IEEE Open Journal of
Intelligent Transportation Systems

Received 5 September 2022; revised 4 November 2022; accepted 21 November 2022. Date of publication 24 November 2022;
date of current version 20 December 2022.

Digital Object Identifier 10.1109/OJITS.2022.3224677

Determination of Takeover Time Budget Based on Analysis of Driver Behavior

FOGHOR TANSHI [1] (Member, IEEE), AND DIRK SÖFFKER [2] (Member, IEEE)

[1] Department of Electrical/Eletronic Engineering, Federal University of Petroleum Resources, Effurun 330102, Nigeria

[2] Chair of Dynamics and Control, Department of Mechanical and Process Engineering, University of Duisburg–Essen, 47057 Duisburg, Germany

CORRESPONDING AUTHOR: F. TANSHI (e-mail: tanshi.foghor@fupre.edu.ng)

This work was supported by the Open Access Publication Fund of the University of Duisburg–Essen, Germany. The work of Foghor Tanshi was supported in part by the Tertiary Education Trust fund (Tetfund) of the Nigerian Government through the Academic Staff Training and Development (AST&D) Scholarship for her Ph.D. study at the Chair of Dynamics and Control, University of Duisburg–Essen, Germany.

This work involved human subjects or animals in its research. Approval of all ethical and experimental procedures and protocols was granted by the Ethics Committee of the Faculty of Engineering, University of Duisburg–Essen, Germany.

ABSTRACT An automated driving system notifies a fallback-ready human driver to resume driving when critical operational and functional limits have been or are about to be exceeded. The point between notification and critical limit is the time budget. Previous studies indicate that interdependencies exist between takeover variables and the time budget leading to performance variations and sometimes accidents. It is known that drivers may delay or respond inadequately depending on the time budget. This contribution focuses on utilizing these interdependencies to evaluate the suitability of the time budget for specific scenarios. A 7 s time budget, eight scenarios, and three secondary tasks were studied in a driving simulator with 70 participants aged between 19 Yrs and 41 Yrs. The results indicate that drivers prioritize takeover effort in decreasing order of relative speed, traffic agents, and junctions. Furthermore, 7 s is suitable at a vehicle speed of 80 Km/h to 130 km/h, maximum two traffic agents and three junctions, and handsfree tasks but too high for lower complexities. Generally, the time budget is a sum of the takeover time and maneuver (e.g., lane change) response time. These results are relevant to safety and adaptive variation of the time budget for successful takeover.

INDEX TERMS Conditional driving automation, driver assistance, driver behavior, safety and human factors, takeover time.

I. INTRODUCTION

AUTOMATED driving systems (ADS) integrate various functions that enable drivers to perform safer and more efficient maneuvers. These functions either optimize hardware systems, warn drivers of eminent traffic danger or suggest safer maneuvers. The Society of Automotive Engineers (SAE) grouped these systems into six levels of driving automation [1]. In level 0, active safety systems enhance driving maneuvers, e.g., power steering. Beginning from level 1, the ADS is equipped to perform some driving functions where the operational design domain is limited until level 5 where this is unlimited. In level 1 to level 3, the human driver serves as the fallback performer of all driving tasks when the functional and operational limits of the ADS have been reached. Level 3, termed "conditional driving automation", is the focus of this contribution.

In conditional driving automation, the "ADS performs the entire dynamic (lateral and longitudinal) driving task (DDT) until system limits (also known as critical situations) are reached" [1]. At that point, the ADS issues a request to intervene (RTI) also denoted as a takeover request (TOR) to the driver to resume performance of the DDT [2], [3]. Usually, the driver has a few seconds to respond and takeover successfully.

The review of this article was arranged by Associate Editor Chongfeng Wei.

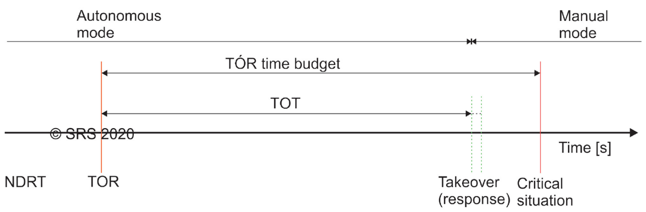

FIGURE 1. Takeover timeline definitions adapted from [5].

A. VARIABLES ASSOCIATED WITH TAKEOVERS AND PERFORMANCE

Different variables associated with TOR such as takeover time, takeover request time budget, non-driving related tasks (also known as secondary tasks), driving environment variables (e.g., speed of ego and surrounding vehicles) are illustrated in Fig. 1 based on [3], [4]. In addition, performance variables or measures are used to evaluate the takeover quality.

- Takeover time (TOT) is the time between TOR and when a considerable change in steering or pedal input by the driver has occurred [2]. The detection of this considerable change is achieved by measuring output values of the steering and pedals or computer vision-based methods [2], [6].
- Takeover request time budget (TOR time budget) is the time between TOR and when the ego vehicle will reach critical situation if present conditions (e.g., speed) persist [3], [4].
- Non-driving related tasks (NDRTs) or secondary tasks are tasks the driver may perform while the ADS is performing the DDT, e.g., reading an email [3].
- Driving environment variables include speed of ego vehicle, traffic density, number of lanes etc. Drivers' ability to have sufficient awareness of these variables in each context strongly influences the performance of takeovers and is denoted as situation awareness [4].
- Situation awareness (SA) is the "perception of elements of current situation using senses, comprehension of their meaning, and projection of their status in the near future" [7]. The level of SA a driver has varies with the aforementioned variables and affects safety [3], [4].
- Mental workload demand of the task indicates the level of individually perceived task difficulty. It can be measured objectively with physiological devices such as eye tracker and subjectively using questionnaires such as the Nasa Task Load Index (NASA-TLX) [8]. It affects performance and safety but is itself not a performance measure. Increased workload indicates increased task difficulty and vice versa.
- Performance variables are objective measures such as TOT, time to collision (TTC) between ego and surrounding vehicles, acceleration (acc.) and lateral displacement (LD) of the ego vehicle from the lane center etc. [9]. An increase in the value of some variables such as TOT, LD, and acceleration indicates poor performance and vice versa. While an increase in the value of other variables such as TTC indicates good performance and vice versa. Although, the TOT is widely used as a performance variable, it is considered unreliable because it often does not reflect the safety of the takeover [9]. Moreover, the TOT indicates when the driver has resumed significant control of the ego vehicle but does not indicate whether the driver has completed the maneuvering necessary to avert the critical situation. In other words, the driver requires additional time besides the TOT to takeover successfully. However, the TOT is still useful because its sometimes indicates the level of complexity of scenarios.

Furthermore, the TOR time budget strongly affects TOT because the driver has to takeover within this time frame to avoid accidents. This contribution focuses on equipping the ADS with the ability to automatically analyze the scenario to budget sufficient time to warn the driver even though it is unable to continue performing DDTs.

B. TAKEOVER TIME, PERFORMANCE, AND TOR TIME BUDGET

In [2], the authors concluded that when drivers have previously experienced at least one takeover, they perform better in subsequent ones indicated by reduced TOT and safer maneuvers. In [3], a TOR time budget of 8 s was investigated for different scenarios. The average TOT for the first takeover experience is 9 s and in subsequent ones, the TOT changes with respect to scenario complexity and speed. In addition, utilization of steering for takeover requires less time compared to applying the brakes. Similarly, the effect of various TOR time budgets ranging from 2.1 s to 5 s on TOT and performance were investigated in [4]. The authors concluded that a short TOR time budget increases SA but results in insufficient time to respond correctly. On the other hand, a long TOR time budget allows sufficient time to respond correctly but sometimes decreases SA. Therefore, it is necessary to analyze critical situations to determine the most suitable TOR time budget for warning drivers that would ensure good SA and successful takeovers.

According to [9], [10], the TOR time budget affects TOT and performance. In addition, a faster TOT does not necessarily mean better performance and safety variables such as workload should be used to evaluate the suitability of the TOR time budget. Increased workload is associated with shorter TOT. Furthermore in [11], a short TOR time budget results in shorter TOT and poorer performances such as risk of somersault, accident, and rear collisions. Likewise [12], [13] concluded that elderly drivers react slower and therefore require more TOR time budget compared to younger drivers. However, an approach to define the TOR time budget was not provided.

The authors of [14] compared 7 s to 4 s TOR time budget in eight scenarios and concluded that 7 s is more appropriate irrespective of the scenario. On the other hand, [15] concluded that the TOR time budget required for exiting a highway ranges between 16 s and 30 s if it is not urgent. Whereas, given this longer time, the participants mostly delayed their responses. In addition, the different characteristics of the exit scenarios where not considered in the conclusion.

In [16], the authors studied a scenario involving a cone avoidance on a test track while the ego vehicle was moving at 60 km/h with which a regression model of TOT, termed reaction time was developed. Similarly using eye data, left and right lane merge scenarios were studied to model TOR time budget using regression in [17]. In both studies, the obtained coefficients are only valid for the studied cases because the characteristics and complexity of the scenarios were not indicated in the models. In addition, the studies did not evaluate the applied TOR time budget suitability.

The authors of [6] investigated the time required by drivers to resume various driving tasks (e.g., glancing at road, mirror, and speedometer, placing feet on pedals, placing hands on steering, and switching off ADS). The results indicate that 90% of drivers require more than 8 s to complete most actions. Specifically, most drivers perform DDT first and defer most actions necessary to gain SA of the scenario (e.g., glance at mirror) to beyond 8 s. The authors also concluded that drivers who perform NDRTs with a hand-held device, e.g., playing a game on a mobile phone require more time. Similarly, studies by [18], [19], [20] have also made the aforementioned conclusion in comparison to NDRTs involving handsfree devices. However, these studies did not include the effect of TOR time budget on drivers' responses.

In [21] the authors evaluated the influence of previous ADAS experience, driver glance behaviors, and other takeover variables on TOT during an on-road experiment. The authors concluded that reduced road glances result in increased TOT and individual reaction times affect TOT. Similarly, in [22], the authors concluded that TOT varies with different drivers who have different reaction times and levels of driving experience. Accordingly, [10] concluded that TOT varies with scenario complexity, prior driving experience with automated driving technologies, and skill. The driving experience in total km driven since obtaining a drivers license also significantly affects performance. More experienced drivers takeover in less time compared to less experienced ones. However, the TOR time budget was not included.

C. RESEARCH STATEMENT AND GOAL

The aforementioned previous studies indicate that TOR time budgets are often chosen arbitrarily. Most studies focus on finding one value that is suitable for all situations irrespective of complexity. Furthermore, if the TOR time budget is too low the driver will not have sufficient time to react correctly and if too high, the driver may ignore the warning or delay response, either of which could lead to accidents. To address this problem, the TOR time budget needs to be varied to ensure appropriateness for different situations. However, a generalizable method for variation of the TOR time budget has not been provided. Furthermore, if the TOT were fully representative of the time required it could be possible to apply supervised learning approaches for time budgeting.

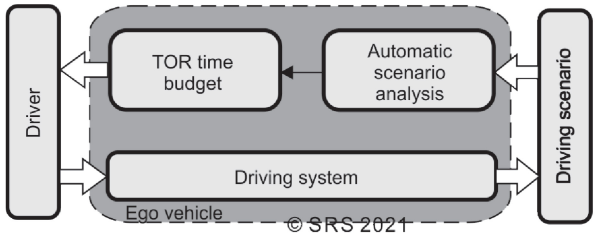

FIGURE 2. **Concept of online budgeting of TOR time.**

The hypothesis investigated in this contribution is "Could TOR time budget be determined based on driver behavior?" If the TOR time budget is too long, performance will decrease in a less complex compared to a more complex scenario. It should be noted that this is an extension of previous conclusions that increased complexity results in decreased performance which doesn't consider the effect of the TOR time budget [3], [10].

The goal of this contribution is to demonstrate how to use driver performance to qualitatively determine TOR time budget and the value that is suitable for specific takeover situations based on specific conditions. The proposed method utilizes the previously mentioned variation in driver behavior based on performance under different takeover conditions to determine the suitability of TOR time budget. To realize this, several scenarios need to be tested. It would not be possible to test all the scenarios that can occur. In addition, utilization of different scenario complexity levels is necessary to distinguish between poor performance due to delayed response and TOR time budget insufficiency. Thus in this contribution, the TOR time budget was held constant to test scenarios with different complexity levels. The long-term goal is to utilize the conclusions of this contribution to equip an ADS to budget time in advance after automatically analyzing the scenario as conceptualized in Fig. 2. In addition, automatic time budgeting would also enable the ADS to evaluate in advance whether the available time would be sufficient to takeover successfully or if additional safety measures (e.g., automatic emergency braking) would be required.

Furthermore, this contribution assumes that the ADS can automatically recognize the task being performed by the driver, predict in advance that a takeover will occur in a few seconds, and automatically recognize and track the variables (e.g., traffic agents) that would influence the TOR time budget required by the driver. The assumed requirements are not part of this contribution.

D. OUTLINE OF CONTRIBUTION

This contribution begins with a brief review of state-of-the-art approaches related to the interdependence between takeover variables. Afterwards, the contribution integrates an approach to further investigate these interdependencies with respect to scenarios and non-driving-related tasks having different complexity levels. Subsequently, the contribution includes an analysis and comparison of experimental results with respect to combinations of scenarios and NDRTs. The analysis utilizes objective performance variables such as TOT which are indicators of driver behavior to determine the suitability of the TOR time budget. Finally, the contribution ends with discussion of results, conclusions, as well as summary and outlook.

II. METHODS

Having established how the presence and magnitude of different variables affect takeovers, driving scenarios and NDRTs having different complexity levels are included to better understand how to budget TOR time online. The included scenarios and NDRTs are taken from a previous contribution [5]. It is assumed that by comparing different complexity levels of scenarios and NDRT combinations, a pattern of variation could be established.

A. TAKEOVER SCENARIOS

The scenarios are modeled as complex dynamical systems whose dimensions (e.g., connectivity, dynamics etc.) are varied between scenarios based on [23] and described in [5]. In this contribution the term 'complexity' integrates the number and interaction between vehicles, pedestrians, and bicyclists. The term 'connectivity' integrates different vehicle behaviors and maneuvers. The term 'dynamics' describes the dynamical changes within the scenario and therefore integrates changes in various vehicle positions and speeds. By definition, the magnitude of different characteristics in the scenarios are varied to study the effects on TOT and driving behavior.

Four takeover scenarios (S1, S2, S3, and S4), each having two complexity levels (I. low and II. high) in which the ADS issues a TOR were designed as illustrated in Table 1 and Fig. 3. For reference purposes, the levels of the scenarios are abbreviated accordingly. The named complexity levels are for the purposes of observing effects between the presence and magnitude of different dynamic traffic scene characteristics, e.g., ego vehicle speed, number of surrounding vehicles etc. This is such that, by varying the magnitude of some dynamic traffic scene characteristics, the difficulty of level II is higher than that of level I. Altogether, the scenarios and their complexity levels amount to eight takeover situations.

Specific traffic scene characteristics for each scenario during which the ADS issues a TOR, are outlined to reveal how the related difficulty increases from level I to level II. The levels of S1, S2, and S3 occurred on a three-lane dual carriage highway, while those of S4 occurred on a single-lane dual carriage country road. In addition, the studied scenarios integrate exits, intersections, and vulnerable road users (e.g., pedestrian) which have been less studied [24].

S1: Fixed obstacle ahead on a highway: In each level of this scenario, the ADS issues a takeover request because of a stationary vehicle ahead on the right lane. The speed of the ego vehicle was 80 km/h in S1|I and increased to 130 km/h in S1|II. In addition, there was an approaching vehicle on the middle lane to the left of the ego vehicle in S1|II moving at a speed of 70 km/h.

S2: Slow vehicle ahead on a highway: In each level of this scenario, the ADS issues a TOR due to a slow vehicle ahead moving at 50 km/h. The speed of the ego vehicle was set to 80 km/h in S2|I and increased to 130 km/h in S2|II. There was also an approaching vehicle in the middle lane to the left of the ego vehicle in S2|I moving at a speed of 70 km/h.

S3: Exit highway: In each level of this scenario, the ADS issues a TOR to the driver to exit a highway while on the right lane (exit lane). The speed of the ego vehicle was set to 50 km/h in S3|I and increased to 100 km/h in S3|II.

S4: Turn right on four junction country road intersection: In each level of this scenario, the ADS issues a TOR to the driver to make a right turn at an intersection. The speed of the ego vehicle was set to 50 km/h in S4|I and increased to 80 km/h in S4|II. In addition, a bicyclist and a pedestrian were present at the intersection on the right adjourning road

TABLE 1. Technical description of scenarios from [5].

Scenarios	Complexity levels I. Low	II. High
S1 Fixed obstacle ahead on a highway	S1|I Speed: 80 km/h No additional traffic	S1|II Speed: 130 km/h Approaching vehicle on middle lane
S2 Slow vehicle ahead on a highway	S2|I Speed: 80 km/h No additional traffic	S2|II Speed: 130 km/h Approaching vehicle on middle lane
S3 Exit highway	S3|I Speed: 50 km/h No additional traffic	S3|II Speed: 100 km/h No additional traffic
S4 Turn right on four junction country road intersection	S4|I Speed: 50 km/h No additional traffic	S4|II Speed: 80 km / h Bicyclist on right bicycle path Pedestrian crossing at right turn

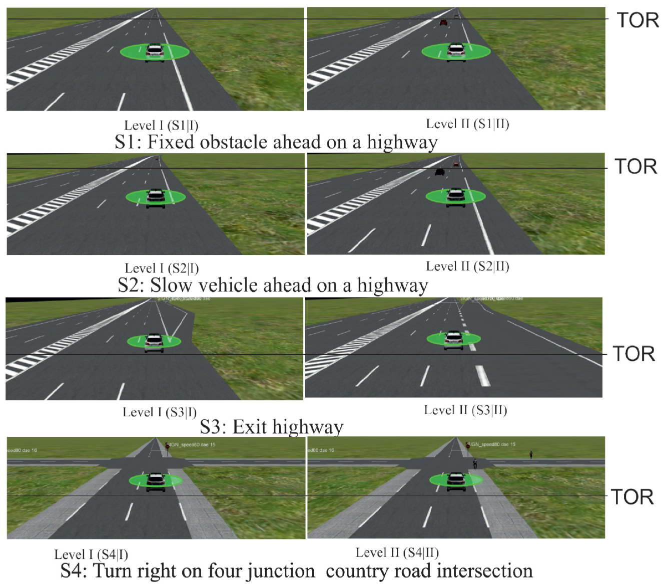

FIGURE 3. Graphical illustration of scenarios indicating point of TOR from [5].

TABLE 2. Complexity levels of NDRT reused from [5].

<table>
<tr><td colspan="3">Proofreading aloud (NDRT 3)</td></tr>
<tr><td colspan="2">Proofreading (NDRT 2)</td><td rowspan="3">Vocal</td></tr>
<tr><td>Reading (NDRT 1)</td><td rowspan="2">Motor</td></tr>
<tr><td>Procedural, Visual, Declarative</td></tr>
</table>

where the driver made the right turn. The pedestrian was crossing, while the bicyclist was making a right turn.

B. NON-DRIVING RELATED TASKS

Similar to the aforementioned scenarios and given that TOT is known to increase with task complexity, NDRTs were designed to integrate additive levels of complexity to aid comparison and understand how to vary TOR time budget. Three levels of NDRT namely reading, proofreading, and proofreading aloud were provided for drivers to perform when ego vehicle was in autonomous mode as illustrated in Table 2. The NDRTs were performed on a handsfree touch sensitive control pad mounted on the right side of the steering as subsequently detailed in section II-E. The increasing multitasking complexity of the NDRTs are explained with the theory of threaded cognition [25] in greater detail in a previous contribution and summarized in the next paragraph [5].

Threaded cognition describes the NDRTs using several cognitive resources namely procedural, declarative, visual, motor, and vocal. The complexity from NDRT 1 to NDRT 3 increases due to increased number of cognitive resources utilized [25]. Procedural resource always executes first and then coordinates all other resources [25]. Visual resource enables perception of text and declarative resource enables memory recall of words when the NDRT is reading. Motor resource enables highlighting of the text by hand when the NDRT is proofreading. Finally, vocal resource enables pronunciation of the correct word aloud when the NDRT is proofreading aloud.

C. TEST PARTICIPANTS

To perform TOR experiments, experienced drivers were invited to drive in the different levels of the designed scenarios previously displayed in Table 1. Each laboratory appointment lasted approximately three hours. First, participants filled a pre-questionnaire about their driving experience and received an introduction to the simulator and the procedure and goal of the study for approximately 15 minutes. During the introduction, the audio sound with which the TOR was issued was played for the participants. Furthermore, the participants were not informed about the takeover situations that they would encounter but where informed to takeover when they heard the audio sound.

Afterwards, the participants performed a test drive for approximately 10 minutes to adapt to the driving simulator. During the test drive, participants practiced how to switch between conditionally automated and manual driving modes. Finally, they performed four experimental drive procedures including filling questionnaires and taking a few minutes' break as detailed in the next subsection. Each complete drive procedure lasted approximately 30 to 35 minutes.

TABLE 3. Participant quantitative descriptive statistics.

Participant variable	Mean	STD	Min	Max
Age [Yrs.]	25.68	4.22	19.33	41.08
Driving experience [Yrs.]	6.44	5.35	0.08	24.42
Driving experience [km/Wk]	187.37	295.96	0.5	2000

A total of 70 drivers (60 males and 10 females) who held valid driver's licenses were recruited. Among the drivers, 28 of them had previously used vehicles equipped with one or more ADAS features, while 27 of them have previously experienced driving simulators. The additional descriptive statistics obtained from the pre-questionnaire are outlined in Table 3. Though no specific age group, type of experience or gender was targeted, the descriptive statistics for weekly driving experience indicates a distribution from very little experience to highly experienced drivers. In addition, the age group which is between 19 yrs and 41 yrs describes young drivers as categorized in [13].

As a reward, the participants either received 15 EUR or attended a three-hour time management seminar. In line with ethics rules for experiments involving humans, participants signed a participation consent declaration. The participants were also informed that their participation was voluntary and were free to discontinue the experiment if desired. In addition, written approval was obtained from the ethics committee of the Faculty of Engineering at the University of Duisburg-Essen, Germany.

D. TEST DESIGN AND PROCEDURE

The experiment was designed such that variations in TOT and performance can be studied with respect to varying traffic scenario and NDRT complexity levels. It is assumed that this is required to determine sufficient time for takeover based on the time demand of variables. Therefore previously described scenarios which have different characteristics that are associated with complexity and therefore affect TOR time budget were designed.

As concluded in [26], when all participants can not experience all scenarios, a randomized sampling approach provides more power compared to repeated measures. Different combinations of the independent variables (IVs) namely scenarios, NDRTs, and ordinal were randomly given to participants during the experiments. The ordinal refers to the order of the drive, e.g., first, second, third, or fourth drive. In other words, $8 \times 3 \times 4$ factor randomized-statistical design approach was employed to study the variation of the between-subject factors (scenario, NDRT, and ordinal levels). Specifically, each participant either experienced scenarios S1|I, S2|II, S3|I and S4|II or S1|II, S2|I, S3|II and S4|I in a random order that ensured even distribution of the scenarios as first, second, third and fourth drives respectively. The participants experienced either set of scenarios using a 4-by-4 permutation ($^4P_4$) which results in 24 distinct sequences each

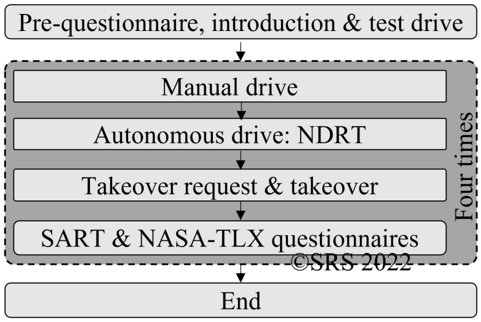

FIGURE 4. Test procedure.

FIGURE 5. Driving simulator, Chair SRS, U DuE, Germany.

that were assigned respectively. Therefore, due to the large number of combinations, all the participants did not experience all the combinations but were distributed evenly. To avoid unbalanced data measures, the participants were not allowed to experience the two levels of the same scenario, e.g., no participant experienced S1|I and S1|II respectively.

As summarised in Fig. 4 The participants were first required to drive manually for about 10 to 15 minutes before being asked to change to autonomous mode where they performed the NDRT. Afterwards, the TOR was issued to drivers 7 s before each critical situation. The TOR time budget of 7 s was chosen based on a previous study [3] integrating scenarios with ego vehicle speed between 70 km/h and 80 km/h and one or no traffic agents in which the drivers delayed response thus indicating the TOR time budget of 8 s is too high. To announce the TOR, an audiovisual interface was utilized. Based on the recommendation of [27] for emergency situations, an audio message: "full autonomous driving assistant has failed" alerts the driver to danger. On the head-up display (HUD) and Control pad, the text message: "failed" was displayed without obstructing the driver's view. Given that the expected warning message was pre-played and shown to the participants, it only served as notification to takeover. The possibility of fear and anxiety with respect to the word "failed" was not considered within the scope of this study. Participants could switch from autonomous to manual by touching the manual button on the control pad or steer and continue driving while applying the vehicle controls. After taking over, the participants filled situational awareness rating technique (SART) [28] and National Aeronautics and Space Agency task load index (NASA-TLX) with pairwise comparison [8] questionnaires. The participants were then given a few minutes' break and the drive procedure was repeated three more times until the four drives where completed. Thus participants did not experience all the takeover scenarios in one drive.

E. TEST ENVIRONMENT

The scenarios were implemented in SCANeR^{TM} studio (a professional driving simulator software by AVSimulation). The data acquiring frequency of SCANeR^{TM} studio is 20 Hz. The driving simulator setup includes five displays that provide 270 ^{0} field of view, a fixed-base driver seat, steering wheel, clutch, brake, and accelerator as displayed in Fig. 5. A rear view mirror and two side mirrors were displayed on the appropriate positions of the monitors. A control pad (touchscreen) displays the driving mode buttons on one-fourth of the screen and three-quarter of the screen was used for performing the NDRTs in conditionally automated driving mode.

F. DATA MEASURES

The measured dependent variables (DVs) include TOT, SA, workload, average lateral displacement and maximum acceleration for comparison with IVs (scenarios, NDRT, and ordinal). The definition and calculation of the measured dependent variables include:

- Takeover time: The time from TOR to 5% difference in brake or steering input depending on method of takeover used by participant. Increased TOT generally indicates increased complexity.
- Average lateral displacement: The average lateral displacement (ALD) from the lane center before and after TOR is expressed as

$$ALD = \frac{\sum LD\ (before - after)\ TOR}{\sum samples\ (before\ +\ after)\ TOR}. \qquad (1)$$

  This is an indication of lateral (steering) control. Increased average lateral displacement indicates poor performance [4].
- Maximum resultant acceleration: The maximum resultant acceleration (MRA) value attained between TOR and takeover is expressed as

$$MRA = \sqrt{acc._{longitudinal}^{2} + acc._{lateral}^{2}}. \qquad (2)$$

  This is an indication of forward collision risk. Increased MRA indicates poor performance [2].
- Situation awareness: This is a subjective rating by participants using (SART) questionnaire [28]. High ratings indicate increased SA.
- Workload: Subjective rating of participant using NASA-TLX with pairwise comparison [8] questionnaires. Increased workload ratings indicate increased task difficulty.

TABLE 4. Quantitative descriptive statistics of dependent variables with respect to scenario levels.

DVs [Mean (STD)]	S1|I	S1|II	S2|I	S2|II	S3|I	S3|II	S4|I	S4|II
TOT [s]	3.33 (2.53)	3.15 (0.89)	2.89 (1.38)	3.44 (1.09)	3.11 (1.32)	3.99 (1.61)	4.60 (2.36)	3.28 (1.68)
ALD $\times 10^{-3}$ [m]	151 (9.37)	14.6 (6.08)	14.6 (7.35)	22 (3.01)	0.103 (0.465)	0.685 (2.84)	0.00867 (0.00156)	0.0843 (0.349)
MRA [m/s^2]	1.61 (0.34)	0.08 (0.05)	2.19 (0.61)	1.06 (0.16)	0.15 (0.30)	0.35 (0.58)	0.23 (0.57)	0.18 (0.36)
SA [SART] [28]	20.45 (7.27)	16.91 (9.03)	20.26 (7.32)	16.00 (7.17)	25.55 (6.00)	24.70 (6.18)	23.14 (7.63)	20.35 (9.08)
Workload [NASA-TLX] [8]	40.51 (21)	47.38 (16.85)	42.02 (19.64)	51.16 (17.66)	33.52 (14.24)	37.79 (16.84)	41.51 (19.07)	40.93 (22.66)

Data from the first drive of three participants who did not understand the instructions when they experienced the first takeover and three other participants who experienced accidents in the first drive are excluded. The three accidents occurred in S2|II, S1|I, and S2|I which are less complex scenarios compared to S1|II and S4|II indicating delayed responses. These are the only accidents recorded.

G. ANALYSIS APPROACH

Parametric analysis assumptions of normality, homogeneity of variances and co-variance were satisfied by the DVs in relation to the IVs except ALD and MRA. Specifically for TOT, normality was satisfied after conversion. In addition, years of driving experience and weekly driving experience from participant descriptive statistics were used as covariates to interpret the influences on TOT. Thus additional MANCOVA assumptions of homoscedasticity and parallel regression line for groups were fulfilled. Significance level $p = 0.05$ was used for the analysis. Parametric MANCOVA, ANCOVA, MANOVA, and ANOVA and their associated outputs which indicate the level of significance of the tests were used to analyze TOT, SA, and workload in relation to the IVs. Furthermore, Kruskal Wallis ANOVA, a non-parametric approach was applied to analyze Avg. L Displ. and MRA in relation to the IVs. Finally, Bonferroni multi-comparison test was applied for post-hoc tests in relation to the IVs.

To analyze the results, the effect of the IVs on the DVs are compared between level I and level II of the same and different scenarios. The analysis is done from the perspective that objective performance measures such as takeover time, average lateral displacement can be used to determine if the drivers delayed, responded promptly or had insufficient time. If the drivers delayed response then the TOR time budget is too high. If drivers were prompt then the TOR time budget is suitable. If the drivers had insufficient time, then the TOR time budget is too low. As an example increased TOT could indicate delayed response in a scenario when its average lateral displacement and or maximum resultant acceleration is compared to that of a more complex scenario. In addition, subjective measures such as SA and workload are used to judge the perceived complexity of the scenarios and NDRTs.

III. RESULTS AND DISCUSSION

The quantitative descriptive statistics of the aforementioned DVs in relation to the scenarios are provided in Table 4. Two-way MANCOVA results that integrate the effect of covariates on DVs are as follows. Weekly driving experience indicates significant effect on DVs ($F(3,160) = 20.51$, $p < 0.00001$; Wilks' $\Lambda = 0.72$; partial $\eta^2 = 0.278$). While years of driving experience indicates marginally significant effect on DVs ($F(3,160) = 2.89$, $p < 0.05$; Wilks' $\Lambda = 0.95$; partial $\eta^2 = 0.051$).

ANCOVA for each DV indicates significant effect of weekly driving experience on TOT ($F(1,162) = 10.897$, $p < 0.05$; $\eta^2 = 0.063$), SA ($F(1,162) = 39.776$, $p < 0.05$; $\eta^2 = 0.197$), and workload ($F(1,162) = 35.387$, $p < 0.05$; $\eta^2 = 0.179$). Thus those who drive frequently takeover faster, have increased SA, and experience reduced workload during takeover situations. There is however no significant effect of years of driving experience on all the DVs. A quantitative measure of driving experience is essential to takeover and comparing both is necessary to identify which is significant. The results thus indicate that drivers who drive more frequently are more skilled/experienced irrespective of the number of years of owning a license and consequently takeover in less time compared to those who drive less. In addition, it is also necessary to control for the effect of the covariate to obtain the actual effect of the IVs as indicated subsequently.

The IVs have significant effects on the DVs where applicable after controlling for the covariates in the aforementioned MANCOVA results. Two-way MANOVA between IVs (Scenarios, NDRT, ordinal) and DVs (TOT, SA, workload) indicate significant interaction effect ($F(282,246.9) = 5.2$, $p < 0.05$; Wilks' $\Lambda = 0.003$; partial $\eta^2 = 0.856$).

One-way MANOVA indicates scenario has significant effect on all the DVs ($F(21,482.96) = 2.4$, $p < .05$; Wilks' $\Lambda = 0.75$; partial $\eta^2 = 0.091$). Furthermore, one-way MANOVA indicates ordinal has significant effect on all the DVs ($F(9,418.75) = 2.71$, $p < .05$; Wilks' $\Lambda = 0.87$; partial $\eta^2 = 0.045$). Likewise, one-way MANOVA indicates NDRT has significant effect on all the DVs ($F(6,346) = 2.54$, $p < .05$; Wilks' $\Lambda = 0.92$; partial $\eta^2 = 0.028$).

A. TAKEOVER TIME

Two-way ANOVA indicates no significant two-factor and three-factor interaction between the IVs and TOT. The individual factors ordinal ($F(7,177) = 7.13$, $p < 0.001$, $\eta^2 = 0.1169$) and scenario ($F(7,177) = 2.57$, $p < 0.01$, $\eta^2 = 0.1016$) have significant effects on TOT. The NDRT levels (Fig. 6) have no significant effects on TOT. However, it is known from existing studies that NDRTs performed on handsfree devices do not significantly affect TOT [18], [29], [19]. Thus, the non-effect of handsfree NDRT on TOT in the context of various NDRT and scenario complexity combinations is now confirmed in this contribution. In other words, NDRTs on handsfree devices do not require increase in the TOR time budget.

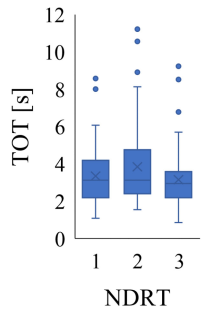

FIGURE 6. TOT for NDRTs.

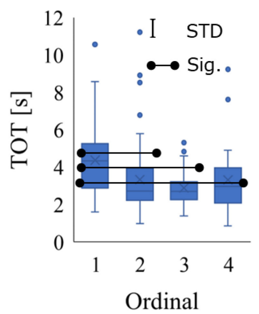

FIGURE 7. TOT for ordinal.

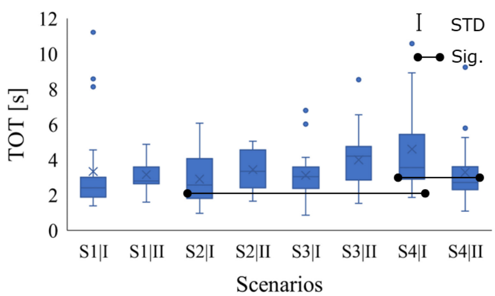

FIGURE 8. TOT for scenarios.

1) TAKEOVER TIME BETWEEN EACH ORDINAL LEVEL (FIG. 7)

Multi-comparison Bonferroni test indicates TOT is significant between first and subsequent drives. In addition, no significance exists between the second and subsequent drives as well as between the third and fourth drives which is also known from a previous study. In other words, the TOR time budget for a particular scenario should be higher when experienced by a driver as the first drive compared to when experienced as a second or later drive.

2) TAKEOVER TIME BETWEEN SCENARIOS

Takeover time between scenario and ordinal levels are illustrated in Fig. 8 and Fig. 9. Post-hoc multi-comparison Bonferroni test with correction for independent samples indicates that TOT is significant between S2|I and S4|I. Specifically, TOT for S4|I is higher compared to S2|I. Considering that S2|I is a more complex scenario due to

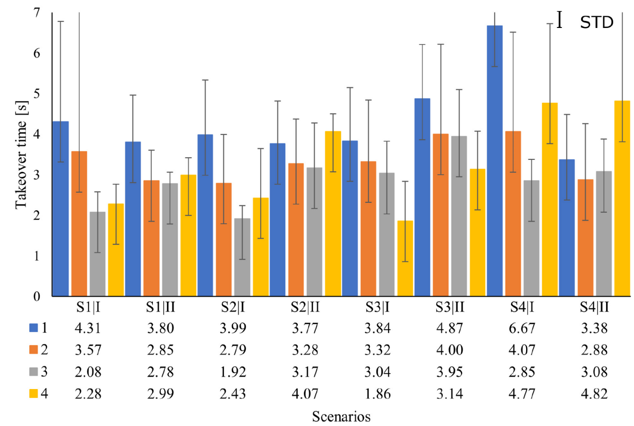

FIGURE 9. TOT for scenarios and ordinal of takeover.

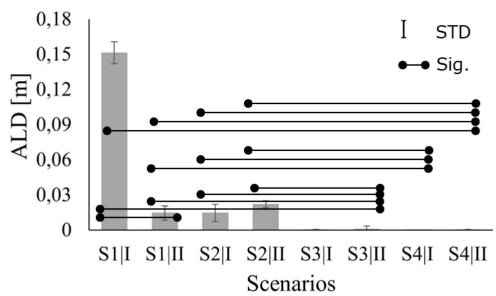

FIGURE 10. Average lateral displacement for scenarios.

a higher ego speed requiring more steering control, the increased TOT in S4|I indicates delayed response due to perceived nonurgency. At this point, it is not yet possible to conclude whether 7 s is suitable or too high for S2|I because it has to be compared to a more complex scenario.

Furthermore, TOT for S4|I (a less complex scenario in comparison) is significantly higher than S4|II which also indicates delayed response due to perceived nonurgency. This indicates that drivers had better assessment of the situation and felt more urgency to respond in S4|II. The lower speed and no traffic agents in S4|I led to increased TOT due to perceived nonurgency. Whereas, TOT is not significant between levels I and II for S1, S2, and S3. Therefore, the TOR time budget of 7 s is more appropriate for S4|II and is excess for S4|I where drivers delayed response to initially assess the situation. In other words, the decreased complexity and delayed response in S4|I indicates that the 7 s time budget is too high for S4|I.

B. AVERAGE LATERAL DISPLACEMENT AND SCENARIO

One-way Kruskal Wallis ANOVA indicates significance between scenario levels and lateral displacement (Fig. 10). Post-hoc Bonferroni multi-comparison indicates significance between different scenarios and lateral displacement.

- It is only in S1 that lateral displacement is significant between its levels. Specifically, the lateral displacement for S1|II is lower than S1|I indicating better performance in S1|II.

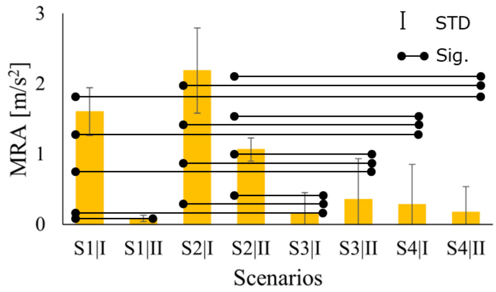

FIGURE 11. Maximum resultant acceleration for scenarios.

- The worst lateral displacement occurred in S1|I which indicates delayed and sudden erratic response.
- The mean lateral displacement in all levels of S3 are lower than all levels of S1 and S2.
- The mean lateral displacement in S4|I is lower than all levels of S1 and S2 except S1|II indicating better performance in S4|I.
- The lateral displacement in S4|II is lower than all levels of S1 and S2.

In summary, better lateral displacement was recorded in S1|II and all levels of S2, S3, and S4 compared to S1|I. Altogether, the increased performance in the more complex scenarios given a 7 s TOR time budget indicates increased effort.

C. MAXIMUM RESULTANT ACCELERATION AND SCENARIO

One-way Kruskal Wallis ANOVA indicates significant effect of different scenarios on MRA (Fig. 11).

- The MRA is significantly better in S1|II compared to S1|I indicating erratic rather than smooth reaction in the former.
- The MRA in S3|I is significantly better compared to all levels of S2.
- The worst MRA was recorded in S2|I.
- The MRA is not significant between the levels of S3 compared to the levels of S4.
- The MRA is significant between the levels of S3 and S4 compared to the levels of S1 and S2 except S1|II.
- The MRA is not significant between scenarios S1|I, S2|I, and S2|II.

Similar to ALD, better MRA was recorded for S3 and S4 compared to S1 and S2. Altogether, the more complex scenarios are better suited for the TOR time budget and resulted in increased effort and significantly better performance.

D. SITUATION AWARENESS

Two-way ANOVA indicates no significant two-factor or three-factor interaction between the IVs and SA. However, individual factors scenario ($p < 0.001$, $F(7,170) = 4.0698$, $\eta^2 = 0.1363$) and NDRT ($F(2,175) = 3.1499$, $p < 0.05$, $\eta^2 = 0.0474$) have significant effects on SA.

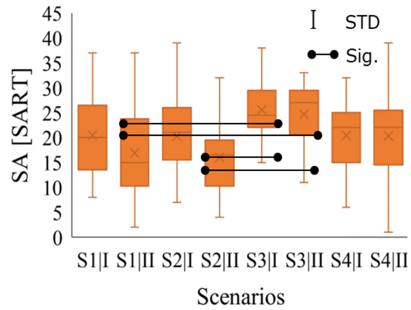

FIGURE 12. SA for scenarios.

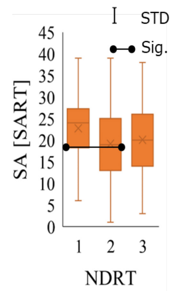

FIGURE 13. SA for NDRTs.

1) SITUATION AWARENESS BETWEEN SCENARIOS (FIG. 12)

Similar to observations for TOT, one-way ANOVA indicates significant effect of scenarios on SA. Bonferroni multi-comparison indicates SA is significant between S1|II and the two levels of S3 as well as between S2|II and the two levels of S3. The mean SA of S1|II and S2|II are significantly lower than the two levels of S3, indicating higher SA in the levels of S3. The increased SA in levels of S3 is due to a simpler scenario with one exit though with increased speed in S3|II compared to S3|I. However, no significance in SA exists between S3|I and S3|II. Altogether, the results indicate that SA is identical in scenarios with three junctions (S4|I, S4|II) and ego vehicle speed that is within 80 km/h compared to scenarios with higher ego vehicle speed range that is up to 130 km/h.

2) SITUATION AWARENESS BETWEEN NDRTS (FIG. 13)

Bonferroni multi-comparison indicates SA is significant between NDRT 1 and NDRT 2, where the mean SA for NDRT 1 is higher. In other words, NDRT 1 results in increased SA compared to NDRT 2. In addition, SA is not significant between NDRT 2 and NDRT 3 nor between NDRT 1 and NDRT 3. Thus the SA for NDRT 3 expected to require more cognitive resources based on the theory of threaded cognition is not significant compared to NDRT 1 and NDRT 2. In other words, utilization of more cognitive resources does not always lead to significantly reduced SA for NDRTs on handsfree devices.

E. WORKLOAD

Two-way ANOVA indicates no significant two-factor or three-factor interaction between the IVs and workload.

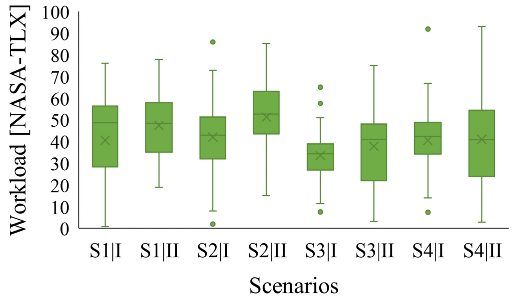

FIGURE 14. Workload for scenarios.

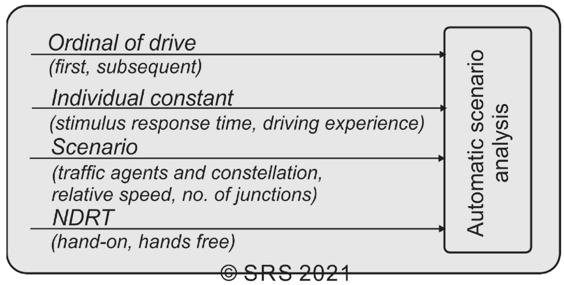

FIGURE 15. Variables for TOR time budget for scenarios.

One-way ANOVA also indicates no significant effect of the individual IVs (scenario, NDRT, and ordinal) on workload. According to [30] NASA-TLX rating for driving tasks, within 28.05% is low, between 28.05% and 41.5% is average and above 41.5% high. The recorded ratings in this contribution range from low to high, with mostly average ratings as illustrated in Fig. 14. Therefore, the rated workload indicates the studied scenarios did not result in overwhelming workload for most drivers within the 7 s TOR time budget.

IV. COMBINED RESULTS AND PREVIOUS STUDIES

The previous contribution [5] related to this work presented the variations between the average values of TOT, SA, and workload between the complexity levels of scenarios. Accordingly, a general qualitative model of TOT was proposed integrating previous takeover experience, NDRT, and assumptions about how drivers estimate scenario requirements during takeover. As an extension, this contribution integrates statistical analysis that interprets the behavior and performance of drivers based on the characteristics of takeover variables to conclude about the TOR time budget suitability.

A. DETERMINATION OF TOR TIME BUDGET SUITABILITY

Furthermore, the new findings of this contribution which indicate delayed response in S1|I, S2|I, S2|II, S3|I and S4|I and accidents in S2|II, S1|I, and S2|I imply that the budgeted 7 s is too high for S1|I, S2|I, S2|II, S3|I and S4|I which are the less complex scenarios. On the other hand, 7 s is suitable for S1|II, S3|II and S4|II indicated by increased performance and effort. The objective results do not indicate that the TOR time budget is insufficient for any of the studied scenarios in addition to the acceptable subjective SA and workload ratings of the participants. Although SA is affected by the NDRT levels, this is compensated for by increased effort which is ideal for takeovers. The effect of scenario complexity is such that the number of traffic agents, relative speed and number of junctions affect the TOR time budget.

The relative speed rather than the absolute speed of the ego vehicle in the different scenarios results in variations in driver behavior and performance. This can be seen in S2|II compared to S1|II because the ALD and MRA in S2|II is higher compared to S1|II in spite of the same absolute speed. Thus the drivers responded poorly in S2|II given that the vehicle in front was moving and didn't pose a risk of immediate collision. Although S1|II and S2|II have the same number of traffic agents, the higher relative speed in S1|II results in better performance indicating that the relative speed inspires more effort than the number of agents. In addition when S2|II is compared to S2|I, the MRA in S2|I is poorer due to delayed response though having a lower relative speed and fewer traffic agents.

Furthermore, only between the levels of S3 that the mean TOT increases in S3|II which is also the higher level with a relative speed of 100 Km/h compared to S3|I with a relative speed of 50 km/h. This indicates that the increased speed in S3|II actually requires more time and effort unlike in the other scenarios where the reverse occurs due to delayed responses in the lower levels. More so, the higher mean TOT in S3|II that has a relative speed of 100 Km/h compared to S2|II with a relative speed of 50 Km/h and S1|I with a relative speed of 80 Km/h indicates increased complexity and consequently higher time budget requirement for S3|II. Thus, based on the results of the DVs obtained for S1|II, S4|II and S3|II, the effort applied by drivers is prioritized in decreasing order of relative speed, traffic agents, and number of junctions.

B. GENERALIZATION OF TOR TIME BUDGET

In addition, from the new results in this contribution and compared to existing results from other studies [2], [12], [18], [21], [22], [29], the variables for budgeting TOR time online considering the defined conditions in the studied scenarios are summarized in Fig. 15 as an extension of Fig. 2. Specifically, more time should be budgeted for the first drive of every scenario irrespective of whether the driver is familiar with the process of switching back to manual driving. In other words, the time related to the ordinal should be subtracted from the TOR time budget in a second or subsequent experience of a scenario.

Furthermore, TOT and consequently TOR time budget is only significantly higher with NDRTs that involve the use of hand-held devices compared to those involving hands-free devices as utilized in this contribution irrespective of the increase in other cognitive resources. More so, individual driving experience [km/wk] defined and utilized in this contribution covaries with TOT which and should be integrated into the TOR time budget. Combining driving experience with individual stimulus response time concluded from previous studies [21], [22], constitute individual reaction time. Altogether, the TOR time budget can therefore also be expressed as a combination of the mean and standard deviation of TOT [s] and maneuver response time (MRT [s]) as

$$TOR\ time\ budget\ [s] \ = Mean\ TOT \pm STD + MRT. \quad (3)$$

Therefore, substituting the mean and standard deviation of TOT values from Table 4 in (3), the MRT for scenarios S1|II, S3|II, and S4|II can be calculated as in (4), (5), and (6). The calculated MRT values correspond to the time required to complete a lane change, take an exit, and turn at an intersection during takeover based on a 7 s TOR time budget which has been established in this contribution to be appropriate for the related scenarios.

$$S1|II : MRT\ [s] = 7 - 3.15 \pm 0.89 = 3.85 \pm 0.89 \quad (4)$$

$$S3|II : MRT\ [s] = 7 - 3.99 \pm 1.61 = 3.01 \pm 1.61 \quad (5)$$

$$S4|II : MRT\ [s] = 7 - 3.28 \pm 1.68 = 3.72 \pm 1.68 \quad (6)$$

Based on, (4) it can also be noted that the MRT of 3.85 s ± 0.89 for a lane change during takeover is higher than in active manual driving which is 2.5 s [31].

C. LIMITATIONS

Though this contribution is limited by the use of a driving simulator for experiments and data collection it provides insights for the future study of TOR time budgeting. Likewise though drivers are informed to treat experiments like real driving situations it is possible that perception of danger would be different compared to on-road driving. In addition, driving simulator experiments may not sufficiently integrate on-road conditions and real vehicle effects such as skidding. The studied scenarios are not exhaustive but demonstrate how to determine TOR time budget suitability using appropriate examples.

V. SUMMARY, CONCLUSION, AND OUTLOOK

This contribution utilizes the interdependence of driver behavior and performance to determine TOR time budget suitability for specific scenario examples. Four takeover scenarios each having two levels of complexity and three NDRTs were investigated with 70 participants. The takeover requests were issued to the drivers at 7 s TTC before each critical situation in the scenarios.

The results indicate that 7 s is too high for scenarios integrating ego vehicle speed of 80 km/h or less, one or no traffic agents, and up to three junctions. Furthermore, a 7 s time budget is suitable for higher ego speeds especially from 100 km/h to 130 km/h and two traffic agents with and without junctions. In addition, the TOR time budget required depends on weekly driving experience and is prioritized by drivers in the order of relative speed, traffic agents, and number of junctions in the scenario.

The results in this contribution are generalizable because the rules, effects and complexity levels of the takeover variables including specific scenario characteristics that require a 7 s TOR time budget are systematically specified. This will form the basis for budgeting suitable time for takeovers in future studies and applications. In addition, the average time required to complete some takeover responses such as lane change, making a turn at an intersection, and taking an exit are provided.

The results of this contribution are relevant to the adaptive budgeting of TOR time in advance and to evaluate if the available time would be sufficient for safety. As next step, the effect of interface support indicating collision hazard, individual variations in age, driving experience, and stimulus response time could be investigated to determine how to adjust the TOR time budget. Finally, quantitative estimation of the variables that determine TOR time budget could also be performed to enable extrapolation to other scenarios.

ACKNOWLEDGMENT

The authors would like to thank Prof. Dr. rer. nat. Johannes Gottschling, University of Duisburg-Essen, Germany for providing additional guidance necessary to perform the statistical analysis in this contribution.

REFERENCES

[1] "Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles." Society of Automation Engineers (SAE). Apr. 2021. [Online]. Available: https://www.sae.org/standards/content/j3016_202104

[2] S. Hergeth, L. Lorenz, and J. F. Krems, "Prior Familiarization with takeover requests affects drivers' takeover performance and automation trust," *Human Factors*, vol. 59, no. 3, pp. 457–470, 2017.

[3] J. Wang and D. Söffker, "Bridging gaps among human, assisted, and automated driving with DVIs: A conceptional experimental study," *IEEE Trans. Intell. Transp. Syst.*, vol. 20, no. 6, pp. 2096–2108, Jun. 2019.

[4] H. J. Kim and J. H. Yang, "Takeover requests in simulated partially autonomous vehicles considering human factors," *IEEE Trans. Human-Mach. Syst.*, vol. 47, no. 5, pp. 735–740, Oct. 2017.

[5] F. Tanshi and D. Söffker, "Modeling of takeover variables with respect to driver situation awareness and workload for intelligent driver assistance," in *Proc. IEEE Intell. Veh. Symp. (IV)*, Jun. 2019, pp. 1667–1672.

[6] T. Vogelpohl, M. Kühn, T. Hummel, T. Gehlert, and M. Vollrath, "Transitioning to manual driving requires additional time after automation deactivation," *Transp. Res. F, Traffic Psychol. Behav.*, vol. 55, pp. 464–482, May 2018.

[7] M. R. Endsley, "Design and evaluation for situation awareness enhancement," in *Proc. Human Factors Ergonom. Soc. Annu. Meeting*, vol. 32, 1988, pp. 97–101.

[8] S. G. Hart and L. E. Staveland, "Development of NASA-TLX (task load index): Results of empirical and theoretical research," *Adv. Psychol.*, vol. 52, pp. 139–183, 1988.

[9] H. Wu, C. Wu, N. Lyu, and J. Li, "Does a faster takeover necessarily mean it is better? A study on the influence of urgency and takeover-request lead time on takeover performance and safety," *Accid. Anal. Prevent.*, vol. 171, Jun. 2022, Art. no. 106647.

[10] M. Jin, G. Lu, F. Chen, X. Shi, H. Tan, and J. Zhai, "Modeling takeover behavior in level 3 automated driving via a structural equation model: Considering the mediating role of trust," *Accid. Anal. Prevent.*, vol. 157, Jul. 2021, Art. no. 106156.

[11] F. Roche, M. Thüring, and A. K. Trukenbrod, "What happens when drivers of automated vehicles take over control in critical brake situations?" *Accid. Anal. Prevent.*, vol. 144, Sep. 2020, Art. no. 105588.

[12] S. Li et al., "Evaluation of the effects of age-friendly human-machine interfaces on the driver's takeover performance in highly automated vehicles," *Transp. Res. F, Traffic Psychol. Behav.*, vol. 67, pp. 78–100, Nov. 2019.
[13] H. Clark and J. Feng, "Age differences in the takeover of vehicle control and engagement in non-driving-related activities in simulated driving with conditional automation," *Accid. Anal. Prevent.*, vol. 106, pp. 468–479, Sep. 2017.
[14] N. Du et al., "Evaluating effects of cognitive load, takeover request lead time, and traffic density on drivers' takeover performance in conditionally automated driving," in *Proc. 12th Int. Conf. Autom. User Interfaces Interactive Veh. Appl.*, 2020, pp. 66–73.
[15] X. Tan and Y. Zhang, "The effects of takeover request lead time on drivers' situation awareness for manually exiting from freeways: A Web-based study on level 3 automated vehicles," *Accid. Anal. Prevent.*, vol. 168, Apr. 2022, Art. no. 106593.
[16] Y. Wu et al., "Eye movements predict driver reaction time to takeover request in automated driving: A real-vehicle study," *Transp. Res. F, Traffic Psychol. Behav.*, vol. 81, pp. 355–363, Aug. 2021.
[17] Q. Li et al., "Drivers' visual-distracted take-over performance model and its application on adaptive adjustment of time budget," *Accid. Anal. Prevent.*, vol. 154, May 2021, Art. no. 106099.
[18] Y. Nakajima and K. Tanaka, "Effects of active and passive secondary tasks in a take-over situation during automated driving," in *Proc. IEEE Int. Conf. Syst., Man, Cybern. (SMC)*, Oct. 2017, pp. 1161–1166.
[19] F. Naujoks, C. Purucker, K. Wiedemann, and C. Marberger, "Noncritical state transitions during conditionally automated driving on german freeways: Effects of non–driving related tasks on takeover time and takeover quality," *Human Factors*, vol. 61, no. 4, pp. 596–613, 2019.
[20] S. H. Yoon, Y. W. Kim, and Y. G. Ji, "The effects of takeover request modalities on highly automated car control transitions," *Accid. Anal. Prevent.*, vol. 123, pp. 150–158, Feb. 2019.
[21] F. L. Berghöfer, C. Purucker, F. Naujoks, K. Wiedemann, and C. Marberger, "Prediction of take-over time demand in conditionally automated driving—Results of a real world driving study," in *Proc. Annu. Conf. Human Factors Ergonom. Soc.*, Oct. 2018, pp. 69–82. [Online]. Available: https://www.hfes-europe.org/wp-content/uploads/2018/10/Purucker2018.pdf
[22] A. Eriksson and N. A. Stanton, "Takeover time in highly automated vehicles: Noncritical transitions to and from manual control," *Human Factors*, vol. 59, no. 4, pp. 689–705, 2017.
[23] D. Dörner, "The logic of failure," *Philosoph. Trans. Royal Soc. London B, Biol. Sci.*, vol. 327, pp. 463–473, May 1990.
[24] A.-K. Frison, Y. Forster, P. Wintersberger, V. Geisel, and A. Riener, "Where we come from and where we are going: A systematic review of human factors research in driving automation," *Appl. Sci.*, vol. 10, no. 24, p. 8914, 2020.
[25] D. D. Salvucci and N. A. Taatgen, "Threaded cognition: An integrated theory of concurrent multitasking," *Psychol. Rev.*, vol. 115, no. 1, pp. 101–130, 2008.
[26] B. Donmez, L. N. Boyle, and J. D. Lee, "Driving simulator experiments: Power for repeated measures vs. completely randomized design," in *Proc. Human Factors Ergonom. Soc. Annu. Meeting*, vol. 50, 2006, pp. 2336–2339.
[27] M. S. Wogalter, K. R. Laughery Sr., and C. B. Mayhorn, "Warnings and hazard communications," in *Handbook of Human Factors/Ergonomics*, 4th ed. New York, NY, USA: Wiley, 2012, ch. 29, pp. 868–894.
[28] R. Taylor, "Situational awareness rating technique (SART): The development of a tool for aircrew systems design," in *Proc. Situational Awareness Aerosp. Oper. Aerosp. Med. Panel Symp.*, Oct. 1989, p. 18.
[29] J. Radlmayr, F. M. Fischer, and K. Bengler, "The influence of non-driving related tasks on driver availability in the context of conditionally automated driving," in *Proc. 20th Congr. Int. Ergonom. Assoc. (IEA)*, 2018, pp. 295–304.
[30] R. A. Grier, "How high is high? A meta-analysis of NASA-TLX global workload scores," in *Proc. Human Factors Ergonom. Soc. Annu. Meeting*, vol. 59, 2015, pp. 1727–1731.
[31] Q. Deng, J. Wang, K. Hillebrand, C. R. Benjamin, and D. Söffker, "Prediction performance of lane changing Behaviors: A study of combining environmental and eye-tracking data in a driving simulator," *IEEE Trans. Intell. Transp. Syst.*, vol. 21, no. 8, pp. 3561–3570, Aug. 2020.

FOGHOR TANSHI (Member, IEEE) received the Dr.-Ing. degree in mechanical engineering from the University of Duisburg–Essen, Germany, in 2021. Her current research interests include driver assistance systems and intelligent vehicles, traffic analysis, intelligent transportation systems, human-machine interfaces and interaction, and cognitive systems.

DIRK SÖFFKER (Member, IEEE) received the Dr.-Ing. degree in mechanical engineering and the Habilitation degree in automatic control/safety engineering from the University of Wuppertal, Wuppertal, Germany, in 1995 and 2001, respectively. Since 2001, he has been the Chair of Dynamics and Control with the University of Duisburg-Essen, Germany. His current research interests include elastic mechanical structures, modern methods of control theory, human interaction with safe technical systems, safety and reliability control engineering of technical systems, and cognitive technical systems.

DOI: 10.1109/OJITS.2022.3224677
URN: urn:nbn:de:hbz:465-20230628-140456-8