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Investigation of the influence of multitasking on drivers' takeover performance in highly automated vehicles

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Abstract
The forthcoming highly automated vehicles (HAVs, SAE Level 3 and beyond) would introduce a new type of human-machine interaction that would allow drivers to be completely disengaged from driving and safely perform other non-driving-related tasks. However there are situations where the HAV system would still need human drivers to take back control within a sufficient lead time. In HAVs, drivers might not only perform a single task but also engage in multiple tasks concurrently. This study investigates the effects of engaging in multitasking on drivers' takeover performance in HAVs. A driving simulator investigation with 8 participants (aged 20-49 years, 4 females and 4 males) was implemented. Results showed that multitasking leads to prolonged takeover time and slowed decision-making. The findings emphasise the importance of including end users in the design process of HAVs.
Keywords:
Highly automated vehicle, takeover control, driving simulator

1. Introduction

The introduction of connected and autonomous vehicles potentially delivers thrilling and transformational opportunities for reducing car accidents and emission, improving road efficiency, connectivity and social inclusion (DfT, 2015; CCAV, 2018). There are several levels of vehicle automation systems and each level offers different functionalities and requires different levels of input from the human drivers. In the low levels of automation such as SAE Levels 0 and 1 human drivers are completely responsible for the safe operation of the vehicle although they may receive single or multiple support and assistance from the vehicle (SAE, 2014; DfT, 2015). In ultimate levels of vehicle automation, such as SAE Level 4 or 5, the vehicle is capable of safely driving the car for the whole journey without human drivers' intervention (SAE, 2014; DfT, 2015). Before the highest levels of vehicle automation systems become available on the road, the highly automated vehicles (HAVs, SAE Level 3) would be a transitional step and might be available quite soon (UKAutodrive, 2016). These HAVs could bring new types of driver-vehicle interaction which would enable drivers to be completely disengaged from driving and safely perform a variety of non-driving-related tasks. However there are still situations that the HAV system might not be able to cope with. In places without network signal or complete road markings, the human driver would need to retake the control of the car within a sufficient lead time (SAE, 2014; DfT, 2015). Guaranteeing a safe and smooth takeover is essential for the safety of HAVs.

1.1 Purpose of study

Previous research has studied the effects of engaging in non-driving-related tasks in HAVs on drivers' performance in taking over control of the car and found it leads to deteriorations in performance (Merat *et al.*, 2012; Gold *et al.*, 2013; Radlmayr *et al.*, 2014; Li *et al.*, 2019a). However, they tend to adopt a single task to distract participants' attention during the automated driving; the effects of engaging in multitasking on drivers' performance remains unclear. To fill this knowledge gap this research aims to investigate the effect of engaging in multitasking on drivers' takeover performance in HAVs.

2. Method

2.1 Participants

The participants in this study were students of Newcastle University. Their detailed demographic data is summarised in Table 1.

Table 1 – Participants demographic data

Participant NO.	*Gender*	*Age (years)*	*Driving Licences*	*Annual Mileage(miles)*
1	Female	20-24	No	N/A
2	Male	20-24	No	N/A
3	Male	45-49	Yes	10000-15000
4	Male	25-29	Yes	3000-6000
5	Female	25-29	No	N/A
6	Female	20-24	Yes	0-3000
7	Male	20-24	Yes	0-3000
8	Female	20-24	Yes	3000-6000

2.2 Driving simulator and HAV scenario

This study used the Newcastle University fixed-based ST software Jentig 50 driving simulator, as shown in Figure 1. It consists of 5 LCD screens mounted in an aluminium cabin. It has all the controls of an actual vehicle including a dynamic force feedback steering wheel, accelerator, brake and clutch pedals, and adjustable driver seat. The dashboard, rear-view and side mirrors are simulated on the screen. It also has 5.1 surround-sound which gives participants an authentic driving experience. This driving simulator has been used in several previous studies and has been proved to be effective and valid in terms of studying drivers' interaction with in-vehicle technologies (Guo *et al.*, 2013; Edwards *et al.*, 2016; Li *et al.*, 2018; Li *et al.*, 2019b; Li *et al.*, 2019a).

Figure 1 –Newcastle University fixed based driving simulator and multitasking in the HAV.

As Figure 2 shows, the HAV scenario used in this study simulates highly automated driving on an urban road with a speed limit of 30mph. It starts with automated driving for one minute. During the one-minute self-driving the drivers had been turned away from the steering wheel, brake and acceleration pedals, and were allowed to shift their attention away from the road and to engage freely in some non-driving-related tasks. At the one-minute time point the automation system sensed a critical incident –a red car suddenly popped up in the road ahead and then it asked the drivers to take back the control of the car and deal with the critical incident by changing lane. Drivers had twenty seconds to stop performing the non-driving-related tasks, regain control of the car and respond to the incident. After the drivers had successfully avoided the red car ahead they were told to pull over to the kerb and the scenario ended (Li et al., 2018; Li et al., 2019a).

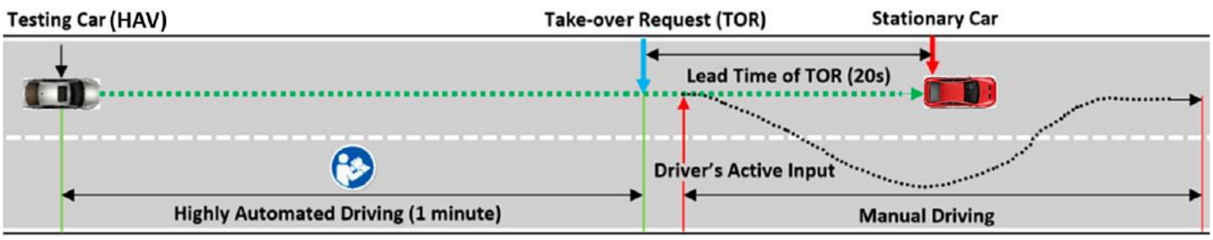

Figure 2 –Illustration of the HAV scenario (Li et al., 2018; Li et al., 2019a).

2.3 Multitasking in HAV

To investigate the effect of multitasking on drivers' takeover performance several tasks needed to be selected to distract the participants in the HAV. Li *et al.* (2019b) reported a variety of user-preferred tasks when a vehicle is performing automated driving. Among these tasks watching a movie, using a mobile phone and drinking coffee were the most popular options and would represent authentic use-cases for an HAV (Li *et al.*, 2019b). They were therefore selected as the non-driving-related tasks for participants during the automated driving period in this experiment (Figure 3). To further distract the drivers the weather condition was changed to snow. Apart from the multi-task situation a "no task" situation was adopted as the baseline condition as opposed to the experimental condition. In the no task situation the participants were not distracted by any tasks and the weather was clear.

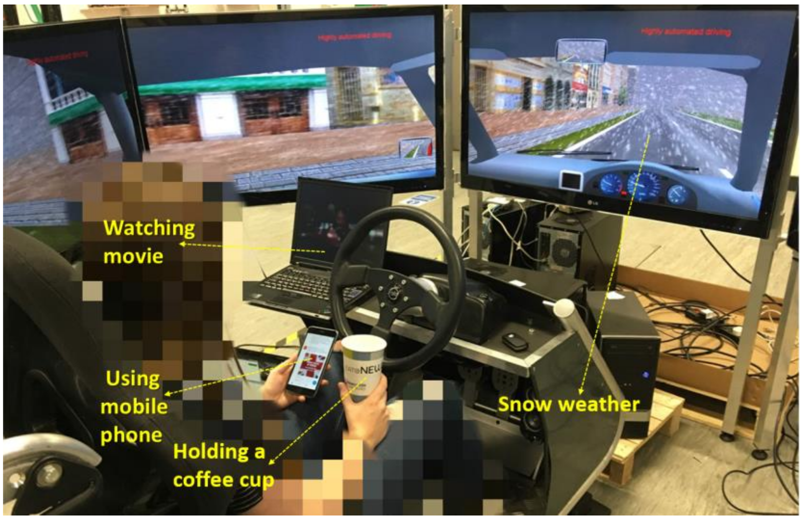

Figure 3 –Participants engaged in multitasking in the HAV.

2.4 Experimental design

This study adopted a within-subject experimental design. The benefit of this type of design is that it allows each participant to be exposed to both the experimental and baseline conditions so that the participants become their own control group, which reduces the negative influence of natural variance between participants on the results. The within-subjects independent variable is the type of non-driving-related tasks which consists of two levels of multi-task and no task.

Table 2 – Dependent variables

Dependent variables	***Unit***
Cup and mobile phone positions	Count
Average takeover trajectories	N/A
Takeover time	s
Indicator time	s
Time to collisions (TTC)	s
Longitudinal acceleration	m/s^2
Steering wheel angle	degree

To quantify participants' takeover behaviour and performance several dependent variables were used as shown in table 2. First, in the multi-task situation, participants' hands were occupied by holding a mobile phone and a coffee cup. At the moment the automation system asks them to take back control of the car they would have to put the cup and mobile phone down somewhere in order to release their hands to grab the steering wheel, therefore the position of where they put the cup and mobile phone would be an important dependent variable to understand their reaction behaviour. Second, the average takeover trajectories are adopted to illustrate participants' takeover behaviour. The time-related takeover parameters include takeover time and indicator time (Gold *et al.*, 2013; Li *et al.*, 2018; Li *et al.*, 2019a). Takeover time measures the time between the time point that the automation system asks the drivers to retake control of the vehicle and the point that drivers generate their first conscious input to the car. This parameter reflects how quickly drivers retake control of the car when asked to do so by the automated vehicle. Indicator time measures the time between the moment that the automation system asks the drivers to retake control of the car and the moment that drivers generate the indicator signal for changing lane. This parameter is adopted to measure the speed of drivers' decision making for the lane change.

Apart from time-related parameters, quality-related parameters include time to collision, longitudinal acceleration and steering wheel angle (Li *et al.*, 2018; Li *et al.*, 2019a). Time to collision refers to the time it would take for the HAV to collide with the stationary red car ahead if it had kept driving at its current speed at the moment when it had successfully avoided the stationary red car ahead. This parameter reflects the success of the drivers' retaking control, where the smaller the time to collision the more dangerous and serious the quality of the takeover. The acceleration refers to the maximum longitudinal acceleration that the drivers executed when reassuming the control of the vehicle. The greater the value of the parameter, the higher the chance that the takeover is becoming unstable. Steering wheel angle refers to the standard deviation in degrees of drivers' operation of the steering wheel. It is a useful parameter to quantify the stability of the retake control. A greater value represents a less stable retaking of control.

2.5 Procedure and data analysis

This study followed the following procedure. Two researchers were involved in the data collection of the study. First one researcher guided the participants to the drive simulator lab while the other set up the HAV scenario on the simulator. After that the participant was given a safety briefing in the laboratory followed by a brief explanation of this study. Then each participant experienced the no task situation first and then the multi-task situation on the driving simulator. After all the participants have finished the driving tests the data collection concluded. Finally the data of participants' takeover performance was extracted from the driving simulator. For the data analysis a Shapiro-Wilks test was implemented for checking normality and then paired samples t-tests were used to investigate the effect of multitasking on takeover performance. The data analysis was executed using SPSS.

3. Results

3.1 Takeover trajectories

Figure 4 shows the mean trajectories participants exhibited when retaking the control from the HAV under no task and multi-task situations. It shows that there are clear gaps between the main trajectories under these two situations. The mean trajectory of the no task situation is smoother and fluctuates less compared to the multi-task situation.

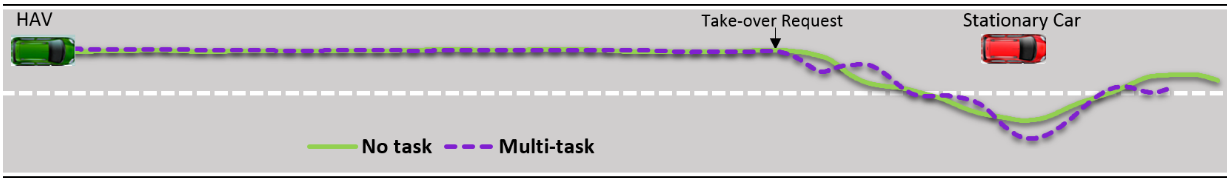

Figure 4– Takeover trajectories of No task and Multi-task situations.

3.2 Cup and mobile phone positions

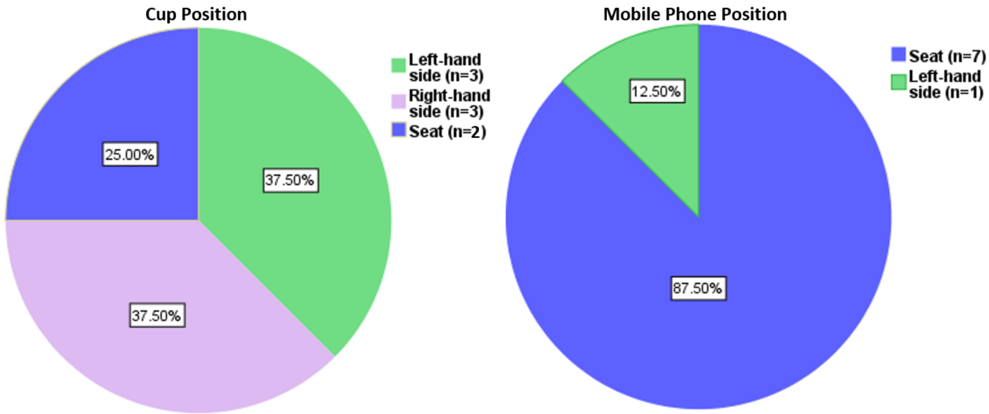

Figure 5 –Cup and mobile phone positions in multi-task situation.

Figure 5 illustrates the proportion of the positions where participants put the cup and mobile phone after the moment that they were asked to take control back from the vehicle in multi-task conditions. In terms of the 'coffee cup', 3 people put it on the left-hand side and 3 put it on the right-hand side. Two people put it on the seat. For the 'mobile phone' 7 people put it on the seat and one person put it on the left-hand side.

3.3 Takeover time

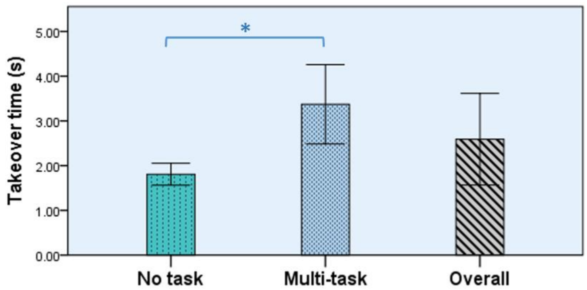

Figure 6 – Takeover time in No task and Multi-task situations, significant difference is highlighted by*.

As displayed in Figure 6 overall, participants had an average takeover time of 2.49s (SD=1.03s). They had a faster takeover in no task situations (m=1.80s, SD=0.24s) than in the multi-task situation (m=3.37s, SD=0.89s). A paired samples t-test revealed that the difference is statistically significant, t(6) = -4.945, p=0.003, with a significant difference of 1.56s (95% CI, 0.79s to 2.34s).

3.4 Indicator time

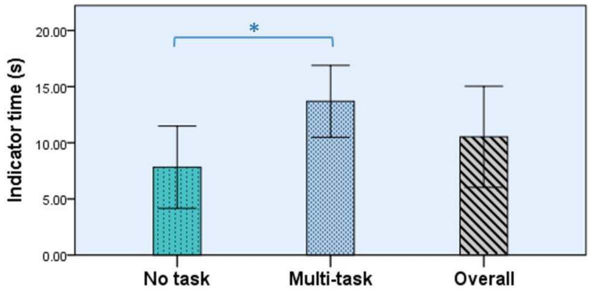

Figure 7 – Indicator time in No task and Multi-task situations, significant difference is highlighted by*.

As showed in Figure 7, overall participants had an average indicator time of 10.22s (SD=4.13s). They made the decision to change lane more quickly in the no task situation (m=6.81s, SD=2.71s) compared to in multi-task situation (m=13.69s, SD=3.20s). A paired samples t-test showed that the difference is statistically significant, t(5) = -7.042, p=0.01, with a significant difference of 6.89s (95% CI, 4.37s to 9.40s).

3.5 Time to collision

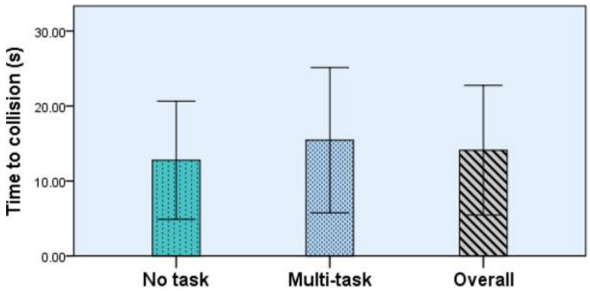

Figure 8– Time to collision in No task and Multi-task situations.

As Fig 8 show the participants had an overall mean time to collision of 14.27s (SD=8.68s). Participants' time to collision in the no task situation (M=12.76s, SD=7.88s) was slightly shorter compared to the multi-task situation (M=15.44s, SD=9.69s). However the difference is not statistically significant as assessed by a paired samples t-test, t(7) = -0.547, p=0.601.

3.6 Longitudinal acceleration

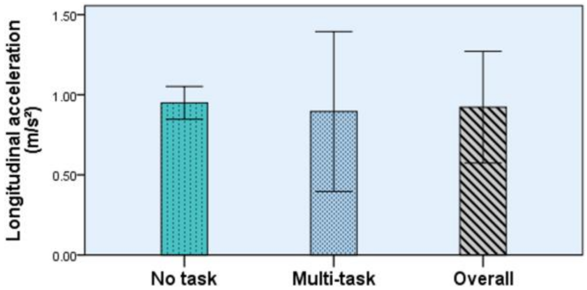

Figure 9– Longitudinal acceleration in No task and Multi-task situations.

Fig 9 shows that the participants exhibited an overall mean acceleration of 0.83m/s² (SD=0.36m/s²). Drivers' acceleration is slightly greater in the no task situation (M=0.95m/s², SD=0.10m/s²) compared to the multi-task situation (M=0.90m/s², SD=0.50m/s²). However, an paired samples t-test showed that the difference is not statistically significant, $t(7) = 0.323$, $p=0.756$.

3.7 Steering wheel angle

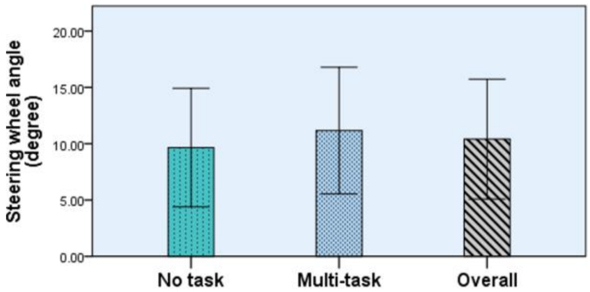

Figure 10 –Steering wheel angle in No task and Multi-task situations.

Figure 10 shows that the participants exhibited an overall mean steering wheel angle of 8.62degrees (SD=4.87degrees). They exhibited a smaller steering wheel angle of 9.66 degrees (SD=5.26 degrees) in the no tasks situation compared to the multi-task situation (M=11.17 degrees, SD=5.63 degrees). However, again, the difference was not statistically significant, $t(7) = -.558$, $p=0.594$.

4. Discussion

The aim of this study was to investigate the influence of distraction caused by multitasking on drivers' takeover performance in HAVs. The results show that compared to a no task situation when the participants engaged in multitasking they exhibited significantly slower time to generate active input to the vehicle, as well as a significant delayed decision to change lane to avoid the stationary red car ahead when reassuming the control of the car from the HAV. This finding could possibly be explained as follows. When drivers were engaged in multitasking they had a relatively higher visual and cognitive task load as their attention might have been distracted by the movie, the content on the mobile phone as well as the weather (snowing effect) compared to the no task situation. In addition, compared to the no task situation, in the multitasking situation participants also had higher manual task load as their hands were occupied by the mobile phone and the coffee cup. At the moment when the HAV system suddenly sensed the red car ahead and asked drivers to intervene the participants would have had to switch their attention from the movie and the mobile phone to the road; find places to put down the phone and coffee cup to free their hands to grab the steering wheel; put their feet on the pedals; regain situation awareness and then make a decision. This entire process might have resulted in the delayed takeover time and time to make the decision for a lane change.

This finding is generally in line with previous findings showing that the 'out-of-the-loop' (OoTL) phenomenon caused by performing non-driving-related tasks significantly prolongs drivers' speed of reaction and decision making when retaking control from the automated vehicles (Endsley and Kiris, 1995; Merat *et al.*, 2012; Gold *et al.*, 2013; Radlmayr *et al.*, 2014; Edwards *et al*., 2018; Li *et al.*, 2019b; Li *et al.*, 2019a). This finding is also in accordance with Zeeb *et al.* (2017) who reported that engaging in non-driving-related tasks with higher manual task load led to slower reaction times when retaking control from the HAVs. Another important finding of this study was the locations where participants chose to put down the cup and mobile phones when being asked to reassume the control of the car. For the coffee cup, they tend to put it down on the left-hand side or right-hand side, depending on the hand in which they were holding the cup; for the mobile phone, the majority of participants chose to put it on the driver's seat. These findings have important implications for car manufacturers in terms of designing the interiors of HAVs. Tailored facilities, such as cup holders on both side of the driver's seat, as well as mobile phone holders near the driver's seat, should be provided to better support users and enhance their experience of interacting with the HAVs.

5. Conclusion

This study aimed to investigate the influence of engaging in multitasking on drivers' takeover performance in HAVs. It found that compared to interacting with the HAV without performing any non-driving-related tasks, engaging in multitasking prolonged the time of taking control and decision making when drivers were retaking the control of the car from the HAVs. The findings of this study have important implications for the design of human-machine interactions in HAVs. It would be necessary for the HAV system to provide additional support, such as a longer time budget for takeover or more information about the driving environment, to the drivers who were engaging in multitasking during the takeover control process. In addition the designers of the interiors of HAVs should consider the non-driving-related tasks that drivers might perform and provide relevant facilities to support them. Overall, this study highlights the significance of incorporating the end-user in the design process of vehicle automation in developing user-friendly automated vehicles. This study revealed important findings, however, there are still some limitations. First, the sample size of the study was small and three participants did not have valid driving licences. Future research could validate the current results using larger sample sizes and only include participants with full driving licences. Second, the current study used several non-driving-related tasks including watching a moving, using a mobile phone and drinking coffee. Future research could adopt different tasks, such as eating, using a laptop or talking with passengers, to explore their impact on drivers' interaction with automated vehicles.

References

1. CCAV (2018) UK Connected & Autonomous Vehicle Research & Development Projects 2018. [Online].Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/737778/ccav-research-and-development-projects.pdf.
2. DfT (2015) The Pathway to Driverless Car: A Code of Practice for Testing. [Online]. Available at:

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/446316/pathway-driverless-cars.pdf

3. Edwards, S.J., Emmerson, C., Namdeo, A., Blythe, P.T. and Guo, W. (2016) 'Optimising landmark-based route guidance for older drivers', Transportation Research Part F: Traffic Psychology and Behaviour, 43, pp. 225-237.
4. Edwards S, Hill G, Goodman P, Blythe P, Mitchell P, Huebner Y. (2018) 'Quantifying the Impact of a Real World Cooperative-ITS Deployment across Multiple Cities', Transportation Research Part A: Policy and Practice 2018, 115, pp. 102-113.
5. Endsley, M.R. and Kiris, E.O. (1995) 'The out-of-the-loop performance problem and level of control in automation', Human factors, 37(2), pp. 381-394.
6. Gold, C., Damböck, D., Lorenz, L. and Bengler, K. (2013) In Proceedings of the Human Factors and Ergonomics Society Annual Meeting. Los Angeles: SAGE
7. Guo, W., Blythe, P.T., Edwards, S., Pavkova, K. and Brennan, D. (2013) 'Effect of intelligent speed adaptation technology on older drivers' driving performance', IET intelligent transport systems, 9(3), pp. 343-350.
8. Li, S., Blythe, P., Guo, W. and Namdeo, A. (2018) 'Investigation of older driver's takeover performance in highly automated vehicles in adverse weather conditions', IET Intelligent Transport Systems, 12(9), pp. 1157-1165.
9. Li, S., Blythe, P., Guo, W. and Namdeo, A. (2019a) 'Investigating the effects of age and disengagement in driving on driver's takeover control performance in highly automated vehicles', Transportation Planning and Technology, 42(5), pp. 470-497.
10. Li, S., Blythe, P., Guo, W. and Namdeo, A. (2019b) 'Investigation of older drivers' requirements of the human-machine interaction in highly automated vehicles', Transportation Research Part F: Traffic Psychology and Behaviour, 62, pp. 546-563.
11. Merat, N., Jamson, A.H., Lai, F.C. and Carsten, O. (2012) 'Highly automated driving, secondary task performance, and driver state', Human factors, 54(5), pp. 762-771.
12. Radlmayr, J., Gold, C., Lorenz, L., Farid, M. and Bengler, K. (2014) 'How traffic situations and non-driving related tasks affect the take-over quality in highly automated driving', In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 58, pp. 2063-2067.
13. SAE (2014) SAE Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems. [Online]. Available at: https://saemobilus.sae.org/content/j3016_201609 (Accessed: August 2018).
14. UKAutodrive (2016) Lords get latest on UK trials. Available at: http://www.ukautodrive.com/lords-get-latest-on-uk-trials/ (Accessed: March 2017).
15. Zeeb, K., Härtel, M., Buchner, A. and Schrauf, M. (2017) 'Why is steering not the same as braking? The impact of non-driving related tasks on lateral and longitudinal driver interventions during conditionally automated driving', Transportation Research Part F: Traffic Psychology and Behaviour, 50, pp. 65-79.