion

The following conclusions are drawn from the results:

Measure names were not consistent across all reviewed literature. For example, the measure name lateral lane position had twelve unique terms; the measurement term time gap had ten unique terms; and the measure name lane departure had eight unique terms.

Often measures in the literature were not defined at all. For example, of the seventeen occurrences of the measure name lane departure in the literature, nine were not defined. Of the 44 instances of
the measure name *lateral lane position*, only ten of the measure terms were defined in the literature. Of the 25 occurrences of the measurement terms *time gap* and *time headway*, only eleven were defined.

When a measure was defined, there was little agreement to composition of the definitions. For example, the measure name *time to collision* had 25 unique definitions; the measure name *brake reaction time* had twelve unique definitions; and measure name *lateral lane position* had ten unique definitions.

Based on the results, there is a need for consistent measurement terms and definitions, proposed below:

**Measure Terms**

Proposed measure Terms:

1. Lane departure
2. Lane change
3. Lateral lane position
4. Steering wheel reversal
5. Distance gap
6. Time gap
7. Distance headway
8. Time headway
9. Accelerator release time
10. Accelerator to brake transition time
11. Brake reaction time
12. Time-to-collision

Measure definitions

Definition classification. In some cases, multiple definitions are proposed for a single measure because there was not strong overwhelming argument for a single measure in each case, and there may be good argument for several alternatives. However, where there are options, researchers must specify which option is being used (e.g., definition A).

Measure definitions are classified in three ways: crash potential, ease of measurement, and consistency with current practices. “Crash potential” means that the measure definition is written to address the theoretical contact points of two vehicles (or one vehicle and an object), should they occupy the same space in time. To occupy the same space, theoretically at least one vehicle must leave its defined area of safety, such as the current driving lane. For example, the definition for lane departure is written so that the moment a vehicle departs its lane (its area of safety), there is potential for crash if the immediately adjacent vehicle does the same thing.

Sometimes an ideal measurement procedure may be difficult or impractical, so definitions with “easier” procedures are also proposed. For example, it is common to review lane departure data on video, so an “easy to measure” definition was written considering video capture.
Finally, for those who prefer traditional measurement techniques, there may be a definition option that uses traditional measurement procedures.

The following definitions are proposed, based on the definition selection criteria described above.

**Lane departure.** The lateral area of a lane belonging to a vehicle is the lane itself and exactly half of the lane striping. Therefore, when two adjacent vehicles cross the centerline of the lane striping, there is potential for vehicle contact or a crash. The lane departure definition only takes into account areas in which lane lines exist. The safety-related lane departure definition considers this:

**Lane departure definition 1 (crash potential).** A lane departure begins when any part of the vehicle (including tire, wing mirror, and body shell) or its cargo is above the centerline of the lane boundary and the driver has not signaled a lane change. A lane departure ends the moment any part of the vehicle is not above the centerline of the lane boundary and the vehicle is in the original lane of travel.

In the cases where a vehicle does not return to its original lane of travel, then the vehicle is either in a different lane on the road or has driven off the road.

In the cases where two lane stripes exist (i.e., in a no passing zone of a two-lane road), lane departure begins when any part of the vehicle
(including tire, wing mirror, body shell) or its cargo is above the center point of entire width of the two lane stripes.

**Lane departure definition 2 (ease of measurement).** Lane departure begins when any part of the tire patch of either front tire (defined as any part of the tire touching the road) touches the lane boundary and the driver has not signaled a lane change. Lane departure ends the moment there are no parts of tire patch of that tire touching any part of a lane boundary and the vehicle is in the original lane of travel. If a vehicle is returning to a lane, the back tires may still be in contact with the lane boundaries at this time. Aiming a video camera at any front tire makes these departures easy to see. Figure 9 shows both lane departure definitions rear elevation view. Note that typically when returning to a lane, both front tires may be inside the lane, but one of the rear tires may be outside the lane.
Figure 9. Lane departure definition and measurement options: crash potential and ease of measurement (rear elevation).
**Lane change.** After further review, lane change was excluded from the list of terms to define because it was difficult to determine exact when a change being or ends. The difficulty is separating the momentary variations in lane position with an overt action to change lanes.

**Lateral lane position definition 1a and b (ease of measurement).** Lateral lane position is defined as the distance between the centerline of the vehicle at the front of the vehicle (version 1a) and the centerline of the lane. The front is used because that portion of the vehicle is most likely to strike another vehicle first. If no right hand lane marking exists, then lateral position is defined from the centerline of the vehicle to the edge of the paved roadway. For reasonably well-balanced passengers cars (50/50 front/rear weight distribution), this point and the center of gravity (cg) should be very close to each other. Further, only for extreme yaw angles will the differences in location matter. In both cases, for tractor trailers, the lateral lane position is determined by the position of the tractor. Admittedly, for double trailers, the lateral lane position of the cg of the cab and cg of each trailer can differ considerably. This is particularly difficult for identifying a lane departure for in some situations a cab could be completely in one lane and a trailer in another. In the future, additional modifications may be needed to better accommodate multiple unit vehicles.

In version 1b, the vehicle reference is the center of gravity of the vehicle, a common reference point for vehicles in simulators.
*Lateral lane position definition 2 (alternate).* Lateral lane position is defined as the distance between the centerline of the vehicle and the centerline of the path in that lane most often traveled by vehicles. The definition accounts for real driving behavior; for example drivers may cut corners. Figure 10 shows lateral lane position definition reference points.

![Figure 10. Reference points for lateral lane position (front elevation).](image)

*Time-to-line crossing (crash potential).* Time-to-line crossing is the time necessary for the any part of the vehicle (including tire, wing mirror, and body shell) or its cargo to cross the centerline of the lane boundary if the vehicle’s controls were frozen (i.e., constant speed, acceleration, and steering angle). Figure 11 shows time-to-line crossing measurement – crash potential.

*Time-to-line crossing (ease of measurement).* Time-to-line crossing is the time necessary for the any part of the tire patch (defined as any part of the tire touching the road) to cross the centerline of the left or
right lane marking if the vehicle’s controls were frozen (i.e., constant speed, acceleration, and steering angle). Figure 12 shows time-to-line crossing measurement – ease of measurement.

Figure 11. Reference points for time-to-line crossing measurement:

- Crash potential (plan view).

[Image of Reference points for time-to-line crossing measurement]
Figure 12. Reference points for time-to-line crossing measurement: ease of measurement (plan view).
Note about lane markers: There are times when the pavement and the painted lane markings are not aligned. By how much and how often this occurs is unknown; data are needed to analyze and make meaningful conclusions. For now, the assumption is that drivers use what is most visible, the lane markings, not the expansion joints or seams in asphalt, for lane guidance.

**Steering wheel reversal.** A good starting point for the steering wheel reversal definition is the one used by Fisher et al. (2002): “the change from the negative (clockwise movement) to a positive (counterclockwise) rotational velocity OR the change from a positive rotational velocity to a negative rotational velocity, when the absolute value of rotational velocity exceeds 3.0 degrees per second.” However, this definition does not take into account angular change. As such, further study – including signal processing, smoothing, and sampling frequency – is required to complete the steering wheel reversal definition.

**Distance gap.** The distance between the longitudinally **front-most point** of a vehicle and the longitudinally **rear-most point** of an immediately preceding vehicle in the same lane. “Front-most” and “rear-most” can include anything mounted to or carried in/on a vehicle, such as a trailer hitch, snowplow, ladder, lumber, muffler, spoiler, etc., and must be specified within the definition.
**Distance headway.** The distance between the longitudinally front-most point of a vehicle and the longitudinally front-most point of an immediately preceding vehicle in the same lane. “Front-most point” and “rear-most point” can include anything mounted to or carried in/on a vehicle, such as a trailer hitch, snowplow, ladder, lumber, muffler, spoiler, etc., and must be specified within the definition. Figure 13 shows distance gap and headway measurement.

![Diagram showing distance gap and distance headway measurement](image)

**Figure 13.** Distance gap and distance headway measurement (plan view)

**Time gap.** The time it takes for the longitudinally front-most point of a vehicle to reach the longitudinally rear-most point of an immediately preceding vehicle in the same lane, if the velocity and acceleration of both vehicles held constant. “Front-most” and “rear-most” can include anything mounted to or carried in/on a vehicle, such as a trailer hitch, snowplow, ladder, lumber, muffler, spoiler, etc., and must be specified within the definition.

**Time headway.** The time it takes for the longitudinally front-most point of a vehicle to reach the longitudinally front-most point of an
immediately preceding vehicle in the same lane, if the velocity and acceleration of both vehicles held constant. “Front-most” and “rear-most” can include anything mounted to or carried in/on a vehicle, such as a trailer hitch, snowplow, ladder, lumber, muffler, spoiler, etc., and must be specified within the definition.

**Accelerator pedal release reaction time.** Accelerator release reaction time is defined as the interval between stimulus onset and initial decrease of accelerator pedal position of more than 5% in 0.1 seconds (Perez, Doerzaph, & Neale, 2004). However, given varying throttle maps per vehicle, it is recommended that a more conclusive study be conducted for a more robust definition.

**Accelerator pedal to brake pedal transition time definition 1 (crash potential).** Accelerator-to-brake transition time is defined as the time between driver decrease of accelerator pedal position of more than 5% in 0.1 seconds and 5% application in 0.1 seconds of the brake pedal, an adaptation of (Perez, Doerzaph, & Neale, 2004. However, given varying throttle maps per vehicle, it is recommended that a more conclusive study be conducted for a more robust definition.

**Brake reaction time.** A good starting point for defining brake reaction time is to use the definition provided by Perez, Doerzaph, & Neale (2004), who define the measure as “the time from stimulus onset to when a driver depresses the brake pedal more than 5% of the total brake pedal range in 0.1 sec.” However, a future study will need to be
conducted to determine whether 5% of the total depression range is a robust measurement.

**Time-to-collision.** If the velocity and acceleration are frozen in time, the time it takes for one vehicle to strike another vehicle or object.

**Road departure.** While road departure was not an intended definition to study, a definition is nevertheless offered. A road is defined as any paved surface open to vehicular traffic; the edge of the paved surface area, including the shoulder, is considered to be off of the road. In cases where a road is unpaved (i.e., gravel or dirt) or is otherwise not clearly defined, each case must be considered on an individual basis.

**Error! Not a valid bookmark self-reference.** summarizes all the proposed measure definitions. The key measurement beginning point and measurement ending point for each definition is listed. For the measure definitions of steering wheel reversal, accelerator release time, accelerator to brake transition time, and brake reaction time, a preliminary definition is offered.
Table 17. Summary of Measurement Beginning and Ending Contact Points

<table>
<thead>
<tr>
<th>Measure name</th>
<th>Measurement beginning contact point</th>
<th>Measurement ending contact point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane departure</td>
<td>Moment any part of the vehicle (including tire, wing mirror, body shell) is above the centerline of the lane boundary.</td>
<td>Moment any part of the vehicle is not above the centerline of the lane boundary and the vehicle is in the original lane of travel</td>
</tr>
<tr>
<td>Time-to-line crossing</td>
<td>Any part of the tire patch (defined as any part of the tire touching the road)</td>
<td>Centerline of the left or right lane marking</td>
</tr>
<tr>
<td>Lateral position</td>
<td>Centerline of the vehicle</td>
<td>Centerline of the right-hand lane marking (If no right hand lane marking exists, use edge of the paved roadway)</td>
</tr>
<tr>
<td>Steering wheel reversal (preliminary)</td>
<td>Change from the negative (clockwise movement) to a positive (counterclockwise) rotational velocity OR the change from a positive rotational velocity to a negative rotational velocity</td>
<td>Absolute value of rotational velocity exceeds 3.0 degrees per second</td>
</tr>
<tr>
<td>Distance gap</td>
<td>Longitudinally front-most point of a vehicle</td>
<td>Longitudinally rear-most point of an immediately preceding vehicle in the same lane</td>
</tr>
<tr>
<td>Metric</td>
<td>Definition</td>
<td>Example</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Time gap</td>
<td>Longitudinally front-most point of a vehicle</td>
<td>Longitudinally rear-most point of an immediately preceding vehicle in the same lane</td>
</tr>
<tr>
<td>Distance headway</td>
<td>Longitudinally front-most point of a vehicle</td>
<td>Longitudinally front-most point of an immediately preceding vehicle in the same lane</td>
</tr>
<tr>
<td>Time headway</td>
<td>Longitudinally front-most surface of a vehicle</td>
<td>Longitudinally front-most surface of an immediately preceding vehicle in the same lane</td>
</tr>
<tr>
<td>Accelerator release time</td>
<td>Stimulus onset</td>
<td>Accelerator pedal released more than 5% of the total accelerator pedal range in 0.1 seconds</td>
</tr>
<tr>
<td>(preliminary)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accelerator to brake transition time</td>
<td>Accelerator pedal released more than 5% of the total accelerator pedal range in 0.1 seconds</td>
<td>Brake pedal depressed more than 5% of the total brake pedal range in 0.1 seconds</td>
</tr>
<tr>
<td>(preliminary)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brake reaction time</td>
<td>Stimulus onset</td>
<td>Brake pedal depressed more than 5% of the total brake pedal range in 0.1 seconds</td>
</tr>
<tr>
<td>(preliminary)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time to collision</td>
<td>If the velocity and acceleration are frozen in time, the time it takes for one vehicle to strike another vehicle or object.</td>
<td>NA</td>
</tr>
</tbody>
</table>
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Appendix A – Lane departure definitions

Examples in sampled literature where measure is mentioned and definition is offered:

Lane departure definition 1

HS51 number of times per lap crossing white sidelines

Each videotape of the driving simulation (showing the driver’s view of the road) was viewed by a rater who counted the number of times per lap that the automobile crossed the white sidelines on the roadway and the number of times that the speedometer registered below 10 mph. To facilitate reliable counting based on the videotaped driver’s view of the road (automobile wheels not visible), two reference marks were established on the face of the TV monitor. The car was counted as being off the road whenever the white sidelines on the road crossed one of these marks (Jenness et al., 2002, p. 594).

Lane departure definition 2

HS20 number of lane deviations

Defined as when the vehicle’s tire came into contact with the lane marker (Blanco, Hankey, & Chestnut, 2005, p. 1977).

Lane departure definition 3

HS21 time out of the lane

Defined as the time from when the tire came into contact with the lane marker until the tire was no longer in contact with the lane marker and the vehicle was in the correct lane (Blanco, Hankey, & Chestnut, 2005, p. 1977).

Lane departure definition 4

HS22 percent of time out of lane

The percentage of time the participant was out of the correct driving lane. (Blanco, Hankey, & Chestnut, 2005, p. 1977).
Lane departure definition 5

**HS66 lane departure duration**

Similarly, the lane departure duration (i.e., the time from the beginning of the lane departure to the moment that the vehicle was completely back in lane) was used as a measure of the effectiveness of the various lane departure warnings (Harder, Bloomfield, & Chihak, 2001, p. 1604).

Lane departure definition 6

**HS65 lane departure**

Any part or whole of any tire outside the lane boundary (Tsimhoni & Green, 2001, p. 1588).

Lane departure definition 7

**A22a lane exceedence**

Several lane exceedences exist. The most common performance measure seems to be LANEX, defined as the proportion of a time any part of the vehicle is outside the lane boundary. An alternative is to count the number of times that the vehicle exceeds lane boundaries. Lane exceedence measures have higher face validity than lane variation measures (e.g. standard deviation) as safety indicators. However, they may be insensitive to small shifts in workload/distraction (due to the implicit threshold). Another variant is to count the number of major lane deviations, where a major deviation is defined as a situation where a part of the vehicle exceeds the lane by more than half of the vehicle width. (Johansson et al., 2005, p. 22).

Lane departure definition 8

**A22b major lane deviations**

Several lane exceedences exist. The most common performance measure seems to be LANEX, defined as the proportion of a time any part of the vehicle is outside the lane boundary. An alternative is to count the number of times that the vehicle exceeds lane boundaries. Lane exceedence measures have higher face validity than lane variation measures (e.g. standard deviation) as safety indicators. However, they may be insensitive to small shifts
in workload/distraction (due to the implicit threshold). Another variant is to count the number of major lane deviations, where a major deviation is defined as a situation where a part of the vehicle (Johansson et al., 2005, p. 22).

**Examples in sampled literature where measure is mentioned but no definition is offered:**

**DA1 lane keeping**

Driver performance measures of lane keeping and speed control were recorded. IVT task performance was measured by response time to the digits, response duration, and the response accuracy (Horrey & Wickens, 2003, p. 9).

**H19 time or distance out of lane**

Driving in the oncoming traffic lane is of course related to higher accident risk. This behaviour is caused by overtakings, but also by the driver shortening the distance of travel in left curves (for right hand traffic). The fraction of distance (or time) traveled in the oncoming traffic lane and the total distance (or time) traveled has been used (e.g. Nilsson, Alm and Janssen, 1991) as a driving performance or risk indicator. This parameter is feasible for rural and motor way driving (Roskam et al., 2002, p. 54).

**HS106 number of lane deviations**

Each measure of driver performance was calculated from raw data from the simulator computers. These variables included variance in longitudinal velocity, mean longitudinal velocity, mean longitudinal velocity deviation, variance in lateral lane position, frequency of lane deviations, variance in steering wheel position, and the frequency of large steering reversals (Tijerina, Panner, & Goodman, 2000, p. 3-335 – 3-336).

**HS125 number of lane violations**

The primary performance measures of interest in the dynamic trials were Total Task Time and Number of Lane Violations. In the static trials, the primary performance measure was Total Task Time. (Other dynamic performance measures of interest were obtained and will be discussed in future reports. These included glance durations and
frequency, total eyes-off-the-road time, number and type of errors, various measures of driving performance and subjective workload measures) (Farber et al., 2000, p. 3-275).

**DA9 number of lane deviations**

No definition (Young & Angell 2003).

**H18 Number of lane exceedences**

Number of lane exceedences per time has been used as a measure of lateral control, e.g. by Tijerina et al. (1999). This measure is feasible for rural road, motorway and highway driving (Roskam et al., 2002, p. 54).

**HF13 number of lane departures**

Measures of temporal vehicle separation (minimum time to collision, minimum headway) were calculated using a radar-based front-to-rear crash avoidance system (to monitor following distance) in conjunction with vehicle velocity. The front-to-rear collision avoidance system was also used to trigger data collection for time-to-collision (TTC) values less than 4s. Each of these measures is closely related to time to collision and is also easily incorporated as a trigger into a separation detection device. Mean TTC was not included in the analysis because of the discontinuous nature of the data (Tsimhoni, Smith, & Green, 2004, p. 605).

**H19 time or distance out of lane**

Driving in the oncoming traffic lane is of course related to higher accident risk. This behaviour is caused by overtakings, but also by the driver shortening the distance of travel in left curves (for right hand traffic). The fraction of distance (or time) traveled in the oncoming traffic lane and the total distance (or time) traveled has been used (e.g. Nilsson, Alm and Janssen, 1991) as a driving performance or risk indicator. This parameter is feasible for rural and motor way driving (Roskam et al., 2002, p. 54).

**HS110 RMS error lane keeping (N)**

The basic tracking (‘lane keeping’) performance was calculated as a root mean squared (RMS) error in the number of pixels of the ‘car’ away from the centre of the
‘lane’. Tracking data were baselined by subtracting the overall mean RMS error for the control blocks (driving only) from the other blocks, i.e. giving the degree to which tracking performance in the conditions was worse than ‘normal’. This baselined RMS error data was subjected to a 2 (concurrent task) X 4 (control modality) X 2 (age) X 2 (gender) ANOVA (Carter & Graham, 2000, p. 3-288).
Appendix B – Lane Change

Examples in sampled literature where measure is mentioned and definition is offered:

Lane change definition 1

HS53 lane change

Lane change initiation was the point the vehicle first moved laterally; the lane change ended when the vehicle was centered in the destination lane (Olsen, Lee, & Wierwille, 2002, p. 1790).

Lane change definition 2

DOT28 lane change

Lane change initiation was the point that the vehicle first moved laterally; the lane change ended when the vehicle was settled in the destination lane. (Lee et al. 2004, p. ii-iii).

Lane change definition 3

DOT32 lane change

The universe of the lane change family of crashes, as defined by this study, includes all crashes occurring on the roadway, in which one vehicle encroaches into the travel lane of another vehicle that is initially traveling in the same direction, and on a parallel path. The definition is broader than what is usually understood by the term "lane change crashes" since, in addition to crashes that occur when one vehicle intentionally changes lanes while traveling straight on a roadway, it includes other lane-encroachment type crashes (Basav, Najm, & Smith 2003, p. 7).

Lane change definition 4

DOT51 lane change

Lane Changes – This measure indicates the frequency of risky maneuvers from one situation to another, especially in response to slower traffic. The number of lane changes on freeways and arterials when using ICC [intelligent Cruise Control] is less than that for manual driving. For example,
on freeways, the rate of lane changes for ICC driving was about 8 per 100 km, in contrast to about 19 for manual. (CCC [Conventional Cruise Control] was about 7). Lane changes for ICC were less likely to result in a closing state; 1.04 lane changes per 100 km of ICC driving resulted in a closing state as compared to 3.46 for manual driving and 1.57 for CCC driving. ICC lane changing also resulted in proportionately fewer instances of ending in states of closing, following, or separating at headways under 0.8 seconds (close) compared to manual driving (14 percent for ICC versus 21 percent for manual). Most importantly, ICC driving resulted in significantly fewer instances of lane changing from closing-close situations (2 percent of lane changes for ICC versus 8 percent for manual and 7 percent for CCC). This is seen as evidence that ICC driving reduces the need for drivers to make safety-critical lane changes in response to slower traffic (National Highway Traffic Safety Administration 1999, p. xxvi).

There are no examples in sampled literature where measure is mentioned but no definition is offered.
Appendix C – Time-to-line crossing

Examples in sampled literature where measure is mentioned and definition is offered:

Time-to-line crossing definition 1

HF22 time-to-line crossing

TLC (Godthelp, Milgram, & Blaauw, 1984) is defined as the time to cross either lane boundary with any of the wheels of the vehicle, given its instantaneous path. As the vehicle approaches the edge or centerline of the road, TLC decreases. TLC reflects the time available for error, assuming a fixed steering strategy (Jamson, et al. 2004, p. 635).

Time-to-line crossing definition 2

HF51 time-to-line crossing

TLC is defined as the time necessary for the vehicle to reach either edge of the driving lane if its controls were frozen (i.e., constant speed and steering angle) at a given point in its course and requires visual information for drivers to estimate it (Reymond et al., 2001, p. 484).

Time-to-line crossing definition 3

G8 time-to-line crossing (TLC)

TLC was developed to enhance preview-predictor models of human driving performance. TLC equals the time for the vehicle to reach either edge of the driving lane. It is calculated from lateral lane position, the heading angle, vehicle speed, and commanded steering angle (Godthelp, Milgram, & Blaauw, 194).

Time-to-line crossing definition 4

H9 time-to-line crossing

Time-to-line crossing is defined as the time to cross either lane boundary with any of the wheels of the vehicle if speed and steering wheel angle are kept constant. As the vehicle approaches the line TLC will decrease until it reaches a
minimum. Under "normal" conditions this will occur when the motion of the car is changed from going towards one line to the other. During this change the car will pass a situation where it momentarily will not move toward any of the line but follow the road perfectly this will result in an indefinite or undefined TLC. The distribution of TLC is not bell-shaped. In order to determine the safety margins we have to look for the TLC minima, which his also the case for TTC. The steering performance could then be described in terms of TLC (min) distribution (Roskam et al., 2002, p. 51).

**Time-to-line crossing definition 5**

**DA33 time to lane crossing**

TLC is the time required for a vehicle to run off the road boundary (road shoulder or oncoming traffic lane) assuming the current steering wheel angle is held constant and there is no further steering intervention by the driver (Paul et al., 2005).

*There are no examples in sampled literature where measure is mentioned but no definition is offered.*
Appendix D – Lateral Lane Position

Examples in sampled literature where measure is mentioned and definition is offered:

Lateral lane position definition 1

HF17 lane position & HF18 standard deviation lane position (SDLP)

Lane position was determined by measuring the absolute deviation of the vehicle (in meters) relative to the center of the vehicle’s lane (Horrey & Wickens, 2004, p. 615).

Lateral lane position definition 2

HF34 standard deviation lateral position (SDLP)

Speed (in kilometers per hour) and lateral position (in millimeters) were measured simultaneously at four points along each curve - the approaching, entry, apex, and exit points - and at three points along the straight section. Lateral position was defined as the distance from the front left wheel of the car to the left white line by the edge of the road (driving in the UK) (Blana & Golias, 2002).

Lateral lane position definition 3

Lateral position = the distance between the right hand wheel and the edge of the road pavement (Steyvers & deWaard, 2000, p. 305).

Lateral lane position definition 4

A20 mean lane position

The mean lane position is defined as the mean distance between a reference point on the vehicle and an arbitrary position in the lane (normally one of the lane boundaries or the lane centre) (Johansson et al., 2005, p. 22).
Lateral lane position definition 5

H6 absolute lateral position

It should be kept in mind that the variation in land width often is of the six dot centimetres and that systems of lane tracking normally are not more accurate that a few centimetres. Lateral position is usually defined as the distance between the right hand part of the front right wheel to the left part of the right hand lane marking. When the line crosses the lateral position it becomes negative (Roskam et al., 2002, p. 51).

Lateral lane position definition 6

HS49 lane deviation

Participants' driving performance was indicated by their speed control and lane maintenance. Lane position was determined by measuring the absolute deviation of the vehicle (unit: meters) relative to the vehicle's lane, reflected by both mean and standard deviations (Zheng, McConkie, & Tai, 2003, p. 1902).

Lateral lane position definition 7

DA25 lane position

Dependent variables were mean driving speed (the average speed at which the subject actually drove), and the proportion of time the center of the vehicle remained on the road during travel (Haas, 2001, p.145).

Lateral lane position definition 8

DA44 road position (tracking)

Road position (tracking), measured as the deviation in percentile of the centre of the vehicle from the centre of the right hand lane. The extreme edge of the left lane position was demarcated as 100%, and extreme right lane position was 0%. Thus, ideal road position for the given task of maintaining the vehicle in the centre of the right lane was 25% (Moller et al., 2005, p. 213).
Lateral lane position definition 9

DOT6 lane position

This analysis investigates driver performance in normal driving situations with ACAS-Disabled and with ACAS-Enabled (Period 4), where the host vehicle is not closing in on a lead vehicle. The following measures of performance are selected for this analysis:

1. Time headway when ACAS vehicle is traveling at constant speed. Time headway is defined as the range between ACAS and lead vehicle (m) divided by the ACAS vehicle speed (m/s).
2. Lane position when ACAS vehicle is traveling at constant speed. Lane position is defined as distance (m) from lane center (positive is right of center).
3. Speed ratio of ACAS vehicle speed over posted speed limit when ACAS vehicle is traveling at constant speed (Najm et al., 2006, p. 4-61).

Lateral lane position definition 10

DA16 lane position

The dependent measures of lane position and speed were measured at seven locations in the roundabout. Lane position was scored using a 9-point scale. Lane position scoring criterion:

0 out of left-lane to left
1 encroaching on left-lane edge
2 centered in left-lane
3 left-lane encroaching on right-lane
4 straddling lanes
5 right-lane encroaching on left-lane
6 centered in right-lane
7 encroaching on right-lane edge
8 out of lane to right
(Davis, 2003, p. 261-22)
Examples in sampled literature where measure is mentioned but no definition is offered:

**HF6 standard deviation of lane position (SDLP)**

An ANOVA was computed using standard deviation of lane position (SDLP) as the dependent measure (Ranney, Harbluk, & Noy, 2005, p. 449).

**E2 lateral position**

Driver performance was measured using speed, lateral position and headway to a lead vehicle (Jamson & Jamson, 2005, p. 1740).

**E21 lane position and movement in lane**

No significant differences were observed between the steering wheel adjustments made in each task type. Nor were any significant differences found for exceeding the boundaries of the lane, deviating position in lane or mean lane position between task types (Lansdown, Brook-Carter, & Kersloot, 2004, p. 98).

**E23 lateral position**

Speed and lateral position were measured with a sample rate of 5 Hz. Averaged driving speed and averaged standard deviation of lateral position (SDLP, a measure of swerving) were calculated for each condition. Possible collisions, near-collisions and deviations out of lane were noted (Cnossen, Meijman, & Rothengatter, 2004, p. 226).

**E25 standard deviation of lateral placement (lateral deviations)**

The primary dependent variable was mean speed. The standard deviation of lateral placement (lateral deviations) and the standard deviation of steering wheel angle (steering deviations) were used as primary task workload measurements of lateral control and steering effort (Godley, Triggs & Fildes, 2004, p. 241).

**A21 standard deviation/variance of lane position**

This is one of the most common performance measures. Its popularity is probably due to its high face validity and computational simplicity. The measure has been shown to be relatively independent of speed. As with other variation
measures, it is strongly dependent on task duration (Johansson et al., 2005, p. 22).

**H1 lateral position**

Lateral position is controlled by steering movements. The aim of lateral control is to keep the car on the road in order to minimise risk of accidents and maximise personal requirements such as comfort. If the driver’s visual attention is taken away from the traffic scene the lateral control may be affected, which may result in lateral instability. The performance of controlling lateral position may be studied through variations in lateral position (e.g., SDLP) and time margin before crossing a lane limit (TLC). The most promising technical/objective measures are described below. Objective lateral position measures are most feasible for highway and rural road driving. In urban driving where there are several intersections and lanes, the lateral position measurement may be measured by subjective ratings; either by the driver or by an observer. For this, separate protocols may be used. The method of subjective ratings have not been used to the same extent as objective measures (Roskam et al., 2002, p. 49).

**H5 absolute lateral position: value as performance measure**

Lateral position reflects strategy. For instance, Brookhuis found that under the influence of sedative drugs drivers drove more towards the relatively safe emergency shoulder compared with a control condition (i.e. they adapted their safety margins) (Roskam et al., 2002, p. 51).

**H7 standard deviation of lateral position: value as performance measure**

Less lateral control may be observed as an increase in standard deviation of lateral position (SDL). In several studies, driver deprivation (drugs, sleepiness) has even shown to cause increase in SDLP; the steering control has become less stable. However, SDLP is influenced by take-covers and voluntary changes in lateral position due to read curvature; effects that may not be related to driving measures (Roskam et al., 2002, p. 51).
H8 standard deviation of lateral position

Measuring lateral position in real traffic requires optical equipment for lane marking detection. Also, of course, visible lane markings are required. Weather conditions, reflections and shades may affect the quality of the measurement. When there are several lane markings, it has to be assured what lane markings are tracked. In urban environment, and markings may not be present, but what the relevant lateral position is may be poorly defined. Lateral position can alternatively be measured manually on video recordings. It should be kept in mind that the variation in land width often is of the size of centimetres and that systems for lane tracking normally are not more accurate than a few centimetres. Care should be taken that for SDLP calculations overtaking maneuvers should be deleted from data (Roskam et al., 2002, p. 51).

DA12 lateral position (N)

The effects of different lateral positions was investigated using a DVP with a 1:2 display ratio either in the driver's line of sight when looking straight ahead or displaced towards the middle of the car, about 24 degrees to the right. In order to see the displaced display, the driver had to take his/her eyes off the road. It was expected that this would affect the quality of driving, seen via the measured performance indicators (braking profile and lateral variability) (Hollnagel, 2003, p. 155).

DA18 standard deviation lateral offset

An initial analysis of the lane-tracking sensor data also reveals some possible indicators of stress. The standard deviation of the lateral offset of the car from the centerline is small during the non-stressful Baseline, but more then doubles in its value in the challenging Control region (Rimini-Doering et al., 2001, p. 62).

DA19 standard deviation lane position

The standard deviation of lane position was calculated during the curved section of the motorway (Parkes, Sexton, & Burton 2001, p. 73).
DA22 lateral position

NASA-TLX ratings were made after each route and EDA and were recorded continuously during the experimental session in addition to speed, acceleration, lateral position and brake activity (Ceci, Hogman, & Patten, 2001, p. 138).

DA27 lateral position

Driver speed and lateral position on the real road were evaluated against the simulator conditions (Jamson, 2001, p. 192).

DA31 lane position variability

Lane position variability is measured with the standard deviation of lane position (SDLP). SDLP is an index of road tracking error or “weaving.” This measure will identify whether a driver’s ability to control the vehicle is maintained or diminished. This measure was calculated over the intervals of interest (microsleep periods) (Paul et al., 2005, p. 20).

DA37 lane position

The primary measures of driving performance were the participants’ average mean and standard deviation of velocity (Experiment 1), headway time (Experiment 2) and lane position (both experiments). Velocity was measured in meters per second. Headway time was measured in seconds. Lane position was measured in meters, relative to the center of the participant’s lane. Positive values indicate deviation to the right of the center of the lane, and negative values indicate deviation to the left. Driving performance was measured at 60 Hz; that is, the value of each measure was recorded 60 times per second, and the resulting data were analyzed for the entire condition (Kubose et al., 2005, p. 78-79).

DA38 standard deviation lane position

The primary outcome was the standard deviation of lateral position (SDLP), a measure of how well participants maintain their lane position. This measure has been shown to have good test-retest reliability (Marcotte et al., 2005), and previous studies have shown performance on versions of this simulator to be sensitive to illicit substance use (Stein,
Allen, Cook, & Karl), sleep apnea (Risser, Ware, & Freeman, 2000), and HIV-associated cognitive impairment (Marcotte et al., 1999) (Marcotte et al., 2005, p. 191-192).

**DA51 SD lane position**

Data were analyzed for each curve section of the experimental runway. Driving performance was quantified as the standard deviation of the lateral position of the simulated vehicle, with respect to the road centerline. This is a simple way to characterize the “stability” of a trajectory (Mestre et al., 2005, p. 300).

**DA56 RMS lane position**

Driving performance was measured by four parameters that were recorded by the simulator: the root mean square (RMS) of the lane position, RMS of the steering wheel rate, the average longitudinal speed and the RMS of the longitudinal speed (Oron-Gilad & Hancock, 2005, p. 314).

**DA62 RMS lane position**

The dependent variables relating to driver performance were analyzed. These include velocity, root-mean-square values of lane position, steering, acceleration, braking, lateral and longitudinal acceleration, number of collisions, and maintenance of speed limit. Maintenance of the speed limit included the subject’s velocity minus the posted speed limit at that frame. The root-mean-square (RMS) value for lane position, steering, acceleration, braking, lateral and longitudinal acceleration were used in the analysis (Stanley, Kelly, & Lassacher, 2005, p. 481).

**HS12 standard deviation lane position**

In addition to maintaining vehicle speed and lane position, participants were also asked to press a button on the steering wheel whenever they detected such changes, and to occasionally carry out a secondary task (Zheng, McConkie, & Simons, 2005, p. 2000).

**HS25 average lateral deviation**

For the driving task, dependent measures based on speed and accuracy of lateral position were derived from the database coordinates. The course was first segmented into
sections of like-radius. For each segment that was obstacle free, average speed (Speed) and the average lateral deviation (Error) were computed. Error was computed as the root mean square of the position of the vehicle subtracted from the coordinates of the centerline of the test track on nearest-neighbor, point-by-point basis. For both Speed and Error, exponential curves were fit relating the measure to the curve radius (Emmerson, 1970). This method resulted in coefficients representing the maximum speed (SpeedMAX) or minimum lateral deviation (ErrorMIN) and how the speed or the error changed as a function of the path radius (SpeedCC, ErrorCC). The percentage of errors (% Error) was computed as the number of times a participant either contacted an obstacle or got lost while avoiding an obstacle divided by the total number of obstacles passed (Ruffner et al., 2005, p. 3).

**HS31 standard deviation lateral position**

The following evaluation measures were computed for each task of each subject from the collected data:
1) Number of Eye Glances (Observed from close-up live video. The total number of glances was obtained by counting glances made away from the road scene by the driver during each task interval -- defined from the initiation of the verbal task command to the initiation of the verbal command for the following task).
2) Velocity Standard Deviation (in m/sec) [in three consecutive 6 sec. Intervals].
3) Lateral Position Standard Deviation (in m) [in three 6 sec. Intervals].

The above standard deviations of velocity and lateral position were measured from 30 samples (5 samples/sec over 6 sec interval). The velocity and lane position standard deviations were computed over three time intervals: 0 to 6 sec, 6 to 12 sec., and 12 to 18 sec after a task command was initiated (Bhise & Dowd, 2004, p. 2257).

**HS47 standard deviation lane position**

There was a significant interaction between ACC condition and SS for lane position standard deviation [F (2, 22) =4.23, p<.05], with high sensation-seekers deviating more within the lane when they used ACC compared to when they drove unsupported. Low sensation-seekers showed no differences across conditions (Rudin-Brown, Parker, & Malisia, 2003, p. 1852).
Driving performance was measured by six variables that were recorded by the simulator. The average number of offroad accidents, average lane position (relative to the center of the road, lane width was 2.54 (m), root mean square (RMS) of the lane position, RMS of the steering wheel rate, average longitudinal speed (with maximum speed limited to 90 kph), and RMS of the longitudinal speed. On a straight road segment, in particular when speed is limited, we expected to find the most pronounced changes in poorer lane positioning and poorer steering wheel control due to the fact that the shoulders allowed a greater margin of safety in lateral control (Oron-Gilad et al., 2002, p. 1851).

Three measures were used to assess driving performance: (1) standard deviation of lane position, (2) line-crossing rate, and (3) speed loss during a trial (Nowakowski, Friedman, & Green, 2002, p. 1821).

Presents the standard deviation of lateral position in the 3 tested conditions. In the driving baseline, the variability in lateral position increased by 75% as a function of curvature (Tsimhoni & Green, 2001, p.1587).

Lateral displacement, speed, steering wheel angle, radar targets, and other dependent variables were recorded by the guidance system at each roadway marker (every 1.2m). Video recordings of the driver's faces from a camera mounted in the LCD case was considered yet not executed due to equipment problems and concern over driver comfort (Steinfeld, Tan, & Bougler, 2001, p. 1652).

For this analysis, age group and task complexity were the independent variables while task performance time, speed stability, lane position stability, subjective ratings, and control activation errors were dependent variables (Feyen & Liu, 2000, p. 4-61).
The following dependent variables were used in the study:
1. Number of collisions
2. Speed level and variation in speed level
3. Lateral position and variation in lateral position
4. Reaction times to the yellow dot and brake reaction time to event 1, 2 and 3.
5. Time headway - defined as the distance expressed in time between two vehicles
6. Time to collision - defined as the time it would take for one vehicle to collide with another vehicle if no action is taken to prevent the collision. (Hakan, 2000, p. 3-268)

The driving performance measures of speed and lane deviations, timing, and subjective ratings were analyzed using an analysis of variance (ANOVA) to determine which control array characteristics were statistically significant, either as main effects or as second-order interactions.

Speed control and lane position were evaluated by comparing the standard deviation of each measure during baseline data collection with the standard deviation recorded during the task performance. Neither number of functions nor number of modes had an effect on any measure of speed deviation; the number of modes had no effect on the lane position deviation (Feyen et al., 2000, p. 3-291).

Each measure of driver performance was calculated from raw data from the simulator computers. These variables included variance in longitudinal velocity, mean longitudinal velocity, mean longitudinal velocity deviation, variance in lateral lane position, frequency of lane deviations, variance in steering wheel position, and the frequency of large steering reversals (Liu, Schreiner, & Dingus, 2000, p. 3-335 – 3-336).

There were three independent variables (i.e. automation, workload and feedback), three dependent variables associated with driving behaviour (i.e. speed, lateral position on road and headway) and six dependent variables
associated with the psychology of the driver (i.e. locus of control, trust, workload, stress, mental models and situational awareness). The three levels of workload were determined by manipulating the throughput of vehicles per hour (VPH) as follows: 800 VPH (Low), 1600 VPH (Medium) and 2400 VPH (High) (Stanton & Young, 2000, p. 3-299).
Appendix E – Steering Wheel Reversal

Examples in sampled literature where measure is mentioned and definition is offered:

Steering wheel reversal definition 1

HF7 steering wheel reversal

A steering wheel reversal was defined as beginning when the steering velocity left a zero-velocity dead band and ending when the steering velocity entered a zero-velocity dead band such that the magnitude of the reversal was 2 degrees or greater (Tijerina, Kiger, Rockwell, & Tornow, 1995) (Ranney, Harbluk, & Noy, 2005, p. 449).

Steering wheel reversal definition 2

HS60 steering wheel reversal

A steering reversal was defined to begin when the steering velocity left a zero-velocity dead band and ended when the steering velocity entered a zero-velocity dead band such that the magnitude of the reversal was 2 degrees or greater (Tijerina, Kiger, Rockwell & Tornow, 1995) (Ranney, Harbluck, & Noy, 2002, p. 1816).

Steering wheel reversal definition 3

A13 steering wheel reversal rate (SR)

SSR is one of the most commonly used driving performance measures. The measure represents the number of times that the steering wheel is reversed by a magnitude larger than a specific angle, or gap. The gap sizes reported in the literature varies between 0.5-10 degrees (Johansson et al., 2005, p. 18).

Steering wheel reversal definition 4

HF30 steering wheel reversal rate (SRR)

For each of the selected sections, the mean steering wheel rate reversals (SRR) per participant were determined. This measure was derived from steering wheel movements analyzed in terms of number of reversals per second (e.g.,
Verwey & Veltman, 1996). A movement was defined as a change from the negative (clockwise movement) to a positive (counterclockwise) rotational velocity when the positive rotational velocity exceeded 3.0 degrees per second (Theeuwes, Alferdinck, & Perel, 2002, p. 101).

**Steering wheel reversal definition 5**

**HF31 steering wheel reversal**

For each of the selected sections, the mean steering wheel rate reversals (SRR) per participant were determined. This measure was derived from steering wheel movements analyzed in terms of number of reversals per second (e.g., Verwey & Veltman, 1996). A movement was defined as a change from the negative (clockwise movement) to a positive (counterclockwise) rotational velocity when the positive rotational velocity exceeded 3.0 degrees per second (Fisher et al., 2002, p. 294).

*Examples in sampled literature where measure is mentioned but no definition is offered:*

**HS58 RMS steering wheel rate**

Driving performance was measured by six variables that were recorded by the simulator. The average number of offroad accidents, average lane position (relative to the center of the road, lane width was 2.54 (m), root mean square (RMS) of the lane position, RMS of the steering wheel rate, average longitudinal speed (with maximum speed limited to 90 kph), and RMS of the longitudinal speed. On a straight road segment, in particular when speed is limited, we expected to find the most pronounced changes in poorer lane positioning and poorer steering wheel control due to the fact that the shoulders allowed a greater margin of safety in lateral control (Oron-Gilad et al., 2002, p. 1841).

**H17 Changes in steering wheel rotational direction (reversal rate):**

**Value as performance measure**

Number of zero crossings reflects the frequency of steering corrections, not the magnitude. Curve following results in a constant deviation from the neutral point (zero angle). As a result, the number of zero crossings decrease during curve
following: a decrease that is not related to performance. Therefore, the road should be rather straight for this indicator to work well (Roskam et al., 2002, p. 54).

**HS108 number of steering reversals**

Each measure of driver performance was calculated from raw data from the simulator computers. These variables included variance in longitudinal velocity, mean longitudinal velocity, mean longitudinal velocity deviation, variance in lateral lane position, frequency of lane deviations, variance in steering wheel position, and the frequency of large steering reversals (Liu, Schreiner, & Dingus, 2000, p. 3-335 – 3-336).

**G6 steering reversals**

Hicks and Wierwille (1979) reported that steering reversals were sensitive to workload (i.e. gusts at the front of a driving simulator) (Gawron, 2000).

**DA14 rate of steering wheel reversals (N)**

The rate of steering wheel reversals of at least 6 degrees in either direction was also calculated to measure erratic steering (Dingus et al., 1989) (Rizzo et al., 2003, p. 203).

**DA57 RMS steering wheel rate (N)**

Driving performance was measured by four parameters that were recorded by the simulator: the root mean square (RMS) of the lane position, RMS of the steering wheel rate, the average longitudinal speed and the RMS of the longitudinal speed (Oron-Gilad & Hancock, 2005, p. 314).
Appendix F – Distance Gap/Distance Headway

Examples in sampled literature where measure is mentioned and definition is offered:

Distance gap/distance headway definition 1

HF46 distance headway

The headway between two moving vehicles can be expressed in terms of distance or time. The distance headway is the bumper-to-bumper gap between the lead vehicle and the following vehicle expressed in meters (or feet). The time headway is the distance headway divided by the speed of the following vehicle. In steady-state following - when the two vehicles are moving at the same speed - the time headway represents the time available to the following driver to reach the same level of deceleration as the lead vehicle in case it brakes. This time is independent of speed. Using Van Winsum and Heino's (1996) terms, time headway during steady-state car-following is referred to in the present study as preferred time headway (Taieb-Maimon & Shinar, 2001, p. 160).

Distance headway/distance gap definition 2

HF26 following distance

Following distance is the distance between the rear bumper of the pace car and the front bumper of the participant's car (Strayer & Drews, 2004, p. 643).

Distance headway/distance gap definition 3

A3 distance headway

Distance headway is defined as the average distance to the lead vehicle (from bumper to bumper). Large values (>~50 meters) are normally discarded (Johansson et al., 2005, p. 15).
Distance headway/distance gap definition 4

A4 mean distance headway

The average distance headway (Johansson et al., 2005, p. 15).

Distance headway/distance gap definition 5

A5 minimum distance headway

The minimum value of the distance headway signal (Johansson et al., 2005, p. 15).

Distance headway/distance gap definition 6

H24 distance headway

Distance headway [metres] to a lead vehicle is defined as the distance to lead vehicle, preferably defined as distance from bumper to bumper. The only difference to time headway is that vehicle speed is not considered. An alternative name is Distance Gap or just Gap (Roskam et al., 2005, p. 55).

Distance headway/distance gap definition 7

DA6 following distance

Following distance is the distance between the pace car and the participant's car (expressed in miles per hour) (Strayer, Drews & Crouch, 2003, p. 28).

Distance headway/distance gap definition 8

DOT41 gap distance

The distance from the rear bumper of the SV to the front bumper of the POV (Zador, Krawchuk, & Voas, 2000, p. 7).
Distance headway/distance gap definition 9

**DOT44 space headway**

The distance between the front bumper of a vehicle and the front bumper of the vehicle it is following (meters per vehicle) (Koziol et al., 1999, p. 5-2).

Distance headway/distance gap definition 10

**DOT45 gap**

The distance between the front bumper of a vehicle and the back bumper of the vehicle it is following (meters). Gap is analogous to the ICC range variable (Koziol et al., 1999, p. 5-2).

Distance headway/distance gap definition 11

**HS6 vehicle headway**

*Vehicle headway* was defined as the temporal latency (in seconds) between successive vehicles as they passed this fixed point on the roadway. Using this method, headway was recorded as the latency from the front of a lead vehicle to the front of a following vehicle. Note that this is not the same as following distance (distance from rear of lead vehicle to front of target vehicle) or following headway (time from arrival of rear of lead vehicle to front of target vehicle), although the measures are highly related (Lerner & Singer, 2005, p. 1903).

*Example in sampled literature where measure is mentioned but no definition is offered:*

**DA42 headway distance**

The analysis focused on the driver’s performance during the deceleration events. The time was broken down into 1-second bins, and average values for the performance variables were computed for each bin. This analysis was performed for 5 variables: (1) forward velocity, (2) accelerator pressure, (3) brake pressure, (4) headway distance (at both minimal and 7 sec), and (5) temporal headway (at 7 sec). To determine statistical significance (unless otherwise indicated, all results were significant with p
< .01), each variable was analyzed by performing, for each subject, a second-order polynomial regression of that variable over the time from the start of the lead-vehicle deceleration event until 7 seconds after the deceleration had started (Wood & Hurwitz, 2005, p. 206).
Appendix G – Time Gap/Time Headway

Examples in sampled literature where measure is mentioned and definition is offered:

Time gap/time headway definition 1

HF5 time headway (TH)

The TH, defined as the time until the front bumper of the follower's car reaches the location on the roadway currently occupied by the rear bumper of the lead vehicle (Lee, 1976) (Gray & Regan, 2005, p.395).

Time gap/time headway definition 2

HF44 temporal headway (TH)

The second measure, the one used in this study, is temporal headway (TH), the time it will take for the following car to reach the position of the lead car (Ben-Yaacov, Maltz, & Shinar 2002, p.335).

Time gap/time headway definition 3

HF47 time headway, HF48 preferred time headway

The headway between two moving vehicles can be expressed in terms of distance or time. The distance headway is the bumper-to-bumper gap between the lead vehicle and the following vehicle expressed in meters (or feet). The time headway is the distance headway divided by the speed of the following vehicle. In steady-state following - when the two vehicles are moving at the same speed - the time headway represents the time available to the following driver to reach the same level of deceleration as the lead vehicle in case it brakes. This time is independent of speed. Using Van Winsum and Heino's (1996) terms, time headway during steady-state car-following is referred to in the present study as preferred time headway (Taieb-Maimon & Shinar, 2001, p. 160).
Time gap/time headway definition 4

A6 time headway

Time headway is defined as the distance to the lead vehicle (from bumper to bumper) divided by the travel speed of the own vehicle. Large values (>~3 seconds) are discarded (Johansson et al., 2005, p. 15).

Time gap/time headway definition 5

H22 time headway: value as performance measure

Time headway [seconds] to lead vehicle is defined as the time to collide into lead vehicle if it stops dead. Time headway is a measure of longitudinal risk margin. The closer and faster a subject travels behind a lead vehicle, the less is the chance to manage avoiding a collision in case of the lead vehicle reduces speed. For a small headway, the time a subject may be distracted by another task without a highly increased risk of accident, is much less than if the time headway is large. The proportion of the time headway less than one second has been used as a risk indicator for car following situations. An alternative name for Time Headway is Time Gap (Roskam et al., 2002, p. 55).

Time gap/time headway definition 6

H23 time headway

Time headway is calculated as the distance to lead vehicle divided by own momentary travel speed. In simulator experiments, the distance to the lead vehicle should be defined as the distance between the bumpers of the cars (Roskam et al., 2002, p. 55).

Time gap/time headway definition 7

HS91 time headway (TH)

Time headway - defined as the distance expressed in time between two vehicles (Hakan, 2000, p. 3-268).
"Self-reported driving behavior was collected using pre- and post-drive questionnaires. This self reported data is not included in this paper. Following was measured using range and range rate sensor data and analyzed as headway (range between the two vehicles divided by the speed of the following vehicle). Deceleration levels were measured using the vehicle’s data acquisition system. Instances of deceleration spanning at least a 15 mph (24.1 km/h) decrease in speed were extracted and the peak deceleration was identified and located within the overall deceleration based on range, velocity, and headway at the time of the peak deceleration. Brake covering was recorded using a video camera placed above the participant’s feet. Time segments were identified in which the driver had placed his or her foot over the brake pedal in a way which permits activation of the brake solely by downward movement of the foot to the pedal (McLaughlin & Serafin, 2000, p. 3-294).

Time headway is defined as the range between ACAS and lead vehicle (m) divided by the ACAS vehicle speed (m/s) (Najm et al., 2006, p. 4-61).

The distance between the front bumper of a vehicle and the front bumper of the vehicle it is following (meters per vehicle) (Koziol et al., 1999, p. 5-2).

The distance between the front bumper of a vehicle and the back bumper of the vehicle it is following (meters). Gap is
analogous to the ICC range variable (Koziol et al., 1999, p. 5-2).

**Time gap/time headway definition 12**

**DOT46 time-headway**

Time-headway – the time between the passage across a given stationary point of the front bumper of a vehicle and the front bumper of the following vehicle (seconds per vehicle) (Koziol et al., 1999, p. 5-3).

**Time gap/time headway definition 13**

**DOT47 time gap**

Time gap – the time between the passage across a given stationary point of the back bumper of a vehicle and the front bumper of the following vehicle. Time gap is analogous to the “time-headway” measure in Chapter 3.0 (Koziol et al., 1999, p. 5-3)

**Time gap/time headway definition 14**

**DOT48 vehicle time-headway**

Vehicle time-headway (or passage time) – the time between the passage across a given stationary point of the front bumper of a vehicle and its back bumper. Vehicle time headway is the difference between the time-headway and the time gap. Vehicle time headway is inversely proportional to speed, and is calculated by dividing the length of a vehicle by the speed in which it is traveling (Koziol et al., 1999, p. 5-3).

Examples in sampled literature where measure is mentioned but no definition is offered:

**HF45 time headway (TH)**

A standard component of most licensing manuals is concerned with educating drivers about perception-reaction time, vehicle stopping distance, and the implication of the two for safe headways from vehicles ahead. This headway is typical defined in terms of time rather than distance, and a
commonly recommended minimum safe headway is 2 s (Shinar & Schechtman, 2002, p.475).

HF49 initial headway time

The independent variables examined in this study were severity of collision situation (initial headway time and deceleration of the lead vehicle)… time-to-collision threshold and speed penalty, and characteristics of the driver (actual deceleration of the driver and actual driver reaction time) (Brown, Lee, & McGehee, 2001, p. 160).

DA36 time headway (TH)

The primary measures of driving performance were the participants’ average mean and standard deviation of velocity (Experiment 1), headway time (Experiment 2) and lane position (both experiments). Velocity was measured in meters per second. Headway time was measured in seconds. Lane position was measured in meters, relative to the center of the participant’s lane. Positive values indicate deviation to the right of the center of the lane, and negative values indicate deviation to the left. Driving performance was measured at 60 Hz; that is, the value of each measure was recorded 60 times per second, and the resulting data were analyzed for the entire condition (Kubose et al., 2005, p. 78-79).

DA43 temporal headway

The analysis focused on the driver’s performance during the deceleration events. The time was broken down into 1-second bins, and average values for the performance variables were computed for each bin. This analysis was performed for 5 variables: (1) forward velocity, (2) accelerator pressure, (3) brake pressure, (4) headway distance (at both minimal and 7 sec), and (5) temporal headway (at 7 sec). To determine statistical significance (unless otherwise indicated, all results were significant with p < .01), each variable was analyzed by performing, for each subject, a second-order polynomial regression of that variable over the time from the start of the lead-vehicle deceleration event until 7 seconds after the deceleration had started (Wood & Hurwitz, 2005, p.206).
Results are described according to driving and secondary task performance. The first section addresses the effects of automation level, and failure type on measures of driving task performance including brake response time (RT), time headway (THW) at point of brake response, time-to-collision (TTC) at point of brake response, number of collisions, and percent reliance. The second section addresses the effects of the same independent variables, with the addition of message complexity, on headway maintenance performance while engaged in the secondary task. Note that the ACC drive was divided into engaged and not engaged portions to capture differences in driving and secondary task performance with manual and ACC control. The analyses were performed using SAS 9.0 software; F statistics are reported from repeated measures ANOVA (Seppelt, Lees, & Lee, 2005, p. 251).

HS7 standard deviation time headway [seconds]

No definition (Rakauskas & Ward 2005).

HS32 time headway (TH)

Baseline time headway (TH) data was collected for all participants prior to training for each road type (Creaser, Lees & White, 2004, p.2262).

HS72 temporal headway

While the current study involved several variables including driver response times to deceleration events and the use of the accelerator and brake pedals the current presentation focuses on the headways that the drivers maintained when deceleration events began. To analyze this variable, an ANOVA was performed with the dependent variable being the temporal distance, $h$, between the vehicles when the lead vehicle started to decelerate, where $h = \frac{d}{v_F}$ (Hurwitz & Wheatley, 2001, p. 1638).

HS95 time headway

In this paper we focus on drivers’ adaptation to a front-to-rear-end collision avoidance system. One of the causes of front-to-rear-end collisions is the lack of sufficient headway between the vehicles. Generally, it is recommended to
maintain a distance of two seconds from the lead vehicle. For our experiment we used a passenger car equipped with a device that measured temporal headway (TH) and alerted the driver when s/he violated the stated minimum distance of one second to the lead car (Ben-Yaacov, Maltz, & Shinar, 2000, p. 3-312).

**DOT26 time headway at brake onset**

The driver performance measures examined included passenger-side experimenter brake assists, driver brake reaction time to the alert, the (constant) required deceleration level to avoid impact at brake onset, time-to-collision (TTC) at brake onset, time headway at brake onset, and peak deceleration throughout the maneuver. Subjective measures included alert noticeability and alert timing ratings (Kiefer et al., 2005, p. 17).

**DOT49 time in closing states**

Time in Closing States (Freeways) – This measure indicates the amount of exposure to situations involving closings on a lead vehicle. Driving with the ICC system resulted in less proportion of time spent closing on a lead vehicle; 5.1 percent of the time for ICC versus 6.8 percent for manual and 5.2 percent for CCC (Koziol et al., 1999, p. xxvi).

**DOT50 time in closing close sub-state**

Time in Closing Close Sub-state (Freeways) – On freeways, driving with the ICC system resulted in the least time spent in states of closing at headways under 0.8 seconds (close) compared to manual or CCC driving (NHTSA, “Evaluation of the Intelligent Cruise…” 1999, p. xxvi).

**DOT53 time in closing states (arterials)**

Time in Closing States (Arterials) – Driving with the ICC system resulted in a greater proportion of time spent closing on a lead vehicle; 8.5 percent of the time for ICC versus 4.4 percent for manual and 6.5 percent for CCC. Although this could represent a safety concern, it is considered safety-neutral because of several important considerations; namely, very little time exposure is involved (only about 0.5 percent of ICC driving is in the closing state on arterials) and there is evidence that the paucity of data on arterials produced unreliable results (an alternative analysis that aggregated
the data over all ICC drivers produced opposite results; i.e., ICC had the least time in closing states) (Koziol et al., 1999, p. xxvii).

**DOT60 time headway**

[Diagram of DOT60 time headway: Time Headway, Time Gap, Vehicle Time Headway, Vehicle Gap, Space Headway.]
Appendix H – Accelerator Release Time

Examples in sampled literature where measure is mentioned and definition is offered:

Accelerator release time definition 1

HF38 accelerator release reaction time

Accelerator release reaction time measures the reaction time to the braking event or the reaction time to the warning. Reaction time to the braking event was calculated for each driver, whereas reaction time to the warning was calculated only for those drivers assisted by the RECAS (Lee et al., 2002, p. 318).

Accelerator release time definition 2

E5 accelerator release reaction time

The accelerator release reaction time is the reaction time of onset of the lead vehicle braking, measured from the moment the lead vehicle applies the brakes, which coincided with the illumination of the brake lights of the lead vehicle (Wiese & Lee, 2004, p. 969).

Accelerator release time definition 3

HS29 time to accelerator release

Time-to-Accelerator-Release (TAR) was measured from the onset of the amber phase to the initial release of the accelerator pedal (operationally defined as the first decrease in accelerator position, after amber onset, of more than 2.5 percent in 0.1 sec) (Perez, Doerzaph, & Neale, 2004, p. 2244).

Accelerator release time definition 4

HS33 time of taking foot off gas pedal (TFG)

This denotes the time between the beginning of the LV’s braking and the moment of subject's complete releasing gas pedal (Li & Milgram, 2004, p. 2273).
Accelerator release time definition 5

HS41 accelerator release time

The main dependent measures collected from the driving tasks were the accelerator release time, brake reaction time, and minimum time to collision (TTC). Accelerator release time is defined as the time from when the lead vehicle began to brake until the driver released the accelerator. Other measures of driver performance including speed, accelerator position, and steering wheel position were also recorded (Reyes & Lee, 2004, p. 2371).

Accelerator release time definition 6

HS17 throttle reaction time (TRT)

The time it took for a participant to remove his/her foot from the throttle pedal (if his/her foot was in this location at stimulus onset) (Neurauter, 2005, p. 1946).

Example in sampled literature where measure is mentioned but no definition is offered:

HS67 accelerator release time

Other dependent variables characterize driver performance. Of particular interest is the decomposed reaction time, which is made up of three measures: accelerator release reaction time, accelerator to brake transition time, and brake to maximum brake transition time. The braking profile was also examined. It was defined by the mean deceleration and the maximum deceleration of the driver during the braking events (Wiese & Lee, 2001, p. 1633).

HS1 time to accelerator release (TAR)

Measured from onset of warning (Brown et al., 2005).

HS120 accelerator release

The percent of imminent collision situations that end in a collision provides a useful measure for the effectiveness of the RECAS. The results, shown in Figure 1, indicate a large benefit associated with the warning. The number of
collisions is lower than the baseline with the late warning and even lower with the early warning, $F(2, 108) = 13.45, p<0.0001$. Analyzing the response process in more detail can reveal how the RECAS affects the drivers' response process to produce this benefit Figure 1 also shows the drivers’ reaction time decomposed, from lead vehicle deceleration to \textit{accelerator release}, from initial accelerator release to initial brake press, and from initial brake press to maximum braking (Lee, McGehee, & Brown, 2000, p. 3-318).

**HS96 mean initial accelerator release, HS97 SD initial accelerator release**

Overall brake reaction and time to initial steering input were compared between the two studies. In addition, we examined the maximum lateral and longitudinal acceleration of both the IDS and the instrumented vehicle used in the test track study. Table 1 presents the means and standard deviations between the IDS and test track studies. Confidence intervals at the 95” percentile also confirmed that these results were equivalent.

As can be seen in Figures 1 and 2, total brake reaction time (defined as the period between the point at which the driver \textit{began to release the accelerator pedal} up to the maximum brake application point) was 2.2 seconds for the IDS and 2.3 seconds on the test track. Time to initial steering (defined as the point at which the driver first began to use steering to avoid the crash) was 1.64 seconds on the IDS and 1.67 seconds on the test track. Time to throttle release was also compared between the two studies (McGehee, Mazzae, & Baldwin, 2000, p. 3-321 – 3-322).
Appendix I – Accelerator to Brake Transition Time

Examples in sampled literature where measure is mentioned and definition is offered:

Accelerator to brake transition time definition 1

HF39 accelerator-to-brake transition time

Accelerator-to-brake transition time specifies the time between driver release of the accelerator and application of the brakes (Lee et al., 2002, p. 318).

 Accelerator to brake transition time definition 2

E6 accelerator to brake transition time

The accelerator to brake transition time is the time from accelerator release to brake application (Wiese & Lee, 2004, p. 969).

Example in sampled literature where measure is mentioned but no definition is offered:

HS68 accelerator to brake transition time

Other dependent variables characterize driver performance. Of particular interest is the decomposed reaction time, which is made up of three measures: accelerator release reaction time, accelerator to brake transition time, and brake to maximum brake transition time. The braking profile was also examined. It was defined by the mean deceleration and the maximum deceleration of the driver during the braking events (Wiese & Lee, 2001, p. 1633).

HS119 accelerator to brake(s)

The percent of imminent collision situations that end in a collision provides a useful measure for the effectiveness of the RECAS. The results… indicate a large benefit associated with the warning. The number of collisions is lower than the baseline with the late warning and even lower with the early warning, F (2, 108) = 13.45, p<0.0001. Analyzing the response process in more detail can reveal how the RECAS affects the drivers’ response process to
produce this benefit Figure 1 also shows the drivers’ reaction time decomposed, from lead vehicle deceleration to accelerator release, from initial accelerator release to initial brake press, and from initial brake press to maximum braking (Lee, McGehee, & Brown, 2000, p. 3-318).
Appendix J – Brake Reaction Time

Examples in sampled literature where measure is mentioned and definition is offered:

Brake reaction time definition 1

**HF1 brake reaction time (RT)**

For back-up warning systems, the first driver behavior parameter is driver brake reaction time (RT; i.e., the time between crash alert onset and the driver triggering the brake switch) (Llaneras, 2005, p. 201).

Brake reaction time definition 2

**HS39 brake reaction time**

The brake RT was defined as the interval from when the lead car’s brake light illuminated until the initial depression on the brake pedal (Levy, Pashler, & Boer, 2004, p. 2317).

Brake reaction time definition 3

**HS18 brake reaction time (BRT)**

The time it took for a participant to begin braking (from stimulus onset). (Neurauter 2005, p. 1946).

Brake reaction time definition 4

**HS26 braking reaction time**

The following dependent measures were recorded. 1) Braking reaction time. This is the time period between the braking event and application of the brakes. 2) Maximum deceleration. This is defined as the peak deceleration between the beginning and end of the braking event (Abe & Richardson, 2004, p. 2233).

Brake reaction time definition 5

**DA48 brake RT**

Brake RT is defined as the time from the point the LV begins to decelerate to when a driver depresses the brake more
than 5% of the total brake pedal range (Seppelt, Lees, & Lee, 2005, p. 251).

**Brake reaction time definition 6**

**E17 brake reaction time**

Brake reaction time was measured using the American Automobile Association reaction driving simulator. The simulator had a driver's seat, signal display board, accelerator pedal and brake pedal. The stimulus was a display consisting of a red light and a green light mounted 3 cm apart on the display board next to the brake pedal. The green light was turned on while the accelerator pedal was being depressed. The participant was to release the accelerator pedal and step on the brake pedal at the point that the red light was turned on at varying intervals for each trials. The simulator measured the elapsed time to the 1/100th of a second when participant released the accelerator pedal and depressed the brake pedal. Then three measurements were taken and the mean value was used in the analysis of the data (Kim & Bishu, 2004, p. 1019).

**Brake reaction time definition 7**

**HS28 time to brake**

Time-to-Brake (TB) was measured from the onset of the amber phase to the onset of brake application (operationally defined as a change of brake position of more than 5 percent in 0.1 sec) (Perez, Doerzaph, & Neale, 2004, p. 2244).

**Brake reaction time definition 8**

**DA3 brake-onset time**

Brake-onset time is the time interval between the onset of the pace car's brake lights and the onset of the participant's braking response (expressed in milliseconds) (Strayer, Drews & Crouch, 2003, p. 28).
Brake reaction time definition 9

**HF24 braking time**

A measure of driver anticipation was defined in terms of brake RT: the time difference between initial braking of the lead car (at a deceleration of 3 m/s²) and braking of the following driver (defined as achieving a deceleration of greater than 1 m/s²) (Jamson, et al., 2004, p. 634).

Brake reaction time definition 10

**HF25 brake onset time**

Brake onset time is the time interval between the onset of the participants' braking response (i.e., a 1% depression of the brake pedal) (Strayer & Drews, 2004, p. 634)

Brake reaction time definition 11

**HS34 time of first pressing brake pedal (TPB)**

This denotes the time between the beginning of the LV's braking and the moment of subject's pressing the brake pedal at first (Li & Milgram, 2004, p. 2273).

Brake reaction time definition 12

**DOT35 SV braking onset**

This analysis focused primarily on required deceleration and time-to-collision based measures at either the point of last-second braking onset or at the point of last-second steering onset. It should be noted that SV braking onset was not defined relative to the brake switch trigger point, since it was observed in the previous work that some drivers had a tendency to momentarily place their foot on the brakes during their last-second braking decision. Instead, as in the first CAMP FCW Project (Kiefer et al., 1999), SV braking onset was defined as the point in time in which the vehicle actually began to slow as a result of braking. More specifically, SV braking onset was defined as five 30 Hz data samples (or 165 ms) prior to SV crossing the 0.10 g deceleration level. (The reader is referred to the earlier Kiefer et al. work for the supporting rationale for this braking onset definition.) (Kiefer et al., 2003, p. 12).
Example in sampled literature where measure is mentioned but no definition is offered:

HS2 time to brake (TB)

Measured from onset of warning (Brown et al., 2005, p. 1893).

G1 average brake RT

No definition given (Gawron, 2000).

DOT23 brake reaction time

The driver performance measures examined included passenger-side experimenter brake assists, driver brake reaction time to the alert, the (constant) required deceleration level to avoid impact at brake onset, time-to-collision (TTC) at brake onset, time headway at brake onset, and peak deceleration throughout the maneuver. Subjective measures included alert noticeability and alert timing ratings (Kiefer et al., 2005, p. 17).

HS42 brake reaction time

The main dependent measures collected from the driving tasks were the accelerator release time, brake reaction time, and minimum time to collision (TTC). Accelerator release time is defined as the time from when the lead vehicle began to brake until the driver released the accelerator. Other measures of driver performance including speed, accelerator position, and steering wheel position were also recorded (Reyes & Lee, 2004, p. 2371).

DOT34 time to initial brake

Our analysis assumes that initial braking or steering onset indicates when drivers judge the start of the event as they followed “last-second maneuver” instructions. That is, our methodology utilizes performance data gathered from test-track controlled studies in which subjects were instructed to wait to conduct a maneuver (brake or steer) at the last possible moment in order to avoid colliding with a vehicle ahead using normal or hard intensity (Smith, Najm, & Lam, 2003, p. 2).
HS14 time of first pressing brake pedal (TPB)

The following indices were measured and recorded during each braking event (with 40 ms resolution): Time of first Pressing Brake pedal (TPB); Time of Maximum Braking force (TMB); Maximum Braking Force (MBF); Minimum Time-to-Collision (MTTC). For all time related indices, time was computed from the instant of LV braking (Li & Milgram, 2005, p. 1942).
Appendix K – Time to Collision

*Examples in sampled literature where measure is mentioned and definition is offered:*

**Time to collision definition 1**

**HS92 time to collision (TTC)**

Time to collision - defined as the time it would take for one vehicle to collide with another vehicle if no action is taken to prevent the collision. (Hakan, 2000, p. 3-268).

**Time to collision definition 2**

**DOT15 time to collision case #2 (TTC2)**

The calculated time (in seconds) it would take the SV to collide with the POV assuming the current vehicle speeds at SV onset, assuming SV acceleration = 0 and the POV continues to decelerate at the current rate of slowing. Note that the prevailing deceleration at SV onset could be 0 (Curry, Greenberg, & Kiefer, 2005, p. 29).

**Time to collision definition 3**

**DOT30 time to collision (TTC)**

Time required for two vehicles to collide if they continue on at their present speed and path (McLaughlin, 1998) (Lee et al., 2004, p. x).

**Time to collision definition 4**

**DOT31 time to collision (TTC)**

Time to collision is the time required for two vehicles to collide if they continue on their present speed and path (Van Winsum & Heino, 1996). The TTC is calculated as the range between the two vehicles divided by their range-rate or relative velocity ($\Delta V$). Take the case of two vehicles that are 100 feet apart. If the front vehicle is moving at 100 feet/second and the following vehicle is moving at 120 feet/second, the range-rate would be 100 feet/second minus 120 feet/second, or 20 feet/second. To calculate the TTC, 100 feet is divided by 20 feet/second. Therefore, the TTC is
5.0 s. In other words, it would take 5.0 s for the following vehicle to collide with the lead vehicle if velocity was constant. However, the TTC parameter assumes constant speed and does not account for vehicle acceleration (Smith, Najm & Glassco, 2002). Talmadge et al. (1997) concluded that TTC seems a likely candidate for use in CAS to activate warnings for drivers. They used an experimental CAS built by the Vehicle Research and Test Center (VRTC) of East Liberty, Ohio for a NHTSA effort, using a TTC collision algorithm. The CAS activated the driver warning system based on this algorithm. If activated, results suggest that a conservative amount of warning time would be 3.0 s TTC for most drivers (Lee et al., 2004, p. 10-11).

**Time to collision definition 5**

**DOT33 time to collision (TTC)**

A popular time-based measure has been the time-to-collision (TTC) defined as “the time required for two vehicles to collide if they continue at their present speed and on the same path.

Three different time-to-collision (or TTC) measures were examined at braking or steering onset. These measures are expressed in seconds. Each of these measures assumes the lead and following drivers maintain "straight ahead" (collision-course) trajectories. Unlike the required deceleration measure, these time-based measures do not provide a direct linkage to stopping distance. (Smith, Najm, & Lam, 2003, p. 2).

**Time to collision definition 6**

**DOT37 TTC-Case 1**

The TTC-Case 1 measure was defined as the time it would take the following and lead vehicle to collide assuming the prevailing following vehicle speed and lead vehicle speed. This is mathematically defined as the range between the two vehicles divided by the difference in speeds between these two vehicles, or \( \text{Range}/\Delta V \). Note that with this measure the lead vehicle and following vehicle speeds are assumed to remain constant throughout the maneuver, and that the current decelerations of either vehicle are irrelevant to the TTC-Case 1 calculation. This measure is sometimes referred to as "momentary TTC (Kiefer et al., 2003, p. 14).
DOT42 time to collision (TTC)

Also, a timeline for a sequence of events introduced the concept of “Time to Collision” (TTC) for forward defined heuristic scenarios. Parameter values were identified for range, range rate, vehicle attitude, host velocity, host deceleration, host vehicle response time, and driver response time. Some of these values can be measured and some can be calculated based on the particular countermeasure capability. TTC was defined as the range divided by the range rate with the units of seconds. The measure of parameter improvement due to a given countermeasure was difficult to characterize. A countermeasure will eliminate or mitigate a crash when it provides an opportunity for the driver to avoid involvement in a crash by improving driver response time allowing the driver to remain in control. This can also be stated as the sum of the driver reaction time and the required stopping distance time or avoidance time (given the road conditions and capability of the vehicle) is less than the calculated TTC (Zador, Krawchuk, & Voas, 2000, p. 23).

HF4 time-to-collision (TTC)

TTC (i.e., the time until the front bumper of the follower’s car contacts the rear bumper of the lead car) (Gray & Regan, 2005, p. 395).

HF20 time to collision (TTC)

TTC reflects the time safety margin adopted by drivers for taking action if the lead car brakes suddenly; the less TTC, the less safety margin. It was defined as the time that would elapse, if both the simulator car and lead car maintained their current speeds, before a collision occurred between them, TTC = s/\delta V, in which s = the distance between the two vehicles and \delta V = the relative velocity of the two vehicles (Jamson, et al., 2004, p. 633).
Time to collision definition 10

HF37 adjusted minimum time to collision (TTC)

The third safety benefit measure is adjusted minimum time to collision (TTC), a continuous measure of the severity of the collision situation. The adjusted TTC is calculated using equations of motion to determine the time to collision if the vehicles continue to travel at their current relative position, velocity, and acceleration (Lee et al., 2002, p. 317).

Time to collision definition 11

HF43 time to collision (TTC)

Two measures are commonly used for converting the distance between vehicles traveling in the same direction into a unit of time. One is time to collision (TTC), or the time it will take for two cars at their present speeds to collide (Ben-Yaacov, Maltz, & Shinar, 2002, p. 335).

Time to collision definition 12

A7 time to collision (TTC)

TTC represents the time until collision with an object (e.g. a lead vehicle) given the current trajectories and velocities of the own vehicle and the object (Johansson et al., 2005, p. 15).

Time to collision definition 13

A8 TTC to a lead vehicle

TTC to a lead vehicle is formally defined as the distance to the vehicle (bumper to bumper) divided by the speed of the vehicle. TTC is only defined if the distance between the vehicles decreases. Small (<~1 second) and large (>~15 seconds) values are discarded (Johansson et al., 2005, p. 15).

Time to collision definition 14

A9 minimum TTC

The minimum values of the time-to-collision (TTC) signal (Johansson et al., 2005, p. 15).
Time to collision definition 15

A10 mean of TTC local minima

The mean of the local minima in the TTC signal (defined above) (Johansson et al., 2005, p. 15).

Time to collision definition 16

H26 time to collision: value as performance measure

Time to Collision (TTC) [seconds] is defined as the time to collide into lead vehicle if vehicle speeds are kept constant. TTC reflects risk margin; the less TTC, the less margin (Roskam et al., 2002, p. 56).

Time to collision definition 17

DOT14 time to collision case #1 (TTC1)

The calculated time it would take the SV to collide with the POV assuming the current vehicle speeds at SV onset, as well as assuming SV and POV acceleration = 0 (at SV onset). Note that the prevailing deceleration at SV onset could be 0 (Curry, Greenberg, & Kiefer, 2005, p. 29).

Time to collision definition 18

DOT20 minimum TTC Case #1 (minTTC1)

The smallest value of TTC1 calculated at any point during the conflict interval (i.e., during the entire approach maneuver) (Curry, Greenberg, & Kiefer, 2005, p. 29).

Time to collision definition 19

DOT21 minimum TTC Case #2 (minTTC2)

The smallest value of TTC2 calculated at any point during the conflict interval (Curry, Greenberg, & Kiefer, 2005, p. 29).
**Time to collision definition 20**

**DOT38 inverse TTC-Case 1**

The inverse TTC-Case 1 measure was simply defined as the inverse of TTC-Case 1, or $\Delta V/\text{Range}$. The rationale for exploring this measure was two-fold. First, as will be discussed later, the inverse TTCCase 1 measure appears in the time derivative of required deceleration, which corresponds to how fast required deceleration is changing per unit time. Second, earlier work by Evans and Rothery (1974) found this measure to be the most robust measure (of those evaluated) for describing driver’s relative motion judgments (judging whether they were closing or “opening” relative to the lead vehicle) under in-traffic conditions with extremely small relative speed/acceleration values (Kiefer et al., 2003, p. 14).

**Time to collision definition 21**

**DOT39 TTC-Case 2**

The TTC-Case 2 measure was defined as the time it would take the following and lead vehicle to collide assuming the prevailing following vehicle speed and lead vehicle speed, as well as assuming the following vehicle acceleration is zero and that the lead vehicle continues to decelerate at the prevailing deceleration value (i.e., at the current “constant” rate of slowing) until it comes to a stop (at which point it remains stopped). This measure is equivalent to TTC-Case 1 for POV Stationary Trials and Constant $\Delta V$ Trials, but differs from TTC-Case 1 for POV Decelerating Trials. It should be noted that in calculating both the TTC-Case 2 and required deceleration measures during POV Decelerating Trials, the movement state of the lead vehicle (stationary or moving) during the “playing out” of the lead vehicle speed and braking assumptions was addressed (Kiefer et al., 2003, p. 14).

**Time to collision definition 22**

**DOT63 forward time-to-collision**

Acceleration or deceleration equal to or greater than 0.5 g coupled with a forward TTC of 4 seconds or less.
All longitudinal decelerations between 0.4 g and 0.5 g coupled with a forward TTC value of ≤ 4 seconds and that the corresponding forward range value at the minimum TTC is not greater than 100 ft. (Dingus et al., 2006, p. 11).

**Time to collision definition 23**

**DOT64 rear time-to-collision**

Any rear TTC trigger value of 2 seconds or less that also has a corresponding rear range distance of ≤ 50 feet and any rear TTC trigger value in which the absolute acceleration of the following vehicle is greater than 0.3 g. (Dingus et al., 2006, p. 11).

**Time to collision definition 24**

**DOT83 forward time to collision (FTTC)**

Acceleration or deceleration equal to or greater than 0.5 g coupled with a forward TTC of 4 seconds or less. All longitudinal decelerations between 0.4 g and 0.5 g coupled with a forward TTC value of ≤ 4 seconds and that the corresponding forward range value at the minimum TTC is not greater than 100 feet (Dingus et al., 2006, p.154).

**Time to collision definition 25**

**DOT84 rear time to collision (RTTC)**

Rear Time To Collision (RTTC) - Any rear TTC trigger value of 2 seconds or less that also has a corresponding rear range distance of ≤ 50 feet AND any rear TTC trigger value where the absolute acceleration of the following vehicle is greater than 0.3 g. Side object detection – Detects presence of other vehicles/objects in the adjacent lane. Lane change cut-off – Identifies situations in which the subject vehicle cuts in too close either behind or in front of another vehicle by using closing speed and forward TTC” (Dingus et al., 2006, p.154).
Example in sampled literature where measure is mentioned but no definition is offered:

**DA8 time to collision (TTC)**

We measured speed, distance, and time-to-contact (TTC) of each oncoming vehicle with the Stalker LIDAR system (Plano, TX). Stalker LIDAR is a semiconductor laser device that measures the speed, distance and direction vehicles are traveling relative to the device. The LIDAR was pointed directly at an oncoming vehicle by the experimenter sitting in the passenger seat. The laser beam was directed at the license place of the oncoming vehicle to ensure accurate results. Oncoming traffic rounding a curve entered the view of the experimenter and participant approximately 1000 ft down the road (Skaar, Rizzo, & Stierman, 2003, p. 93).

**DA28 time to collision (TTC)**

Based on the three components of intersection approach we developed the Object Movement Estimation Under Divided Attention (OMEDA) task, a dual task with two parts. The primary tasks are a TTC estimation task for the first part (OMEDA1) and a collision detection task in the second part (OMEDA2). Both are obtained when the moving object(s) travel towards a visible or occluded end point. The secondary task in both parts is a visual divided attention task that requires the participant to identify peripheral duplication of a centrally presented stimulus (in this case a geomeasureal shape). The following dependent measures are obtained: (1) The mean absolute error in estimating Time-to-Contact (absolute TTC error) across all trials and the mean proportion of shape matching errors across all trials for OMEDA1. (2) The percentage of collision detection errors and of divided attention errors across all OMEDA2 trials, and the proportion of correct simultaneous collision detections and shape matching detections (Read, Ward, & Parkes, 2001, p. 241).

**DA30 time to collision (TTC)**

Three within-subjects independent variables were investigated: the TTC (2, 3.5 and 5 s), speed (24, 35, and 61 mph), and type of collision event (collision event or non-collision event) (Andersen, Saidpour, & Enriquez, 2001, p. 256).
DA50 time to collision (TTC)

Results are described according to driving and secondary task performance. The first section addresses the effects of automation level, and failure type on measures of driving task performance including brake response time (RT), time headway (THW) at point of brake response, time-to-collision (TTC) at point of brake response, number of collisions, and percent reliance. The second section addresses the effects of the same independent variables, with the addition of message complexity, on headway maintenance performance while engaged in the secondary task. Note that the ACC drive was divided into engaged and not engaged portions to capture differences in driving and secondary task performance with manual and ACC control. The analyses were performed using SAS 9.0 software; F statistics are reported from repeated measures ANOVA (Seppelt, Lees, & Lee, 2005, p. 251).

HS16 minimum time-to-collision (MTTC)

The following indices were measured and recorded during each braking event (with 40 ms resolution): Time of first Pressing Brake pedal (TPB); Time of Maximum Braking force (TMB); Maximum Braking Force (MBF); Minimum Time-to-Collision (MTTC). For all time related indices, time was computed from the instant of LV braking (Li & Milgram, 2005, p. 1942)

HS40 time to collision (TTC)

Overall response time (ResT) was computed as the sum of RT and TT. Control performance was related to the safety margin (TTC) at point of braking (Manser & Ward, 2004, p. 2361).

HS43 minimum time to collision (TTC)

The main dependent measures collected from the driving tasks were the accelerator release time, brake reaction time, and minimum time to collision (TTC). Accelerator release time is defined as the time from when the lead vehicle began to brake until the driver released the accelerator. Other measures of driver performance including speed, accelerator position, and steering wheel position were also recorded (Reyes & Lee, 2004, p. 2371).
DOT1 standard deviation time to collision, DOT2 mean time to collision

The initiation time and intensity of driver response to rear-end pre-crash dynamic scenarios were investigated at different speed bins. Response initiation was measured by time-to-collision or TTC (range/range rate) for LVS and LVM scenarios, and by time headway TH (range/host vehicle speed) for LVD scenario (Najm et al., 2006, p. 201).

HF2 time-to-collision (TTC)

The primary dependent measure for the altered backing trials was the subjective rating of warning timing appropriateness provided by drivers. The alerted backing trials also provided an opportunity to gather additional vehicle dynamics data to characterize driver backing performance (average, minimal and maximum braking speeds; deceleration rates, TTC, brake and accelerator pedal position, etc.) (Llaneras, 2005).

HF8 minimum time to collision

Measures of temporal vehicle separation (minimum time to collision, minimum headway) were calculated using a radar-based front-to-rear crash avoidance system (to monitor following distance) in conjunction with vehicle velocity. The front-to-rear collision avoidance system was also used to trigger data collection for time-to-collision (TTC) values less than 4s. Each of these measures is closely related to time to collision and is also easily incorporated as a trigger into a separation detection device. Mean TTC was not included in the analysis because of the discontinuous nature of the data (Belz, Robinson, & Casali, 2004, p. 159).

HF50 time to collision (TTC)

The independent variables examined in this study were severity of collision situation (initial headway time and deceleration of the lead vehicle)... time-to-collision threshold and speed penalty, and characteristics of the driver (actual deceleration of the driver and actual driver reaction time) (Brown, Lee, & McGehee 2001, p. 467).
DOT25 time-to-collision (TTC) at brake onset

The driver performance measures examined included passenger-side experimenter brake assists, driver brake reaction time to the alert, the (constant) required deceleration level to avoid impact at brake onset, time-to-collision (TTC) at brake onset, time headway at brake onset, and peak deceleration throughout the maneuver. Subjective measures included alert noticeability and alert timing ratings (Kiefer et al., 2005, p. 17).