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Analyzing Transitional Stages During Transfer of Control in an Automated Vehicle

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Analyzing Transitional Stages During Transfer of Control in an Automated Vehicle

BY

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THESIS

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Original approval signatures are on file with the University of New Hampshire Graduate School.

DEDICATION

I dedicate this to my parents, other family members and all those who supported, inspired, and motivated me through out this journey.

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ABSTRACT

Analyzing Transitional Stages of Driver During Transfer of Control in an Automated Vehicle

By

Divyabharathi Nagaraju

University of New Hampshire, May 2021

The level 3 automation vehicles provide time for drivers to participate in a non-driving task when vehicle automation is on. However, the vehicle requests the driver to take control of the vehicle when the system reaches its limitations. Many researchers have studied different hand-over procedures, and the effect on take-over time and driving performance. There is limited research on analyzing the driver's transitions during the transfer of control in an automated vehicle. The goal of our research work is to find out the order of a series of transition stages that a driver goes through during take-over in an automated vehicle. Sub goals were to find out the take-over time and interleaving time by varying take-over request times. Additionally, the influence of take-over request time on transition stages is evaluated. An experimented was conducted with 15-sec and 30-sec take-over request times. Take-over request time includes pre and emergency audio alerts. Pre alert time is varied in two take-over request times scenario by having 8 sec of constant emergency alert time. From the results, two orders of series of transition stages are found, naming Interleaving order and Suspension order. The percentage of occurrence of interleaving order during take-over is found 80 % in 30 sec take-over request time. Maximum mean take-over time 21.06s (S.D 7.81) is found in a 30-sec scenario Interleaving order. The driver’s interleaving time is 18.72s in the 30-sec scenario, whereas 9.28s in the 15-sec scenario. From the results, we observe that the different take-over times affect the driver’s order of series of transition stages and the time duration between stages during take-over.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The automotive industry has made tremendous growth over a few decades. Society of Automotive Engineering (SAE) categorized the vehicles into six different levels based on automation features. They are starting from level 0 till level 5. Currently, on-road, we have the level 2 automation vehicle. Level 2 vehicles have driver assistance features such as lane centering, adaptive cruise control. However, the driver is responsible for driving and should control the inputs as needed for safety. Tesla Autopilot system is in level 2 vehicle type. The next expected smart vehicle on the road would be level 3. In level 3 vehicles, the drivers are expected not to drive while the automation feature is turned on. However, the driver should take control of the vehicle upon the system's requests. Vehicle automation has a negative effect on situational awareness and mental workload. As the level of automation increases, the level of reaction times increases. (Eriksson et., 2016). Level 3 vehicles are allowing time for drivers to involve in non-driving tasks. Engagement in non-driving tasks affects the visual and cognitive processing of the situation. Especially, visual-manual tasks lead to poorer driving performance (Johnston et al. 2018). The time needed to take over depends on how long the driver needs to gather information from the environment and develop sufficient situational awareness and then acting accordingly. The amount of take-over time required in noncritical situations in an automated vehicle is studied [1]. Given shorter take-over request time leads to worse driving quality [23]. Many researchers have studied the impact of different warning systems and handover methods on take-over time [22, 16, 23]. It is required to understand the transition of control between the automated vehicle and the driver to provide better design and safety systems for the future.

A research paper [9] described that the transition of control is not a single stage, but a series of ten stages (Janssen et.al,.2019) in a model. However, it is essential to observe in an experimental scenario what the transitional stages are during take-over in an automated vehicle.

We evaluate the following research question in our research work:

Research Question 1: What are the transitional stages of a driver during take -over time?

1. Does the order of transition stages vary with different take-over request times?
2. Does the time difference between different stages vary with an increase in take-over request time?

Research Question 2: Is there a relation between take-over time and non-driving task performance?

1. Given higher take-over request time, the driver tends to focus more on the non-driving task rather than immediately take-over
2. More Interleaving could be observed in higher take-over times

The goal of our research work was to find out the order of a series of stages during take-over in an automated vehicle with an experiment scenario. Sub-goal was to analyze how the two different take-over request times affect the driver's behavior on take-over time, transition stages, and task involvements.

1.2 Background Research

The vehicles are categorized into 6 different automation levels based on the supporting features by the Society of Automotive Engineers. Six different levels are Level 0, Level 1, Level 2, Level 3, Level 4, Level 5. In Level 0 – Level 2 the driver should drive the vehicle with the help of few driving assistance features which can control steering, brake and accelerate parameters in certain situations. However, the driver should constantly supervise the driving conditions when these supporting features. In SAE level 3 drivers are expected not to drive the vehicle when these automated features are being used. However, the system requests for control, the driver should be able to take over the control of the vehicle. So the driver should be seated in the driving seat and the vehicle will operate only when all the conditions are met as per the design guidelines. The available advanced vehicle in the market is a level 2 vehicle. Example Tesla Autopilot level 2 vehicle which has advanced driver assistance systems with supporting features such as self-parking, lane centering, automatic lane change, traffic-aware cruise control, semi-autonomous navigation on limited access. Next level 3 vehicle would be expected on road. Level 4 and level 5 are fully automated vehicles, so the vehicle doesn't require the driver to take-over. Features and examples for each SAE level are shown in figure 1.1.

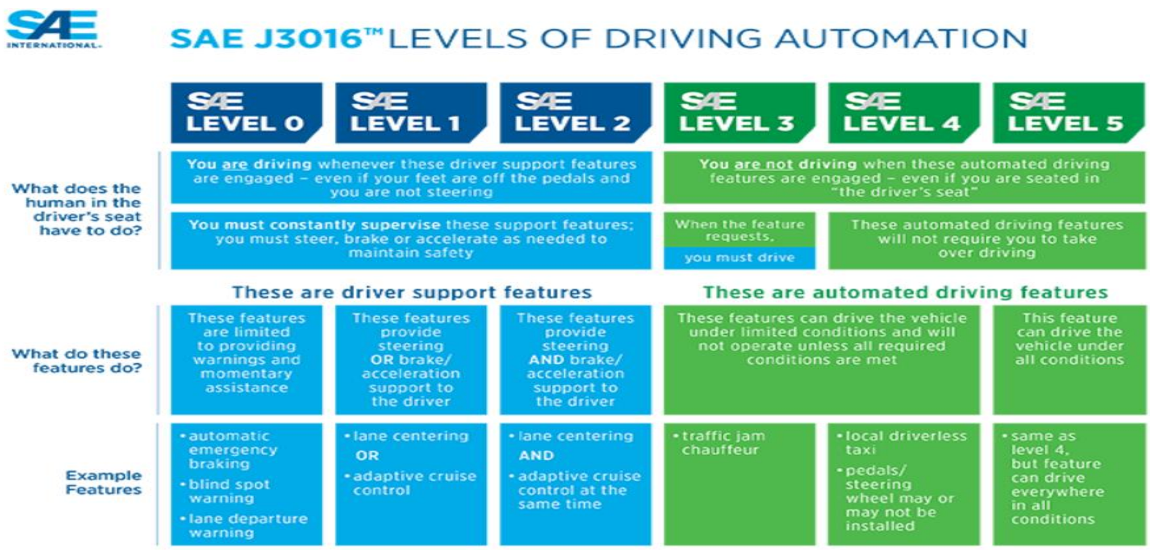

Figure 1.1: SAE levels classification and description (copyright@ WWW.SAE.ORG)

Speed and quality of take-over processes are important in an autonomous vehicle as part of safety concerns. The idea of pre-alerts system is to identify in advance that the handover signals will be passed in sometime does not apply to all traffic situations. There will circumstances where the ACC system cannot predict that the handover is going to happen. This delay will again cause the issue in take over time and can result in accidents. Daniel et al.,[21] focused on understanding the hand over process and explained the ways of improving the driver's performance during the handover process. Based on the literature they discussed 2 categories of handover situations. One is the way of handover and the second is the cause of the handover. Way of hand over is split into 4 types as Immediate handover, Stepwise handover, Driver Monitored handover, and System Monitored hand over. The cause of handover is categorized into 5 types as Scheduled handover, Non-scheduled system-initiated handover, Non-scheduled user-initiated handover, Non-scheduled user-initiated emergency handover, and Non-scheduled system-initiated emergency. Driver experience with the hand over situations has a relation to delay time. The time delay will be less if the driver have good knowledge about the system and experiences of the hand over situations. Results showed that the handover process can be improved by effective training of the driver, a better human-machine interface and by predicting the take-over times.

Lutz et al.,[14] investigated the influence of augmented reality information on the take-over process. Task switching and situation awareness is studied in automated vehicles. In the automated driving scenario, the driver uses his/her time and information processing capabilities to perform non-driving task-related activities. They studied two AR concepts in the driving simulator study to check how the augmented reality helps drivers bring back into the loop during take-over requests in an automated vehicle. The two AR concepts are "AR red" and "AR green". AR red concept projects restricted corridor information on the driving screen. AR green projects a piece of safe corridor information through which the driver can pass through. An experiment was conducted with 46 persons and the results show that the AR concept didn't have a significant effect on the take-over times. However, reaction time is influenced by the AR concepts.

Alexander et al.,[1] focused on determining the take-over time in noncritical situations in an automated vehicle. An experiment was conducted with two scenarios. Drivers were asked to read a newspaper or to monitor the systems and be ready to take-over the control when the system request the control. The experiment was conducted with 3 scenarios manual, highly automated driving, and highly automated driving with a secondary task. The control transition requests were given in both visual and audio forms. The results showed that when the driver involved in a secondary task took a long time to take over the control of the vehicle.

The paper [22] focused on discussing the taxonomy and challenges involved in an autonomous vehicle handover situations. In the research paper Roderick et al.,[22] discussed questions related to the reliability of the autonomous systems along with situational awareness level of the driver and the vehicle. The driver should be aware of the situations to respond and take control of the vehicle in an autonomous vehicle. Using a cell phone while the cruise control feature is activated in the system, will increase workload and decrease situational awareness. The vehicle has the data related to the current state of the vehicle with the environment from the sensors, cameras, and eye trackers. It is important how and when the system will request the driver for handovers. A system with better situational awareness can assist the driver to make decisions while taking the control of the vehicle. The scheduled and non-scheduled handover situations are classified as below.

Scheduled: The automated vehicles depending on their level of automation can only operate features under certain conditions. When the vehicle is in complex environments and informs those scenarios are beyond its operational capabilities. When the automated vehicle reaches its boundary limitations and realizes that it can't handle and requires the driver to take over. The vehicle informs the driver about the situation priorly and provides time to respond. In such a scenario, a vehicle provides an appropriate alerts and warning to the driver to take over the control of the vehicle before giving up control. The driver should be aware that the vehicle can't control all the situations and should be ready at any time to take-over and be aware about the driving context.

Non-scheduled system initiated: Due to sudden change in the road conditions or unexpected environmental scenarios the vehicle requires the driver to take over the control of the vehicle. The driver may not have been expecting this take-over request behavior from the vehicle. Even though the driver is not ready or unaware of the handling process the systems handovers.

Non-scheduled system initiated emergency: Due to the system's internal failure, the vehicle can't handle anymore and it is completely system failure but not due to the external conditions. The time is crucial in these scenarios as the actions to be taken immediately. In this scenario the system should decide whether the control has to be given to the driver or it has to stop the vehicle due to emergencies.

Natasha Merat et al., [23] investigated the driver behaviour in a highly automated vehicle with fixed and variable resuming control interval. An experiment was conducted in a driving simulator with two conditions. The first condition is when the system request for take-over at a regular interval when the automation is off. The second condition is when the transition to manual was based on the length of the time drivers were looking away from the road. Drivers on average took 35 – 40 sec to get proper control of the vehicle during the transition from automation to manual. Driver visual attention to the surrounding environment was measured using the eye-tracking data. The results show that if the driver is expecting system automation is going to transit then the driver's ability to regain control of the vehicle would be better.

The relation between the take-over request time and reaction time is studied by Gold et al., [23]. Many researchers mentioned that visual non-driving task reduce situational awareness by taking drives eyes and cognitive load away from the road. An experiment was conducted to analyze the take-over process of an inattentive driver involved in using a tablet computer. Results demonstrated that driver reacted faster by making decisions quickly in short take-over request time and the driving quality was worse. Paper suggested that 8 sec take-over request time could be sufficient for the driver to understand and react to a scenario.

Walch et al., [16] measured driver performance in an automated vehicle with different warnings and handover methods during take-over. Examples of assisting systems are lane departure warning systems, pedestrian warning systems, high-speed alert systems etc., Example of warning types are audio, visual, haptic or a combination of multiple types. An experiment was conducted and tested for 4-sec, 6-sec, take-over request times with different warning types and handover procedures such as immediate handover, step-wise handover, and system monitored handover. From the analysis of data it is found that participants preferred the combination of audio and visual alerts for the warnings. Driver performance was better at 6 sec take-over request time.

Unstructured transition timing for distracted drivers in emergencies is examined by Mok et al., [6]. The paper focused to find out the amount of time required for a driver to safely take-over in critical situations. Critical situation in the experiment was a curve road with oncoming traffic and the driver was asked to respond when the system requested otherwise allowed to perform a non-driving task when the automation is on. The driver was asked to watch a video when the system was in automation mode. The experiment was tested with 3 different take-over request times which is 2 sec, 5 sec and 8 sec. The results demonstrate that minimum of 2- 5 sec is needed to take a transition control. However, the driving performance was not explained during that take-over time.

A theoretical model that described the transition stages during the transition of control in an automated vehicle is shown below in figure 1.2(Christian, Shamsi, Andrew, et al., 2019). Each stage is defined: (0) working on a non-driving task(1) the driver receives an external warning that their input is needed for the driving task, (2) they disengage for the first time from their original tsk to start a period of interleaving attention between the original task and the driving task, (3) they orient towards the driving screen, (4) they suspend their original task, (5) there is a physical transition of control of the vehicle or some input from the human driver is needed, (6) the human driver drives or contributes crucial input to the car to drive, which is followed by another interleaving period during which (7) the human no longer needs to provide input the car, (8) they disengage from driving, (9) orient to their original non-driving task, and (10) resume suspended activities on their original task.

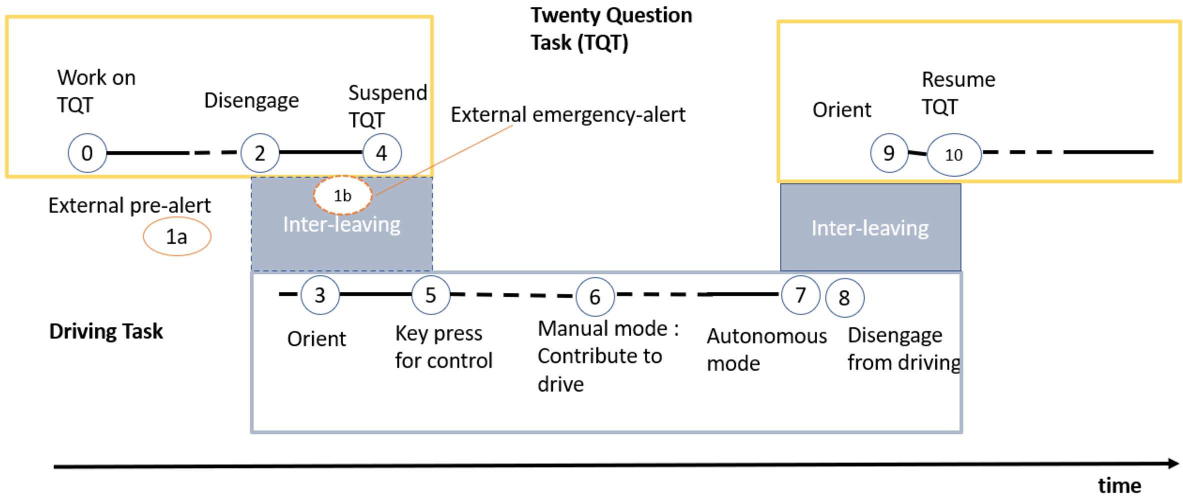

Figure 1.2: The stages of a transition of control in an automated driving context, as seen from an interruption perspective. The figure is a modification of fig.1 in Janseen et al., (2019).

As shown in the findings of prior related research, researchers focused on studying the effects of various factors such as non-driving tasks, take over alert method, and duration of alerts on take-over time. However, no research on explaining what are the transition stages that the driver goes through during transfer of control and how does the take-over time affect these transition stages order. It is also important to see how long does the driver take to transit from one stage to another.

2 EXPERIMENT STUDY

2.1 Participants

Advertisement about the experimental research was given at the University of New Hampshire. Interested participants were asked to register. The experiment was conducted at the Human-Computer Interaction Lab, University of New Hampshire. Out of 21 students, 12 female (57%) and 9 male (42.8%) participated in the experimental study. 3 participants' incomplete data were discarded due to system fault. Instruction sheets about the experiment procedure and consent forms were distributed to the participants before the experiment and participants were requested to fill the pre-survey forms. Training on the driving simulator and non-driving task was given and the experiment was conducted after the participants were comfortable with the tasks.

2.2 Tasks

Driving task: Driving task involves handling the longitudinal and lateral controls of the vehicle. The driver is responsible for driving the vehicle safely on road without any crashes in the BeamNg simulator using Logitech steering wheel and pedals. The driver is responsible for driving in the manual mode of the vehicle only. In autonomous mode, the vehicle drives by itself and does not require any actions unless it requests.

Non-driving task: Twenty questions task (TQT) is the non-driving task in our experiment. The twenty questions task is about guessing an item from the list of items. The items list and question were predefined. Participants were trained to remember the items and related questions before the experiment. Two persons were involved in this task, the first-person is the participant who guesses the chosen item, and the second person is called the experimenter from another end to answer the participant's questions. The experimenter gives only a yes/no, correct/incorrect response. The twenty questions task items and corresponding questions were shown in the below diagram:

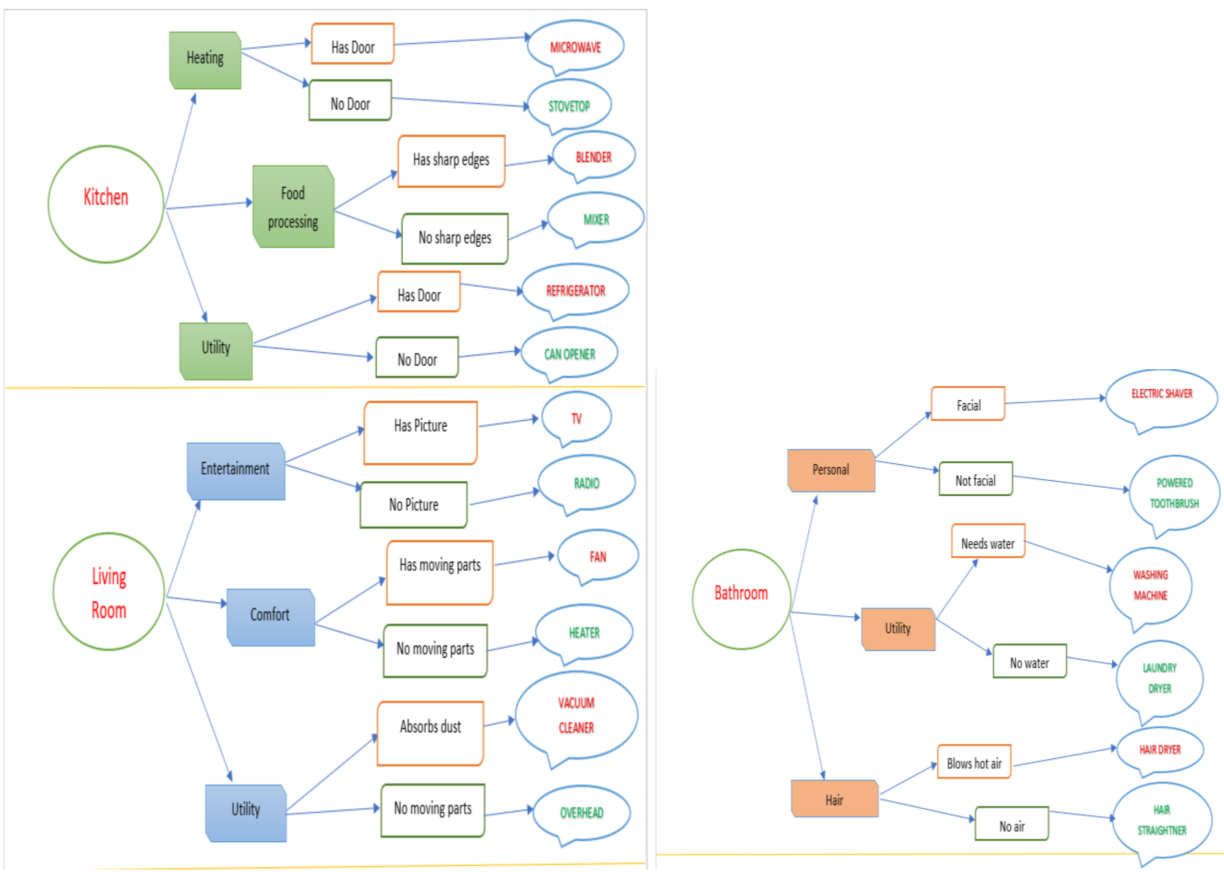

Figure 2.1: Twenty question task items and corresponding questions list

As an example participant 3, TQT conversation is shown below from the autonomous mode 1:

Experimenter: Start!
Participant: bathroom ?
Experimenter: No
Participant: Kitchen ?
Experimenter: no
Participant: living room?
Experimenter: Yes
Participant: utility ?
Experimenter: No
Participant: entertainment ?
Experimenter: no
Participant: comfort?
Experimenter: yes
Participant: moving parts?
Experimenter: yes
Participant: fan ?
Experimenter: correct!
Experimenter: New Game!
Participant: bathroom?
Experimenter: Yes
Then system alert : Take-over request 1
Continues..

Participants played multiple games in a row while the simulated vehicle in the game was under the control of automation.

2.3 Equipment

Figure 2.2: The experiment study set up in HCI lab, UNH

The above figures demonstrates the experiment set up at the Human-computer Interaction lab, University of New Hampshire. The experiment was conducted in the setup, and data was collected.

Driving Simulator: Driving environment was created using the BeamNg game and Logitech hardware steering wheel, pedals. BeamNg provides the driving environment with vehicle controls. Two modes are created in BeamNg with manual mode and autonomous mode. In manual mode, the participant is responsible for controlling the vehicle. In autonomous mode the vehicle drives by itself and doesn't require any inputs from the participant. The driving environment is projected on 3 computer screens. 4 markers were placed on the 4 corners of the center screen. Eye tracker is calibrated for center driving screen using these markers. 5 area of interests was created around the driving screen using makers. The area of interest for the driving screen covers the 3 driving screens and the area around the steering wheel and area above the center driving screen.

Ergoneers Eye tracker: Eye tracker is placed on participants to collect eye data and front video. The data is collected at 60 Hertz. An eye tracker is calibrated for the center driving screen before the experiment begins using markers.

Dell laptop: Laptop is placed on the right side of the steering wheel while the participants can easily access both steering wheel and laptop. Laptop is used by participants to perform Twenty Question Task. The participant interacts in the laptop skype app. The key typing data was collected and analyzed for TQT performance. 4 markers were placed on the 4 corners of the laptop. An Area of Interest (AOI) was created for the laptop area to observe the participants glances at laptop.

D-lab: D lab software is used to collect the data from multiple systems in real-time and the data is recorded synchronously. Eye tracker, participants keyboard typing, experimenter keyboard typing, and system transition modes and alert timings was streamed to the D-lab.

2.4 Design

The transition from manual to autonomous mode and vice versa is provided by audio alerts.

Below figure 2.3 indicates the transition from manual to autonomous mode. Before the vehicle switches to the autonomous mode, it provides a beep audio sound followed by audio message "Autonomous mode". After the message, the vehicle is in autonomous mode, then vehicle drives by itself.

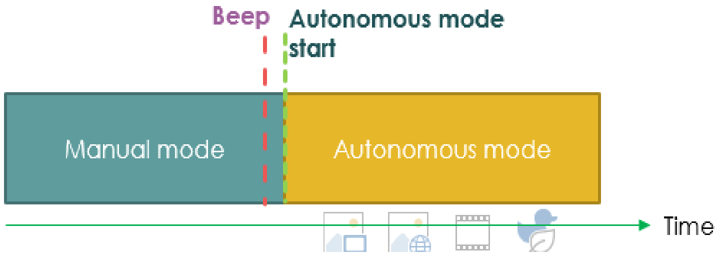

Figure 2.3: Manual to Autonomous mode transition

The transition from autonomous mode to manual mode is shown in figure 2.4. The vehicle should inform the driver priorly before giving up its control. There are 2 alerts during this transition. The system warns with a pre-alert saying "There is a narrow road and merging ahead" and gives some time before the next alert. If the participant doesn't take over the control of the vehicle then the system provides an emergency audio alert "Emergency take-over the control". The given time between pre-alert and start of manual mode is considered as take-over time. In this study, the take-over time is varied to observe the changes in driver and take-over behavior. There are two take-over scenarios 15-sec and 30-sec scenarios. In 15-sec scenario, the time between pre-alert to emergency alert is 7 seconds and after an emergency alert, there will be 8 seconds time before the vehicle forceful manual transition. In 30-sec scenario, the time between pre-alert to emergency alert is 22 seconds and after emergency alert there will be 8 seconds time before the vehicle forceful manual transition. Participants can take the control of the vehicle anytime after the pre-alert by pressing the space key on keyboard next to the steering wheel. If the participant fails to respond in the given take-over time then the system forcefully transits to manual mode. During the take-over time the vehicle is in autonomous mode. Once the vehicle switches to manual mode it provides a audio alert saying" Manual mode started".

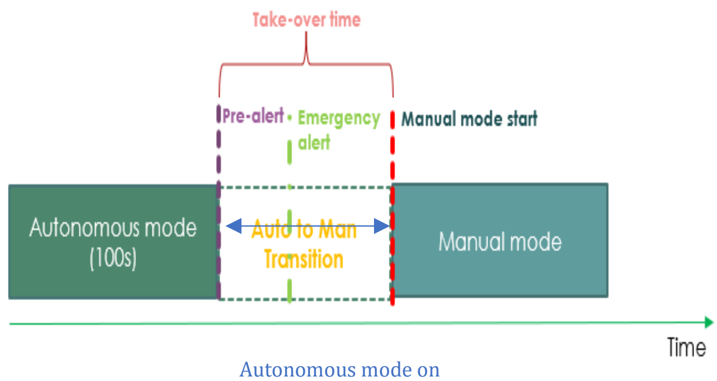

Figure 2.4: Shows the transition of autonomous to manual mode

Experiment begins with a manual mode, where the participant is responsible for driving and each manual mode is of 65 sec. Once the system switches to autonomous mode and notifies the same. The participant can leave control of the vehicle and focus on TQT. The autonomous mode duration is 100 sec and the participant should be ready to take the control of the vehicle when the system requests for control in the autonomous mode. Figure 2.6 demonstrates the sequence of modes from the beginning until take-over request 1. The switching between manual mode to autonomous mode and vice versa continues alternatively.

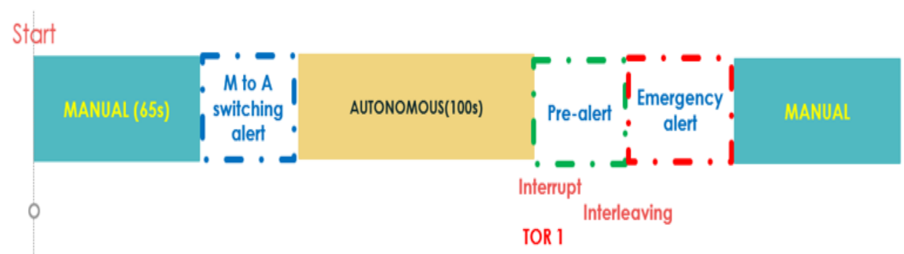

Figure 2.5: Initial transition modes until take-over request 1

In the complete experiment, there are 4 manual modes, 4 autonomous modes, and 3 take-over requests. Each experiment duration is approximately 11 minutes and each participant repeats the experiment twice for 15 sec and 30 sec scenarios.

Figure 2.6: Alternative manual and autonomous mode from start to end of the experiment

2.5 Procedure

After the participant is trained on the tasks and experiment procedure, calibration of eye tracker is performed and then the experiment is conducted. Once the experiment starts the participant performs driving in manual mode and TQT in autonomous mode. The participant should drive the vehicle safely in manual mode without any crashes. During the transition, participant should take over the control of the vehicle safely. After the end of one autonomous mode, the TQT is paused at the manual mode and resumed by the participant in the next autonomous mode. The participant is requested to guess the item from the TQT, and the guessing game continues till the system transits to manual mode from the autonomous mode. The participant should keep guessing the item in the TQT task until the end of the experiment as many items as possible. At the end of the 4th autonomous mode experiment stops. After completing scenario 1, the same experiment is conducted for scenario 2.

3 DATA VISUALIZATION

3.1 Data Export and visualization in MATLAB

After collecting the data from 21 participants. The data was viewed in video in D-lab software. 2 participant’s data were discarded due to incomplete data. For 2 participants third take-over data was removed and only the first 2 take-over data were considered due to missing data. For 2 participants the gaze moved out from the area of interest after few transitions, and the data was replaced with manual calibrations. Offline marker detection, eliminate eye blinks and fill gaps features from D-lab software are used to remove noise in the data. The data was exported and analyzed using MATLAB and R software. Each participant's data is visualized using the MATLAB software. One of the participant data is shown below:

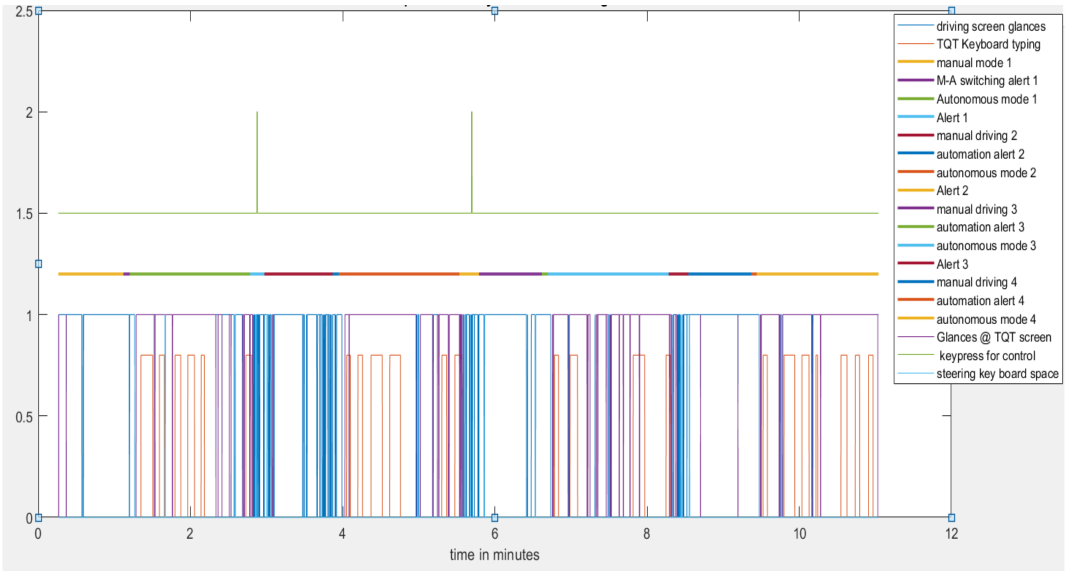

Figure 3.1: Visualization of a participant data in MATLAB

From figure 3.1, the blue lines indicate participant's glances at the driving screen. Purple lines indicate participant's glances at the laptop screen. The top green color data indicates the keypress by the participant during the take-over time. Multiple colors in the middle of the visualization indicate the system's operating modes and alerts with respect to time. Red line indicates keyboard typing data of the participant while guessing the TQT. The description of the data lines is shown on the left side of the graph plot.

The participant’s data was viewed more closely to evaluate the data. The total duration of the existing data and missing data was calculated. To analyze the missing data, the duration of missing data was calculated. For each participant, the percentage of recorded data time duration (Data_Present) and missing data (Data_Absent) time duration was calculated. The average of all participants was calculated and shown in figure 3.2 for both scenarios. From figure 3.2 we can see that the eye tracker data was collected for 65% of the time and 35% of the time the data was missing. We analyzed the missing data. For each participant, the duration of missing data was calculated and the average of all participants missing data duration is calculated and demonstrated in figure 10.

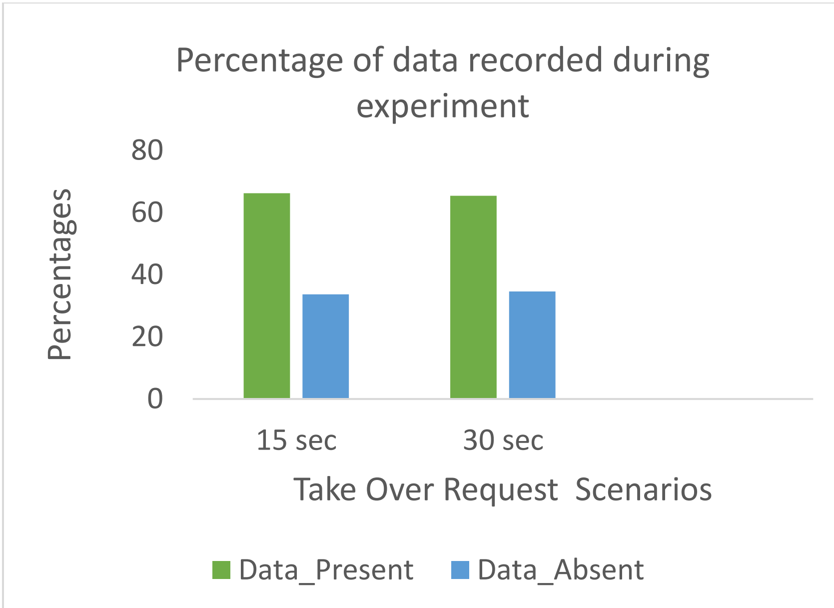

Figure 3.2: Percentage of data in Experiments

Figure 3.3 visualizes the distribution of missing data duration for both scenarios 15 sec and 30 sec. The highest percentage of missing data around 72% has a time duration gap of less than 200 ms. A participant glance cannot look away and come back to a point in less than 200 ms. Approximately 10% of the missing data time duration is between 200 ms – 400 ms in both scenarios. Another small percentage of missing data has a time duration between 400 ms – 1s. Since the time durations are very small, the collected data looks appropriate.

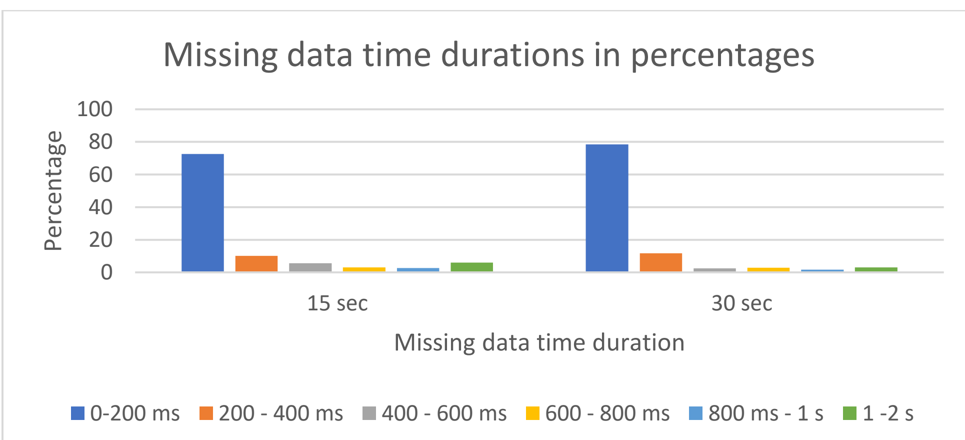

Figure 3.3: Missing data time durations among participants in both scenarios

3.2 Measurements /Dependent Variables

Transition stags are explained in figure 1.2. To measure and evaluate each stage measuring parameters are chosen. The parameter corresponding to each stage and the description is given below.

- Stage 0: Performing twenty question task

When the vehicle switches to autonomous mode, the autonomous mode is on for 100 sec. The participant performs the TQT in autonomous mode. Time stamp of start of autonomous mode is considered as stage 0.

- Stage 1: External alert

As there are 2 alerts. Timestamp of the first occurrence of pre-alert message was considered for measurement

- stage 2: Disengage from TQT

The timestamp of the first glance of driver away from the laptop screen after pre-alert was considered

- stage 3: Orient to driving

The timestamp of the first glance of driver at the driving screen after the pre-alert was considered

- stage 4: TQT suspension

Last moment where the participant worked on TQT. Working on TQT is considered by combining TQT typing and a glance at the laptop screen. Last glance or TQT typing data found before the physical key press is considered.

- stage 5: Physical transfer of control

The timestamp of the key press is considered, the keyboard was placed on the left side of the steering wheel. If the key press doesn't exist, then the start time of immediate manual mode is considered.

- stage 6: Contribute to driving

The timestamp of the start of manual mode is considered. The complete 65 sec of manual mode is the driving task.

- stage 7: Alert

The First Timestamp of the beep was considered and the system provides audio alert of the autonomous mode transition

- stage 8: Disengage from traffic

Timestamp of the first glance away from the driving screen after the vehicle switches to autonomous mode

- stage 9: Orient to original TQT

Timestamp of first glance at the laptop screen is considered after the vehicle transit to autonomous mode.

- stage 10: Continue TQT task

TQT task performance in autonomous mode is considered. Glance at the screen and keyboard typing data of the laptop is considered.

4 RESULTS

4.1 Take-over time analysis

Take-over time is the amount of time that the driver takes to respond to a system request in an automated vehicle. When the vehicle requests the automatic control, it provides alerts and a certain time is allotted to the driver to take necessary actions. In the experiment, take-over time is considered as the time difference between stage 1 and stage 5. Stage 1 was an alert from the system to take-over and stage 5 was the keypress to get the control of the vehicle. The distribution of take-over times of the participants is shown in figure 4.1 for both 15 sec (left) and 30 sec (right) scenarios. The green vertical line represents the pre-alert time and the red vertical line indicates the emergency alert. The yellow line indicates the time out. In the 15 sec scenario, 27.27% of take-overs were between pre-alert and emergency alert time, and 50.9% were after the emergency alert. 21.8% take–overs are forceful transitions which means that the keypress was not detected within take-over request time. Given higher take-over request time, 40 % of the take-overs were after pre-alert before the emergency alert. Only 12.72% forceful take-overs. The forceful transitions were reduced given higher take-over time. The driver's behaviors are different in 15 sec and 30 sec scenarios.

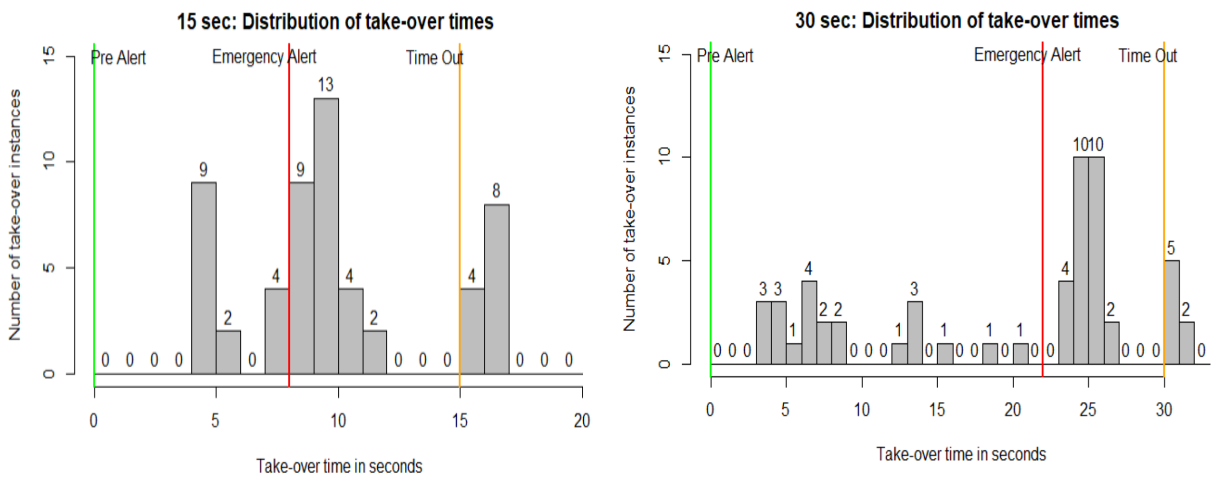

Figure 4.1: Distribution of take-over times in 15 sec and 30 sec

scenario	Pre-alert Range	Emergency Alert range	Forceful transition
15 sec	15	28	12
30 sec	22	26	7

Table 4.1: Number of take-over instances in specific time durations

Driver's TQT task involvement was evaluated for forceful take-over transitions to understand the relationship among them. In 15-sec scenarios, during half of the forceful transitions, participants didn't type any question and during another half of the forceful transitions, participants typed only one question. In 30 sec scenarios during all the forceful transitions participants performed the TQT. Among 7 forceful transitions, 1 take-over had 1 question, 4 take-overs had 3 questions, 2 take-overs had 2 questions. It is observed that during 30-sec scenario participants attempted more questions than the 15-sec scenario. However, if the participant is not responding to any question and to better understand the driver's focus the eye glance data must be analyzed.

Scenario	Key press not detected	TQT not attempted	TQT questions
15 sec	12	6	6
30 sec	7	-	7

Table 4.2: Analysis of TQT task in forceful transitions

15 sec and 30 sec take-over times are compared to see the differences between both scenarios. Mean, Median, and standard deviation values in both scenarios are shown in table 2. Given higher take-over request time, take-over time is increased to 19.18 with a standard deviation of 24.56. The results found matching the hypothesis. The take-over times are different under different request times. One-way ANOVA test is performed between 15 sec and 30 sec scenario and predicted values are almost the same as the mean values.

Parameter	Scenario	Mean	Median	Standard Deviation	Predicted Values using ANOVA (seconds)
Take-over Time	15 sec	9.72	9.50	3.11	9.80
Take-over Time	30 sec	19.18	24.56	9.09	19.75

Table 4.3: Take-over time statistics comparison

4.2 Transition stages analysis during take-over time

During take-over time, the participant transition stages order is analyzed. Using the measuring parameters explained in measuring parameter section, the order of stages are calculated. There are 2 orders of series of transition stages found. One is the Interleaving order and second is the Suspension order. In the Interleaving order, the driver interleaves between driving and non-driving tasks. After the system alert, the driver looks away from non-driving task and looks at driving scenario. After a while, on the non-driving task, this transition between the non-driving task driving screen continues multiple times. The order of stages in Interleaving order is stage 1 -> stage 2 -> stage 3 -> stage 4 -> stage 5 -> stage 6.

In Suspension order, the driver directly suspends non-driving and moves to the driving task. There is no switching between driving and non-driving during take -over. The order of series of stages are : stage 1 -> stage 2 -> stage 4 -> stage 5 -> stage 6.

In the 15 sec scenario, both orders have an almost equal percentage of occurrence whereas in the 30-sec scenario, the percentage of occurrence of the Interleaving pattern is 80% and the suspension pattern is only 20%. This shows that given higher take-over request time participants follow Interleaving order rather than suspension order.

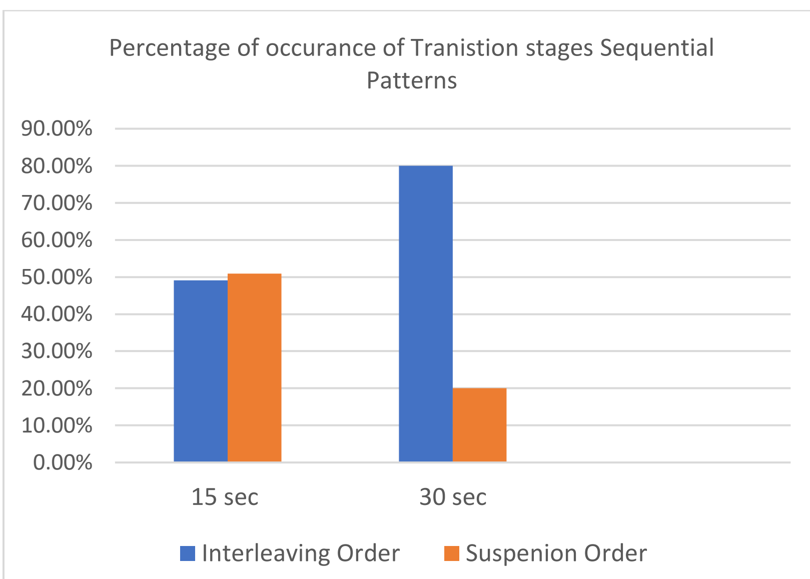

Figure 4.2: Percentages of patterns occurred during the transition from autonomous to manual in 15 sec and 30-sec take-over request time

Each participant take-over series of order is shown in figure 4.3 for 15 sec (top) and 30 sec (down) scenarios. In 15 sec scenario, 4 participants had an Interleaving order of series of stages in all 3 take-overs. 5 participants had suspension order in all 3 take-overs. 10 participants had a combination of Interleaving and suspension order in 3 take-over scenarios. In the 30 sec scenario, 13 participants had to leave the order in all 3 take-over instances. The participants followed the same set of transition stages order in all 3 take-overs. Only 2 participants had suspension order in their all take-over instances and 4 participants had a mix of Interleaving and suspension order pattern. Comparing 15-sec and 30-sec scenarios, it is observed that given higher take-over request time participants allowed the Interleaving order of stages during all take-over instances.

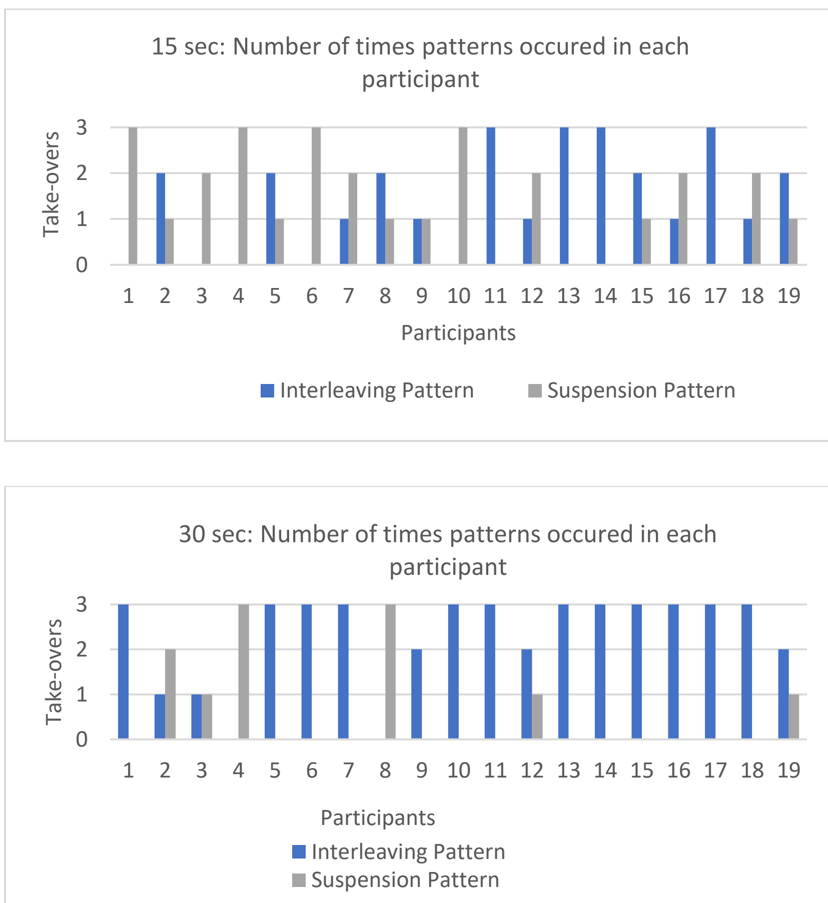

Figure 4.3: Count of pattern occurrence during take-over in each participant

Scenario Number of participants	Pattern 1 only	Pattern 2 only	Pattern 1 & 2 mix
15 sec	4	5	10
30 sec	13	2	4

Table 4.4: Count of patterns observed in participants

We calculated the amount of time that the driver took to transition from one stage to another. Mean and Standard deviation for the time differences between adjacent transition stages are calculated based on pattern category in both scenarios and it is illustrated in table 4.5 (Average by the participant). In pattern 1, the driver takes 15.31 seconds to suspend the TQT task after oriented the driving screen. The driver comes back quickly to driving after orienting in 15 sec scenario. The average take-over time is higher in pattern 1 in both scenarios than in pattern 2 due to the interleaving process.

Pattern 1	**Number of instances (N)**	**Stages 1-2**		**2-3**		**3-4**		**4-5**		**1-5**		**2-5**	
		M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
15 sec	27	0.30	0.71	1.08	0.98	5.81	2.67	4.06	3.77	11.24	3.69	10.95	3.60
30 sec	44	0.46	0.59	3.22	3.16	15.31	6.89	2.07	1.18	21.06	7.81	20.60	7.67
Pattern 2		**1-2**		**2-4**		**4-3**		**3-5**		**1-5**		**2-5**	
15 sec	28	0.96	1.51	3.80	3.25	0.84	0.66	2.65	3.83	8.25	3.28	7.29	3.83
30 sec	11	0.97	2.22	4.8	7.14	1.20	1.86	1.91	1.45	8.89	7.81	7.91	5.65

Table 4.5: Mean and SD (in sec) between adjacent stages in patterns (averaging by participant)

4.3 Likelihood probabilities of transition stages

The transition stages probabilities are calculated during the take-over time. L statistic measures whether a transition from one affective state to another is more likely than the second state's base rate.

In our research paper, L statistics are calculated excluding self-transitions (when a student remains in the same affective state both before and after) using the below equations. Shamya et al [FILL]., provided the L statistic that calculates the likelihood of an affective state (prev) will transition to a subsequent (next) state, given the base rate of the next state occurring.

$$Lprev \rightarrow next = \frac{P(next|prev) - Pnext}{1 - Pnext} \quad \ldots\ldots (1)$$

The expected probability, P(next) for an affective state is the percentage of times that the state occurred as a next state.

The conditional probability, P(next|prev) is given by

$$P(next|prev) = \frac{count(prev \rightarrow next)}{count(prev)} \quad \ldots\ldots (2)$$

where Count (prev → next) is the number of times the prev state transitioned to the next state, and

Count (prev) is the number of times the state in prev occurred as the previous state.

L = 0 is treated as chance, while L > 0 and L < 0 are treated as transitions that are more likely or less likely (respectively) than chance.

The average likelihood values of transition stages excluding self-transitions are shown in table 4.7. The self-transitions are excluded in this experiment as the focus is on the likelihood of transitions from one stage to another stage ignoring the transitions within the same stage because drivers will stay in non-driving and driving tasks for a long time while performing tasks. It is more likely that the driver will orient at the driving screen before pressing the key while transitioning from TQT task to driving task during the take-over time in both scenarios. From the results, we can see that the likelihood probabilities are matching the pattern 1 order of series of stages. Given higher take-over request time the likelihood probabilities of transition stages are more evident with strong probability values and standard deviation values.

Transitions	L values (15sec)	15 sec SD	L (30 sec)	30 sec SD	Cohen's d
0 -> 3	0.79	0.31	0.94	0.064	0.67
0 -> 5	-0.25	0.31	-0.17	0.27	0.27
3 -> 0	0.56	0.32	0.70	0.28	0.46
3 -> 5	0.20	0.34	0.15	0.27	-0.16

Table 4.6: L values probabilities average by participant

Cohen's is calculated for 15 sec and 30 sec mean L values using the below equation:

$$Cohen's\ d = \frac{Mean2 - Mean1}{sqrt[\frac{Mean2^2 + Mean1^2}{2}]} \text{ ....} (3)$$

Mean 1 is the mean L values in 15 sec scenarios

Mean 2 is the mean L values in 30 sec scenarios

Transitions (Agg by participant)	L values (15sec) Mean	L values (15 sec) SD	L values (30 sec) Mean	L values (30 sec) SD
Interleaving order				
0 -> 3	0.90	0.23	0.95	0.07
0 -> 5	-0.12	0.19	-0.12	0.15
3 -> 0	0.71	0.27	0.73	0.24
3 -> 5	0.04	0.20	0.09	0.12
Suspension Order				

0 -> 3	0.69	0.38	0.88	0.14
0 -> 5	-0.48	0.54	-0.47	0.52
3 -> 0	0.32	0.42	0.48	0.48
3 -> 5	0.48	0.61	0.47	0.53

Table 4.7: Average Likelihood of transition stages during take-over separating patterns

To observe the significant difference between the L value transition stages in the 15-sec and 30-sec scenario paired T-test was performed for likelihood probabilities (excluding self-transitions). From the p-value, we can see that there is a significant difference between transition stages probabilities in 15-sec and 30-sec take-over request scenarios.

Transitions (Agg by participant)	T value	DF	p-value
0 -> 3	-1.97	18	0.06
0 -> 5	-1.21	17	0.24
3 -> 0	-1.87	18	0.08
3 -> 5	0.73	17	0.47

Table 4.8: Paired T - test for transition probabilities of 15 sec and 30 sec scenarios

4.4 TQT task evaluation during take-over time

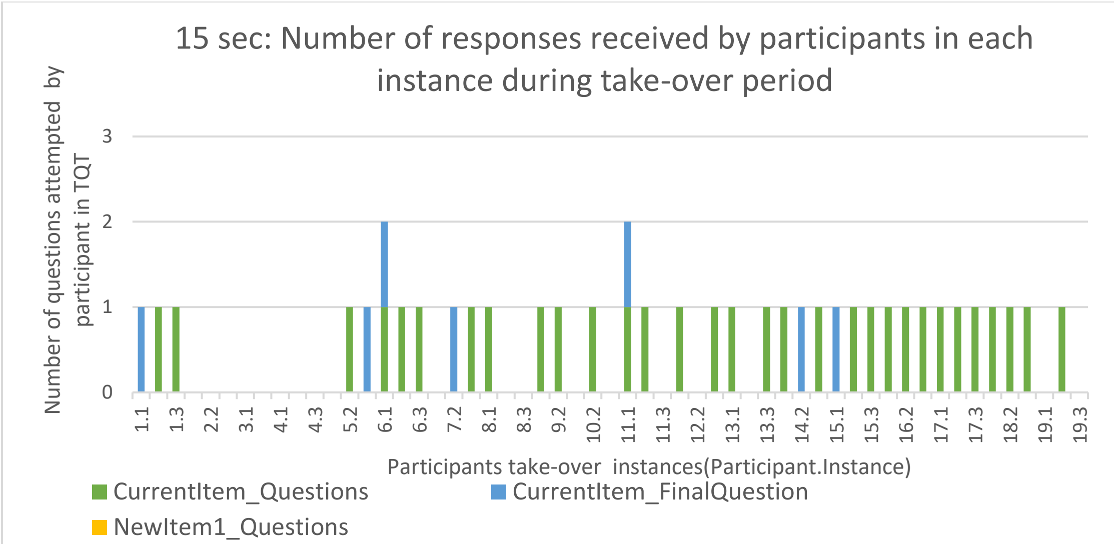

Figure 4.4: TQT task performance during take-over time in 15 sec scenarios

In 30-sec scenarios, the participants attempted a greater number of questions than 15-sec scenarios. In 32 instances participants continued to complete the current item, whereas in 11 instances participants attempted guessing new items after completing the current item. Participants started guessing a new item after guessing the current item in 11 take-over instances. This depicts that given higher take-over request time participants tend to involve more on the non-driving task rather than suspending the task even after warnings.

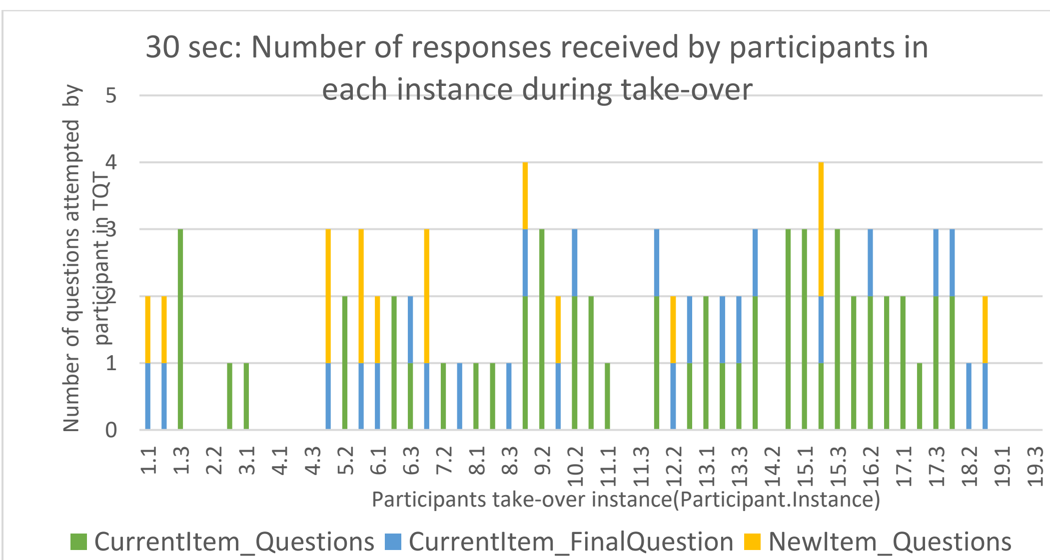

Figure 4.5: TQT task performance during take-over time in 30 sec scenarios

scenario	Stopped	Attempted Not Finished	Finished & stopped	New Item started
15 sec	19	29	7	0
30 sec	12	19	13	11

Table 4.9: Participants TQT typing analysis during take-over time

4.5 Relation between take-over time and TQT responses

The relation between the number of responses received by the participants during take-over and the take-over time is observed using a linear mixed effect model. Figure 4.6 shows that there is a positive correlation between the take-over time and the number of responses received by the participant. The take-over time was delayed to the involvement in the TQT task. A maximum of 3 questions was asked by the participant in the 30-sec scenario.

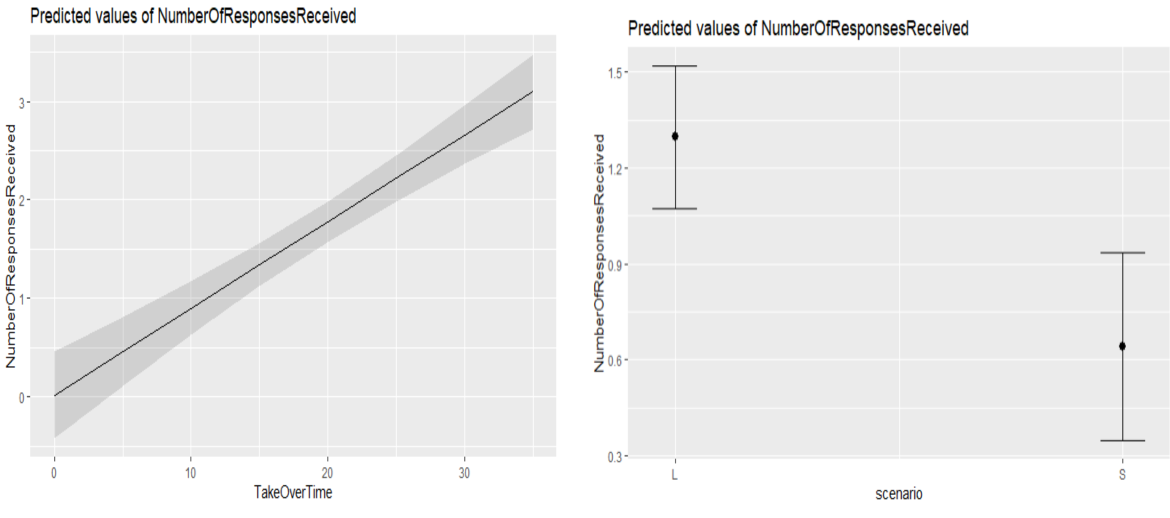

Figure 4.6: Linear mixed effect model for number of responses and take-over time parameters

Figure 4.7 shows the time spent on driving and non-driving tasks during the take-over time. During the 15-sec TOR scenario, drivers spent 61.37% of time on driving tasks and 38.62% on non-driving tasks. In the 30-sec TOR scenario, drivers spent 42.8% of time on driving tasks and 57.12% on non-driving tasks. With higher take-over request time, the driver spent more time on completing non-driving tasks.

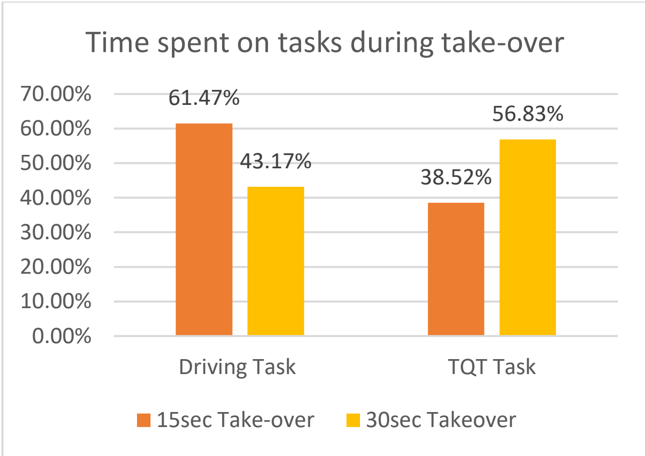

Figure 4.7: Time spent on tasks during take-over time

4.6 Participants TQT items analysis

The table 4.10 below shows the participants TQT items analysis during the whole experiment. In both scenarios 15 sec and 30 sec the participants TQT items analysis is shown. In 15 sec scenario, on an average participants attempted 6.11 items and guessed 4.95 items correctly. In 30 sec scenario on an average participants attempted 6.53 items and guessed 5.64 items correctly. It is observed that in 30 sec participants guessed 0.58 items incorrect which is less than 15 sec scenario incorrect items value that is 0.74. The average is calculated by all participants total number of items by the total number of the participants.

Scenario	Items attempted	Items guessed correctly	Incorrect items guessed
15 sec	6.11	4.95	0.74
30 sec	6.53	5.64	0.58

Table 4.10: Participants TQT items analysis

4.7 Driver transitions during Interleaving:

The interleaving period is defined as the time duration between external alert and physical transfer of control. Table 4.5 shows the Interleaving period between non-driving and driving tasks was higher with 22-sec pre-alerts. On average, drivers switched 7 times between both the tasks in 30-sec scenarios, whereas only 4 times during the 15-sec scenario. Out of 110 take-over instances, 27(s=13, L=14) take-over instance had a direct transition from non-driving to driving task (st 4 -> 5, which means working on NDT-> suspending -> keypress) without Interleaving which is 24.545% take-over (including S & L) instances.

Scenario	Average Transition count/instance 0 -> 3	Average Transition count /instance 3 -> 0	Average Transition count/instance 0-> 5	Average Interleaving time (st 2- st 5)
15 sec	3.78	3.30	0.236	9.285sec
30 sec	7.12	6.70	0.25	18.725sec

Table 4.11: Average transition times and interleaving duration in both scenarios

4.8 Transition from manual to autonomous mode

Resume Time: Resume time was observed during the transition from manual to autonomous mode. Resume time is the time that the driver takes to transit from manual driving to non-driving tasks after the alert. Figure 4.8 shows the distribution of the resume time of participants in 15-sec TOR (left) and 30-sec TOR (right). The mean of resume time is higher in 30 sec than 15 sec. In the experiment design, the transfer of control from manual mode to autonomous has no difference in both scenarios. ANOVA test was performed for resume time in both scenarios. However, the resume time is observed to see if there is much difference in driver behavior during resume time.

There was no much difference in resume time mean, median, standard deviation values in 15-sec and 30-sec scenarios.

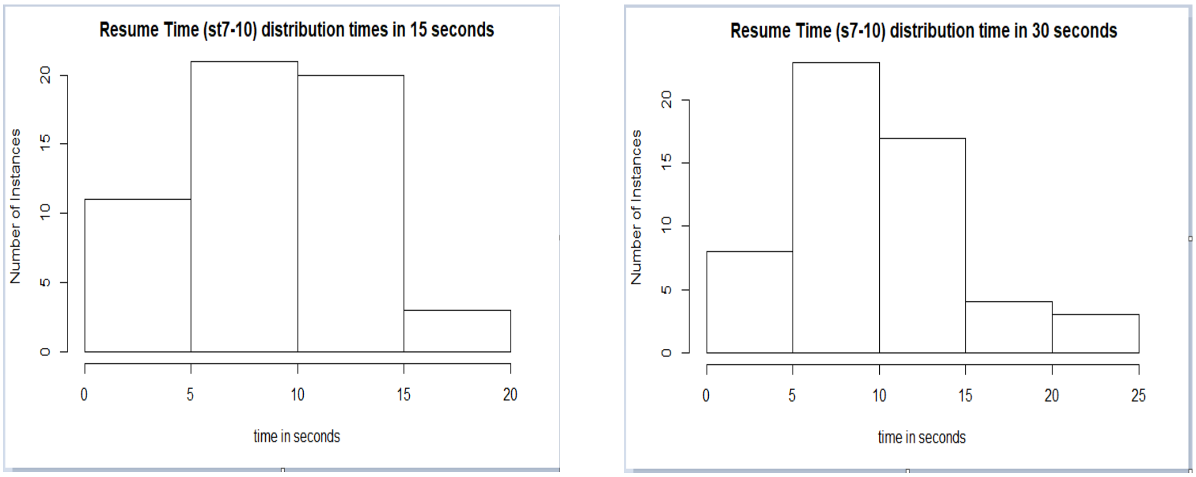

Figure 4.8: Distribution of Resume times in 15 sec and 30 sec TOR

Parameter	Scenario	Mean	Median	Standard Deviation	Predicted Values using ANOVA (seconds)
Resume Time	15 sec	8.776	9.2	4.673	8.8
Resume Time	30 sec	9.812	9.533	4.785	9.8

Table 4.12: Resume Time statistics comparison

4.9 Transition stages during resume time:

During resume time, the Order of series of stages falls mainly into 6 patterns. The order of stages in patterns were defined below:

Pattern 6: stage 6 -> stage 7 -> stage 8 -> stage 9 -> stage 10 ;

Pattern 7: stage 6 -> stage 7 -> stage 8 -> stage 10 -> stage 9 ;

Pattern 8: stage 6 -> stage 8 -> stage 7 -> stage 10 -> stage 9 ;

Pattern 9: stage 6 -> stage 7 -> stage 9 -> stage 8 -> stage 10;

Pattern 10: stage 6 -> stage 7 -> stage 9 -> stage 10 -> stage 8 ;

Figure 4.9 shows the occurrences of percentages of patterns in both scenarios. Pattern 6 is the highest percentage of occurrence among all the patterns.

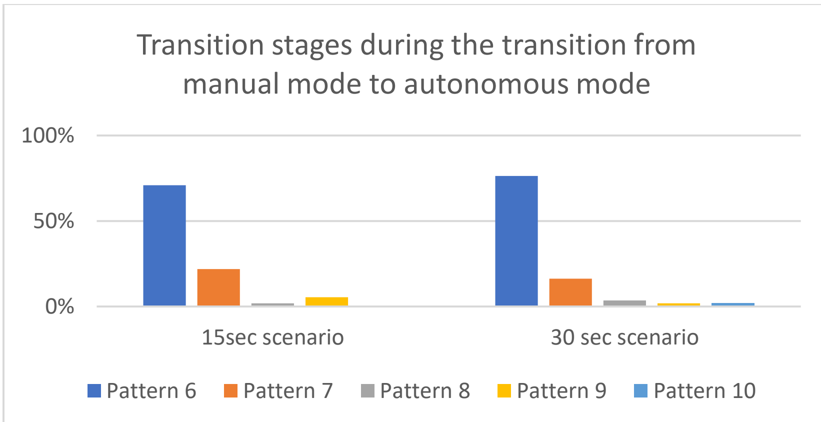

Figure 4.9: Patterns of transition stages during resume time in both scenarios

4.10 Conclusion

The expected autonomous vehicle on road would be a level 3 automated vehicle that requests the driver to take control of the vehicle when it reaches its limitations. There is limited existing research work on the transition of control in an automated vehicle. Our research work focused on finding the order of series of transition stages from the autonomous mode to manual transition in an automated vehicle. The driver's transition stages are analyzed by varying take-over request time. Results show that given higher take-over request time leads to the Interleaving order of transition stages. Take-over time and interleaving time are higher in 30 sec take-over request time compared to 15 sec take-over request time. It is more likely that the participants will orient at the driving screen before taking over the control of the vehicle. Our results are specific to a designed driving scenario. Due to safety concerns in an automated vehicle, more research work is required to understand the driver transitions in various conditions.

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APPENDIX I

Definitions:

Non-driving task: In a car, actions performed by a driver other than driving (steering, braking, acceleration) is considered as non-driving task. It could be as simple as reading text messages, talking in a phone, using mobile, checking emails, listening to songs etc..

Adaptive cruise control: This feature can control the steering, acceleration, and brakes of the vehicle to support the driver.