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Road vehicles — Ergonomic aspects of transport information and control systems — Simulated lane change test to assess in-vehicle secondary task demand

Véhicules routiers — Aspects ergonomiques des systèmes de commande et d'information du transport — Essai du changement de voie simulé pour évaluer la demande de tâche secondaire à bord du véhicule

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 26022 was prepared by Technical Committee ISO/TC 22, *Road Vehicles*, Subcommittee SC 13, *Ergonomics applicable to road vehicles*.

Introduction

Many advances are being made in introducing a wide range of information, communication, entertainment and driver assistance systems in motor vehicles. Navigation aids, emergency messaging systems and wireless communication, including e-mail and internet access, are all possible. Since many of these features require the driver's attention it is important to recognise that, on one hand, these systems provide information and assistance but, on the other hand, have the potential to distract the driver as well.

The lane change test (LCT) described in this International Standard, is a dual-task method that is intended to estimate secondary task demand on the driver resulting from the operation of an in-vehicle device in a laboratory setting. The method is simple and inexpensive so that it can be used by vehicle manufacturers, in-vehicle device manufacturers, and other organizations.

The driver behaviour and attentional demand principles embodied in the LCT only apply to the operation of a typical passenger car, as the vehicle dynamics model, driver eye height, and lane change dimensions and geometries are scaled for such vehicles.

The test procedure specified in this International Standard uses software to set up the LCT task on a computer, and to calculate the primary task performance measures. Appropriate software is available from the ISO Central Secretariat.

Road vehicles — Ergonomic aspects of transport information and control systems — Simulated lane change test to assess in-vehicle secondary task demand

1 Scope

This International Standard describes a dynamic dual-task method that quantitatively measures human performance degradation on a primary driving-like task while a secondary task is being performed. The result is an estimate of secondary task demand.

The method is laboratory based, and this International Standard defines the method, the minimum requirements for equipment to support the method, and procedures for collecting and analyzing data derived from the method.

The method is applicable to all types of interactions with in-vehicle information, communication, entertainment and control systems; manual, visual, haptic and auditory, and combinations thereof. Secondary tasks requiring speed variations to be performed cannot be tested with this method. It applies to both Original Equipment Manufacturer (OEM) and aftermarket in-vehicle systems. It also applies to systems either portable or integrated into the vehicle. The driver behaviour principles, the specific task procedures and driving task correspond only to the operation of a passenger car.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
adaptive model
reference path trajectory adapted to each participant

2.2
baseline
test condition with the primary task only

2.3
basic model
nominal reference path trajectory is the same for all participants

2.4
calibration task
type of reference task used for the purpose of comparing different tests or test results between sites, or over time at a given site

2.5
course
path along which the simulated vehicle actually travels

2.6
dual task
two tasks concurrently performed, primary task plus a secondary task

2.7
environment
physical surroundings in which data are captured

2.8
goal
system end state sought by the driver and which is meaningful in the context of a driver's use of an in-vehicle system

EXAMPLE Obtaining guidance to a particular destination; magnification of a map display; or cancelling route guidance.

2.9
integrated system
two or more in-vehicle devices, which provide information to, or receive output from, the driver of a motor vehicle, whose input and/or output have been combined or harmonized

EXAMPLE 1 An in-vehicle entertainment system and route guidance system which use the same visual, manual and auditory interface.

EXAMPLE 2 An in-vehicle entertainment system whose auditory output mutes when a mobile phone call is made or received.

2.10
lane change
lateral displacement of a vehicle from current lane to another lane, including crossing one or two lanes

2.11
lane change task
series of prescribed lane change manoeuvres that are the main component of the primary task in the lane change test

2.12
outlier
an observation that lies outside the overall pattern of a distribution

2.13
manufacturer
organisation or person designing, developing, producing, integrating and/or supplying in-vehicle equipment

2.14
path deviation measure
mdev
difference between a reference path trajectory and an actual driven course

2.15
portable system
nomadic device
device which provides information to, or receives output from the driver of a motor vehicle, that can be used within the vehicle without installation or can be rapidly and easily installed in and removed from the vehicle

2.16
primary task
course following and manoeuvring control activity which a participant performs throughout the duration of a test (simulated substitute for driving)

2.17
reference task
a standardized secondary task which can be used to compare different levels of performance degradation

2.18
run
driving used to collect LCT data, typically consisting of 18 lane changes accomplished over a 3 minute period in either single task or dual task conditions

2.19
secondary task
interaction with an in-vehicle information, communication, entertainment, or control system, carried out concurrently with the primary task

2.20
secondary task demand
sum of perceptual, cognitive and motoric activity required by a secondary task

2.21
single task
one task (primary or secondary task) without additional activity (as opposed to dual task)

2.22
task
process of achieving a specific and measurable goal using a prescribed method

NOTE Ultimately, it is for the users of this International Standard to determine tasks that are meaningful in the context of a driver's use of an in-vehicle device.

EXAMPLE 1 Obtaining guidance by entering a street address using the scrolling list method, continuing until route guidance is initiated (visual-manual task).

EXAMPLE 2 Determining where to turn based on a turn-by-turn guidance screen (visual task).

2.23
track
three-lane, straight, simulated roadway

2.24
trial
investigation of one participant undertaking one repetition of one secondary task

3 Lane change test (LCT)

3.1 Principle and overview

The lane change test (LCT) is a simple laboratory dynamic dual task method that quantitatively measures performance degradation in a primary driving task while a secondary task is being performed. The primary task in the LCT is a simulated driving task which resembles the visual, cognitive and motor demands of driving.

In the LCT, a test participant is required to do a primary task consisting of driving at a constant, system-limited speed of 60 km/h along a simulated straight three-lane road containing a series of lane changes defined by signs displayed on a screen. Simulated vehicle position is controlled by means of a steering wheel. Participants are instructed in which of the lanes to drive by signs that appear at approximately regular intervals on both sides of the track. The LCT is performed by participants according to pre-test instructions contained in this International Standard (see Annex A). The method may be implemented in a laboratory, in a driving simulator, in a mock-up or in a real vehicle.

There is no limitation to the definition of a secondary task according to this International Standard as long as the secondary task is compatible with the LCT procedure.

EXAMPLE Secondary tasks requiring speed variations to be performed are not accommodated.

3.1.1 Application of the LCT

In a typical application of the LCT, the primary task performance degradation resulting from a certain secondary task can be compared to the performance degradation resulting from a reference task (see Annex B). A reference task is a standardized secondary task which can be used to compare different levels of performance degradation. Such standardized reference task can also be employed to compare different test sites or to verify consistency in repeated testing.

For product development purposes, the LCT can also be used to compare alternative HMI candidates or solutions rather than comparing each of these solutions to a reference task (see Annex C).

3.2 Participants

Participants shall be licensed drivers having a similar level of familiarity with the secondary task under investigation. Other relevant characteristics of the participants shall be recorded (gender, age, driving experience and previous experience with the LCT). 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-subject design.

3.3 Equipment

3.3.1 Display of visual driving scene

The LCT visual driving scene shall be realised with a monitor or projector with a net refresh rate of at least 50 Hz. A minimum resolution of 1024×768 pixels with a colour depth of 24 bit (also called True Color) is required. The size of the display device must meet the requirements defined in 3.4.3.

3.3.2 Testing environment

The illumination level in the testing environment shall be appropriate to the secondary task. Simulated engine sound is optional and, if used, shall be adjusted to a low level.

Participants shall be comfortably seated directly in front of the primary task visual display while performing each test. The seat shall not swivel or rock. A seat belt shall be used if it is assumed that the use of a seat belt might influence the test results (e.g. restrictions in posture and reach).

3.3.3 Steering wheel and simulation characteristics

For the lateral control of the simulated vehicle, a computer game steering wheel can be used for a laboratory/monitor setup. For seating buck or real vehicle testing, movement of the steering wheel shall provide signals to replicate movements of the game steering wheel. 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 20 N. A centering (breakout) force, which is optional, shall be no more than 12 N. Adapting LCT to a real vehicle is discussed in Annex D.

The overall transport delay between an initial steering input and a visual display response shall be < 120 ms (not including the simulated vehicle model delay).

The steering wheel sensor shall have a resolution less than 1,5 degrees.

With the steering wheel turned 90 degrees from the straight ahead position, the simulated vehicle shall, at a constant speed of 60 km/h, complete a 360 degree turn in between 13 s and 17 s, corresponding to a turning circle of 70 m to 90 m in diameter.

3.3.4 Vehicle dynamics

The simulated vehicle shall be programmed to respond approximately like a typical passenger car in terms of its size and inertial properties. Yaw rate to steer angle characteristics shall be represented by a first order lag with an equivalent time constant of approximately 0,15 s (±0,03 s), including vehicle mathematical model response and other simulation transport delays (see 3.3.3).

3.3.5 Measurement recording

All vehicle parameters (i.e. position on track, steer angle, heading angle, heading (yaw) rate, etc.) are recorded at a sampling rate of at least 10 Hz. Additional parameters and information such as a unique time stamp, track number and markers for tasks (typically set manually by the experimenter) shall also be recorded. The LCT simulation shall have a minimum update rate of 100 Hz. In addition, secondary task performance shall be recorded (see 3.7.3). These data are needed to ensure the participant's compliance with the instructions (see Annex A).

3.4 Scenario design

3.4.1 Simulated roadway and surroundings

The simulated roadway (see Figure 1) consists of a straight, three-lane track. A series of lane changes are defined by roadside signs placed at approximately regular intervals. The road is located on a plain green field. Figure 2 shows the dimensions of the lanes and the markers (delineators). The road surface is grey (like a typical paved road). Lane markings are white.

The simulated roadway shall be displayed as if viewed from an eye point 120 cm ± 10 cm over the road surface. This is consistent with that of a typical passenger car.

NOTE 1 The roadway and lane change geometries and the vehicle dynamics are not scaled to correspond to a truck or other large commercial vehicle.

Minimum track length shall be 3 000 m corresponding to 3 min of driving at 60 km/h. This is sufficient in length to collect 2 min of LCT data.

NOTE 2 According to the signs in Figure 1, the participant has to change from the current (middle lane) to the right lane.

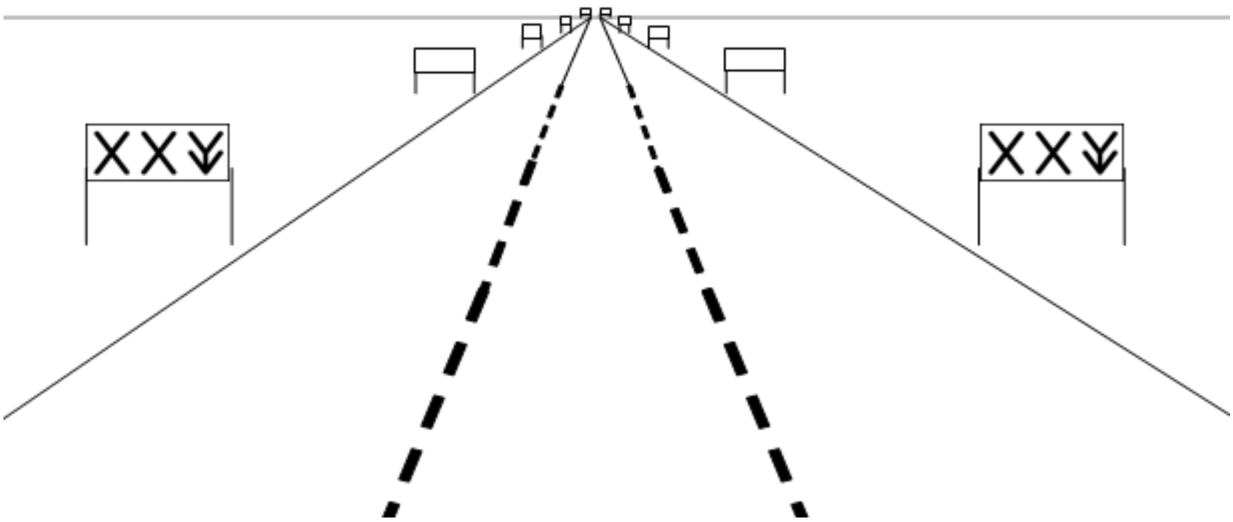
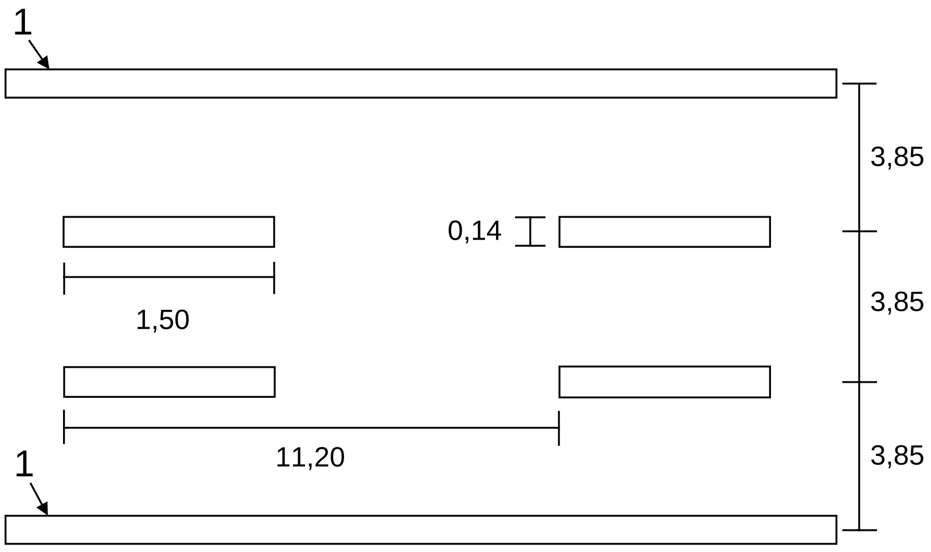


Figure 1 — Simulated roadway

Dimensions in metres



Key

1 road edge line

Figure 2 — Dimensions of the road markers (not to scale)

3.4.2 Signs

Both “START” signs and “Lane Change” signs appear in pairs on both sides of the simulated roadway (see Figure 1 for example of sign positions). “Lane Change” signs are rectangular and have a thin black border and black symbols on a white background (see Figure 4). The signs are 2,0 m wide and 1,0 m high and the lower border is 1,0 m above the ground. The downwards arrow on the “Lane Change” sign indicates the target lane. In Figure 4, (a), (b), and (c) show the left, middle and right lanes, respectively. Dimensions of the “Start” sign can be the same as the “Lane Change” sign, but the colours shall be different from those of the “Lane Change” signs (see Figure 3). The “START” sign shall appear approximately 150 m before the first “Lane Change” sign.

Figure 3 — “Start” sign

Figure 4 — “Lane Change” signs

3.4.3 Experimental and measurement setup

3.4.3.1 Participant's view of display

The horizontal viewing angle to the display for the road scenery (monitor or screen) shall be between 20° and 55°. The eye-to-display distance shall be no less than 60 cm. The horizon of the visual scene shall be between –5° and +5° from the participant's eye point height.

3.4.3.2 Steering wheel location

The steering wheel shall be located where it does not interfere with the visual scene of the LCT. It shall be capable of being handled comfortably.

3.4.3.3 Standard scenario

The standard scenario for a 3 000 m test track is as follows:

— only the scripted instructions are given to the participants (see Annex A),

— speed is specified and limited to 60 km/h, resulting in a duration of about 180 s per track,

— there are 18 pairs of “Lane Change” signs along a track.

3.4.3.4 Lane change sign spacing

The lane change signs are always visible but blank until the lane indications on the signs appear (i.e. pop-up) at a distance of 40 m before the signs. The mean distance from sign to sign is 150 m (a minimum of 140 m plus an exponentially distributed random variable with a mean of 10 m), so that the mean duration between two lane changes is about 9 s (at a speed of 60 km/h).

3.4.3.5 Ordering the lane change directions

The number of the six possible lane changes (from left lane to middle lane, from left lane to right lane, etc.) shall be balanced within 18 pairs of signs. This balancing also applies if tracks longer than 3 000 m are used. If the total number of pairs of signs on a track is not a multiple of 18, balancing shall be done to the extent possible. The presentation order of lane change signs in tracks used for different runs shall be randomised to avoid learning effects. At least five different orders shall be used randomly for different runs.

3.4.3.6 Secondary task equipment

The equipment for evaluating the secondary task shall be positioned where the participants can properly interact with it. The position depends on the purpose of the test, e.g. systems intended for vehicle use shall be positioned in their intended locations in the vehicle relative to the participant.

3.4.3.7 Document the setup

Because experimental setting effect may have an impact on the results, description of the setup, viewing distance and angle to road scene and type of road scene presentation, testing environment (personal computer, buck or complete car), and type of seat shall be reported.

It has been shown that better lane change trajectories have resulted when using a driving simulator instead of a personal computer [12], presumably due to the increased visual realism in a driving simulator. This emphasises the need to describe precisely each equipment setup before comparing the results of different experimental contexts.

3.5 Experimental design

3.5.1 General

A within-subject design shall be used (see Clause B.1). This allows for each participant to experience both the single and dual task conditions and facilitates statistical comparison between the two conditions. Furthermore, the experimental design shall be designed to minimize carry over or training effects between the two conditions (for an example see Figure 5).

The secondary task(s) is (are) conducted in the dual task runs. The secondary task can either be performed block wise (the same secondary task repeated within one track is a blocked run) or in a mixed design (different secondary tasks given within one track is a mixed run). See Annex B.2 for rationale. Dual task runs [primary task plus secondary task(s)] are conducted between baseline runs.

Each participant performs identical secondary tasks of equal difficulty but with different presentation order. The order of secondary tasks, the track parts used and the combinations between secondary task and track parts used shall be counterbalanced or randomised.

Start and end points of each secondary task operation are recorded, as well as driving performance during single and dual task conditions for later data analysis. Start point is typically as soon as the verbal instructions have been given. End point is the last operation made by the participant on the secondary task (e.g. a button press) which leads to a predefined final state.

Total time on task for each secondary task shall be no less than 2 min. This means that at least 12 lane changes during which the secondary task is being performed shall be taken into account.

During the LCT in dual task conditions, the experimenter shall monitor participant behaviour to ensure that the participant is following the instructions and engaging in both tasks as instructed.

If the participant does not follow the experimental instructions (as described in Annex A) this part of the data shall be excluded from data analysis. Furthermore, if the participant does not perform the secondary task, this shall be recorded and considered in the evaluation of the interface design.

3.5.2 Baseline runs

In the experimental design, and once training is completed, baseline run data are collected at the beginning, in the middle and at the end of the experimental phases. If only 2 baseline runs are carried out to avoid overly long experimentation time, these runs shall be at the beginning and at the end of the experimental phases. Mean deviation values (mdev) in the baseline runs can later be compared to check for learning effects. The participant is free to use both hands for steering. One track with 18 signs (about 3 min) shall be used for each baseline run.

A participant shall accomplish at least one baseline run at the beginning of the experimental phase without a lane change error (wrong lane or missed lane change). This will ensure an adequate level of skill and training (see Annex A). It will also provide at least one baseline suitable for calculating the participant's adaptive model (see Annex E). To establish baseline performance for comparison with dual task performance, the mdev values from several error-free baseline runs can be averaged.

3.5.3 Blocked runs

Given a blocked design, either the same secondary task with different parameters or a new task of the same type is repeated within a single run for a duration of at least 2 min (see Figure 5).

With a blocked design a driving distance of 3 km (corresponding to 3 min) should be sufficient to collect data for at least 2 min, with time for instructions for each secondary task item considered.

3.5.3.1 Mixed runs

In a mixed design, different secondary tasks (ST) are repeated within a single run (see Figure 5). With a mixed design, each secondary task shall be repeated enough times to record 2 min of data for each secondary task. This will require more than one run if there is more than one secondary task.

For analysis, the combination of all of the results of a given secondary task are used to calculate a single mean deviation.

3.6 Procedure

3.6.1 Participant instructions and training

All participants shall receive identical instructions. These shall be read to the participant. As described in Annex A, the participant shall receive:

— information on the general purpose of the test, and in particular instructions on the lane change task,

— training on the primary task only,

— training on the secondary tasks only,

— training on the dual task situations,

— instructions before first baseline run,

— instructions before dual task testing, and

— if required, instructions during dual task testing.

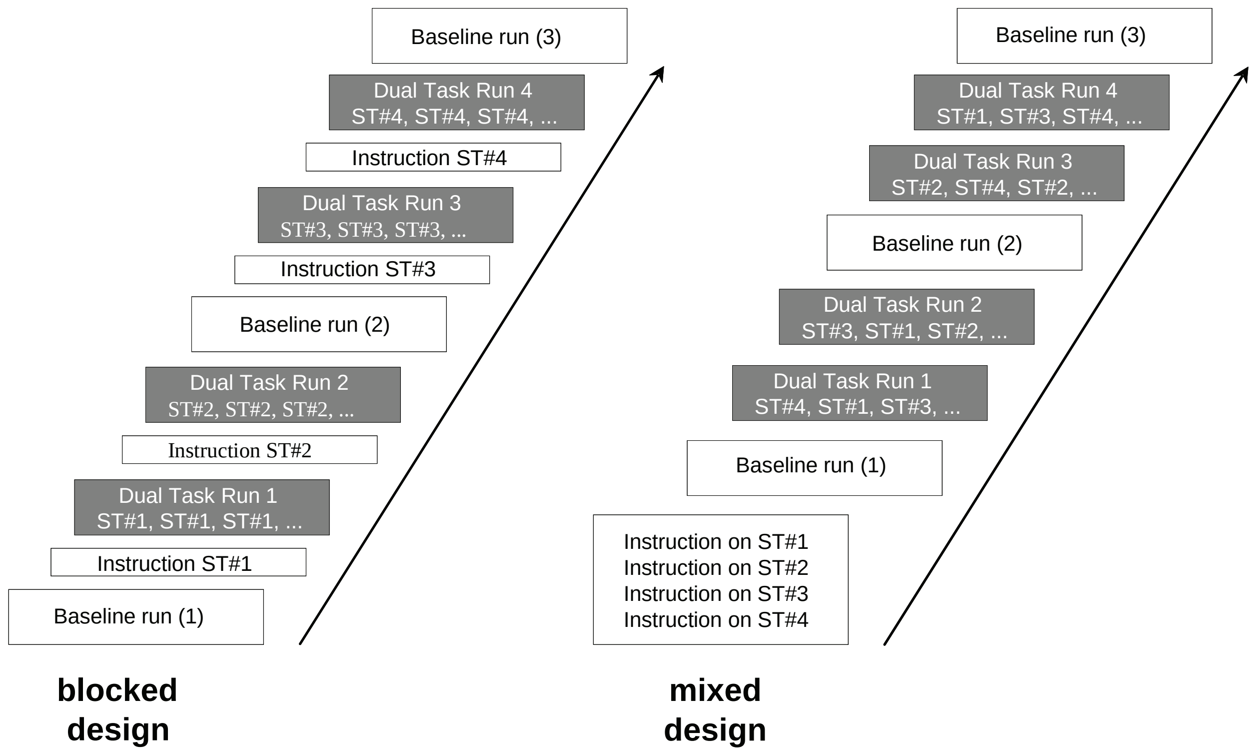


Figure 5 — Example of blocked and mixed experimental design

If a participant fails to meet the baseline criterion for minimum mdev (see Clause A.2) due to improper lane positioning, the importance of staying in the middle of the lane between lane changes shall be emphasized. Upon request, participants shall be instructed to perform the primary task and the secondary task as described in Clause A.4.

3.6.2 Allocation of attention in dual task conditions

3.6.2.1 General

The interpretation of LCT performance measures depends upon the way that participants allocate attention between the primary task and the secondary task they are performing at the same time. Because the lane change test is a divided attention method, in order for the measures generated by the LCT (mdev) to be consistently interpretable, an assumption is made that the participant is allocating attention in such a way that if the secondary task demand increases, it will lead to degradations in primary task performance.

However, participants may allocate attention differently than this, even when carefully instructed. If they do, it may lead to LCT results that obscure important differences between the secondary tasks in their demands on participant attentional resources. For example, two tasks may produce similar mdev values, but differ significantly in the number of errors made on each secondary task, the number of extra (unnecessary) secondary task entries made on each task, or the number of secondary tasks completed during the run [10]. Information on the interpretation of LCT measures is given in Annex F.

There are at least three different ways in which a participant might allocate attention between the tasks during an LCT.

3.6.2.2 More attention to the primary task

Participants might allocate attention so as to try to optimize their performance on the primary task, and let the secondary task performance suffer when they become overloaded. It is possible, for example, that because the demand associated with the lane changes is approximately periodic (rather than continuous), a participant might use a strategy in which activity on the secondary task is suspended during the lane change, and resumed when the lane change is completed. Such a strategy might lead to better mdev scores, but degrade secondary task performance, by slowing it down, increasing errors (if task information is forgotten or there is difficulty resuming it), or leading to extraneous control inputs or display search time.

3.6.2.3 More attention to the secondary task

Participants might allocate attention so as to maintain or optimize their performance on the secondary task and let their performance on the primary task suffer. Under this attentional strategy, overload from dual task demands would become apparent in mdev measures, while secondary task performance may not degrade from that observed in a single task condition.

3.6.2.4 Attention to both primary task and secondary task

Participants are asked to manage both tasks concurrently according to the instructions in Annex A (e.g. through frequent task-switching), with similar attentional allocations to both tasks. Under this attentional allocation, degradations in performance would be expected to show up on both tasks when their combined demands exceed a participant's momentary resource capacity. Therefore, both mdev measures and secondary task performance measures would be expected to show degradation.

3.6.2.5 Interpretation of dual task results

Attentional allocation is not yet fully understood, and it is not clear that instructions or incentives will ensure that the allocation of attention between tasks will be the same for all participants. The literature on dual-task methods has demonstrated that results are best interpreted when measurements of both tasks performed concurrently are obtained together with measurements of each of the tasks done in a single task condition.

3.6.3 Test procedure details

The main purpose of the lane change test is to compare performance degradations resulting from each of two or more secondary tasks. One of the secondary tasks could typically be a reference task (see 3.1). The test shall be performed as a “within-participant” procedure. This means that, for each participant, performance shall be established and compared under dual task conditions for runs with the secondary task(s) under test, and for runs with reference task(s) if appropriate.

The experimenter shall give the participant instructions on when to start the secondary task (see A.6). Start and end point of operation of the secondary task shall be recorded. A secondary task starts immediately after the experimenter's verbal instruction is finished, or when the participant starts performing the secondary task, whichever event occurs first. If there is a delay between end of instructions and participant start of secondary task, start of task shall be considered to be at end of instructions.

3.7 Performance measures and data analysis

3.7.1 Path deviation measures of secondary task demand

Two path deviation measures can be used to quantify the effect of secondary task demand on primary task performance. These path deviation measures can be calculated using an adaptive model (adaptive mdev) or a basic model (basic mdev). The adaptive model calculates a reference path trajectory (adapted curve) for a baseline run for each participant. The adaptive model and method shall be used to quantify and compare task demand for various dual task conditions. The basic model can also be used to compare a participant's path performance to a nominal reference path trajectory that is the same for all participants. Use of the basic model is optional.

These mean path deviation measures cover important aspects of the participant's performance. These include detection (late detection of a sign or missing a sign), quality of the manoeuvre (slow lane change results in larger deviation), and lane keeping quality, all of which may result in an increased deviation.

3.7.1.1 Adaptive model

The adaptive model shall be used to quantify the differences between experimental conditions. The effect of secondary task demand is measured by the adaptive mdev which is the mean deviation between the actual driving course of the participant along the track and the reference path trajectory from the adaptive model (see Figure 6 for a symbolic example of the model path and actual driving data). This reference path is adjusted to each participant in order to better match their actual driving behaviour in response to the signs in the baseline task. The result of the adaptation calculation is that the start of the lane change, the lane change length, and the overall lateral position in the lane (as shown by the solid line in Figure 6 and the solid red line in Figure 7) are adjusted to match the baseline behaviour of the respective participant. The details of these adaptation procedures and the calculation of the resulting adapted path trajectory are given in Annex E.

3.7.1.2 Basic model

The basic model is similar in concept and application to the adaptive model, except that the reference path trajectory is nominal and the same for each participant (see Figure 8). The measure of the effect of secondary-task demand is the basic mdev which is the mean deviation between this nominal basic path model trajectory and the actual driving course of the participant along the track (see Figure 6). The nominal basic path model trajectory is based on the sign geometry and spacing as described in 3.4.3.4. Once the instruction content of the sign becomes visible (pops-up), a reaction time of 600 ms to initiate the lane change is assumed. A participant would cover a distance of 10 m within this time (16,67 m/s $\times$ 0,6 s $=$ 10 m). Therefore, the basic model trajectory turns 30 m before a lane change sign to take reaction time into account. The basic lane change has a length of 10 m regardless of whether it is a single or a double lane change, as shown in Figure 8.

3.7.2 Performance calculation using the adaptive mean deviation value

The mean deviation (adaptive mdev) between the adaptive model path trajectory and the participant's actual driving course shall be calculated as the performance parameter of main interest. Only the section(s) of the track in which the participant is performing the respective secondary task shall be used for analysis, i.e. those sections where the experimenter gave instructions are excluded from the analysis if such instructions last more than 1 s.

To facilitate this, the relevant sections shall be marked by the experimenter during each run with appropriate markers in the recordings. Trials with secondary tasks which were not completed (due to participants inability or time limits), however, can be included in the analysis as long as the participant worked on the secondary task to their best ability, as instructed.

NOTE According to the signs, the driver has to change from the middle to the right lane and then to the left lane. Note that Figure 6 is not to scale (driving direction is from left to right). The average path deviation is the total area between the reference path trajectory of the adaptive or basic model and the driving course (m^2) divided by distance driven (m).

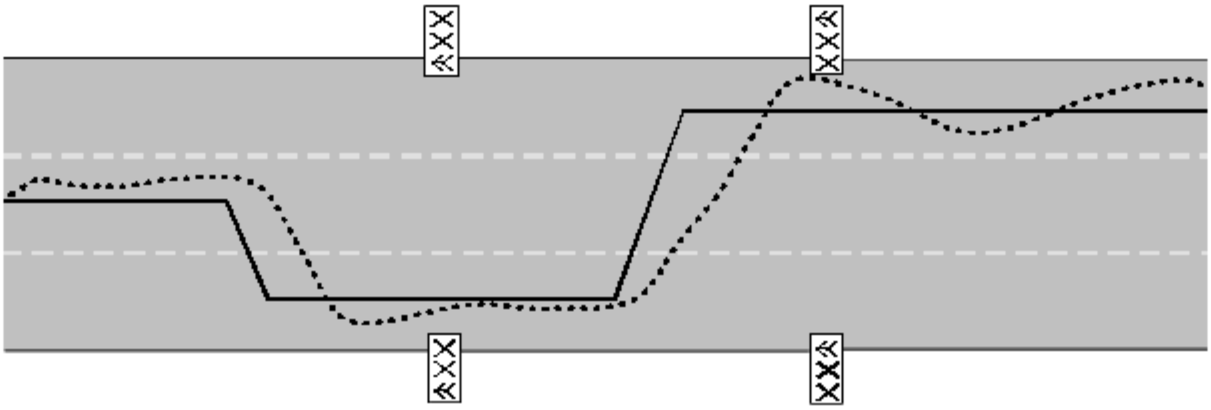
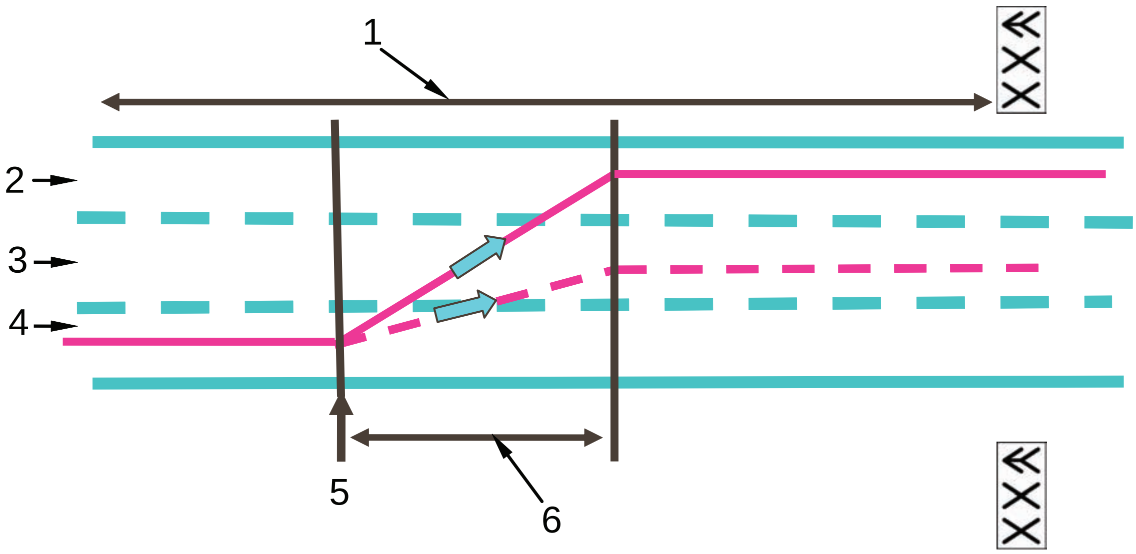


Figure 6 — Comparison of reference path trajectory (solid line) and actual driving course (dotted line)



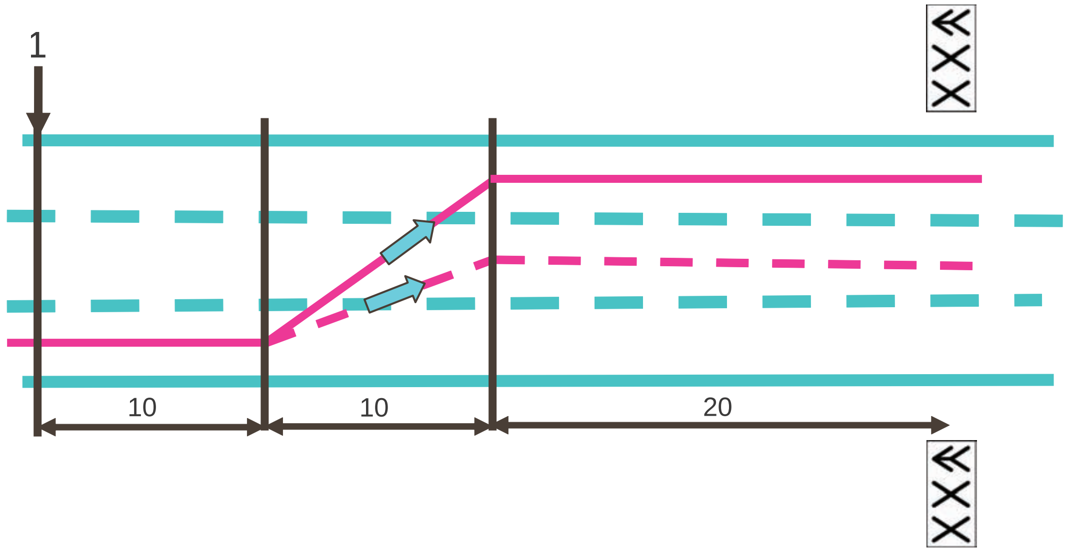
Key

1 sign content pop-up (40 m)
2 adapted left lane position
3 adapted centre lane position
4 adapted right lane position
5 adapted start of lane change
6 adapted lane change length

NOTE: Dashed line shows an incorrect lane change.

Figure 7 — Adaptive model trajectory parameters relative to sign content pop-up and sign position

Dimensions in metres



Key

1 sign content pop-up

Figure 8 — Basic model trajectory values relative to sign content pop-up and sign position

The mean deviation (mdev) between either the adaptive or basic model path trajectory and the actual driven course can be calculated as follows:

$$\frac{1}{S}\sum\left[x_{\text{deviation},i}\left(\frac{y_{i+1}-y_{i-1}}{2}\right)\right] \tag{1}$$

$$x_{\text{deviation},i} = \left|x_{\text{position},i} - x_{\text{reference},i}\right|$$

where

$x_{\text{deviation},i}$	is the lateral deviation;
S	is the length of the data segment analysed;
y	is the longitudinal vehicle position along the track;
$x_{\text{position},i}$	is the actual vehicle lateral position on the track;
$x_{\text{reference},i}$	is the lateral position of the reference (adaptive or basic) path trajectory.

This calculation is done across all data segments which are relevant for a certain experimental condition. In other words, the invalid data segments (e.g. time for instructions by experimenter) are removed and the remaining valid data are handled as if they were one continuous set of data. The same applies to an experimental design where secondary tasks of one experimental condition are distributed over several experimental runs. In baseline runs mdev is calculated for the section between the start sign and 50 m after the last of 18 lane change signs.

The resulting mdev values shall be calculated for each participant and each experimental condition of interest, for example, for baseline driving, for dual task conditions with each secondary task under test, and with a reference task.

3.7.3 Measures of secondary task performance

Because participants may allocate attention in multiple ways during the LCT, measurements of primary task performance (adaptive mdev) and secondary task completion time, number of secondary task completions and number of errors, shall be obtained. These secondary task measures are described in Clause F.1.2 and their relevance will depend on the type of task.

3.7.4 Analyzing differences between dual task conditions

An evaluation is accomplished by comparing mdev values. This can involve comparing performance in two different dual tasks, or comparing dual task performance with the baseline condition. The mdev differences can be statistically analyzed (e.g. ANOVA, t-Test, Friedman Test, etc., depending on the specific design and research question). All statistical parameters relevant to the comparison shall be reported (e.g. t-values, F-values, p-values, degrees of freedom, sample size, and outliers). In data diagrams, error bars with standard errors are recommended. The data should be examined for outliers because they can influence the distribution of mean deviation. Any treatment of outliers shall be reported.

In general, while comparisons of mdev values (as discussed above) provide an overall measure of dual task differences, mdev alone may not be sufficient to explain the differences between two secondary tasks with similar mdev values, as discussed in Annex F. Similarly, not finding a statistically significant difference between mdev values does not prove that the tasks are equivalent. Additional performance variables for the primary task and the secondary task are discussed in Annex F and can be considered in order to provide a more complete assessment of those tasks. These measures can also help to determine whether the main performance degradations from resource overload are reflected in the primary task measure (mdev), or whether some changes in dual task performance are reflected in secondary task measures.

3.8 Validation

Initial validation results are summarized in Annex G. Data are shown from a study comparing dual task performance with eight secondary tasks of varying levels of difficulty, using both LCT and an over-the-road vehicle. The results show a correlation between mdev in LCT and standard deviation of lane position over-the-road. The results of driving simulator studies are also discussed. Additional validation studies should be carried out, as experience is gained with the application of LCT.

Annex A
(normative)

Instructions to participants

A.1 Before training on the primary task

Outline for instructions to participants prior to primary task training:

— Welcome the participant and give a brief overview of the purpose of the test, its expected duration and the test procedure, driving a simulated roadway, changing lanes and simultaneously performing various tasks.

— Emphasize that the intention is not to test participant skills but rather how tasks of different complexity might affect “driving performance”.

— Explain the three lane test track, duration of each run, that the participant has to drive at 60 km/h in a speed-limited system, how to change lanes when the lane change signs appear.

— Describe the lane change signs and the significance of the symbols.

— Ask the participant to try to stay in the middle of the lane when driving straight.

— Instruct participants to begin a lane change as soon as the symbols appear on a sign, but not before.

— Instruct participants to complete the lane change quickly and efficiently. Mention to the participant that an efficient lane change typically is finished before the sign is reached.

— Provide opportunity for the participant to ask questions.

— Ask the participant to get seated at the simulator monitor (or in seating buck or vehicle) and to adjust the seat and steering wheel to a comfortable position. When necessary (e.g. restrictions in posture and reach), the participant shall be asked to fasten the seat belt.

— Repeat driving instructions and inform participant that at the end of the track, the simulation will end.

A.2 Training on the primary task

The participants shall be trained on the primary task without performing secondary task(s). The primary task should be referred to as the “driving task.” An mdev value with the adaptive model of less than 0,7 m in the baseline condition can be used as an acceptability criterion. Alternatively each participant should reach an mdev value of less than 1,2 m using the basic model. One practice run (3 min) is usually sufficient. If the criterion is not reached, however, practice should be continued until the participant reaches the criterion level and feels comfortable with the driving task.

The experimenter shall let the participants become used to the simulated vehicle response by crossing freely over the lanes and using large steering wheel inputs for the lane changes.

During training on the primary task the experimenter shall give feedback as necessary to participants to ensure that they:

— Perform good lane keeping when driving straight,

— Begin a lane change as soon as the symbols appear on the sign, but not before,

— Complete the lane change quickly and efficiently, and

— Stay in the centre of lane between lane changes.

The participant shall complete at least one baseline run without a lane change error (wrong lane or missed lane change), to ensure their suitability to participate and to provide at least one error free baseline for use in the adaptive model.

A.3 Training on the secondary tasks

Prior to conducting the test trials in accordance with 3.6.3 for any task, each participant shall be given a clear explanation of the system operation and the secondary tasks of interest. A secondary task should be referred to as an "added task." Each participant should be told how many secondary tasks will be evaluated, and whether the test is a mixed or blocked design. The meaning of mixed or blocked design will be explained. Each participant shall have at least two and up to five practice trials for each secondary task being investigated. Fewer practice trials may be used if the participant is adequately prepared for the task. For a secondary task which has no clear task duration (continuous tasks) practice should be performed for at least 30 s. Training on the secondary task shall be performed under single task conditions. If participants cannot successfully complete the practice task at least once in five trials then the interface design and training protocol should be reviewed.

The number of practice trials shall be recorded for each participant and task. Data to be viewed or entered for a secondary task in practice trials should be different from those used in test trials but equal in difficulty. Each practice task should be completed using the designated method, and the experimenter should aim to ensure the appropriate completion of the task by coaching or assisting if the participant is having difficulty with the task.

If it becomes necessary to give instructions about the secondary tasks to be performed during dual task experiments, these instructions shall be as short and concise as possible. Care should be taken to ensure that the participant understands these short instructions.

It is recommended, that each participant, as part of the testing, perform a calibration task, ideally two times (with two different difficulty levels). Such calibration tasks can facilitate quality control within a laboratory, and support the comparison between test sites. When two levels of difficulty are employed, a calibration task provides a test of sensitivity of the experimental test setup. For example, if a test cannot distinguish two levels of calibration task which were significantly different in previous tests, the procedures and results of the current study should be reviewed.

A.4 Training in dual task condition (primary task plus secondary task)

The participants shall experience the dual task situations. The data to be viewed or entered for the secondary task in such a trial shall be different from those used in other trials (training and test) but equal in difficulty.

— Tell the participant how he/she will be asked to commence a secondary task, how the task should be initiated and how participant should indicate completion of the task.

— Instruct the participant to "do both the driving task and the added task to the best of your ability with equal emphasis on your performance for both, complete the lane changes quickly and efficiently and stay in the centre of the lane between lane changes, perform the added task as instructed."

A.5 Instructions before first baseline run

The experimenter shall remind the subject to:

— Perform good lane keeping when driving straight and stay in the centre of the lane between lane changes.

— Begin a lane change as soon as the symbols appear on the sign, but not before.

— Complete the lane change quickly and efficiently.

A.6 Instructions before dual task testing

The experimenter shall describe in sufficient detail the secondary task(s) to be performed during the next dual task run and instruct the participant to start the secondary task without delay, but not until the complete instructions are given. If completion of a secondary task is not obvious to the experimenter, participants shall be instructed to verbally inform the experimenter when the task is completed. Instructions on the overall procedure (blocked or mixed design) shall be given to the participant.

A.7 Instructions during dual task testing

During the dual task conditions the experimenter shall tell the participant when to start a secondary task using verbal instructions that are as short and as clear as possible (e.g. “Now set your navigation destination to 'Coolidge Drive'”). Immediately after the participant has finished a secondary task, the experimenter shall explain and initiate the next task. It is important that the participant performs a secondary task in the prescribed sequence, e.g. ABC, not ACB. If required, guidance on how to perform a secondary task shall be provided.

Annex B
(informative)

Experimental plan

B.1 Repeated measures

It is understood that both driving skills in general as well as performance in the LCT may vary between participants. This, however, is compensated for by conducting the experiment with a repeated measures (within-subject) design, and using a corresponding ANOVA. Strictly, in a within-subject design each participant serves as his/her own control which increases statistical power. To reach a minimum statistical power the use of at least 16 test participants is recommended (see 3.2). If small effects are expected the sample size should be increased accordingly [14]. As a further means to increase the efficiency of the test, participants should be homogeneous with respect to age or other demographic factors.

B.2 Dual task phase

In the dual task phase a secondary task under test, e.g. operating a Transport Information and Control System (TICS), is conducted concurrently with the primary task. The type of secondary task in the dual task phase may either be blocked (the same secondary task within one run of 3 min) or mixed (different secondary tasks within one run). If a mixed design is conducted, the individual secondary tasks shall be marked digitally during data collection.

Both designs (blocked and mixed) have advantages and drawbacks. The drawback of a blocked design is that it might appear unnatural or artificial (e.g. changing the station or sound setting of the radio over and over again). On the other hand the blocked design is easy to instruct and the participant has only one secondary task to keep in mind. Furthermore, subjective ratings can be more easily obtained after a blocked run.

In a mixed design the participant shall memorize all secondary tasks under test. Therefore the learning and training effort for a mixed design is much higher than for a blocked design. At the same time, a mixture of secondary tasks within one run can appear more natural. However, it is crucial for data analysis that the overall run be sufficiently long for all secondary tasks. As a result, short tasks (e.g. sound adjustment) need to be performed more often than longer tasks (e.g. destination input).

An unpublished study done at the laboratory of DaimlerChrysler in 2005 with 18 participants (13 males, 5 females, age: 22 to 40 years) systematically compared blocked versus mixed presentation of six secondary tasks. The tasks were: unpacking a paper handkerchief, map book search, another more difficult map book search, changing a cassette, sound adjustment on a radio, and an input to a navigation system. The analysis of the LCT mean deviation values showed that the tasks differed significantly from each other [$F(5,85) = 10,77$, $p < 0,001$]. The design (blocked versus mixed), however, did not produce a significant main effect [$F(1,17) = 1,57$, $p = 0,23$]. Most importantly, there was also no significant interaction between secondary tasks and the design [$F(5,85) = 1,16$, $p = 0,34$]. Thus, the conclusions on the secondary tasks would not be different for the blocked mode as compared to the mixed mode. Task durations were also not significantly different between blocked and mixed presentations [24,4 s versus 27,8 s, $F(1,17) = 1,93$, $p = 0,183$]. The small difference of 3,4 seconds was mainly due to the two map book tasks. During this experimental study, the expected advantages and disadvantages of the two designs were confirmed. However, estimating the right number of tasks for a mixed design turned out to be quite difficult.

B.3 Reference task

The reference task is a standardized secondary task. The purpose of a reference task is to provide a specific level of interference that results in a corresponding level of performance in the primary task. The reference task should be capable of unambiguous operation in terms of its response and performance and, when combined with the primary task, should result in a driver state that constitutes a reference level of degradation in terms of driving performance. A reference task especially designed for comparing different test sites or tests is called a calibration task.

A number of reference tasks related to car driving have been suggested, such as the radio tuning task described in the Alliance of Automobile Manufacturers Statement of Principles. However, these reference tasks are not unambiguously defined and may lead to variations depending on setup and execution. Other non-driving related tasks have been used by the ADAM project [11] and [17] for example, but these are also hard to unambiguously define. Generally, most reference tasks which can be applied in a dual task scenario (such as driving simulator scenarios or field tests) can be used together with the LCT.

NOTE ISO/TS 14198[1] is intended to define one or more calibration tasks which may be used as reference tasks.

B.4 Data analysis

The above-mentioned structural similarity of the LCT to a classical reaction time experiment (pop-up signs serve as stimuli and the steering manoeuvre is considered the response) enables calculation of some equivalents to reaction time, for example the time between sign onset and the initiation of the lane change manoeuvre. A measure for the lane keeping quality between the signs could be used to apply the similarities to a driving simulation study. Also, the quality of the lane changing manoeuvres could be evaluated as an index of how much a driver is distracted by a secondary task under test. Finally, the number of missed signs could be used as a further index of demand due to a secondary task.

To keep the data analysis simple on one hand, but on the other hand to allow for the complexity of driving, a single measure was developed which covers all of these features: the deviation (mdev) of the actual driving course from an adaptive or a basic model path. Figure B.1 illustrates how these different features of driving behaviour contribute to the deviation measure: performing badly with respect to any of these driving features leads to an increase in the deviation index. More elaborated analyses are discussed in Annex F.

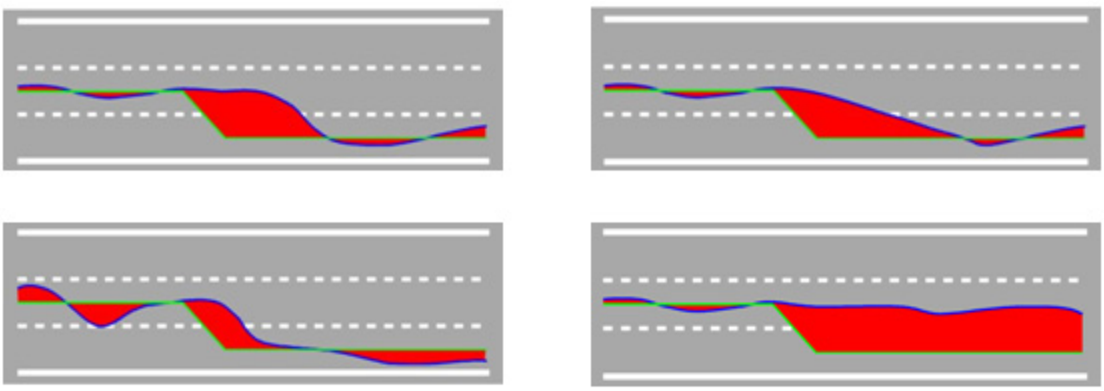


Figure B.1 — Deviation from the adaptive or basic model

NOTE Figure B.1 illustrates how late responses (upper left), slow manoeuvres (upper right), poor lane keeping (lower left) and missed signs (lower right) increase the deviation between the recorded driving course (blue line) and the adaptive or basic model path (green line). Driving direction is from left to right.

Annex C
(informative)

Background and rationale

C.1 Methods to measure secondary task demand

Young, Regan & Hammer (2003) identified the following scientific techniques for measuring driver distraction:

— on-road or test track studies,

— driving simulator studies,

— dual task studies,

— eye glance monitoring studies,

— the visual occlusion method,

— the peripheral detection task, and

— measurements of static task time.

There are considerable differences between these methods with regard to the expected quality of empirical studies and results. Each of these methods has its advantages and disadvantages. Some of the relevant dimensions are objectivity, reliability, sensitivity, validity, intrusiveness and efficiency and there are strong interrelations between these dimensions as discussed below.

Objectivity means that neither the experimenter nor the experimental setting (laboratory, hardware) have a systematic influence on the results. In principle, one should get the same results at each testing site.

Reliability refers to the consistency or reproducibility of test results. A reliable method yields accurate measurements across several trials, different populations and in different forms. Reliability reflects the accuracy (both technical and procedural) of measurement.

Sensitivity is closely linked to reliability. Sensitivity refers to the ability of a test to discriminate. Additional to reliability, good sensitivity requires a fine scaled measurement. For example, a test which employs only ratings “good, medium, poor” as a final result will be less sensitive than the same test when a 10-point scale is used.

Validity addresses whether or not the method really measures what it is supposed to measure. In this case the method should measure or estimate the effect of secondary task demand on driver performance and not something else. Ideally, the method should predict the increase of the probability to have a crash or other problem for a given secondary task. The question of validity is closely linked to the realism of the scenario. However, a realistic scenario does not guarantee high validity. It is also important that the correct variables are measured (those which indicate demand). Furthermore, validity (in a technical sense) can only be demonstrated when reliability is given.

Intrusiveness can be seen as a sub-criterion of validity. If the method for measuring secondary task demand influenced the normal operation of the secondary task or the normal situation of driving in combination with the TICS the method could be called intrusive and validity might well be decreased.

Finally, **efficiency** means that the quality of the results and the effort to get these results should be balanced. One could equip hundreds of vehicles with the target secondary task and compare the accident data after two or three years with a control group. Validity of this method would be very high but cost, duration and safety for the test participant would be unacceptable. The other extreme would be filling in a checklist by a single expert. This would be an inexpensive approach, but the above mentioned quality criteria (e.g. objectivity) would hardly be met.

C.2 LCT Principle

The intent of the LCT method is to have the following properties:

a) good face validity,

b) reflect manual, visual and cognitive components of driving,

c) contain elements important to the driving task:

  — course following and manoeuvring,

  — event detection,

d) discriminate between secondary tasks of varying levels of demand,

e) provide quantitative results,

f) be a replicable measurement method, and

g) be useful in most stages of product development and in actual vehicles.

C.3 The lane change test as a combination of driving simulation and probe reaction tasks

The LCT was designed to combine the advantages of both driving simulator studies and probe reaction tasks [17]. The general setting in a driving simulator can be very similar to real driving. Furthermore, the driving situation is not dangerous for the test participants and the setting (e.g. events like vehicle ahead braking) can be controlled by the experimenter. However, the more realistic the scenario in a driving simulator, the more difficult and ambiguous data analysis and interpretation can be. Typically one measures variables of longitudinal and lateral performance (among others) and changes in one variable must be interpreted in the light of the other variable. For example, changes in lateral performance must be interpreted differently for a driver who decides to reduce speed when he or she is asked to make an input on a TICS as compared to a test subject who prefers to keep speed constant. Realistic scenarios have some limitations. For example, surprising events (e.g. pedestrian enters road unexpectedly) can be employed only a few times since otherwise they are not really surprising anymore. Therefore it can be difficult to collect enough corresponding data points to provide an appropriate and meaningful statistical analysis.

The peripheral detection task (PDT) represents one example of a so-called probe reaction task. In such tasks, a simple stimulus (e.g. a sound or a small light) is presented repeatedly and a test participant typically has to respond with a simple key press as soon as possible. Reaction time to the probe stimulus is measured while the participant performs a TICS task. This typically represents a dual-task paradigm (see below). It is assumed that reaction time in this paradigm reflects spare cognitive capacity, and probe reaction time is an index for the cognitive complexity of the task done concurrently [16]. When the probe paradigm is used in automotive research to study secondary task demand it is sometimes used as a ternary task with (1) driving (real or simulated), (2) TICS-task, and (3) probe reaction task. The advantages of such a reaction time paradigm are the good experimental control (at least for the dual task approach), the high number of responses one can get within limited time and, resulting from this, the high reliability which is typical for reaction time experiments. The disadvantage of a dual task approach with probe reaction times is that the realism is quite low. Instead of driving, the participants do nothing between two stimuli and this might well lead to different strategies in terms of attention allocation as compared to a driving scenario. The ternary task approach (which incorporates real or simulated driving) can be questioned in terms of intrusiveness since the third task (perceive the probe stimulus and respond to it) is neither part of the driving task in a real situation nor of the TICS task.

The LCT has features of both the driving simulation approach and the probe reaction paradigm. It can be regarded as a simple driving simulation with stimuli (pop up signs) and responses (initiating lane change manoeuvre) embedded in the driving task. From another point of view, the LCT can be seen as a stimulus-response paradigm with complex stimuli (the arrow signs), complex responses (steering manoeuvre), and a lane keeping task between two consecutive lane changes. This view probably avoids the possible misunderstanding that the lane change test is meant to involve a realistic driving simulation, which is not necessarily the case.

To avoid the above mentioned trade-off between lateral and longitudinal control performance, the latter was completely eliminated. To this end, speed is controlled by the LCT software to 60 km/h.

C.4 Primary and secondary task in the LCT

The primary task in the LCT is a simulated driving task which reflects in terms of complexity, the visual, cognitive and motor demands of driving. The primary task requires a certain amount of attention to be adequately performed. The average interval of 9 s between two lane changes was selected according to pilot tests during development of the LCT. Longer intervals might lead to an unwanted number of cases where short secondary tasks can be performed completely between two lane changes. On the other hand, shorter intervals would increase primary task difficulty too much. Performing a secondary task concurrently with the primary task will lead to an attentional draw away from the primary task to the secondary task. As a consequence, performance in the primary task may change and be degraded. This performance change in the primary task is measurable in that case.

Secondary tasks (different from “subsidiary tasks” that are used to estimate the spare capacity of a participant in a certain situation by measuring subsidiary task performance) are tasks carried out concurrently with the primary task. There is no limitation to the definition of a secondary task according to this International Standard as long as the secondary task is not systematically confounded with the LCT procedure (e.g. haptic feedback on the steering wheel which might be dependent on the steering wheel angle). Rather, it is up to the experimenter to select the secondary tasks to be examined, and to determine how these tasks should be applied. Typical secondary tasks are:

— in-vehicle tasks (e.g. select a radio station; adjust the car radio to a certain frequency; change the sound settings; change the CD in the CD player; set a new destination in a navigation system; change the map scale of a navigation map),

— sub-activities of in-vehicle tasks (e.g. browse through a menu system from one application to another application; use an alpha-numerical speller),

— artificial tasks designed for research purposes (e.g. visual search tasks to induce a certain level of visual load, or mental calculation tasks to induce cognitive load), and

— other activities (e.g. eating, drinking, searching for coins, reading paper maps).

How these tasks are applied depends on the specific research question. For example, it might be required to start a radio tuning task on an integrated system from a default setting where the telephone function is selected. The task then starts with a change to the audio system. In another case, the task might start with the radio system already activated.

It is important that the selection and application of the task items follow good experimental standards of human factors research. This includes, for example, balanced item difficulties, balanced number of input steps, randomized or counterbalanced assignment of test items to experimental factors. Care should also be taken to ensure that the test items require only short and unambiguous instructions. This is particularly true when the experimenter has to instruct repeatedly during the dual task test phase (e.g. reads names of radio stations to be set by the test participant).

Annex D
(informative)

Adapting LCT to a real vehicle

D.1 General

The LCT may be performed with a real vehicle placed in a simulator. It may be possible to replace the vehicle's steering wheel with a computer game steering wheel. However, it is recommended that the standard steering wheel be used since this would allow for the use of controls on and around the steering wheel as well as any other in-vehicle systems. Steering wheel input forces should be kept to a reasonable level. This can be achieved by running the engine for cars with engine driven power steering pumps, or having electric servo pumps or direct acting electric servo motors active. If these options are not possible, every effort should be made to reduce the required steering wheel forces. For this type of application, all components that are not required to transfer steering wheel movement to the steering rod should be disconnected.

D.2 Suggestion for procedure to adapt a real vehicle for LCT

— This annex describes one possible way to adapt a real vehicle to a driving simulator for LCT. Several other ways of adaptation might be possible as well.

— The steering wheel movement should be tuned to replicate that of a computer game steering wheel in terms of ratio between steering wheel movement and resulting computed turning circle. (A maximum steering wheel movement of approx ±120° should be anticipated.)

D.3 Procedure for vehicles where servo assistance can be used for limiting steering wheel forces

Front wheels of the test vehicle should be placed on swivelling plates to reduce friction to ground.

Movement of one front wheel shall be transformed into an electrical signal compatible with the LCT software, either from the movement of one of the swivelling plates or directly from the front wheel (e.g. via an attached rod).

D.4 Procedure for vehicles where standard steering assistance cannot be used

The vehicle should be lifted, at least its front wheels slightly off the ground and both front wheels should be removed.

The ball joints of the steering rods should be disassembled from the steering knuckles on both sides of the vehicle.

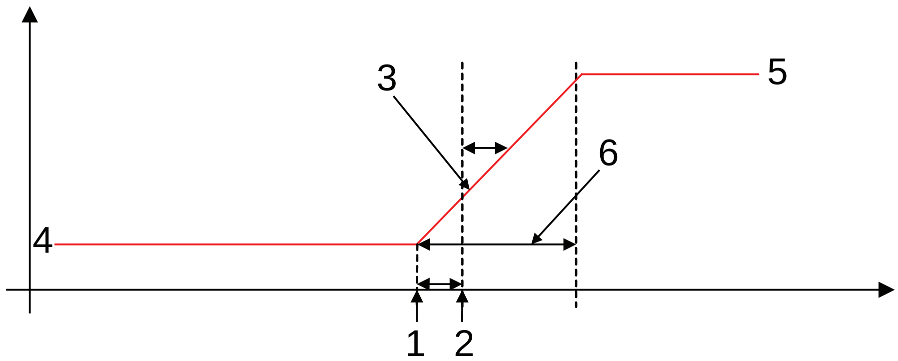
One of the steering rods should be connected to a device that transfers the mechanical movement of the rod when the steering wheel is turned into an electrical signal compatible with the LCT software.

Annex E
(normative)

Calculation of LCT metric using an adapted path trajectory for each participant

E.1 General

This annex describes the method to calculate a reference path trajectory (curve) adapted to each participant using a recorded trial, named *baseline*, where the participant drives with the LCT on a complete track without any secondary task. The adaptation is done by calculating for each participant an individual *StartLaneChange*, *LaneChangeLength* and the lateral positions on each lane *AdaptedPosXlane1, AdaptedPosXlane2, AdaptedPosXlane3.*



Key

1 *StartLaneChange*

2 position of the lane change sign

3 average distance

4 *AdaptedPosXlane2*

5 *AdaptedPosXlane3*

6 *LaneChangeLength*

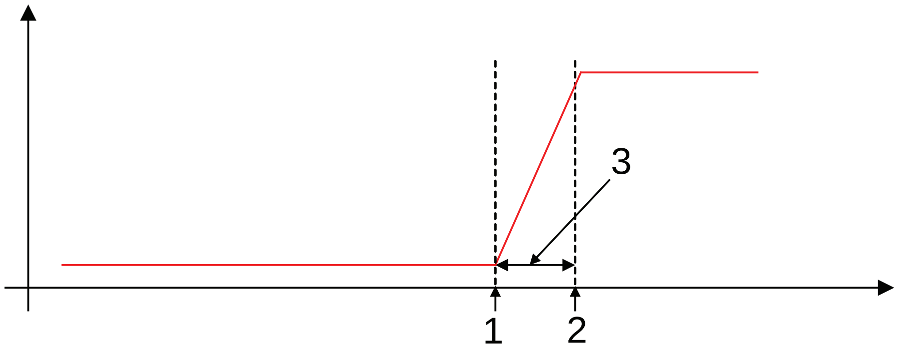
Figure E.1 — Parameters to calculate the adapted path trajectory (curve)

The same two parameters as the basic model path trajectory are used (*Start Lane Change* distance and *Lane Change Length*) but an intermediate variable is added: the *Average Distance*, which corresponds to the distance between the lane change sign position and the middle of the lane change.

The *adapted curve* is then obtained in two stages by calculating, firstly, the *Average Distance* and secondly, the *Lane Change Length*.

E.2 Average distance

To calculate this distance, two steps are needed. The first one concerns the calculation of an adapted curve with fast lane changes. The second concerns comparison between this curve and the baseline trial done by the participant to find the *Average Distance* completed by the participant on this track.



Key

1 *Start Lane Change*: $Px_2 = LCX_0$,
$Py_2 = LCY_1$

2 *End Lane Change*: $Px_2 = LCX_a$,
$Py_2 = LCY_1 + \varepsilon$

3 *Lane Change Length*

Figure E.2 — Definition of fast lane change

E.2.1 Fast lane change curve

To begin, the set of lane change signs is defined by P points, one for each lane change. Each lane change is defined by its longitudinal position LCY_i and its lateral position expected after the lane change LCX_i. LCX_i can have only three possible values *PositionXLane1*, *PositionXLane2* and *PositionXLane3* depending of the attended trajectory position after the lane change. LCY_i is the position of the lane change sign on the track in metres. Mathematically, this set can be represented by:

$$LaneChangePoints = \left\{\left\{LCY_p, LCX_p\right\} / \, p \in [0 : P-1]\right\} \tag{E.1}$$

A curve with fast lane changes at each lane change sign on the test trial is defined. A fast lane change corresponds to a lane change with a lane change length of 0,01 m. For each lane change there are two points in the new set. The first is at the position of the lane change with the lateral position corresponding to the previous lane change. The second is just after the position of the lane change ($\varepsilon = 0{,}01$ m) with the lateral position corresponding to this lane change. Mathematically, this curve, named *Curve0Points*, is defined by a set of points as follows:

$$Curve0Points = \left\{\left\{Px_j Py_j\right\} / \, j \in [0 : 2 * P-1]\right\} \;\Big|$$

$$\begin{cases} Px_0 = 0 \quad Py_0 = LCY_0 \\ Px_1 = LCX_0 \quad Py_1 = LCY_0 + \varepsilon \\ \forall j \geq 2 \wedge (j \equiv 0 \,(\mathrm{mod}\,2)) \quad Px_j = LCX_{\frac{j}{2}-1} \quad Py_j = LCY_{\frac{j}{2}} \\ \forall j \geq 3 \wedge (j \equiv 1 \,(\mathrm{mod}\,2)) \quad Px_j = LCX_{\frac{j-1}{2}} \quad Py_j = LCY_{\frac{j-1}{2}} + \varepsilon \end{cases} \tag{E.2}$$

$\varepsilon = 0{,}01 \, m$

Then, this curve is stamped using a constant sample rate (*SampleRate* = 0,1 m) to obtain the following signal:

$$Curve0 = \left\{\left\{curve0x_n curve0y_{,n}\right\} / n \in [0 : N-1]\right\} \quad with \quad N = \frac{BaseLineLength}{SampleRate} \tag{E.3}$$

Figure E.3 shows the fast lane change curve obtained by this method.

Dimensions in metres

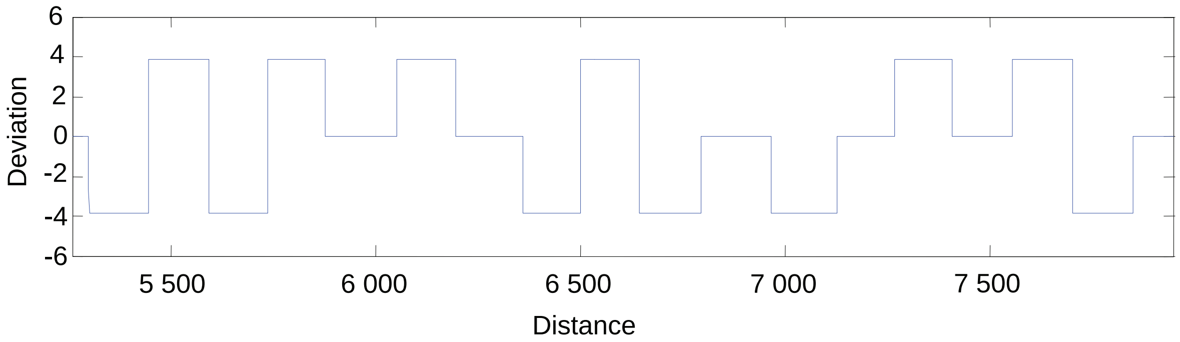


Figure E.3 — Curve with fast lane changes

E.2.2 Comparison with participant's baseline data

Then, the participant's trajectory is also stamped on the trial without secondary task, to obtain the following signal:

$$Baseline = \left\{\left\{baselinex_n, baseliney_n\right\} / n \in [0 : N-1]\right\} \quad with \quad N = \frac{BaseLineLength}{SampleRate} \tag{E.4}$$

A correlation method is used to evaluate the distance between the lane change signs position and the realized lane changes by the participant in the baseline. This method calculates the correlation between one curve and another curve which is translated by n*SampleRate* meter, with n taken several values between 0 and N. Then, it calculates several values, one by each transition value. The maximum correlation value gives the nearest transition curve. To evaluate the *Average Distance*, a high precision of the correlation maximum peak is needed, which is obtained by unbiased correlation, calculated between the two signals. Mathematically, this curve, named Correlation *Curve0Baseline*, is defined by a set of points as follows:

$$CorrelationCurve0Baseline = \left\{R(m) / m \in \left[-N : N-1\right]\right\}$$

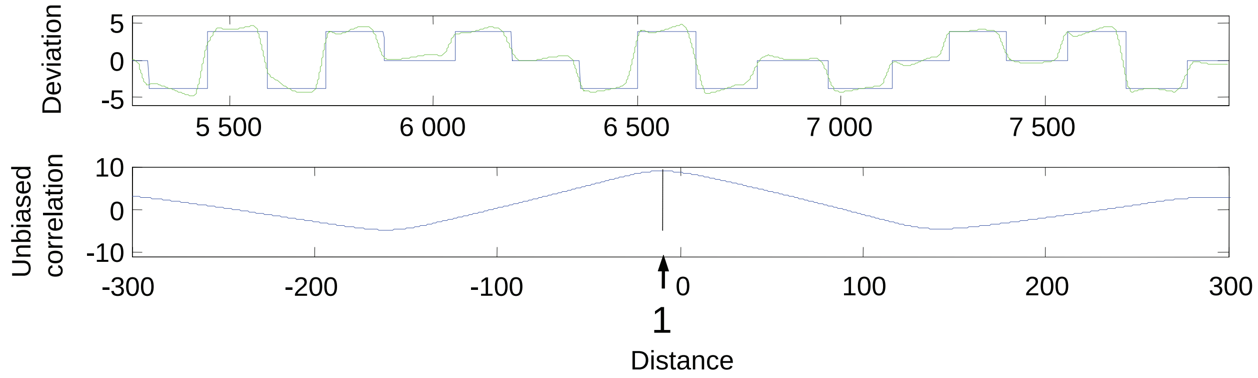
$$\begin{cases} \forall m \in \left[0 : N-1\right] \quad R(m) = \dfrac{1}{N-|m|} \sum_{n=0}^{N-m-1} baselinex_{n+m} curve0x_n \\ \forall m \in \left[-N+1 : -1\right] \quad R(m) = \dfrac{1}{N-|m|} \sum_{n=0}^{N-|m|-1} baselinex_n curve0x_{n-m} \end{cases} \tag{E.5}$$

Figure E.4 shows the Curve 0 (first schema in blue), the baseline completed by the participant (first schema in green) and the correlation values for transition between −300 m and 300 m (second schema). Then, the position of the maximum correlation value is at 9,8 m. That means that the participant is at the middle of the lane change 9,8 m after the lane change positions. This value corresponds to an average value considering all lane changes of the baseline run.

Then, the participant's *Average Distance* is given by the position of the correlation maximum between –100 m and +100 m (9,8 m after the lane change sign in Figure E.4). Mathematically, this distance, named *AverageDistance*, is defined by:

$$\exists AverageDistance \in [-100:100] \;\middle|\; \forall m \in [-100:100] \quad R(AverageDistance) \geq R(m) \tag{E.6}$$

Dimensions in metres



Key

1 maximum position = –9,7 m

Figure E.4 — Correlation between the participant's baseline data and the curve 0

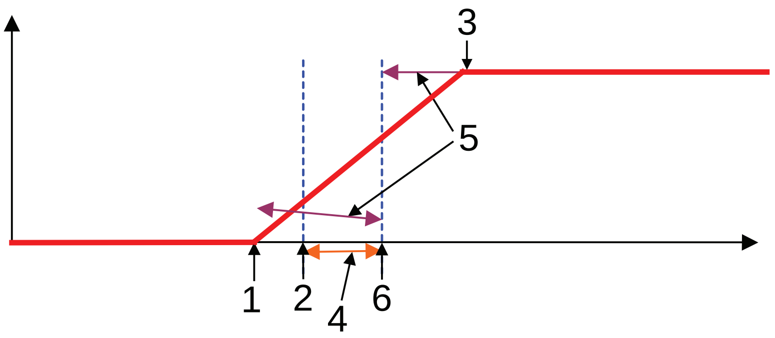
E.3 Average lane change length of the adapted path (curve)

The next step is to define the better lane change length. The choice method is, firstly, to define several curves with different lane change lengths, secondly, to adapt the lateral positions on each lane, thirdly to compare them to baseline data to find the better match.

E.3.1 Adapted paths (curves) with variable lane change lengths

Several Lane Change Lengths between 10 m and 80 m, one per metre are defined in a set. Mathematically, this set of lane change lengths, named *LaneChangeLengths*, is defined by a set of values as follows:

$$LaneChangeLengths = \left\{ LaneChangeLength_k \;/\; k \in [0:K-1] \right\} \quad with\ K = \frac{(80-10)}{1} + 1$$
$$\begin{cases} LaneChangeLength_0 = 10 \\ \forall k \in [1:K-1] \quad LaneChangeLength_k = LaneChangeLength_{k-1} + 1 \end{cases} \tag{E.7}$$



Key

1 *Start Lane Change*: $PX_2 = LCX_0$, $Py_2 = LCY_1$ + AverageDistance – (LaneChangeLength$_k$/2)

2 lane Change Sign Position

3 *End Lane Change*: $Px_3 = LCX_1$, $Py_3 = LCY_1$ + AverageDistance

4 *Average Distance*

5 *Lane Change Length*$_k$/2

6 Position of the middle of Lane Change

Figure E.5 — Definition of lane change with variable lane change lengths

As shown in Figure E.5, several curves are calculated with the *Average Distance* defined above and with several *Lane Change Lengths* (one by lane change length). Then, the middle of the lane change is positioned at *AverageDistance* of the lane change sign, calculated at the first stage. The start lane change is (*LaneChangeLength$_k$*/2) metres before and the end at (*LaneChangeLength$_k$*/2) metres after. Each curve is defined by a set of points *CurvePoints$_k$*: mathematically, these curves, named *CurvePoints$_k$*, are defined by several sets of points as follows.

$$\forall k \in [1:K-1] \quad CurvePoints_k = \left\{ \left\{ Px_{k,j} Py_{k,j} \right\} / j \in [0:2*P-1] \right\} \quad \Bigg| \quad \left\{ \begin{array}{l} Px_{k,0} = 0 \quad Py_{k,0} = LCY_0 + AverageDistance - \dfrac{LaneChangeLength_k}{2} \\ Px_{k,1} = LCX_0 \quad Py_{k,1} = LCY_0 + AverageDistance + \dfrac{LaneChangeLength_k}{2} \\ \forall j \geq 2 \wedge (j \equiv 0 \,(\mathrm{mod}\,2)) \quad \Big| \\ \qquad Px_{k,j} = LCX_{\frac{j}{2}-1} \quad Py_{k,j,} = LCY_{\frac{j}{2}} + AverageDistance - \dfrac{LaneChangeLength_k}{2} \\ \forall j \geq 3 \wedge (j \equiv 1 (\mathrm{mod}\,2)) \quad \Big| \\ \qquad Px_{k,j} = LCX_{\frac{j-1}{2}} \quad Py_{k,j} = LCY_{\frac{j-1}{2}} + AverageDistance + \dfrac{LaneChangeLength_k}{2} \end{array} \right. \tag{E.8}$$

These curves are sampled with the constant sample rate *SampleRate* to obtain several curves, one for each *Lane Change Length*.

$$\forall k \in [0:K-1] \quad \forall n \in [0:N-1] \quad FirstCurve_k = \left\{ curve_{x,k,n}, curve_{y,k,n} \right\} \tag{E.9}$$

E.3.2 Lateral position adaptation

This step consists of calculating the position on each lane realized by the participant during the baseline trial for each curve. This work is done three times by curve, once by lanes. For example, to adapt the position in lane1 in the curve *k,* the following phases are realized. All $FirstCurve_k$ points which have as lateral position *PosXLane1* are selected in a set named $Lane1PointSet_k$. Then, the mean of baseline lateral positions on these points is calculated and give the adapted position for lane1 for curve *k*, $AdaptedPosXlane1_k$. Mathematically, theses adaptations, named $AdaptedPosXlane1_k$, $AdaptedPosXlane2_k$, $AdaptedPosXlane3_k$ are defined as follows:

$$\begin{aligned}
&\forall k \in [0:K-1] \quad AdaptedPosXLane1_k = \frac{1}{size(Lane1PointSet_k)} \sum_{l \in Lane1PointSet_k} baseline_l \\
&\quad with \quad Lane1PointSet_k = \left\{ \; l \in [0:N-1] \quad / \left| \; curve_{x,k,l} = PosXLane1 \right. \right\} \\
&\forall k \in [0:K-1] \quad AdaptedPosXLane2_k = \frac{1}{size(Lane2PointSet_k)} \sum_{l \in Lane2PointSet_k} baseline_l \\
&\quad with \quad Lane2PointSet_k = \left\{ \; l \in [0:N-1] \quad / \left| \; curve_{x,k,l} = PosXLane2 \right. \right\} \\
&\forall k \in [0:K-1] \quad AdaptedPosXLane3_k = \frac{1}{size(Lane3PointSet_k)} \sum_{l \in Lane3PointSet_k} baseline_l \\
&\quad with \quad Lane3PointSet_k = \left\{ \; l \in [0:N-1] \quad / \left| \; curve_{x,k,l} = PosXLane3 \right. \right\}
\end{aligned} \tag{E.10}$$

Then, each curve $CurvePoints_k = \left\{ Px_{k,j} Py_{k,j} \right\}$ is adapted in term of lateral lane positions by replacing $Px_{k,j}$ by respectively $AdaptedPosXlane1_k$ if $Px_{k,j}$ value was *PositionXLane1*, $AdaptedPosXlane2_k$ if $Px_{k,j}$ value was *PositionXLane2*, $AdaptedPosXlane3_k$ if $Px_{k,j}$ value was *PositionXLane3*.

Dimensions in metres

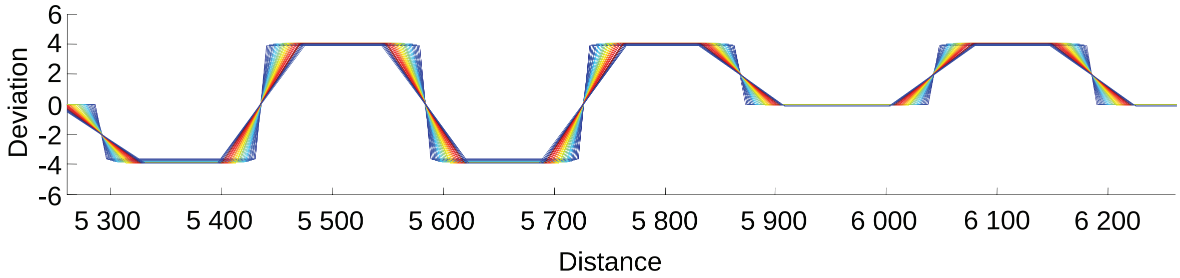


Figure E.6 — Set of curves with several lane change lengths

These curves are sampled with the constant sample rate SampleRate to obtained several curves, one for each LaneChangeLengthk.

$$\forall k \in [0:K-1] \quad Curve_k = \left\{ \left\{ curvex_{k,n}, curvey_{k,n} \right\} / \, n \in [0:N-1] \right\} \tag{E.11}$$

The results are illustrated in Figure E.6.

E.3.3 Nearest adapted path (curve) selection

This step is done, firstly, by the calculation of all correlations and secondly by the selection of the curve with the highest correlation.

In the correlation calculation, the goal is to compare the correlations between the baseline data curve and the curves with different *LaneChangeLengths*. Then, the correlation has to be normalized by the norms of the two curves to allow this comparison. Mathematically, the correlation between each $Curve_k$ and *Baseline* data is given with the following formulas:

$$\forall k \in [0:1-K] \quad CorrelationCurveBaseline_k = \frac{1}{\left|curve_k\right|}\frac{1}{\left|baseline\right|}\sum_{n=0}^{N-1} baselinex_n curvex_{k,n}$$
$$\left|baseline\right| = \sqrt{\sum_{n=0}^{N-1} baselinex_n^2} \quad and \quad \left|curve_k\right| = \sqrt{\sum_{n=0}^{N-1} curvex_{k,n}^2} \qquad \text{(E.12)}$$

The selection of the curve which has the highest $CorrelationCurveBaseline_k$ is done by comparing all values and by selecting the highest one. This is shown in Figure E.7, where the maximum value is observed for a lane change length of 35 m. Then, this *LaneChangeLength* corresponds to the average *Lane Change Length* of this subject.

The AdaptedCurve is the one associated with this *LaneChangeLength.* Mathematically, SubjectLaneChangeLength, SubjectStartLaneChange and the AdaptedCurve is calculated by:

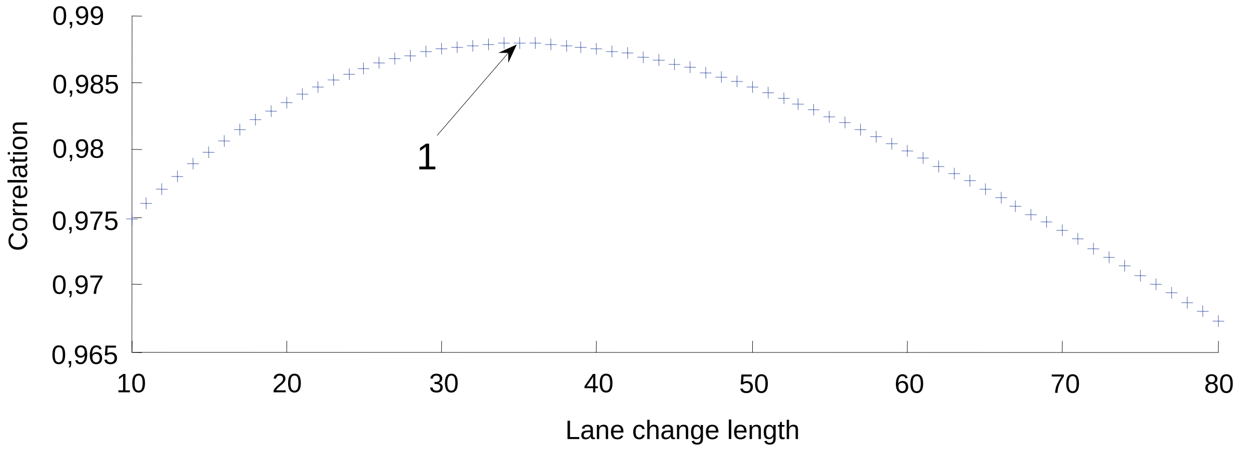
$$\exists ParticipantK \in [0:K-1] \quad \Big|$$
$$\forall k \in [0:K-1] \quad CorrelationCurveBaseline_{SubjectK} \geq CorrelationCurveBaseline_k$$

Then,

$$ParticipantLaneChangeLength = LaneChangeLength_{SubjectK} \qquad \text{(E.13)}$$
$$ParticipantStartLaneChange = AverageDistance - \frac{SubjectLaneChangeLength}{2}$$
$$AdaptedCurve = Curve_{SubjectK}$$

This is illustrated in Figure E.8.

Dimensions in metres

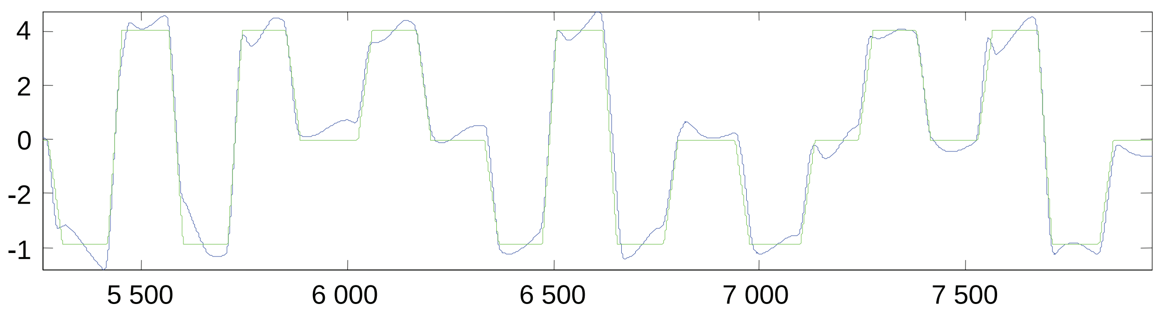


Key

1 maximum value

Figure E.7 — Values of correlation for each lane change length

Dimensions in metres



NOTE The position of each lane is 3,9 m in lane 1, –0,1 m in lane 2, and 4 m in lane 3. Example data are for participant 1 Adapted Curve StartLC –26,6 LengthLC35.

Figure E.8 — Example of adapted curve (in green) compared to baseline data (in blue)

Annex F
(informative)

Interpretation of LCT measures

F.1 Procedures for ensuring interpretability of LCT measures

All measurements of performance described in this clause should be based on tasks that were completed (that is, in which the goal was reached). Incomplete tasks should not be included in the calculations, but should be tallied and reported.

In order to ensure the interpretability of LCT measurements, the following steps may be taken whenever the LCT is applied.

F.1.1 Assessment of single task performance

Include in the assessment conditions in which a "single task" performance of each task are obtained. For the primary task, the baseline run/s provide the "single task" condition.

For each of the secondary tasks, this is usually obtained with a run that follows training on the secondary task. If such a secondary task trial is not obtained, it can be added to the training protocol. On this test trial, the participant simply performs the task one time to evaluate whether the task has been adequately learned, and to obtain baseline performance.

F.1.2 Secondary task measures

In the secondary task single task trials, two measurements of performance should be obtained: mean task completion time and number of errors made or error rate.

The mean task completion time is the time from the requested start of a task ("Please begin now.") to its completion (when the participant indicates they are done with the task, or when the task's end state is reached). Computing the mean time requires that individual epochs of task performance be marked for extraction from the data stream.

NOTE For very long tasks, mean task completion time may be subject to ceiling effects, if the length of an LCT run truncates task completion, or constrains the number of tasks completed. In such a case, the time associated with the length of the LCT run could, perhaps, be used as a proxy for task time. Task duration by itself may not be a meaningful metric for assessing an auditory / vocal secondary task, because the driver's eyes are more likely to remain on the road while performing the task. However, when task durations are used as a metric to compare performance under dual versus single task conditions using an STP ratio, the comparison may be a useful way to assess relative performance degradations.

Two types of errors should be included in a count of total number of errors. (There is no need to retain separate counts of these two types of errors. It is only necessary to ensure that both types are included when obtaining a count). The two types of errors in individual control inputs are:

- errors affecting successful task completion: these include control inputs which may cause a participant to fail to complete the task successfully. (Note: it is not unsuccessful task completions that are to be counted, but errors including those which may lead to an unsuccessful task completion),

- extraneous control inputs: these errors are control inputs that either result in a "non-optimal" path to the task goal (one that is longer, for example, than the most efficient path), or which may represent recovery from an error of the first type (corrective inputs). Note that while extraneous inputs do not necessarily produce an unsuccessful task completion, they are errors in the sense that they can reflect extra participant workload and result in performance degradation under some conditions.

The following are examples of how to score the two types of errors:

— a participant entered a destination and when selecting a State from a list of States, the participant thought the cursor was positioned on “MI”, but the “MN” (the selection below “MI”) was actually selected. That would be an error if the participant failed to correct it, and if the participant did correct it, it would lead to extraneous inputs. Thus, the tally of total errors would reflect both types of behaviour,

— a participant entered a phone number, and mis-entered the digits which were errors affecting successful task performance, and would be counted. If the participant corrected them, then they would be counted as extraneous input errors. Or if a participant hit “Cancel” at the end of a correctly entered phone number instead of “Send”, that would be counted as an error, and

— a participant scrolled a map to find a Point-of-Interest (POI) and scrolled past it, backed up, and got lost, but then found the POI. The extra control inputs (once the POI was passed the first time) would be counted as extraneous input errors.

To score both types of errors, experimenters should define a start state and an end state for each task, along with a sequence of control inputs to go from the start state to the end (or goal) state. This sequence will define an ideal number of specific inputs which would reflect the optimal path to the goal state of the task. If a participant makes more control inputs than that optimal number, the extra inputs should be counted as “extras”. If a participant makes an error (and does not correct it), that would be apparent because that control input would be different from anything in the defined sequence for the task.

Application of these secondary task metrics will depend upon the experimental design of the LCT test (blocked or mixed), as shown in Table F.1.

Table F.1 — Application of secondary task metrics within different LCT experimental designs

Secondary task metric	Blocked design	Mixed design
Mean task completion time	Mean duration of task epochs across an LCT run	Mean duration of task epochs across all task occurrences
Total number of errors	Total errors in tasks summed across a run	Total errors summed across all task occurrences

F.1.3 Secondary task performance ratios

For a selected secondary task measure, performance in dual task conditions can be compared to the same measure taken under single task conditions using secondary task performance ratios.

A secondary task performance ratio for completion time can be expressed as:

$$\text{STP ratio(CT)} = \frac{\overline{x}_{\text{TCT,dual}}}{\overline{x}_{\text{TCT,single}}}$$

where

$\overline{x}_{\text{TCT,dual}}$ is mean task completion time for secondary task under LCT;

$\overline{x}_{\text{TCT,single}}$ is mean task completion time under single task conditions.

A secondary task performance ratio for number of errors can be expressed as:

$$\text{STP ratio(NE)} = \frac{x_{\text{NE,dual}}}{x_{\text{NE,single}}}$$

where

$x_{\text{NE,dual}}$ is total number of errors made during secondary task under LCT;

$x_{\text{NE,single}}$ is total number of errors made during one task measured in single task condition multiplied by number of task occurrence in LCT.

NOTE If the number of errors in the denominator is zero, the evaluator should use the value of the numerator directly in making a decision.

In general, ratios are not recommended for the primary task measure mean deviation. Algebraic differences in mean deviation values between two conditions should be used instead, as prescribed in 3.7.4.

F.2 Interpreting mean deviation differences and secondary task ratios

Mdev differences and secondary task ratios can be used to help determine if a secondary task is producing any performance degradation under multitasking conditions. With the adaptive model the mdev difference is almost certain to be positive, and unlikely to be significantly negative. A selected STP ratio may or may not be greater than 1,0. If the STP ratio is not greater than 1,0, the mdev value alone can be used to assess the secondary task demand. If the STP ratio is greater than 1,0, both the mdev value and the STP ratio can be used to assess the secondary task demand.

F.3 Additional primary task metrics derived from the LCT

It is well known that various dimensions of secondary task demand have qualitatively different effects on primary task performance. In particular, a main distinction commonly made between visual manual and auditory-cognitive tasks ([19], [18], [9], [15]), is that visual manual tasks (e.g. radio tuning) generally have a main effect on tracking control while auditory cognitive tasks (e.g. phone conversation) affect event detection performance but have little effect on tracking control. Although most real world secondary tasks involve both visual manual and auditory cognitive components their respective weightings differ. Many auditory tasks (e.g. mobile phone conversation or voice interaction) could be viewed as purely auditory cognitively demanding (i.e. they impose no need to take the eyes off the road or the hands off the wheel).

As described in 3.1, the LCT may be regarded as a combined tracking and event detection task with the mdev presumed to measure both visual manual demand (in terms of reduced tracking control performance during and between lane changes) and auditory cognitive demand (in terms of missed and/or delayed detection of the lane change signs). There are advantages of having the mdev measure as a single, combined, measure of these effects in that it is simple and easy to calculate mdev. However, the distinction between tracking control and event detection performance offers a way to improve sensitivity and diagnostic value of the method. Some studies have shown the mdev measure to be insensitive to effects captured by other metrics [13]. Moreover, in many evaluation settings, it is clearly desirable to be able to tell what feature of the HMI design caused the deviation from the reference path. For instance, a complex voice interface (inducing a high number of missed or delayed responses to the signs) may yield the same mdev score as a simple visual HMI located far away from the normal line-of-sight (yielding excessive lane weaving), but for a different reason. In general, while mdev provides an overall measure of dual task differences, it may not be sufficient to explain the differences between two secondary tasks with similar mdev. In order to understand the respective impacts of different HMI design options it can be useful to include additional measurements or metrics sensitive to these specific effects. Metrics that can be used as a complement to mdev are defined and described below.

The first metric, *modified standard deviation of lateral position,* can be used to quantify the effects on tracking performance. The second, the *proportion of missed or erroneous lane changes,* reflects cases where signs are missed or incorrectly responded to (i.e. changing to the wrong lane). The third, *mean delay in lane change initiation,* can be used to assess late detection of signs. The first metric is mainly sensitive to visual-manual demand while the last two are mainly sensitive to auditory-cognitive demand [15]. These metrics are further defined below.

Modified SDLP (standard deviation of lateral position)

This metric represents the higher frequency variation in lateral position related to reduced tracking control, thus disregarding the lower frequency variation associated with the lane changes. It reflects the amount of "overshooting" at the end of a lane change and weaving in the target lane. It is computed by applying a high-pass filter to the lateral position course signal, although this partitioning is never perfect since the lane changes also involve some higher frequency components. However, empirical results have shown that this metric efficiently singles out the effect of reduced mid-frequency tracking performance from the low frequency effects related to sign detection [15].

Specifically, the metric is defined as the standard deviation of the lateral position course signal, high-pass filtered at 0,1 Hz. The unit is in metres. The computation consists of the following two steps:

— filter the lateral position course signal with a second order Butterworth high-pass filter with cut-off frequency 0,1 Hz. The lateral position signal to use is the lateral position relative to the lane centreline (i.e. not to the basic model path), and

— calculate the standard deviation of the resulting filtered lateral position course signal.

Proportion of missed or erroneous lane changes

This metric is defined as the proportion of all commanded lane changes where either (1) the subject did not respond to the lane change sign at all or (2) a lane change was made, but to the wrong lane. The metric is computed according to the following method.

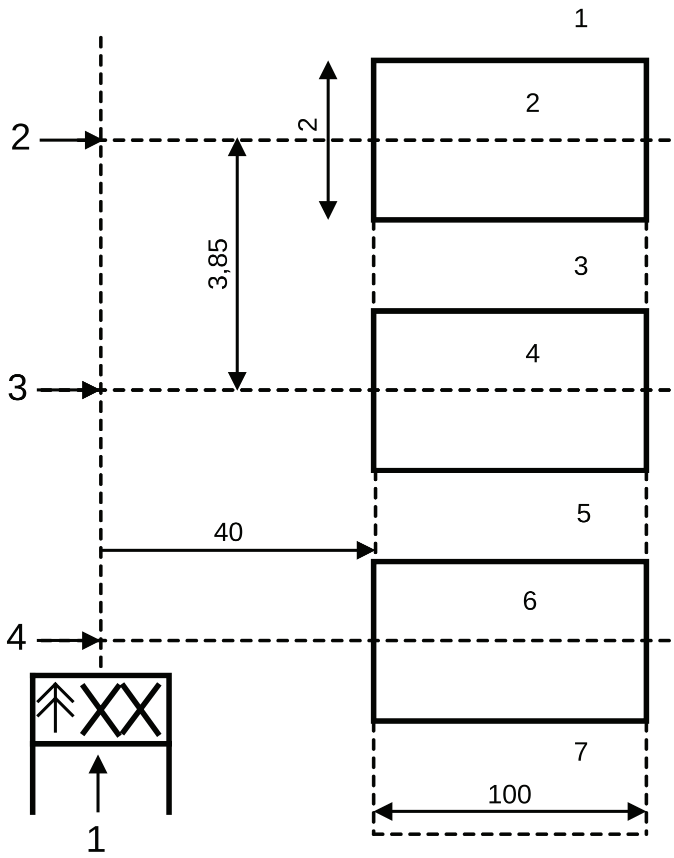
The geometry used as the basis for the calculation is illustrated in Figure F.1. The vehicle trajectory (path) is analysed in a region between 40 m and 140 m after the sign. Within this region, three "boxes" are defined, representing the three target regions for a lane change. These boxes thus laterally cover the central regions of the three lanes. Adding the 4 regions adjacent to the boxes, the road could be divided into seven areas, as illustrated in Figure F.1.

If the participant manages to reach *any* of the target areas (2, 4 or 6) after the lane change, the area where most time is spent is defined as the participant *selected lane* (in the rare case where exactly the same amount of time is spent in two target areas, no selected lane is assigned). If the selected lane does not correspond to the target lane (i.e. the lane commanded by the sign) *or* if none of the target areas (2, 4 or 6) were reached, the lane change is counted as *incorrect*. The final value is then obtained by dividing the number of incorrect lane changes with the total number of signs.

For a blocked design, the ratio is calculated for the entire track. However, if a mixed design is used, each lane change has to be associated to an experimental condition (e.g. a specific secondary task). The basic principle for this mapping is that a lane change should be associated with the condition that was present at the point of sign appearance for that lane change.

It should be noted that it is theoretically possible to also distinguish between missed and erroneous lane changes. However, this adds substantial complexity to the calculation since it requires taking into account where the subject was positioned before the current lane change. This could be a potential extension to future versions of this International Standard.

Dimensions in metres



Key

1 sign position

2 left lane

3 central lane

4 right lane

Figure F.1 — Geometry of the target areas used to calculate the proportion of missed or erroneous lane changes

Mean delay in lane change initiation

This metric is defined as the time (in seconds) elapsed between the moment the sign appears (i.e. 40 m before the sign is reached) and the initiation of the lane change. The metric only applies to correct lane changes, as determined by the method described in the previous section. The adaptive model takes this into account, for a given participant on the average, thereby reducing the baseline mdev value.

The lane change initiation point is defined in terms of the most significant steering action towards the new lane, which is identified by means of the following method, composed of three steps.

a) Detection of the relevant vehicle trajectory change

The most significant change in vehicle trajectory (path) is identified based on the derivative $\delta = \mathrm{d}x/\mathrm{d}y$ of the lateral position signal x, where y is the longitudinal position along the track. The lane position signal and (if necessary) the derivative, should be appropriately low-pass filtered, depending on the resolution of the signal. Based on this, the longitudinal position y_{max} corresponding to the maximum absolute value of the derivative between 30 m before the sign and 30 m after the sign (δ_{max}) is identified. Next, the longitudinal position y_{30}, representing the point where the derivative signal first reaches 30 % of δ_{max} is identified. This location represents a first approximation of the lane change initiation point.

b) Detection of the relevant steering action

In this second step, a possible steering action, corresponding to the trajectory change identified in step a), is searched for. This is done within a “search zone” beginning 60 m before the sign and ending at y_{30} (as calculated above). In order to be considered valid, the steering action needs to be:

1) in the correct direction [i.e. the direction of the trajectory change identified in step a)]

2) associated with a steering wheel angle larger than 2° and smaller than 5° in absolute value

If a steering action meeting this criterion exists within the search zone, the y position corresponding to the local minimum/maximum in steering wheel angle that represents the initiation of the steering action is identified as the lane change initiation point. If the steering action is preceded by a plateau, the y value that corresponds to the last value of the plateau should be chosen.

c) Calculating the mean delay

The lane change delay is calculated as the time difference between the appearance of the lane change sign and the lane change initiation point as defined by the steering action exceeding the threshold value. The final value is the mean delay for a particular experimental condition (e.g. a specific secondary task). The association between lane changes and experimental conditions in a mixed design should follow the same principles as for the calculation of proportion of missed or erroneous lane changes (outlined in the previous section).

F.4 Possible future development

In the future, development of a measure which combines the degradation on both LCT and secondary task performance into a single index may be useful. However, one has not been developed at this time.

Annex G
(informative)

Initial validation of LCT

As described in [11] and [17], two approaches to validation were followed during the initial development of the LCT within the Advanced Driver Attention Metrics (ADAM) project (Daimler and BMW, Germany, 2002-2004):

— correlation with a criterion (i.e. data from a field study), and

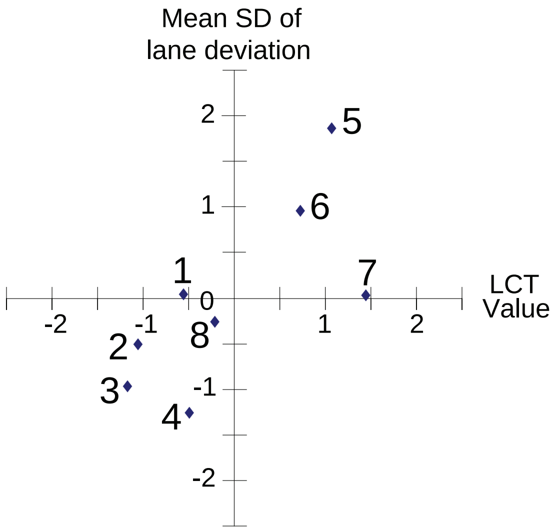
— testing secondary tasks with logical order of difficulty.

Following the correlation approach, eight secondary tasks were tested both with the LCT and in an equipped vehicle on a German highway. The tasks were: using a navigation speller of the integrated navigation system, using the navigation map, sound adjustment, entering a telephone number, changing a cassette, selecting candies by colour, unwrapping a chewing gum, and reading a paper train schedule. In the field study, 30 participants (15 male, 15 female, mean age: 54 years) completed the secondary tasks while driving on a highway with moderate traffic. Driving data as well as additional behavioural data and eye glance measures were recorded. In the laboratory, the same secondary tasks were tested with a different sample of 30 participants (24 male, 6 female, mean age : 51,6 years). Figure G.1 shows the results for the LCT and the Standard Deviation of Lane Deviation derived from the field study. The values were standardized to ease comparison (z-Transformation) and showed a correlation of $r = 0{,}715$.

A second approach to test the validity of the LCT was to employ secondary tasks with a logical order of difficulty. One weakness of the correlation approach is that the true ordering of the secondary tasks with respect to their difficulty remains unclear, even though field tests have sometimes been called a “ground truth” criterion. Another shortcoming of this approach is the need to replicate the secondary tasks in different environments (on road and laboratory). Therefore, a further study employed pairs of secondary tasks with a known order of difficulty. In a mainly visual pair tasks, participants had to search an array of symbols for a predefined target symbol. In the easy condition, the target was the only one in its colour, whereas in the difficult condition there were also other symbols of the same colour. The first has been called single feature search whereas the latter is a feature conjunction search [20]. It is a well established fact that a feature conjunction search requires more visual attention and produces longer search times, making this task undoubtedly more difficult than the single feature search task. Therefore, other than in a study with natural tasks, the expected result is known in advance and an additional test (e.g. field or driving simulator) is not required. Two cognitive tasks in this study were counting forward in steps of two (easy) and counting backwards in steps of seven (difficult). Finally, in a motoric or haptical task the participants had to plug a small wooden stick in a board with holes along the edge without visual control. In the easy condition the holes were larger and the end of the stick was round, whereas in the difficult condition the holes were smaller and the stick was sharp edged. The mdev values of the LCT were clearly different for the visual search task and for the cognitive counting task, but not for the haptical task. This study demonstrated clearly that the LCT is generally able to differentiate secondary tasks according to their visual or cognitive demand.

Prior to these validation studies, a set of 12 secondary tasks was tested in the ADAM project with 85 participants in a high-end driving simulator with a 360° field of view and an advanced motion system. A combined measure calculated from variables of longitudinal and lateral control, eye glance behaviour, and subjective ratings was used as a criterion value for the 12 tasks. The correlation over the 12 tasks with the LCT value was $r = 0{,}835$. When only objective data from the driving simulator were used (subjective ratings eliminated) the correlation was $r = 0{,}754$.

Additional validation studies at a future time would be useful.



Key

1 selecting candies
2 navi map
3 adjusting sound
4 train schedule
5 changing cassette
6 chewing gum
7 entering telephone number
8 navi speller

NOTE $r = 0,715$; $p = 0,046$ (Pearson)

Figure G.1 — Correlation of laboratory LCT results and lane deviation from a field study

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