Driving with an L3 – motorway chauffeur: How do drivers use their driving time?

Johanna Wörle & Barbara Metz
Würzburg Institute for Traffic Sciences GmbH, Veitshöchheim Germany

Abstract

Advances in the technology of automated driving (AD) raises the question how AD might change driving in general. Especially the option for users to engage in other activities is seen as a major benefit. The aim of the presented study was to investigate which non-driving related activities (NDRAs) drivers want to engage in during conditionally automated driving and what proportion of the driving time they spend on these activities. In a driving simulator study, N=31 drivers used an L3-motorway chauffeur during six driving sessions which took place at six different days. Drivers were free to bring whatever they want to engage in during the drives and to use the AD function as they liked. Handling of the system, drivers' state and drivers' engagement with self-chosen side tasks was continuously annotated by the experimenter for all drives. After every drive, evaluation and acceptance of the system was assessed with a questionnaire. Drivers spend an average of 80% of the time the AD function was active on NDRAs. Only when they were fatigued this number decreased. The time spend on activities that involved both hands increased over the drives. By far the most popular activity was smartphone use. The relevance of the study findings is interpreted with regard to safety and societal benefits.

Introduction

Automated driving is expected to yield benefits such as an increased travel comfort and a more productive use of travel time. When reaching the level of conditional automation, i.e. level 3 according to the SAE classification (SAE, 2018), drivers will not be required to monitor the system and are allowed to engage in secondary activities. Users want to spend the time travelling in an automated vehicle for activities such as private communication, route information, eating and drinking, entertainment, work, wellness and sleep (Dungs et al., 2016). The engagement in such side-activities or secondary activities is widely investigated in human factors research in terms of their distractive potential or the ability to take over the driving task when being engaged in side-tasks. This "new role" of the driver in highly automated driving is subject to investigation in many research projects.

The work presented here is part of the research project L3Pilot (https://www.l3pilot.eu/). Two assessment areas in the L3Pilot project are potential safety impacts as well as socio-economic impacts of automated driving. For both of

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these impact areas, drivers' engagement in secondary tasks is relevant. High distraction due to side activities can cause drivers to react slower to take-over requests and thus provoke safety-critical situations. On a socio-economic level, when using a highly automated driving system, travel time could be used for work or otherwise being productive and thus create a societal profit. For both evaluation areas, it is important to know what kind of activities drivers engage in and for how long they execute the activities.

The distractive potential of side tasks

The ability of drivers to respond to a take-over request (TOR) highly depends on the driver state before the TOR. The driver might, for instance, be fatigued or distracted and thus not immediately be ready to take over.

The German consortium research project Ko-HAF investigated drivers' ability to take-over control from automated driving when being engaged in different non-driving related tasks (NDRTs). Befelein et al. (2017) showed that the type of NDRT has an impact on take-over times and the subjective criticality of take-over situations. For highly motivating tasks such as playing Tetris® take-over times were prolonged.

In a Wizard-of-Oz driving study simulating a SAE level 3 vehicle, drivers experienced take-over situations when being engaged in natural NDRTs (Naujoks et al. 2019). The tasks were chosen such that different workload areas were addressed: Drivers were listening to an audio book (auditory workload), executed a search task where they had to turn around and reach for a bag at the central console (motoric workload), read a magazine (motoric, visual and cognitive workload) and played Tetris® on a tablet (motoric, visual and cognitive workload). Take-over times were longest in the search task and the reading task and the take-overs were subjectively evaluated as being more critical by the drivers. The authors conclude that tasks that involve a motoric component and tasks that require the driver to turn away from the driving scene require longer take-over times.

In a meta-analysis of 129 studies with SAE level 2 or higher, Zhang et al. (2019) found side-tasks which involve hand-held devices as well as visual-motor tasks to increase reaction times to a TOR by 1.33 seconds and 0.29 seconds. When drivers had their eyes closed before the TOR, reaction times were increased by 1.19 seconds.

Monotonous NDRTs can impact drivers' take-over performance such that drivers get fatigued by the tasks and react slower to a TOR due to their fatigue (Jarosch et al. 2019). On the other hand, an activating task can have a positive impact in that respect compared to executing no side-task (Vogelpohl et al. 2018).

It can thus be concluded that NDRTs can have a negative impact on take-over performance especially when drivers engage in motoric side tasks. On the other hand, the engagement in side tasks can keep the driver activated and prevent them from becoming fatigued.

The use of travel time in automated driving

The use of travel time is also of interest in terms of productivity. While drivers are not occupied by executing the driving task, they have time for other activities like e.g. in public transportation. In a survey on rail commuters, reading for leisure, window gazing and people watching, text messages and phone calls, working, studying, listening to music and checking emails were among the most popular activities during the rail travel (Lyons et al. 2013). This might be transferable to the automated driving context, because – like in public transportation – the driver is rather a passenger.

In an internet-survey, 5000 respondents from 109 countries were asked what secondary activity they would be willing to engage in while using a highly automated driving system. Most frequently chosen options were listening to the radio, interacting with other passengers, observing, eating, phoning and mailing (Kyriakidis et al. 2015). It should be noted that many of these activities are executed in manual driving as well. It was also found that, not surprisingly, the higher the automation level, the more drivers would be willing to engage in side activities.

Another survey yielded similar results. 1500 respondents from the USA, Japan and Germany stated private communication, route information, eating and drinking, online information search, passive entertainment , shopping, organization, work and wellness (in that order) as the main activities they would execute if their vehicle would operate in level 3 automated mode (Dungs et al., 2016). In a follow-up survey respondents stated "sleeping and relaxing" as the most desired activity followed by "working and being productive", "eating and drinking", "entertainment" and "beauty, wellness and fitness" (Becker et al., 2018).

A variety of side activities can be expected from drivers during automated driving. The aim of this study was to investigate what activities drivers engage in during an automated drive and what proportion of their travel time they use for side activities.

Method

N = 31 participants (mean age = 37, sd = 11.75) completed 6 drives in a high-fidelity driving simulator (see Figure 1). The simulator runs with the simulation software Silab® (WIVW GmbH, Veitshöchheim, Germany). The participants always drove on a simulated highway and had an L3 motorway chauffeur (L3MC) available. In all drives, drivers were free to use the L3MC as they liked, meaning they could activate and deactivate it and engage in NDRTs as they wished. They were instructed that they could use the function as they like but that they need to be able to take back control if requested by the system. For the description of the system and the responsibility of the driver, the wording of the German Road Transport Law on the driver's responsibility when using an L3 automated driving system (BMJV, 2017) was used in the instruction.

Throughout all drives, the experimenter continuously coded via a tablet application if the driver was engaged in secondary tasks. The coding on the tablet was saved synchronized with the rest of the data in one data log. Furthermore, subjective evaluation of the motorway chauffeur as well as drivers opinion on potential NDRTs was assessed with a questionnaire developed within L3Pilot (see Metz, Rösener, Louw, Aittoniemi, Bjorvatn, Wörle et al. in prep.).

Figure 1: High-fidelity motion-base driving simulator from the outside (left) and from the inside (right)

Tested function

The L3MC was implemented according to the “average” function tested in the L3Pilot project in the on-road driving tests. The system had a speed range of 0 – 130 km/h. It adopted the driven speed to the surrounding traffic as well as to speed limits along the road. The upper limit of the supported speed range was 130 km/h. This means that on sections with no speed limit, the system kept a speed of 130 km/h. The system was able to execute lane changes automatically and as a consequence was able to overtake slower vehicles. System limits were exits from and entrances to motorways, construction sites, sections with bad or missing lane markings and heavy rain. If a system limit was reached, the system issued a TOR with a take-over time of 15 seconds (for a reference see Griffon, Sauvaget, Geronimi, Bolovinou, & Brouwer, 2019).

Experimental procedure

Drivers were invited to participate in a study on long-term effects of an L3MC on user behaviour. The study consisted of six driving sessions. For an overview see Table 1.

Before every session, drivers were asked to bring with them any items they would plan to use during an automated drive (e.g. smartphone, newspaper). At the beginning of the 1st session, they were informed about the study and gave their informed consent. Then, they completed an extensive pre-drive questionnaire (L3Pilot pre-questionnaire). After that, every driver completed an introductory drive where they learned the system handling and where they experienced the behaviour of the vehicle at a TOR. Then, drivers completed their first 35-minute drive with the system. After the drive they filled in an extensive post-drive questionnaire (L3Pilot post-drive questionnaire).

The following sessions all started with a short version of the pre-questionnaire. Then the drivers completed their test drives. During the six sessions, driving situations and environment differed with regard to traffic density (e.g. with and without traffic jam), frequency and reasons for TORs and length and reason of sections outside ODD (e.g. construction site, highway intersection, heavy rain). After the drives, a short version of the post-drive questionnaire was filled in. Only in the 6th session after the test drive, all drivers completed the full version of the post-drive questionnaire. Then they were compensated for their participation.

Table 1: Overview of study procedure

Session	*Procedure*
1	Full pre-drive questionnaire Introductory drive 35 minutes' drive on motorway Full post-drive questionnaire
2	35 minutes' drive on motorway Short post-drive questionnaire
3	1,5 hours' drive on motorway Short post-drive questionnaire
4	35 minutes' drive on motorway Short post-drive questionnaire
5	1,5 hours' drive on motorway Short post-drive questionnaire
6	35 minutes' drive on motorway Full post-drive questionnaire

In all drives, the participants were instructed to use the system as they would use it in their real life. They were free to activate or deactivate the system and to attend to self-chosen NDRTs. The 3rd and the 5th drive differed from the other 4 drives because they were longer and more monotonous. During one of the two drives, the drivers were sleep deprived, meaning that the drive started at 6 am and drivers had been instructed to sleep a maximum of 4 hours the night before the drive. The order of those two drives was balanced across drivers. To avoid that effects of driver state are mingled with effects of repeated usage, the session without sleep deprivation is always presented as 3rd session and the session with sleep deprivation as 5th session.

Analysed parameters

During all sessions a variety of parameters were logged, including questionnaire data, data from the driving simulator, eye tracking data and information coded by the experimenter. It was coded whether participants were engaged in NDRTs, whether the NDRT actively involved the driver's hands (manual distraction, e.g. through browsing on a smartphone, holding food) and whether drivers closed their eyes for a longer time. From this coded data, the proportion of time with active L3MC spent on NDRTs, spent on NDRTs with active involvement of the hands and spent with closed eyes were analysed. Furthermore, it was coded which types of NDRTs were actually executed during the drives.

Before the first session, drivers rated how frequently they engage with various NDRTs in manual driving. After the sixth session, they rated how frequently they would engage in various NDRTs if they would be driving with L3MC. After each session, they filled in a short questionnaire assessing their evaluation of the L3MC. For statistical testing, ANOVAS with a within-subject design were calculated.

Results

Already during the first drive with L3MC drivers spent about 70% of time with the system active on various NDRTs. There was a large variability between N=2 drivers who did not engage in any NDRT at all and N=8, who spent more than 90% of the driving time on NDRTs. In the following sessions, all drivers used at least 10% of driving time for NDRTs or closing the eyes; on average about 80% of time was spent on NDRTs or closed eyes. There was a significant effect of session on the proportion of time spent on NDRTs (F(5, 145)=5.3386, p=.00016) which was caused by a drop in session 5 – drive with sleep deprivation - from about 80% of time to 60%. The drop went hand in hand with an increase of driving time with closed eyes from 0% in drives that were not monotonous to 27% on average during the drive with sleep deprivation.

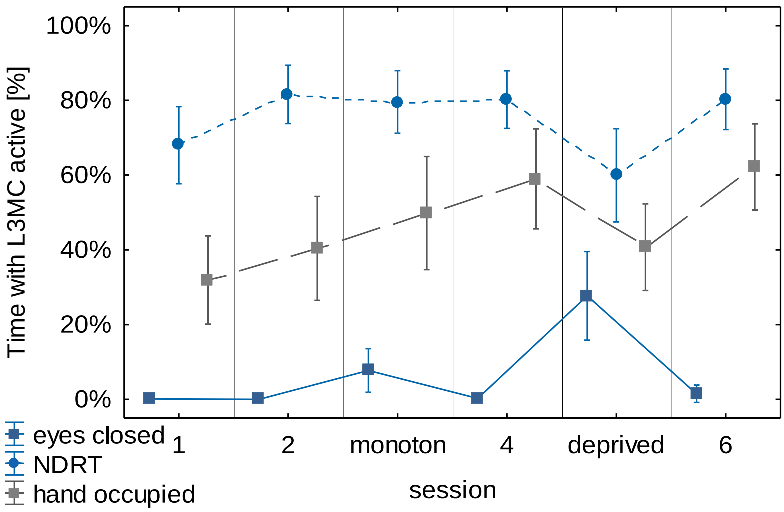

Figure 2: Proportion of time driving with activated L3 ADF that was spent on NDRTs. The graph shows means and 95%-interval of confidentiality.

A more detailed analysis showed a change in the type of NDRT with repeated usage: there was a significant rise of time spent on tasks that actively involved the hands (F(5, 145)=4.4653, p=.00082) from 30% of driving in the first session to 60% of time in the sixth session. The increase of time spent on NDRTs involving the hands was reflected in the answers given to the questionnaire item „ I would use the time the system was active to do other activities." Already after the first session, there was a strong agreement with the statement and agreement significantly rose further in the following sessions (see figure 3, F(5, 125)=5.0505, p=.00030).

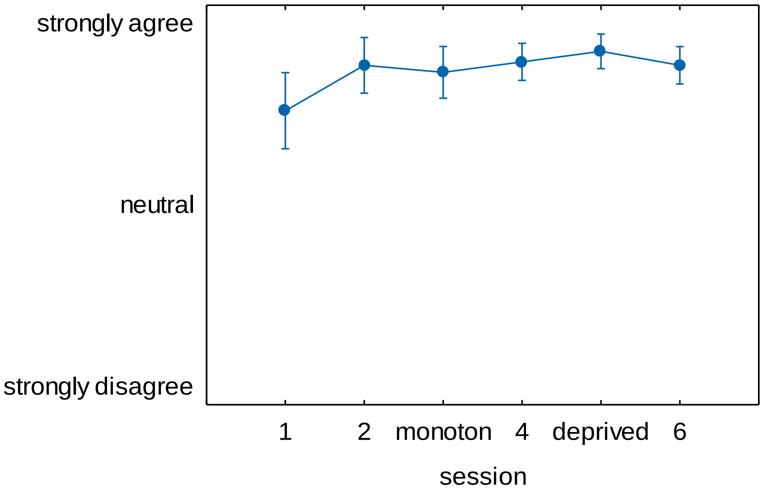

Figure 3: Subjective agreement with the statement „ I would use the time the system was active to do other activities." The graph shows means and 95%-interval of confidentiality.

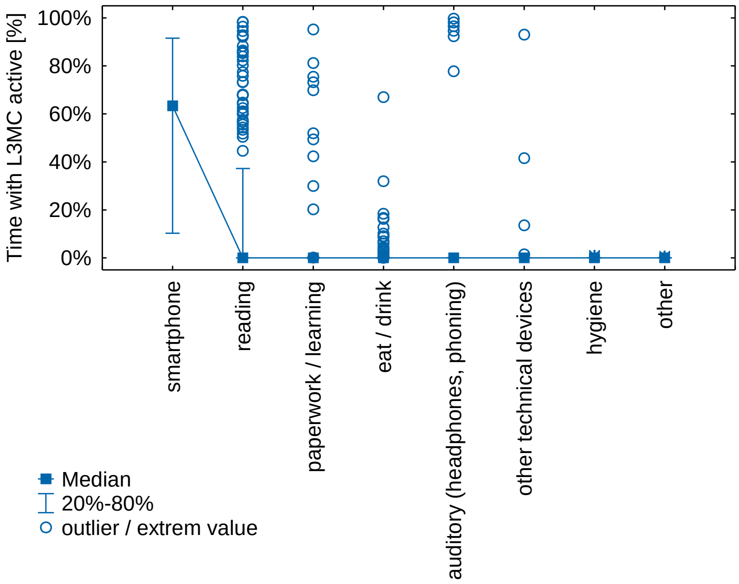

Figure 4: Proportion of time spent on different NDRTs during the time driving with L3ADF active. The graph shows median, 20% until 80% interval and outliers.

Analysis of the types of NDRTs actually done showed that drivers mostly attended to their smartphones with on average 60% of driving time over all drivers and sessions. The next frequent type of NDRT was reading (this included papers, magazines, books and e-readers). This type of NDRT was done less often but if it occurred, drivers sometimes spent more or less the whole drive reading. The same was the case for doing paper works and listening e.g. to music over headphones. N=5 out of 31 drivers attended to paper work during at least one drive. The rest of the sample never used their driving time in the experimental sessions for work related tasks.

Figure 5 shows that in the questionnaire the order of various NDTRs based on their rated frequency remained in large parts the same between manual driving and assumed driving the L3MC. Drivers would attend most frequently to auditory tasks like listening to music or audiobooks followed by interaction with a passenger. The biggest difference between manual driving and potential driving with L3MC occurred for all NDRTs related to a smartphone (calling, texting, apps, internet, social media). Drivers expected that they would attend to those NDRTs way more frequently if they had the system available. The frequency of doing no NDRTs was expected to be lower with L3MC. NDRTs related to work were expected to be done on average every now and then. N=1 driver stated that he / she would do work tasks very frequently, 30% stated that they would work frequently and another 30% at least every now and then.

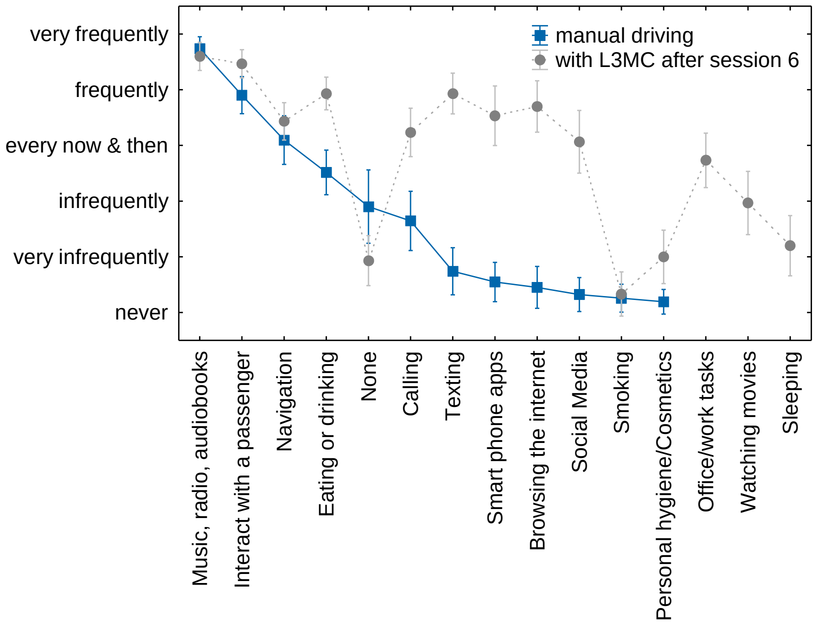

Figure 5. Subjective evaluation of the frequency with which various NDRTs are done during manual driving and would be done while driving the L3MC.

Discussion

Subjective ratings as well as actually measured driver behaviour show an increase of willingness to engage in NDRTs with repeated usage of the L3MC. It has to be noted however, that both subjective as well as objective measures started from an already high level in the first session and raised up to 80% of driving time spent on NDRTs during the following sessions. The main variation in how drivers spent their time with L3MC active can be explained by the manipulation of drivers' state. When being fatigued, drivers use less time to engage actively in NDTRs, instead they choose to close their eyes and use the time in the vehicle to relax and rest or even to sleep.

It needs to be noted that in the instruction given to the drivers it was emphasized that they need to be ready to take control back if required by the L3MC in case of a TOR and that drivers experienced various TORs during all sessions. Nevertheless, they decided to use the driving time for resting when being tired. 50% of the sample stated that they would never sleep when driving with the system, but the other half of the sample can imagine to sleep at least sometimes, 10% would even sleep very frequently when driving with the system. This result supports the worry that drivers might misuse L3 systems to doze or sleep although this is clearly outside the allowed usage of L3-systems.

The two most frequent NDRTs in manual driving and also during hypothetical driving with L3MC could not systematically be studied within the presented experiment: neither was a radio or music system available in the simulator nor was a passenger present during the sessions. Nevertheless, since these two tasks are probably the two most common side tasks in manual driving, there is no reason to doubt that drivers would attend to them while driving with an L3MC. Compared to manual driving, all NDRTs related to a smartphone are rated as being much more frequent when driving with an L3 system. The ranking of potential NDRTs from the questionnaires is in line with what is known from the literature. For instance Kyriakidis et al. (2015) report that listening to music, interaction with passenger and eating and drinking were listed as the most likely side tasks in highly automated driving.

This result from the questionnaires is supported by objective data: smartphone usage was the most frequent NDRT in the study. Also quite frequently drivers used the time in the vehicle to read (a task not included in the questionnaire). Sixteen percent of the sample used the driving time with the function active for work related tasks. Compared to the results of the questionnaires, it seems that drivers used the driving time in the experiment less frequently for work than they imagine they would do in real life. In the questionnaire, in total 63% of the sample stated that they would work while driving with the system at least every now and then if not more frequently. This figure fits the 65% of the sample, who stated in the pre-study questionnaire that they could do part of their work while travelling. This result is of special interest for researchers who evaluate the potential benefit of L3 systems for society. One potential benefit of L3 systems is that driving time can be used for new tasks and is no longer occupied with driving. The monetary value used in cost-benefits analyses for the spared driving time differs between time used for work and time used for leisure. Based on our results it can be assumed that drivers would use L3 systems to work in the car but that most of the time would be spent on leisure activities, like reading, listening to music or using the smartphone.

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