UNIVERSITY OF CALIFORNIA

Travel Behavior Changes Among Users of Partially Automated Vehicles

A Research Report from the University of California Institute of Transportation Studies

Scott Hardman, Assistant Professional Researcher, Institute of Transportation Studies, University of California, Davis

May 2020

REPORT No.: UC-ITS-2019-04 | DOI:10.7922/G2CV4G0N

ITS UC DAVIS INSTITUTE OF TRANSPORTATION STUDIES

Technical Report Documentation Page

1. Report No.
UC-ITS-2019-04

2. Government Accession No.
N/A

3. Recipient's Catalog No.
N/A

4. Title and Subtitle
Travel Behavior Changes Among Users of Partially Automated Vehicles

5. Report Date
May 2020

6. Performing Organization Code
ITS-Davis

7. Author(s)
Scott Hardman, PhD, https://orcid.org/0000-0002-0476-7909

8. Performing Organization Report No.
UCD-ITS-RR-20-13

9. Performing Organization Name and Address
Plug-in Hybrid & Electric Vehicle Research Center
Institute of Transportation Studies, Davis
1605 Tilia Street
Davis, CA 95616

10. Work Unit No.
N/A

11. Contract or Grant No.
UC-ITS-2019-04

12. Sponsoring Agency Name and Address
The University of California Institute of Transportation Studies
www.ucits.org

13. Type of Report and Period Covered
Final Report (October 2018 – December 2019)

14. Sponsoring Agency Code
UC ITS

15. Supplementary Notes
DOI:10.7922/G2CV4G0N

16. Abstract
Partially automated battery electric vehicles (BEVs) are being sold to and used by consumers. Estimates indicate that as of the end of 2019, there were over 700,000 Partially Automated Tesla Vehicles—the subject of this study—on the roads globally. Despite this, little research has been done to understand how they may be changing travel behavior. In this study, qualitative interviews with 36 users of Tesla BEVs with Autopilot were conducted. The goal of this was to understand how Autopilot is used, user experiences of the system, and whether the system has any impact on drivers' travel behavior. The focus of the last of these aims was to determine whether Autopilot could cause or was causing an increase in vehicle miles traveled (VMT) among the study participants. Results from the interviews showed that partial automation leads to consumers travelling by car more and being more willing to drive in congested traffic. These changes are due to increased comfort, reduced stress, and increased relaxation due to the partial automation system, and because of the lower running costs of a BEV. The results also point to a need for further research of partially automated vehicles that are already on the market, as 11 of 17 reasons for increased VMT that have been identified in modeling studies of fully automated vehicles (not yet commercially available) applied to users of Autopilot.

17. Key Words
Level 2 driving automation, autonomous vehicles, vehicle miles traveled, travel behavior, electric vehicles, interviews

18. Distribution Statement
No restrictions.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	29	N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

About the UC Institute of Transportation Studies

The University of California Institute of Transportation Studies (UC ITS) is a network of faculty, research and administrative staff, and students dedicated to advancing the state of the art in transportation engineering, planning, and policy for the people of California. Established by the Legislature in 1947, ITS has branches at UC Berkeley, UC Davis, UC Irvine, and UCLA.

Acknowledgements

This study was made possible through funding received by the University of California Institute of Transportation Studies from the State of California via the Public Transportation Account and the Road Repair and Accountability Act of 2017 (Senate Bill 1). The author would like to thank the State of California for its support of university-based research, and especially for the funding received for this project. The author would also like to thank the 36 participants that agreed to take part in an hour-long interview about their experiences with a partially automated Tesla electric vehicle. Thanks to Seth Karten for editing this report.

Travel Behavior Changes Among Users of Partially Automated Vehicles

UNIVERSITY OF CALIFORNIA INSTITUTE OF TRANSPORTATION STUDIES

May 2020

Scott Hardman, *Assistant Professional Researcher, Institute of Transportation Studies, University of California, Davis*

[page intentionally left blank]

TABLE OF CONTENTS

Executive Summary

Partially automated battery electric vehicles (BEVs) are being sold to and used by consumers. We estimate that as of the end of 2019, there were over 700,000 Partially Automated Tesla Vehicles—the subject of this study—on the roads globally. Despite this, little research has been done to understand how they may be changing travel behavior. The majority of existing research on automation and travel behavior is focused on fully automated/driverless vehicles. That research shows how these driverless vehicles, if not properly regulated, could change travel behavior and increase vehicle miles traveled (VMT). As partially automated vehicles could reduce drivers' workload, they also have the potential to change travel behavior.

Among the most common partially automated BEVs are Tesla BEVs with Tesla's partial automation system, "Autopilot." As these vehicles are partially, not fully, automated, the human driver is still considered to be in control of the vehicle with the system assisting by controlling speed, acceleration, braking, and steering. A previous study (Hardman, Lee and Tal, 2019) found that Tesla BEVs with Autopilot have higher VMT than those without Autopilot, and that there is a positive relationship between Autopilot use and VMT. The study did not determine whether higher VMT was caused by Autopilot.

In this study we conducted qualitative interviews with 36 users of Tesla BEVs with Autopilot. The goal of this was to understand how Autopilot is used, user experiences of the system, and whether the system has any impact on drivers' travel behavior. The focus was to determine whether Autopilot could cause or was causing a change in travel behavior among the study participants. Results from the interviews found the following:

- Tesla buyers did not purchase their vehicles because of Autopilot; prior to using Autopilot they were unaware of the benefits of the system.
- Users report positive experiences with Autopilot, and generally find that it takes away a substantial portion of the mental load required for driving. They mostly use the system on freeways.
- Once users have experience using Autopilot, they find it reduces stress, reduces tiredness, increases comfort, and increases feelings of safety.
- The system is particularly beneficial on long trips (that can be tiring) and in stop and go traffic (which can be stressful).
- Because Autopilot increases comfort, reduces stress, and increases relaxation in drivers, it appears to change travel behavior. Drivers report taking more trips, choosing to drive rather than fly, and being more willing to drive in stop-and-go traffic.
- Changes to travel are not just due to Autopilot, they are also a result of the lower running costs of a BEV (which sometimes includes free charging from Tesla superchargers) compared to an internal combustion engine vehicle.
- The results suggest that partially automated BEVs could increase VMT. A large number of automated BEVs could cause a systemwide increase in VMT, which would have implications for road and infrastructure funding.

Introduction

According to the 5-level classification of vehicle automation by the Society of Automotive Engineers (SAE), partially automated vehicles correspond to level 2 (SAE, 2014). SAE defines this level as: “The vehicle may be able to control both steering and acceleration/deceleration using information from the external environment. The human driver is considered to be performing all driving tasks.” We estimate there are at least 700,000 such partially automated electric vehicles on the roads globally (based on the number of Tesla vehicles sold with the system as a minimum number of these vehicles), generating billions of vehicle miles per year. Level 2 systems could take some of the pressure of driving away from human drivers and create a less stressful and more comfortable driving experience, so could impact travel behavior.

Previous studies have found that reduced stress and increased comfort are reasons why fully automated (“driverless”) vehicles (SAE Level 5 vehicle) will change travel and increase vehicle miles traveled (VMT) (Harb *et al.*, 2018; Pudāne *et al.*, 2019). If partially automated vehicles substantially increase driver comfort, they also could lead to changes in travel. To date no studies have investigated whether partially automated vehicles will increase VMT, meaning we risk unforeseen changes to travel behavior with both the imminent spread of partial automation and potential spread of full automation. The aim of this study is to explore how drivers use partially automated electric vehicles, whether they have experienced any changes to their travel, and why this is the case. To explore these questions, we conducted 36 qualitative interviews with owners of partially automated vehicles in California. The respondents are all owners of Tesla electric vehicles with “Autopilot,” Tesla’s version of a partial automation system.

According to Tesla, Autopilot can “*match speed to traffic conditions, keep within a lane, automatically change lanes without requiring driver input, transition from one freeway to another, exit the freeway when your destination is near, self-park when near a parking spot and be summoned to and from your garage.”* The system is designed to assist drivers, with Tesla stating *“Every driver is responsible for remaining alert and active when using Autopilot, and must be prepared to take action at any time”* (Tesla, 2018). The Tesla owner manual describes the different features of Autopilot which are: traffic-aware cruise control, autosteer, autopark, lane assist, collision avoidance assist, and speed assist (Tesla, 2019).

Literature Review

Researchers are beginning to study the impact of fully automated or driverless vehicles on travel. They have investigated perceptions of the vehicles, whether people would use them, and how they could impact travel and why. Below we review these studies, we focus on these because they are relevant to our study of partially automated vehicles and because there are few studies on partial automation at present. Table 1 summarizes the findings relating to VMT and travel behavior from the literature.

Perrine et al. (2018) found that driverless vehicles would lead to long-distance travel increasing by about 12%. Using National Household Travel Surrey (NHTS) data, Schoettle and Sivak (2015) modelled the impact of automated vehicles on travel behavior and found that per vehicle VMT would increase by 75%, though their model assumes no increase in total VMT. Wadud et al. (2016) used a framework to understand the potential impacts of automated vehicles on travel demand and carbon emissions. They highlight uncertainty in what impacts the vehicles will have due to the introduction of complementary technologies and other changes in travel behavior. They suggest that the vehicles could have a positive or negative impact on VMT and emissions depending on how they are used. This conclusion aligns with findings by Childress et al. (2015) that automated vehicles could reduce VMT by 35% or increase it by 19.6%. Based on traffic simulations, Patella et al. (2019) found that fully automated vehicles would increase highway miles by 8%, but only increase total VMT by 1%. One study simulated the use of fully automated vehicles using chauffeur driven cars (Harb *et al.*, 2018). The study found that driverless vehicles could lead to increases in VMT by 4–341%. Existing evidence suggests that automated vehicles have the potential to change travel behavior, and most studies find that they could increase VMT. Three recent literature reviews also found this to be the case (Milakis, Van Arem and Van Wee, 2017; Taiebat *et al.*, 2018; Soteropoulos, Berger and Ciari, 2019).

The reasons why automated vehicles will increase VMT are of interest to our study, and a summary of the reasons is shown in Table 1. Reduced cost of travel is likely to cause an increase in long distance trips, simply because consumers generally respond to reduced travel costs (Perrine, Kockelman and Huang, 2018; Taiebat *et al.*, 2018). Increased comfort and a reduced feeling of fatigue also have the potential to increase VMT (Zmud, Sener and Wagner, 2016; Bierstedt *et al.*, 2019; Pudāne *et al.*, 2019). Automated vehicles also give consumers the potential to multitask. Pudāne et al. (2019) detected several such activities that travelers may partake in, including: working, sleeping, eating, washing, brushing teeth, attending to children, reading, exercising, watching TV, relaxing, and browsing the internet. Increased comfort, reduced fatigue, and ability to multitask may lead to consumers having a lower value of time while in an automated vehicle, making them more willing to travel further and more often (Perrine, Kockelman and Huang, 2018; Kolarova, Steck and Bahamonde-birke, 2019). These factors may also lead to consumers shifting from airplane or train travel in favor of automated vehicles for long distance trips (Perrine, Kockelman and Huang, 2018; Pudāne *et al.*, 2019). Increases to VMT could also result from owners sending driverless cars out on errands (Harb *et al.*, 2018) or from travel between clients of ride-sourcing or shared vehicle services like UBER/Lyft or GIG (Zhang, Guhathakurta and Khalil, 2018). Studies have also found the potential for currently underserved populations (e.g., elderly, less mobile) to travel more (Wadud, MacKenzie and Leiby, 2016; Harb *et al.*, 2018; Patella *et al.*, 2019), though this increase may have more societal benefits than the disadvantages of the corresponding increase in VMT.

A small number of studies have examined the effects of partial automation. Hardman et al. (Hardman, Lee and Tal, 2019) found differences in VMT among Tesla owners clustered according to how much they used Autopilot. Frequent Autopilot users had significantly higher annual VMT than did infrequent users and those who did not have Autopilot. This points to a relationship between using Autopilot and VMT, but the study was unable to determine a causal relationship as it did not control for self-selection—i.e., persons with high VMT choosing to buy a Tesla with Autopilot and then using Autopilot frequently. Other studies on partial automation focus on issues such as trust in the technology, perceptions of safety and comfort (Abraham *et al.*, 2017; Dikmen and Burns, 2017; Lee *et al.*, 2018; Lin, Ma and Zhang, 2018), how drivers learn about the technology (Abraham, Reimer and Mehler, 2018), driver interventions when using automation (Tenhundfeld *et al.*, 2019), impact on the number of vehicle collisions, and other issues (Chan, 2017; Endsley, 2017). We were unable to identify any studies on the impact of partial automation on travel behavior.

While there appears to be agreement that fully automated vehicles could lead to increases in travel, to our knowledge, no research has been undertaken to understand whether semi-automated vehicles will lead to similar trends. Our study aims to address this gap in the literature.

Table 1. Summary of literature on the types of VMT that are expected to increase from driverless vehicles, the reasons for these increases, and references for articles with these findings.

	Potential changes to travel behavior	**Reference**
Types of VMT increases that could be seen	More long-distance trips	(Zmud, Sener and Wagner, 2016; Harb *et al.*, 2018; Perrine, Kockelman and Huang, 2018)
	More local trips	(Harb *et al.*, 2018)
	Mode shift from airlines	(Perrine, Kockelman and Huang, 2018)
	Residential location change	(Milakis, Van Arem and Van Wee, 2017; Kolarova, Steck and Bahamonde-birke, 2019)
	Workplace location change	(Kolarova, Steck and Bahamonde-birke, 2019)
	Empty vehicle miles—errands	(Harb *et al.*, 2018)
	Empty vehicle miles—relocation of a shared vehicle to the next client	(Zhang, Guhathakurta and Khalil, 2018)
Why VMT could increase	Reduced travel costs	(Perrine, Kockelman and Huang, 2018; Taiebat *et al.*, 2018)
	Reduced stress and fatigue and increased comfort	(Zmud, Sener and Wagner, 2016; Bierstedt *et al.*, 2019; Pudāne *et al.*, 2019)
	Demand from new users (e.g., older people)	(Wadud, MacKenzie and Leiby, 2016; Harb *et al.*, 2018; Patella *et al.*, 2019),
	Easier to go out and drink alcohol	(Harb *et al.*, 2018)
	Ability to do non-driving activities	(Harb *et al.*, 2018; Pudāne *et al.*, 2019)
	More willing to drive at night	(Harb *et al.*, 2018)
	Lower value of time while travelling	(Perrine, Kockelman and Huang, 2018)
	Improved traffic flow and reduced travel times	(Childress *et al.*, 2015)
	Reduced parking costs	(Childress *et al.*, 2015)
	Miles shifting between vehicles	(Zhang, Guhathakurta and Khalil, 2018)

Methods

In this study we conducted qualitative semi-structured interviews with partially automated electric vehicle owners. We chose a qualitative approach because we do not yet have a detailed understanding of how drivers use automation, which would be needed to develop a questionnaire survey. We entered the interviews with a protocol of topics we wanted to explore but permitted digressions, alteration of the order of the topics discussed, and discussion of new topics. This gives interviewees the freedom to raise topics that are important to them and may not be known issues to the interviewee. The interviews included the following topics:

1) Household information (number of household members, interviewee education and career, household vehicles, etc.)
2) Purchase motivations
3) Use of Tesla (commuting, weekend trips, etc.)
4) Benefits of ownership
5) Any changes to travel from owning the vehicle
6) Do they have Autopilot? (This was the first mention of Autopilot by the interviewer if the interviewee did not mention it on her/his own.)
    a. Experience/use/perceptions of Autopilot
    b. Activities while using Autopilot
7) Any changes to travel from Autopilot
8) Hypothetical scenario where you can't use Autopilot anymore. How would that impact the way you travel?
9) Supercharging (This was the first mention of supercharging by the interviewer if the interviewee did not mention it on her/his own.)
10) Hypothetical scenario where supercharging isn't free anymore. How would that impact the way you travel?
11) Any other topics interviewees wanted to discuss

The interviewer did not mention Autopilot until the interview was well underway. This was to see whether interviewees would mention it themselves either as a reason for purchasing the vehicle, a benefit of owning the vehicles, or as a reason they think their travel has changed in their current vehicle compared to their prior vehicle. The same was done with supercharging. To enable calculation of VMT, respondents were also asked how many miles they had driven in their Tesla (which they checked on an app) and how long they had owned the vehicle.

All interviews were conducted by the same sole interviewer (the author of this paper) in an attempt to reduce bias resulting from how questions were posed. We employed a theoretical sampling approach in selecting interviewees (Glaser and Strauss, 1999)—i.e., an approach aimed at covering as diverse a population as possible and achieving saturation. This approach resulted in 36 interviews. First, we used a purposeful sampling strategy to obtain a demographically and geographically diverse set of interviews. Due to resource and time limitations, we were geographically constrained to Northern California, sampling people in the Sacramento area, East Bay Area, South Bay Area, Peninsula, North Bay Area, and Northern Central Valley. Demographically we sought a sample that had different ages, genders, and household sizes. Saturation was assessed by reviewing interview notes and memos (summaries written by the interviewer immediately after each interview). Saturation appeared to have been reached at 29 interviews; however at that point, only 3 interviewees (10%) were female—considerably less than the estimated 22% of Tesla owners who are female (Lee, Hardman and Tal, 2019). Thus, we recruited more females, resulting in a sample that included 9 women (25%) among 36 interviewees. After we completed these additional interviews and a few new topics emerged, we were satisfied in reaching saturation with the sample. To illustrate this, in the first 10 interviews, 20 new themes relating to Autopilot emerged, while in the last 10 interviews only 3 new themes emerged.

All interviews were audio recorded and transcribed, the results in this study are from a preliminary analysis of interview transcripts. Full inductive analysis of interviews on a line-by-line basis, which will include more detailed coding, is ongoing. Results from that analysis will form the basis of an upcoming publication.

Results

Table 2 shows socio-demographic information for interviewees. Among 36 interviewees, 27 were male and 9 female. Interviewees were aged between 30 and 75 years, with a mean of 50 years, which is slightly higher than the average for Tesla owners—46.5 years (Lee, Hardman and Tal, 2019). The average number of people in each household was 2.47, which is slightly lower than the Tesla average of 2.89. This is perhaps related to our sample being slightly older than average, such that children may have left the household. The average number of vehicles in the household was 2.47, which is similar to the Tesla average of 2.53. Interviewee home locations were all in Northern California in and around the Bay Area, Sacramento Area, and Central Valley. The main vehicles of the interviewees were all Tesla BEVs: 22 Tesla Model 3, 12 Tesla Model S, and 2 Tesla Model X.

Table 2. Socio-demographic information for interviewees.

Interviewee	Gender	Age	People in Household	Home Location	Profession	Vehicles in Household	Vehicle
1	Male	45	4	Sacramento Area	Professor	2	Model 3
2	Female	65	2	Sacramento Area	Retired	2	Model 3
3	Male	45	3	Sacramento Area	Business	2	Model X
4	Male	45	2	Sacramento Area	University Faculty	2	Model S
5	Male	45	6	Sacramento Area	Data Scientist	4	Model S
6	Male	35	4	Sacramento Area	Programmer	2	Model 3
7	Male	55	3	Central Valley	IT Support	2	Model 3
8	Male	40	5	Sacramento Area	Restaurant Owner	4	Model 3
9	Female	60	1	Central Valley	Retired	1	Model S
10	Male	35	3	Sacramento Area	Programmer	2	Model 3
11	Male	30	2	Sacramento Area	Insurance Broker	2	Model 3
12	Male	75	2	Sacramento Area	Retired	2	Model S
13	Male	45	4	Sacramento Area	Physiotherapist	3	Model 3
14	Male	67	2	Sacramento Area	Retired	3	Model 3
15	Male	70	2	Sacramento Area	Retired	2	Model 3
16	Male	55	3	East Bay Area	Retired	4	Model 3
17	Male	30	1	East Bay Area	Sales	2	Model 3
18	Male	60	2	Vacaville Area	IT	2	Model 3
19	Male	40	5	Vacaville Area	Dentist	2	Model X
20	Male	65	2	North Bay Area	Retired	3	Model S
21	Male	65	2	Bay Area Peninsula	Retired	4	Model S
22	Male	50	3	Bay Area Peninsula	Philanthropy	2	Model 3
23	Male	30	1	East Bay Area	Manufacturing	1	Model 3
24	Male	70	1	Bay Area Peninsula	Author	1	Model 3
25	Male	40	3	Sacramento Area	Programmer	2	Model 3
26	Male	35	2	Bay Area Peninsula	Programmer	2	Model 3
27	Female	55	1	Bay Area Peninsula	Physiotherapist	1	Model S
28	Male	35	1	Bay Area Peninsula	Automotive Service	11	Model 3
29	Male	70	1	Sacramento Area	Contracting	2	Model S
30	Female	72	2	East Bay Area	Retired	2	Model S

Interviewee	Gender	Age	People in Household	Home Location	Profession	Vehicles in Household	Vehicle
31	Female	35	3	East Bay Area	User experience researcher	3	Model S
32	Male	50	1	Sacramento Area	IT Security	1	Model 3
33	Female	60	2	East Bay Area	Federal Government	2	Model 3
34	Female	52	2	North Bay Area	Tourism	4	Model S
35	Female	30	1	East Bay Area	911 Dispatcher	1	Model 3
36	Female	70	2	East Bay Area	University Dean	2	Model S

Purchase Motivations and Benefits of Ownership

We briefly mention purchase motivations and benefits of ownership, as they have some relevance to respondents' views on and use of Autopilot. A future study will explore in more detail why these interviewees purchased their Tesla and the benefits ownership they report. Purchase motivations and benefits of ownership are conceptually different and do not necessarily align with one another. Motivations are why adopters choose the vehicle, while benefits are what they experience after they have purchased the vehicle. We allowed interviewees to list purchase motivations and benefits without any cues from the interviewer.

The most prominently mentioned purchase motivation was the lower emissions of electric vehicles (mentioned by 18 interviewees). This was followed by the performance of the vehicles (15 interviewees), the longer electric driving range compared to other electric vehicles (12 interviewees), a perception that the vehicles are 'high technology' (11 interviewees), the vehicles and Tesla being perceived as 'cool' (9 interviews), and the aesthetics of the vehicles (9 interviewees). Though lower emission was mentioned the most often, it was rarely mentioned first or mentioned as the most influential factor; it was often a secondary motivation after performance, technology, or the 'coolness' of the vehicles. Lower running costs was mentioned by only 4 interviewees as a factor that impacted their purchase decision. When asked specifically about purchase incentives (the US federal tax credit and the California clean vehicle rebate), interviewees mentioned this as influential in their purchase decision. However, when further discussing the topics, 24 interviewees conceded that they would still have purchased the vehicles without these incentives, and they were just a nice thing to have. This supports a similar finding from interviews with Tesla owners in 2015 (Hardman and Tal, 2016). Only 2 interviewees mentioned Autopilot as a purchase motivation. Both were older retired interviewees who hoped Autopilot would allow them to maintain independence (in travelling/driving) for longer than a vehicle without automation.

The most prominent benefit of ownership was performance (mentioned by 26 interviewees). Those who were not motivated to purchase the vehicle due to performance still saw this as a benefit of ownership. The next most prominent benefit, mentioned by 19 interviewees, was the improved quality of the driving experience—being smooth, quiet, and having fewer vibrations (typically referred to as vehicle refinement (Matthew Harrison, 2004)). Autopilot was the third most prominent benefit, mentioned by 18 interviewees. The higher number of people mentioning this as a benefit compared to a motivation is in part because buyers did not anticipate or could not understand how they would use Autopilot. Additional benefits of ownership include low maintenance (16 interviewees), not going to gas stations (16 interviewees), software updates (13 interviewees), and the lower emissions of the vehicle (11 interviewees).

Experiences Using Autopilot

Interviewees were asked to describe their experiences with Autopilot. Autopilot is reportedly used most often on freeways or interstates and in clear whether, supporting findings from a previous publication (Hardman, Lee and Tal, 2019). Some users are more confident in the system and use Autopilot on rural and local roads and in adverse weather (e.g., fog). Use of the system is particularly prevalent on long trips and in stop-and-go traffic. Respondents report that during these long trips and in stop-and go-traffic, the system is most beneficial to them.

> *"But as far as long distance travel, like when we went to Canada for instance. Again, probably less than 10% was manual driving."* Interviewee 11

> *"The best feature of it is in stop and go traffic, I don't feel homicidal like I used to."* Interviewee 18

Despite Autopilot being a partial automation system that still requires human driver input, respondents perceive the system as taking away a substantial portion of the driving task. Some interviewees likened using Autopilot to using transit (e.g., bus or train) where they sit there as a passenger and are not required to input anything to the vehicle controls.

> *"It's almost like at that point you really feel like you're just like a passenger on a bus or something, you're just sitting there, you know?"* Interviewee 5

> *"It feels similar to when I take the train somewhere. I'm a passenger and that's just exactly what it feels like. The car's doing all the work."* Interviewee 10

Interviewees reported that because of the reduced need for driver input, they felt less stressed, less tired, and more relaxed while using Autopilot. While stress levels, tiredness, and relaxation may all be interconnected, interviewees articulated their experiences of Autopilot mentioning one or two of these issues, though one interviewee mentioned all three. Drivers also reported an increased feeling of safety. Figure 1 shows a count of the number of interviewees mentioning these benefits. We explore these in more detail below.

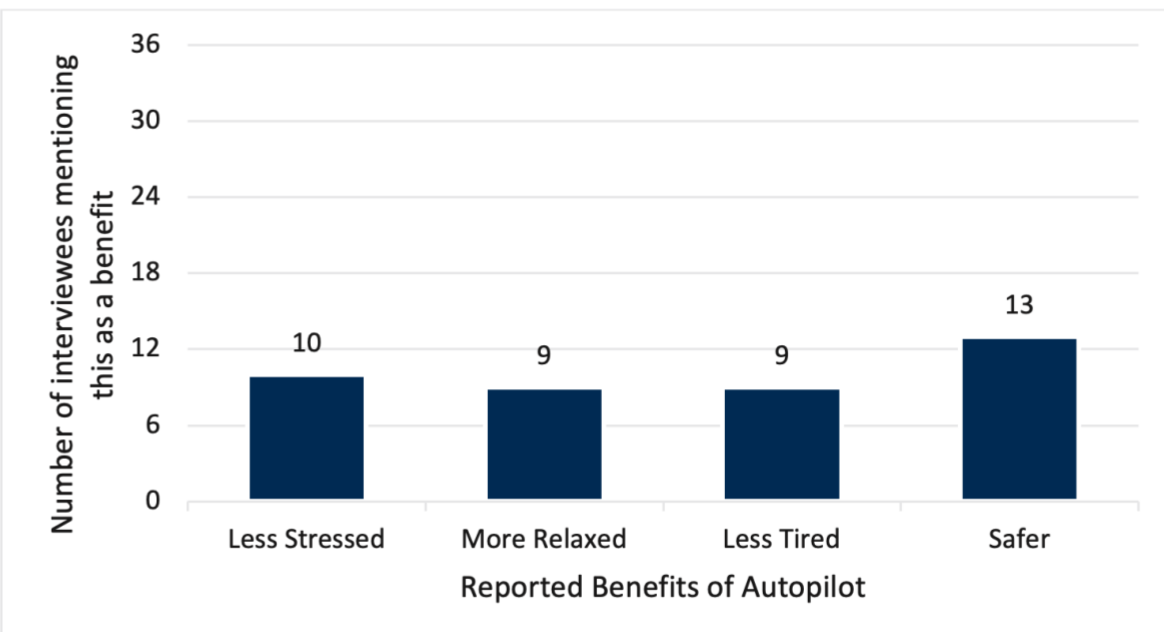

Figure 1. Reported benefits of Autopilot for users. Interviewees were asked to describe their experiences using Autopilot, they were not explicitly asked what the benefits were.

Less Stressed

Drivers report feeling less stressed both on longer journeys and at times of high traffic volumes (stop-and-go traffic). The reduction in feelings of stress was because interviewees perceived the autopilot system to take over much of the driving task. Ten (10) interviewees mentioned reduced stress while using Autopilot.

> *"It does lower your stress level by the time you get to your destination, even if it is like an eight-hour drive, you don't feel it."* Interviewee 11

> *"Well I don't feel how I used to feel when I'm in traffic, which is aggravating in any normal car. Because the car is doing all the driving. It doesn't have the stress associated with being in traffic."* Interviewee 10

Less Tired

Again, interviewees focused on longer trips and stop-and-go traffic when mentioning being less tired, though some interviewees spoke about their commutes. Those that mentioned their commutes drove further to work than the average for California households (e.g. Interviewee 7 drive 29 miles each way, see quote below). Interviewees reported being less mentally and physically tired—though most focused on the former—both while in transit and upon arrival at their destination. Nine (9) interviewees mentioned this.

> *"Even after 12 hours of driving, I had enough energy to go paint the town red. It made me realize how the enhanced Autopilot suite just reduces physical and mental fatigue. And allowed me to be not just a better driver for that time, but a more fun driver to be with rather than a grouch [laughs]."* Interviewee 8

> *"Um, so it really was, my first experiencing Autopilot, it was mind blowing. Just because the amount of fatigue that it takes out of driving."* Interviewee 11

> *"Something I didn't learn until after several trips to Southern California, several trips to Nevada, a trip to Utah: that when you get to your destination, you, you're not as tired. I mean, it's just an enjoyable vehicle and when you get out you're just not as tired. When you get to the end of your 200, 300, 400, 500 mile drive in a day, you're, I won't say rested, but you have more energy."* Interview 14

> *"It's [Autopilot has] revolutionized my commute and I actually get home feeling a whole lot less worn out, because my commute is about 29 miles one way."* Interviewee 7

More Relaxed

Perhaps because of the reduced stress and tiredness drivers feel they report being more relaxed. Again, interviewees focused on longer trips and stop-and-go traffic. Nine (9) interviewees mentioned experiencing this.

> *"I drove to LA and got on 5, put it on Autopilot, it was the most relaxing drive."* Interviewee 12

"I'm probably more relaxed, one of the things I don't like about traffic is trying to match the speeds of who's in front of me and constantly judging, if I need to slow down or stop. So it's [Autopilot] taking away almost all of that. I feel like I'm not as stressed-out about driving for 30 to 40 minutes every day as I thought I would've been." Interviewee 6

Increased feeling of safety

Interviewees also perceived the system as increasing vehicle safety: 13 interviewees mentioned this as a benefit. One reason for this perception of Autopilot increasing safety was because it is effectively always on, while human drivers may suffer lapses in focus. Another reason was interviewees believing the vehicles sensors were able to see things they were unable to, for example in fog.

"Just having the radar attentiveness to the car in front of me and the safety features, it's saved me grief many times already." Interviewee 7

"It paid for itself pretty much on that first trip, the way I like to call it, is because of the fog in the mountains, uh, etc. Where I had limited visibility, the car was, you know, a couple of miles ahead of me per se in knowing when to stop, when to correct for lanes, etc." Interviewee 8

"I only have two eyes and the car has eight. So it's seeing things I'm not seeing, so it's safer." Interviewee 10

Activities While Using Autopilot

We note that Autopilot is only a driving assistance system and should not be relied upon fully, the human driver is still supposed to be in control and alert at all times when using the system. Nevertheless, interview participants report multitasking while using Autopilot. Some interviewees report listening to podcasts or music, thinking about their day, or talking to passengers. Since these tasks are also typically done while driving a non-automated car, we do not discuss them here. We only focus on tasks that are not typically done or are not supposed to be done while driving.

"It definitely enables more multitasking. Don't know necessarily whether that's a good thing or not, but yeah, no, it definitely enables more multitasking." Interviewee 25

It should also be noted that interviewees were sometimes unwilling to share accounts of their multitasking behavior, and the interviewer did not push interviewees to share more than they were comfortable with. One reason interviewees were unwilling to share their accounts of multitasking may be because they were aware that it was not legal to do so. Interviewee 9 remarked: *"Well, technically that's illegal, but there could be times when that has happened."* Because interviewees were often unwilling to share these findings on multitasking while using Autopilot, this finding should be treated as preliminary and non-exhaustive.

Of the 36 interviewees, 18 shared information on tasks they have undertaken while using Autopilot. Of these, 9 indicated that most of the time they still keep their eyes on the road.

Mobile phone use

The most common form of multitasking reported was mobile phone use, particularly responding to text messages or emails. We note that people also do this in non-automated vehicles, though interviewees appear to report doing this for longer periods of time than non-automated vehicle users would. When one interviewee was asked whether they text more or less in their partially automated BEV, they responded *"I would say more because I feel more comfortable."* Eleven (11) interviewees reported using their phone while Autopilot was engaged.

> *"I'll look at my phone, or maybe I'll text somebody, or email, or look up something or listen to music or you know, in stop-and-go you don't need to look up as much because you're only going two miles, five miles an hour, you know what I mean?"* Interviewee 5

Observing the surroundings

Four (4) interviewees reported looking at the surrounding environment outside of the car more often when Autopilot was engaged.

> *"We drive to the coast quite a bit. When you're in an area, you just want to look around, Autopilot is on so it's watching the car in front of you. It's staying in the lane and you can actually take longer ... divert your attention a little longer maybe than you should."* Interviewee 7

> *"It felt like there's a security blanket watching me when I was looking at my phone or looking at the sky, looking at the mountains. Rather than having to constantly look at where I'm going."* Interviewee 17

Sleep

Interviewees were not specifically asked whether they had fallen as asleep while using autopilot. Three (3) interviewees reported falling asleep while using Autopilot. For one of these interviewees it was clear that this was not intentional behavior. For 2 interviewees it was unclear whether this was accidental or not.

> *"There are definitely times where I kind of nodded off and I felt myself nod off. The first time, my hand didn't slip from the wheel, but I just noticeably nodded off. And then I woke up and the car was still driving fine."* Interviewee 25

> *After being asked how long he had been asleep: "Could be 5 minutes, 10 minutes, depends. Sometimes I'll wake up and fall back asleep again or something. Ideally, I would like to stay awake, while Autopilot's engaged. But if I'm just dead tired, I mean, I just, I have to, I do, do doze off."* Interviewee 28

Other

Three interviewees reported eating with two hands while using Autopilot, one interviewee reported putting shoes on and tying a necktie while using Autopilot, and another reported doing karaoke with his sons. Increased physical interaction with human passengers was reported by one interviewee, and another reported petting their dog while using Autopilot.

> *"Or on the highway I sit on the auto driving, and I feel very good about it. We can do karaoke in the car and all this kind of things."* Interviewee 25

Changes to Travel

Interviewees were asked whether they believed their travel had changed in their BEV (without mention of whether it was a result of Autopilot or not) compared to previous vehicles they had owned. If they reported changes, they were asked why they believed their travel had change. In this study, 16 interviewees thought they had experienced no change to their travel, 12 believed it had increased, 3 thought it had maybe increased, and 2 stated they had experienced a small increase. Three (3) people did not say whether their travel as changed as they were unable to make a judgement. No interviewees reported travelling less. In sum, 17 of 36 interviewees acknowledged having some increase in vehicle travel. The most common changes to travel were doing more trips, driving rather than flying, and being more willing to travel in congestion, which we explore below.

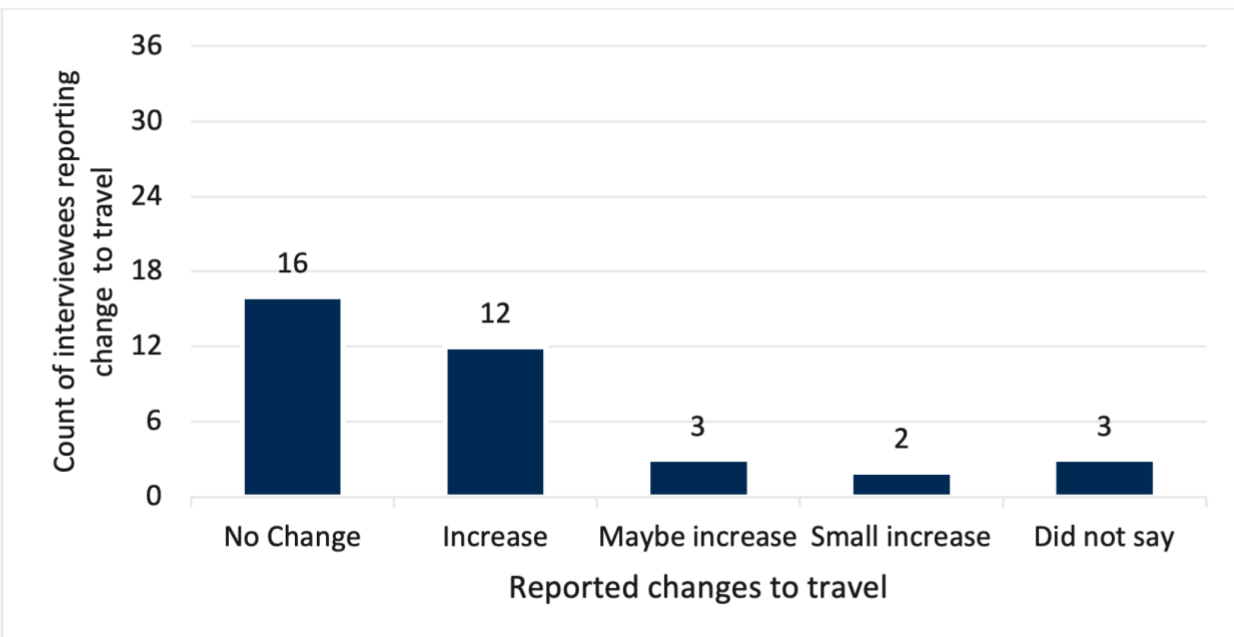

Figure 2. Number of interviewees who self-reported a change in their amount of travel with a Tesla BEV compared to the previous vehicle they owned. Interviewees were asked to consider if the travel they do in their current Tesla BEV is any different to previous vehicles they have owned. Autopilot was not mentioned in this question.

More Trips

Seventeen (17) interviewees reported making more trips in their partially automated BEV compared to previous vehicles. These interviewees stated that they believed they would not have completed these trips in their prior vehicle.

> *"The eagerness to do the trip is definitely a function of [Autopilot], I can drive to South Dakota and barely touch the steering wheel."* Interviewee 7

> *"Well, I'm more inclined to drive more frequently with an electric vehicle in general, and then Autopilot's helpful again in the circumstances that I mentioned, you know, driving far or in congested, right?"* Interviewee 5

Mode Shift from Airlines

Nine (9) interviewees indicated shifting some of their travel from airlines to driving in their partially automated vehicle. Many of these interviewees mentioned driving to cities on the west coast (e.g., Portland, LA, Seattle) rather than flying as the change to their travel (All interviewees lived in Northern California).

> *"I'd go to see my family in Oregon, and I'd fly up at least once a month, but now I drive that—just hit Autopilot. So yeah, I haven't flown in a year, I used to fly pretty regularly, but now I don't have to."* Interviewee 23

> *"I don't know what this means for your studies, but I think it's even maybe a little bit more because of the comfort factor, because it's easier to take trips and less tiring, less stressful there's probably a few times I could have chosen to fly, but I chose to drive instead. I might not have done that before."* Interviewee 25

Driving in Stop-and-Go Traffic

Ten (10) Interviewees reported being more willing to drive in stop-and-go traffic because of autopilot. The lack of need to continually monitor the traffic and make continuous changes to braking and acceleration was seen as beneficial and allowed interviewees to be more relaxed.

> *"The best feature of it is in stop-and-go traffic, I don't feel homicidal like I used to."* Interviewee 18

> *"I don't care if the car's stopping every five feet for the next 30 minutes, because I'll sit there, I'll look at my phone, I'll text someone, or email, or listen to music."* Interviewee 5

Reasons for Changes to Travel

Most of the interviewees who reported increases in travel associated with owning the Tesla related this to Autopilot, but this was not the only reason cited. One interviewee stated this explicitly:

> *"I think the Autopilot impact is probably like, I don't know, between 30% and 40%. It's significant. It's not everything, but it's pretty significant. It's the biggest single ingredient I would say."* Interviewee 28

Other reasons interviewees gave were: the lower running costs of their BEV, which in some cases includes free use of Tesla Superchargers; the vehicles being more refined (quieter, smoother, and fewer vibrations) than the previous vehicles they owned; and the vehicles having lower emissions, which removed a feeling of guilt some interviewees experienced from driving internal combustion engine vehicles previously.

Autopilot

Of the 17 interviewees who indicated their travel had changed, 13 attributed this to Autopilot, specifically because of the reasons explored previously (being more relaxed, less stressed, and less tired). However, all of these interviewees cited additional reasons for the increase in travel. Autopilot alone was not mentioned by anyone as the sole reason their travel increased.

> *"The eagerness to do the trip is definitely a function of [Autopilot], I can drive to South Dakota and barely touch the steering wheel, or put my hand on there and just be present, not have to be ... because there's a certain amount of fatigue associated with all the corrections you're doing, slowing down for the car in front of you, passing cars. So, that's all effort to some measure."* Interviewee 7

> *"Yeah, to drive as much as you like, because you're only driving 5% of the time, it's not as demanding as driving yourself."* Interviewee 23

Interviewees who cited Autopilot as a reason for travel increase were also asked to consider a scenario in which they could not use Autopilot and to describe how this would impact their decisions on travel. Ten (10) of these 13 interviewees indicated that they would then not travel as much. This may suggest that although interviewees report other reasons for their increase autopilot may be the actual cause of the increase.

Lower Running Costs

The lower running costs of a Tesla BEV were mentioned by 13 interviewees. Of these interviewees, 3 stated that the only reason for changing their travel behavior was reduced travel costs. Nine (9) mentioned lower running costs in combination with Autopilot as reasons for changing their travel.

> *"Before, I would say, okay this is going to cost me round trip $150-200. Now it's like, we drove to northern Washington. It didn't cost us anything because of the 5000 free super charger miles."* Interviewee 7

> *"I'm much less likely to think about the expense of gas, the gas prices. Oh this trip is going to cost me $50 to go to Reno or wherever it happens to be. I do not think of what the trip is going to cost me. I think about where am I going to stop and charge? And it charges me, I don't have free supercharging in my vehicle.... But it's still way less than four bucks a gallon."* Interviewee 18

> *"Yeah, I've had a couple of trips where, should I fly or drive? If I'm not in a hurry, it's just easier to drive. It doesn't cost anything."* Interviewee 29

Nicer/More Refined Vehicle

Interviewees also believed the car was nicer to drive than previous vehicles. This was because of the luxury nature of Teslas, because of reduced noise levels, and reduced engine vibrations. Fifteen (15) interviewees mentioned this as a reason their travel had changed, two of whom mentioned this as the sole reason for their travel changes. Ten (10) interviewees mentioned the more refined nature of the vehicle in combination with Autopilot for reasons their travel had changed.

> *"When you're on a serious trip, you know, for a couple hours from the lack of vibration, the engine vibration. You come there far more rested. There's absolutely no doubt. And part of that may be just from the lack of noise as well."* Interviewee 3

Lower Emissions

Three (3) interviewees indicated they increased their car travel due to the vehicle having fewer emissions. These interviewees were particularly conscious of climate change and emissions, this led them to decide to drive rather than fly but also increased the number of total trips they took, their prior travel was constrained due to a feeling of guilt when driving a conventional vehicle.

> *"There's less pollution. I'm not creating as much greenhouse gases from flying."* Interviewee 19

> *"One of the pluses for me is that you're not polluting anything. It's easier, it's cleaner, it's cheaper, it's more comfortable"* Interviewee 33

Discussion

Insights from the 36 interviews conducted in this study show that partially automated BEVs could increase VMT and explain why this may occur. Here we compare the findings from our study on partial automation and travel behavior to those found via a search of the broader literature on full automation and travel behavior. Table 3 compares the results of the current study to those from the literature summarized in Table 1, regarding what types of VMT increases are expected with driverless vehicles and the possible reasons for such increases. Of the 17 reasons identified in driverless vehicle studies we detected 11 of these in our study of partially automated vehicles. We did not explore all of these 11 reasons in detail above—notably, not 'residential location change' and 'workplace location change,' because our findings on these were inconclusive. Only one respondent reported moving to a house further away from their workplace as a result of owning a partially automated BEV, and only one respondent reported moving to a workplace that was further away from home as a result of owning a partially automated BEV. Further 'Demand from new users (e.g., older people)' was not explored in detail as it was only mentioned by two interviewees. More research is needed to understand the impact of partial automation on these issues. We also detected three additional reasons not seen in driverless vehicle studies. First the lower emissions of the vehicles were connected with travel behavior changes. Drivers also mentioned an increased feeling of safety, but it was not clear whether this was connected to the reported changes to travel. Finally, drivers mentioned that driving was more fun in a Tesla BEV, but again it was not clear if this was connected to the increase in travel.

The qualitative insights from this study lead us to conclude that partially automated BEVs could change travel behavior by increasing the amount that vehicle owners travel by road. The increase is due to: the automated system making drivers feel more relaxed, less tired, and more comfortable; the refined nature of Tesla BEVs; and reduced travel costs. This leads to more trips (17 interviewees), a shift from air travel to vehicular travel (9 interviewees), and a greater willingness to drive in stop-and-go traffic (10 interviewees). Autopilot appears to be at least partially responsible for the change in travel for 13 interviewees, and perhaps fully responsible for 10 of these 13 interviewees.

Table 3. Comparisons of VMT and travel behavior changes seen in driverless vehicle studies and changes observed in the Tesla Autopilot owner interviews. A green check mark indicates whether this has been reported, a green check with a question mark indicates evidence for the change was not conclusive but could not be ruled out, a red cross indicates the change has not been observed.

	Potential changes to travel behavior	Changes expected from driverless vehicles	Changes seen in partially automated vehicles
Types of VMT increases that could be seen	More long trips	✓	✓
	More local trips	✓	✓
	Mode shift from airlines	✓	✓
	Residential location change	✓	✓?
	Workplace location change	✓	✓?
	Empty vehicle miles—errands	✓	X
	Empty vehicle miles—relocation of a shared vehicle to the next client	✓	X
Why VMT could increase	Reduced travel costs	✓	✓
	Reduced stress and fatigue and increased comfort	✓	✓
	Demand from new users (e.g., older people)	✓	✓
	Easier to go out and drink alcohol	✓	X
	Ability to do non-driving activities	✓	✓
	More willing to drive at night	✓	✓
	Lower value of time while travelling	✓	X
	Improved traffic flow and reduced travel times	✓	X
	Reduced parking costs	✓	X
	Miles shifting between vehicles	✓	✓
	Travelling is more fun	X	✓?
	Increased perception of safety	X	✓?
	Lower emissions	X	✓

Conclusion

The purpose of this study was to understand whether partially automated BEVs would change travel behavior and, if so, the reasons for these changes. The purpose was not to quantify any such changes, but to understand what changes occur and why. The interviews reveal several new findings. First, there does not appear to be a self-selection issue whereby interviewees purchased an automated vehicle with plans to travel more; only 2 interviewees purchased a Tesla BEV because of the Autopilot feature and the hope that they could travel more in older age. Drivers typically learned about the benefits of Autopilot after using it in the vehicle they own. Second, Autopilot reduces the mental workload of driving, resulting in drivers feeling more relaxed, less tired, and less stressed. Third, Autopilot increases drivers' perceived ability to engage in non-driving tasks (e.g., emailing, texting, eating, etc.). Fourth, autopilot gives drivers an increased feeling of safety. Fifth, partial automation does appear to induce changes to travel behavior. Interviewees report driving on long trips rather than flying, taking more trips, and being more willing to drive in congested (stop-and-go) traffic. Finally, the interviewees attributed their increase in travel not only to automation, but also to lower running costs and the refined nature of the vehicles.

Policy Implications

At present no policy mechanisms exist that could be used to prevent VMT increase in partially automated BEVs. Prior to 2019, BEV drivers in California pay no road use fee, and, after 2019, they began paying a flat $100 fee in addition to their existing registration fees. Additionally, BEV drivers also do not pay gas tax. This means that a partially automated BEV driver travelling 10,000 miles per year will pay the same towards road infrastructure as someone who drives an internal combustion engine vehicle 15,000 per year. A use-based fee, such as a road user charge, could potentially be a more equitable way to charge drivers for their road use and could have the added benefit of curbing VMT increases.

The activities that owners in this study engaged in while using Autopilot may warrant further investigation in terms of safety and regulating permissible activities during use of partially automated vehicles. This recommendation is based on the finding that drivers' activities included those prohibited for drivers of non-automated and partially automated vehicles, such as texting and emailing.

References

Abraham, H. *et al.* (2017) 'What's in a name: Vehicle technology branding & consumer expectations for automation', *AutomotiveUI 2017*, pp. 226–234. doi: 10.1145/3122986.3123018.

Abraham, H., Reimer, B. and Mehler, B. (2018) 'Learning to Use In-Vehicle Technologies: Consumer Preferences and Effects on Understanding', *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 62(1), pp. 1589–1593. doi: 10.1177/1541931218621359.

Bierstedt, J. *et al.* (2019) 'Projecting travelers into a world of self-driving vehicles: estimating travel behavior implications via a naturalistic experiment', *Transportation Research Part D: Transport and Environment*. Elsevier, 107(August), pp. 23–36. doi: 10.3141/2493-11.

Chan, C.-Y. (2017) 'Advancements, prospects, and impacts of automated driving systems', *International Journal of Transportation Science and Technology*. Tongji University and Tongji University Press, 6(3), pp. 208–216. doi: 10.1016/j.ijtst.2017.07.008.

Childress, S. *et al.* (2015) 'Using an Activity-Based Model to Explore the Potential Impacts of Automated Vehicles', *Transportation Research Record: Journal of the Transportation Research Board*, 2493(2493), pp. 99–106. doi: 10.3141/2493-11.

Dikmen, M. and Burns, C. (2017) 'Trust in Autonomous Vehicles', *IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, pp. 1093–1098. doi: https://doi.org/10.1109/SMC.2017.8122757.

Endsley, M. R. (2017) 'Autonomous Driving Systems: A Preliminary Naturalistic Study of the Tesla Model S', *Journal of Cognitive Engineering and Decision Making*, 11(3), pp. 225–238. doi: 10.1177/1555343417695197.

Glaser, B. G. and Strauss, A. L. (1999) *The Discovery of Grounded Theory: Strategies for Qualitative Research*. New York: Routledge.

Harb, M. *et al.* (2018) 'Projecting Travelers into a World of Self-Driving Vehicles: Estimating Travel Behavior Implications via a Naturalistic Experiment', *Transportation Research Board 2018 Annual Meeting*, pp. 1–17.

Hardman, S., Lee, J. H. and Tal, G. (2019) 'How do drivers use automation? Insights from a survey of partially automated vehicle owners', *Transportation Research Part A: Policy and Practice*. Elsevier, 129(February), pp. 246–256. doi: 10.1016/j.tra.2019.08.008.

Hardman, S. and Tal, G. (2016) 'Exploring the Decision to Adopt a High-End Battery Electric Vehicle Role of Financial and Nonfinancial Motivations', *Transportation Research Record Journal of the Transportation Research Board*, pp. 20–27. doi: 10.3141/2572-03.

Kolarova, V., Steck, F. and Bahamonde-birke, F. J. (2019) 'Assessing the effect of autonomous driving on value of travel time savings : A comparison between current and future preferences', *Transportation Research Part A*. Elsevier, 129(August), pp. 155–169. doi: 10.1016/j.tra.2019.08.011.

Lee, C. *et al.* (2018) *Consumer Comfort with In-Vehicle Automation : Technology of Today Drives Acceptance of a Self-Driving Future*.

Lee, J. H., Hardman, S. and Tal, G. (2019) 'Who is buying electric vehicles in California? Characterising early adopter heterogeneity and forecasting market diffusion', *Energy Research & Social Science*, 55.

Lin, R., Ma, L. and Zhang, W. (2018) 'An interview study exploring Tesla drivers' behavioural adaptation', *Applied Ergonomics*. Elsevier, 72(July 2017), pp. 37–47. doi: 10.1016/j.apergo.2018.04.006.

Matthew Harrison (2004) *Vehicle Refinement: Controlling Noise and Vibration in Road Vehicles*, *Vehicle Refinement: Controlling Noise and Vibration in Road Vehicles*. doi: 10.1016/B978-0-7506-6129-4.X5000-7.

Milakis, D., Van Arem, B. and Van Wee, B. (2017) 'Policy and society related implications of automated driving: A review of literature and directions for future research', *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*. Taylor & Francis, 21(4), pp. 324–348. doi: 10.1080/15472450.2017.1291351.

Patella, S. M. *et al.* (2019) 'Carbon Footprint of autonomous vehicles at the urban mobility system level : A tra ffi c simulation-based approach', *Transportation Research Part D*. Elsevier, 74(August), pp. 189–200. doi: 10.1016/j.trd.2019.08.007.

Perrine, K. A., Kockelman, K. M. and Huang, Y. (2018) 'Anticipating Long-Distance Travel Shifts Due To Self-Driving Vehicles', *Transportation Research Board 2018 Annual Meeting*, pp. 1–17. Available at: http://www.caee.utexas.edu/prof/kockelman/#RESEARCH_&_REPORTS:_Self-Driving,_Automated,_&_Connected_Vehicles.

Pudāne, B. *et al.* (2019) 'How will automated vehicles shape users' daily activities? Insights from focus groups with commuters in the Netherlands', *Transportation Research Part D: Transport and Environment*, 71(December), pp. 222–235. doi: 10.1016/j.trd.2018.11.014.

SAE (2014) *Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems*. Available at: https://saemobilus.sae.org/content/j3016_201401.

Schoettle, B. and Sivak, M. (2015) *Potential impact of self-driving vehicles on household vehicle demand and usage*, *University of Michigan Transportation Research Institute*.

Soteropoulos, A., Berger, M. and Ciari, F. (2019) 'Impacts of automated vehicles on travel behaviour and land use: an international review of modelling studies', *Transport Reviews*. Taylor & Francis, 39(1), pp. 29–49. doi: 10.1080/01441647.2018.1523253.

Taiebat, M. *et al.* (2018) 'A review on energy, environmental, and sustainability implications of connected and automated vehicles', *Environmental Science and Technology*, 52(20), pp. 11449–11465. doi: 10.1021/acs.est.8b00127.

Tenhundfeld, N. L. *et al.* (2019) 'Trust and Distrust of Automated Parking in a Tesla Model X', *Human Factors*. doi: 10.1177/0018720819865412.

Tesla (2018) *Autopilot*. Available at: https://www.tesla.com/autopilot (Accessed: 14 December 2018).

Tesla (2019) *Tesla Model S Owners Manual*. Available at: https://www.tesla.com/sites/default/files/model_s_owners_manual_north_america_en_us.pdf (Accessed: 3 June 2019).

Wadud, Z., MacKenzie, D. and Leiby, P. (2016) 'Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles', *Transportation Research Part A: Policy and Practice*. Elsevier Ltd, 86, pp. 1–18. doi: 10.1016/j.tra.2015.12.001.

Zhang, W., Guhathakurta, S. and Khalil, E. B. (2018) 'The impact of private autonomous vehicles on vehicle ownership and unoccupied VMT generation', *Transportation Research Part C: Emerging Technologies*. Elsevier, 90(October 2017), pp. 156–165. doi: 10.1016/j.trc.2018.03.005.

Zmud, J., Sener, I. N. and Wagner, J. (2016) *Consumer Acceptance and Travel Behavior Impacts of Automated Vehicles Final Report PRC 15-49 F*. Available at: https://static.tti.tamu.edu/tti.tamu.edu/documents/PRC-15-49-F.pdf.