A Review of the Lane Change Test (LCT) as a Surrogate Method for Measuring Driver Distractibility

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# Executive Summary

In-vehicle systems continue to develop due to advances in technology. However, car manufacturers must take into consideration that the tasks allowed by in-vehicle systems can distract drivers from their primary task of driving. As a result, research has been conducted on driver distractibility. One test that has been developed in order to study driver distractibility is the lane change test (LCT). The purpose of this current report is to review research that has utilized the LCT, including how the LCT measures driver distractibility and limitations in research findings.

Key findings of the research review are:

* The LCT is a cheap and quick surrogate method (method that examines only certain aspects of driving tasks) for measuring driver distractibility that combines aspects of driving simulations and reaction time tasks.
* Driver distractibility is mainly measured using the mean deviation - deviation from a normative driving path due to performing a secondary task (additional task to driving).
* The LCT has been used in several studies to examine its sensitivity (ability to distinguish between tasks and task difficulties), learning effects, alcohol effects, impacts of different types of interfaces, effects of different touchscreen feedback, and effects of auditory cues.

In summary:

* The LCT does not reflect overall driving performance since it is a surrogate method. Therefore, results from LCT studies, such as Huemer & Vollrath (2010)’s study on alcohol effects, cannot be used to draw conclusions for overall driving performance.
* Realism of the LCT could be improved through the use of verbal lane change commands rather than visual signs. More studies should be done in this area.
* More research needs to be done on different types of secondary tasks and task difficulties to further determine sensitivity of the LCT.
* Learning effects are present for the LCT primary task and secondary tasks. However, these learning effects can be used to evaluate learnability of in-vehicle systems.

# Introduction

As technology advances, in-vehicle systems also advance, increasing the number of tasks a driver can do while inside their vehicle. Drivers can speak on the phone via bluetooth, use navigation or entertainment systems, and so on. However, this advancement of in-vehicle systems and increase in available tasks can lead to drivers being distracted from the main task of driving. As a result, research has been done on driver distractibility, with researchers searching for a valid and reliable method that can measure and quantify the degradation in driving performance that occurs when drivers are driving and performing an additional task simultaneously (Mattes & Hallen, 2009). This additional task is referred to as the “secondary task,” whereas the “primary task” is driving.

Researchers are specifically looking for a surrogate method rather than a direct method of measuring driver distractibility. Surrogate methods only simulate and assess certain aspects of driving tasks rather than directly assessing overall driving performance through the use of objective measures (Young, Regan, & Lee, 2009). An example of a direct method is a driving simulation, where the driving performance of participants are examined in a controlled, realistic, and safe environment (Young et al., 2009). However, the realism of driving simulations can make data analysis difficult, since performance measurements must take into account the different actions of participants (Mattes & Hallen, 2009). Driving simulations also require a high level of expertise to operate and can be very expensive to use (Young et al., 2009). Another method of measuring driver distractibility, reaction time tasks with automotive research, also has the issue of lacking realism since no driving is done in between the presentation of two stimuli (Mattes & Hallen, 2009).

In addition to being valid and reliable, the method must be efficient and simple enough that in-vehicle system manufacturers are able to perform the method without expensive and intricate equipment (Mattes & Hallen, 2009). The method must also be able to clearly determine the most demanding in-vehicle secondary tasks, allowing the remaining issues regarding the in-vehicle system design to be answered via more laborious testing methods (Mattes & Hallen, 2009). The lane change test (LCT) was created to meet all of these requirements, introducing a dual-task approach that combines elements of driving simulations and reaction time tasks. The primary task of the LCT is a driving simulation on a straight, three-lane road that has signs on both sides of the road. These signs instruct the participant to switch into a particular lane, and when participants see these signs, they are to switch into the indicated lane.



Figure 1. Image of the LCT. The road is straight and consists of three lanes with lane change signs on both sides of the road (Mattes & Hallen, 2009).

Participants simultaneously perform a secondary task, and the degradation on the primary lane-changing task is measured (Mattes & Hallen, 2009). This degradation amount indicates the amount of driver distraction and distinguishes the difficulty levels of the secondary task (Mattes & Hallen, 2009).

This report will cover:

* Background, methods, results, and discussion of the LCT based on information reviewed in research articles that utilize the LCT.
* The background section will explain what the LCT is in addition to providing the necessary context as well as the history of its development.
* The methods section will cover the methodology used in LCT experiments and why those particular methods are used.
* The results section will cover results from various LCT studies, and the discussion section will expand on those results by explaining their meaning and what should be done with the LCT now or in the future.
* Limitations, advantages, and disadvantages of the LCT will also be included in the discussion section.

# Background

The lane change test (LCT) is described on the ISO 26022:2010 as a “dynamic dual-task method that quantitatively measures human performance degradation on a primary driving-like task, while a secondary task is being performed” (ISO, 2010, p. 1). In short, the LCT measures the amount of error made by the driver during the primary task of driving by comparing the performance of the LCT task that contains a primary and secondary task, where the secondary task that acts as a distractor. Formally, the LCT’s primary task can be defined as “the course following and maneuvering control activity which a participant performs throughout the duration of a test as a simulated substitute for driving” (ISO, 2010, p. 2). The primary task is meant to simulate driving, but it is not meant to substitute it, as it will be discussed later. Meanwhile, the secondary task is “the interaction with an in-vehicle information, communication, entertainment, or control system carried out concurrently with the primary task” (ISO, 2010, p. 3). The secondary task is meant to simulate a task which the in-vehicle system affords, as well as its resulting weight on driving performance.

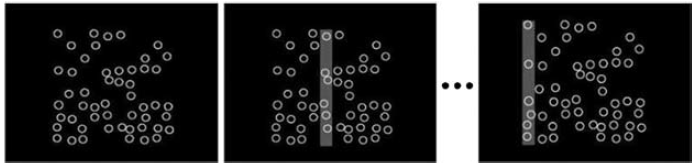
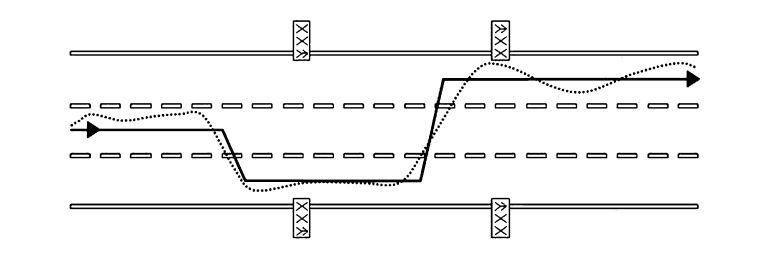


Figure 2. Example of a difficult secondary task. This task is the visual search task, where the participant must find the larger circle on the screen and move the grey bar over the circle with the left and right keys on a keyboard.

Another fundamental aspect of the LCT is the mean deviation from the normative path, which is the single measure chosen to evaluate driving degradation due to secondary tasks. The normative path is the ideal path the driver would take if all the lane changes were performed perfectly, whereas the mean deviation is the average deviation between the normative path and the actual path the driver takes during the trials (see Figure 3) (Mattes & Hallen, 2009). The mean deviation takes into account important aspects of the driver’s performance, including: perception, quality of the maneuver and lane keeping quality; the decision to use a single measure that encompasses all these aspects of driver’s performance was to ensure simplicity and efficiency (Mattes & Hallen, 2009).Therefore, the LCT, a surrogate technique to real driving, is able to find statistically significant driving performance degradation due to secondary task demand.

Figure 3. The normative path (solid line) is the ideal path, whereas the actual driving path (dotted line) is the path taken by the driver during the trial. The mean deviation is the average area between these two paths (Mattes & Hallen, 2009).

As mentioned before, the LCT is a surrogate technique to more sophisticated driving tests. The technique is needed due to high-fidelity simulations requiring extensive time, training, and preparation to be performed as needed. The LCT, in comparison, is affordable and relatively easy to implement; besides, it affords being adopted by most vehicle manufacturing companies (Mattes & Hallen, 2009). In short, a reliable technique like the LCT widely benefits the car manufacturing industry as a whole. Nevertheless, the LCT’s ability to detect significant levels of driver distractibility is not sensitive enough to detect the fine shades of gray between tasks performance degradation (Mattes & Hallen, 2009). The limitation is appropriate, however, since implementing a more robust set of tools to the test would increase the complexity of its execution and take away the simplicity that allows it to be used so widely. Lastly, being a technique that filters out “extremely demanding secondary in-vehicle tasks,” the LCT is meant to be used as a preliminary task to the more resource intensive high-fidelity simulations or real on-road tests (Mattes & Hallen, 2009, p. 109). Therefore, the LCT works as a first step in identifying the true culprits of in-vehicle driver distractibility.

The LCT came originally from the ADAM (Advanced Driver Attention Metrics) research project, which set about finding a surrogate technique to more expensive and ecologically realistic techniques (Breuer, Bengler, Heinrich, & Reichelt, 2003; Mattes & Hallen, 2009). The ecological realism refers to the technique being ecologically valid, which is brought about by designing it to be close to a real situation. Moreover, ecological validity leads to higher external validity, which refers to the extent to which the data collected can be generalized to the population as a whole. The technique also implemented features from driving simulations and reaction time in an effort to maintain a realistic driving experience while still being able to make sensitive measurements (Mattes & Hallen, 2009). By retaining aspects of a real driving experience, the technique’s external validity is increased. However, despite “featuring aspects of real driving such as perception, reaction, maneuvering, and lane keeping,” the LCT is not meant to represent a realistic driving simulation, which is why it is referred to as a surrogate driving task (Mattes & Hallen, 2009, p. 110). Moreover, during the aforementioned ADAM research project, multiple surrogate methods besides the LCT were designed and tested, which as listed below:

* Occlusion method - This method is used exclusively to assess visual or visual-manual demand due to use of in-vehicle systems while driving (ISO, 2017).
* Simple reaction time measurement - This method is a basic reaction time test that measures the key press as soon as a simple visual stimulus is shown on screen (Mattes & Hallen, 2009).
* Choice reaction time measurement - This method uses the primary task of driving, but includes a three-choice reaction task which guides the driving (Mattes & Hallen, 2009).
* Fixed-base driving simulation - This method is a simple driving simulation with a car following the driver and with surrounding traffic (Mattes & Hallen, 2009).

These methods were tested with a set of 12 secondary tasks (Mattes & Hallen, 2009). Such an enterprise ended with the LCT as the method of choice due to its advantages over the others once the measurements were correlated to the results collected from a high-end driving simulator (Mattes & Hallen, 2009). Since then, multiple studies have used the LCT as the evaluation method for measuring driver distractibility. These studies have examined the effects of other factors on LCT and secondary task performance and will be discussed further in the report, such as:

* Alcohol effects (Huemer & Vollrath, 2010)
* Learning effects (Petzold, Bar, Ihle, & Krems, 2011; Petzold, Bruggemann, & Krems, 2014)
* Different modes of touchscreen feedback (Pitts, Skrypchuk, Wellings, Attridge, & Williams, 2012)
* Whether the LCT is administered on a personal computer (PC) versus a fixed-base simulator (Bruyas, Brusque, Tattegrain, Auriault, Aillerie, & Duraz, 2008)
* Types of interfaces (Harbluk, Burns, Lochner, & Trbovich, 2007)
* Auditory cues (Sun, 2016)

Throughout the years since its creation in the ADAM research project, the LCT has been continuously tested to verify its validity and reliability. Validity refers to the degree to which the findings truly represent the effect being measured (Brewer, 2000). Reliability refers to the degree where the LCT produces stable and consistent results (Brewer, 2000). A paper from 2007, which tested the LCT’s ability to assess visual-manual and speech-based navigation system’s operations set as secondary tasks, stated that “the present results provide support for the use of the LCT in the evaluation of speech-based, as well as manual interface, a definite advantage for LCT over the Occlusion method, which is narrower in scope” (Harbluk et al., 2007, p. 21). As such, the LCT has the ability to use different modalities as secondary tasks in its assessment of driver distractibility. Also, a paper from 2008, which tested consistency and sensitivity of the LCT when presented with different demand levels of secondary tasks, discovered that for both auditory tasks and visual-manual tasks the LCT could differentiate between varying demand levels of the same modality (Bruyas et al., 2008). Therefore, not only can the LCT be used to assess different modalities, but it is sensitive enough to detect varying demand levels between these modalities. A more recent paper from 2013 tested the LCTs sensitivity to tasks involving tracking, visual searching, memory, and data entry; results showed that dual-tasks drivers performance was significantly lower than the baseline of single-task driving, suggesting the LCTs sensitivity to detecting performance degradation for these tasks (Rodrick, Bhise, & Jothi, 2012). Finally, the LCT was introduced to the ISO (International Organization for Standardization) in 2010, which reinforces its status as a reliable and valid method for assessing driver’s distractibility (ISO, 2010).

The LCT, like any other test, has certain requirements that need to be met for it to be correctly executed. These requirements are carefully detailed in the ISO 26022:2010 manual (ISO, 2010). The most important aspects of these requirements, however, are described below:

* Methods of the LCT - The LCT follows a within-subjects design, which allows participants to experience all relevant conditions and facilitates statistical comparisons. Additionally, speed variations are not supported by the LCT, as the speed shall always remain at a constant of 60km/h. Finally, tasks that require the driver to follow navigation instructions are not supported by the LCT, as these instructions would interfere with the primary task.
* Participants of the LCT - Participants shall be licensed drivers having a similar level of familiarity with the secondary task under investigation. Also, at least 16 participants shall take part in the evaluation of a single secondary task or in the comparison of two or more secondary tasks for a within-subjects design.
* Equipment of the LCT - The monitor or projector of choice for the LCT shall have a refresh rate of at least 50HZ, plus a minimum resolution of 1024 x 768 pixels with color depth of 24 bit. Also, the illumination level in the testing environment shall be appropriate to the secondary task. The seat shall not swivel or rock, and a seatbelt shall be used if it is assumed that its use might influence the test results. A computer game steering wheel can be used for a laboratory/monitor setup. The steering wheel force displacement characteristics shall be approximately linear, and the tangential force at the rim to turn the steering wheel shall be no more than 20N.

# Method

The LCT can be used to measure distractibility by comparing people’s performance of a single task versus a dual-task (Mattes & Hallen, 2009). In a single task, people will only have to complete the primary task meaning just the lane change task. For dual-task, people will have to complete a secondary task, which is an additional task along with the lane change task. The performance on the single task is compared to the performance on the dual-task to measure a person’s distractibility by comparing the:

* The reaction time is measured from when the participant sees the sign to the start of their lane change.
* The quality of the lane change considers the speed that the participant is going at and the amount of signs that they missed.
* The deviation measure is a measurement that covers the overall performance of the participants by taking into account the performance, perception of the signs (when they miss signs), the quality of the lane change, and their lane keeping ability.

In the analysis of the mean deviation values, it compares the baseline tasks to the lane change tasks that include the secondary tasks (Mattes & Hallen, 2009). The findings show that there is a more pronounced difference in the steering when the lane change task occurs over two lanes compared to one lane, so the lane change task typically contains only three lanes versus five lanes.

In a LCT driving simulation, there are three lanes presented where participants are told to drive straight and maintain a speed of 60 km/h (Mattes & Hallen, 2009). During the task, they are presented a sign to signify which lane to change into. Participants are asked to change lanes as soon as they see the sign and that the lane change should be done before they pass the sign, which also helps them to stay in the center lane. Participants are not told how to manage the tasks at hand, so it is up to them to determine how they would like to manage the tasks given to them.

Before participants begin the different lane change tasks, they are familiarized with the LCT so they can get used to the tasks at hand (Mattes & Hallen, 2009). The first trial consists of the primary task to get a baseline to compare the dual-task to, which will help measure a person’s distractibility. Depending on if people want to use one type of secondary task or multiple types of secondary tasks, there are advantages and disadvantages to one type of secondary task versus two or more types of secondary tasks:

* With the use of only one type of secondary task, it is easier for people to understand, but the downside is that it is not as realistic since people can do more than one task when driving.
* In the use of multiple types of secondary tasks, it is more realistic, but it is harder for people to do since there are multiple types of tasks that they will have to learn.

There are different kinds of secondary tasks that can be used. For example, in a study used to examine two kinds of navigation systems, there are nine secondary tasks (Mattes & Hallen, 2009). Each of the tasks helps simulate the different kinds of actions that people may do when they are driving. The nine secondary tasks involves:

* The easy mental tasks are easy tasks that require thinking.
* The hard mental tasks are difficult tasks that require thinking.
* The easy visual tasks are easy tasks that use visuals.
* The hard visual tasks are hard tasks that use visuals.
* The remote control map scaling task is where participants adjust the navigation system map to a specific size through using buttons
* The remote control show point of interest task is where participants select navigation destinations given to them using buttons.
* The remote control navigation input is where participants input an address using buttons.
* The touch screen navigation input is where participants input an address using a touch screen.

There are also baseline performance measurements taken at the beginning, middle, and end of the testing procedure (Mattes & Hallen, 2009). After each trial, participants are given a questionnaire to rate the difficulty of the trials. The questionnaire contains a list of questions for people to rate from a scale from 1 to 5, 1 being easy and 5 being hard.

# Results

In the use of questionnaires during the previously mentioned study, it was seen that participants rated the easy cognitive task as the easiest secondary task (Mattes & Hallen, 2009). The task that received the highest difficulty rating was the remote control navigation system. There also is a correlation between the mean deviation and subjective rating meaning that the LCT results relate to the subjective ratings. It was also found that:

* Participants performed better on the easy cognitive task compared to the hard cognitive task.
* Participants performed better on the easy visual task versus hard visual task.
* Participants also performed best on the remote control map scale, then the remote control point of interest, then the remote control destination input and the worst on the remote control map scroll.

The difference in results signifies that different secondary tasks affect driving performance (Mattes & Hallen, 2009). Additional studies regarding the sensitivity or ability of the LCT to distinguish between tasks reveal:

* The LCT was able to distinguish between difficulties within auditory and visual-manual secondary tasks, but failed to differentiate the easiest visual-manual task and hardest auditory task (Bruyas et al., 2008; Harbluk et al., 2007)
* The LCT was able to detect differences between visual-manual and cognitive tasks for lane excursions (the amount of times the participant deviates in a task) and deviation measures, but it is not sensitive to difficulties within the tasks (Young, Lenne, & Williamson, 2011).

There are also advantages and disadvantages to using the LCT:

* An advantage of using the LCT is that it showed high correlations with the findings of high-end driving simulations and the LCT is a more affordable option compared to a high-end driving simulation (Mattes & Hallen, 2009).
* A disadvantage with the lane change task is that it does not consider other environmental factors. For instance, it does not consider traffic conditions, traffic is a factor that would potentially impact people’s interaction and driving, so the lane change task results may not translate well to real life scenarios.

In a study experimenters wanted to see if alcohol impaired lane change tasks, where participants were either given alcohol or given a placebo (a non-alcoholic drink) and given the task of a LCT or lane keeping task (where participants had to stay within the lane) (Huemer & Vollrath, 2010). They tested the participants blood alcohol content every 20 to 30 minutes. Participants given alcohol performed worse than participants given the placebo in the lane keeping task. In the LCT, there was only a small effect between participants being given alcohol and the placebo, meaning that there was relatively no difference between being given alcohol and driving in a distracted scenario. The results of the LCT does not mean that there is not an influence of alcohol, since there have been previous findings that show the influence of alcohol on driving performance.

Despite the advantage of the lane change task being affordable to use, it is important to consider other factors that will influence the participant’s performance on the LCT:

* In an alcohol-related study, there were only small amounts of impairments on lane change tasks due to alcohol use (Mattes & Hallen, 2009; Huemer & Vollrath, 2010).
* There also has been studies that show that there are learning effects associated with the lane change task and artificial secondary tasks (i.e. tasks not associated with actual driving) and the effects remain stable over time (Petzold et al., 2011). Although after learning the lane change task, it is still not enough to perform at an optimal level.
* A later 2014 study by Petzoldtz et al. further studied the learning effect with the LCT and found that learning effects were also present when using the LCT with realistic secondary tasks. The study also found that when two secondary tasks are similar, there is a transfer of learning from one task to another.
* Bruyas et al. (2008) found that participants performed better (i.e. had a lower mean deviation) when the LCT was presented on a fixed-base simulator versus a PC. This may be due to the greater immersion of the fixed-base simulator, where the participant is actually sitting in a car compared to sitting at a desk.



Figure 4. LCT on PC (left) versus LCT on a fixed-base simulator (right) (Bruyas et al., 2008).

* Pitts et al. (2012) found that feedback (can be visual, haptic - vibrations, or audible - sound and occurs upon touch) for secondary tasks on touchscreens did not affect performance, but participants preferred multimodal (i.e. more than one type) feedback over solely visual feedback even if their performance did not improve.
* In a study by Harbluk et al. (2007), participants had a greater mean deviation and longer lane change initiation time when they were engaged in secondary tasks for both a visual-manual and speech-based navigation system.
* A thesis study by Sun (2016) found that adding auditory cues (“right,” “left”) in addition to the visual signs indicating the direction of the lane change has an effect on reaction time (i.e. time between the cue and the steering angle leaves the normal lane-keeping angle). Cues that were spatially congruent (e.g. “right” comes from the right side of headphones) and asynchronous (i.e. auditory cue presented before visual sign) decreased reaction time. Percentage of correct lane changes, however, was not affected by the auditory cues.

# Discussion and Recommendations

The LCT is a good method to use due to affordability, ease of use, and its correlation with high-end driving simulation tasks. High-end driving simulations are seen as reliable for the measures of speed, vehicle steering, and reaction time (Irwin, Shum, Leveritt, & Desbrow, 2013). However, since the LCT is a surrogate method and therefore does not examine the full driving experience, the LCT lacks realism, meaning that it is not a good representation of real-world scenarios (Mattes & Hallen, 2009). One factor contributing to the lack of realism is the use of signs to tell participants to change lanes. Rather than signs, verbal lane change commands can be utilized in the LCT studies, and performance differences can be observed (use of signs versus use of verbal commands). Although there is some research on the use of auditory cues in addition to visual signs (Sun, 2016), there is a lack of studies where the lane change signs altogether are replaced with verbal or auditory lane change instructions.

Although the study done by Huemer and Vollrath (2010) revealed that alcohol did not significantly impair performance in the LCT, the experimenters did not consider the alcohol tolerance of the participants and they did not check to see if different alcohol blood content levels would influence the participant’s performance. If future studies examine alcohol effects on the LCT, all of these factors must be taken into consideration in order to provide more in-depth results.

Existing studies on the sensitivity of the LCT provide mixed results regarding whether or not the LCT can distinguish between task difficulties and task types. One factor that could be affecting sensitivity is stated by Young et al. (2011), which is the lane change instructions given to the participants. Researchers must ensure that consistent instructions are given regarding when the lane change should be completed to ensure results on performance are also consistent. Nevertheless, further research needs to be done with varying tasks and task difficulties, with perhaps more focus being put on realistic secondary tasks that could actually be done by drivers to increase the realism of the LCT method. These tasks could be focused on different types of interfaces of in-vehicle navigation systems, since the study done by Harbluk et al. (2007) did not examine the difference in secondary task performance between visual-manual and speech-based interfaces. More studies on task performance for these two interfaces could reveal which interface is prone to higher driver distractibility.

Learning effects associated with the LCT can cause issues as the LCT is supposed to be a standardized method for measuring driver distractibility. However, Petzoldt et al., 2014 points out that LCT research could take a different path and focus on evaluating the learnability of in-vehicle devices. More research can be done with the LCT to observe the extent of learning effects with particular types of tasks, and these results could provide more insight as to which types of tasks performed while driving are more easily learnable and will eventually not add significantly to driver distractibility.

Although one study on the effects of different types of feedback for touchscreen secondary tasks did not find anything significant with regards to driver and task performance (Pitts et al., 2012), more research can be done in this area as more in-vehicle navigation systems implement touchscreens. Different types of visual, haptic, and audible feedback could be examined in future studies. Even if there is no impact on performance, subjective ratings of different types of feedback are still something for manufacturers to take into consideration when designing in-vehicle systems.

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