Public Perceptions of Self-driving Cars: The Case of Berkeley, California

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ABSTRACT

Self-driving vehicles represent a technological leap forward that can offer solutions to current transportation problems and dramatically change how people approach mobility. While self-driving cars have the potential to improve safety and increase quality of life, many people appear reluctant to adopt the technology, because they are uncomfortable with safety, liabilities, and control. Public attitudes toward self-driving cars are increasingly important as the public shapes the demand for the technology, policies that govern them, and future investments in infrastructure. Moreover the nature of the technology means that the truly transformative benefits are only realized once self-driving cars are adopted en masse. We investigate public attitudes toward self-driving cars using the responses of 107 likely adopters in Berkeley, California as a case study. What do these people find most and least attractive about self-driving cars, and how do they envision the inclusion of the technology? Would they adopt this technology and in what form? Do an individual's demographics, existing travel behavior, and relationship to cars and technology affect his or her opinion about self-driving cars? We find that individuals are most attracted to potential safety benefits, the convenience of not having to find parking, and amenities such as multitasking while en route; conversely, individuals were most concerned with liability, the cost of the technology, and losing control of the vehicle. Men are more likely to be concerned with liability, and less likely to be concerned with control than women. Individuals with higher income are most concerned with liability, and those with lower income appear to be more concerned with safety and control. Single-occupancy vehicle commuters and cyclists were most concerned with giving up control. All groups were concerned with costs. We present this case study to inform those creating this technology how self-driving cars will likely be perceived by the public.

INTRODUCTION

Transportation by automobile in the United States is becoming increasingly unsustainable. Rising carbon emissions, increasing congestion, and high traffic accident rates are a few consequences of auto use. Self-driving vehicles offer an alternative form of individualized transportation that can be adapted to reduce such negative impacts. While self-driving cars have great potential to improve the safety, efficiency, and sustainability of our auto-oriented transportation system, many challenges remain, particularly with public perceptions of safety, liabilities, and control. The ability of self-driving vehicles to effect transformative change depends largely on how successful the vehicles are in attracting drivers from private automobiles. Once a critical mass of self-driving vehicles has been established, network benefits and other economies of scale enable environmental, safety, and travel time improvements. Public attitudes toward self-driving cars become increasingly important as the public shapes the demand and market for the cars, the policies that govern them, and future investments in infrastructure. This study investigates attitudes of likely adopters towards self-driving cars using the responses of 107 residents of Berkeley, California as a case study.

BACKGROUND

The need for a different form of individual transportation

Since the mid-twentieth century, automobiles have been the dominant mode of travel both within and between cities. While point-to-point travel on demand confers benefits to the individual, it does so at great costs to society. Automobile travel, particularly single occupancy vehicle (SOV) driving, contributes intensely to traffic congestion, traveler delays, and vehicle pollution. Traffic congestion costs the U.S. economy more than \$120 billion, and produces 56 billion pounds of CO2 (*1*). Automobile accidents are a major concern as well. In 2010, there were approximately 35,000 vehicle fatalities in the U.S.; 90% of vehicle crashes can be attributed to driver error (*2*). Moreover, cars consume valuable resources. On average, cars sit unused almost 22 hours out of every day (*3*).

Improvements to the transportation system thus far have been incremental and targeted to specific concerns. For example, converting gasoline-powered vehicles to electric drive helps reduce transportation-related carbon emissions, but does little to reduce congestion or motor vehicle fatalities. Intelligent Transportation Systems (ITS), such as variable message signs, promise safety improvements, but do not explicitly address transportation's contribution to climate change. Transportation Demand Management (TDM) strategies like congestion and parking pricing schemes can go a long way to addressing transportation problems. However, these strategies are best used in combination with improvements in technology.

Self-driving cars represent a technological leap forward that can offer solutions and dramatically change today's transportation network. A self-driving car (also known as an autonomous car, personal automated vehicle, driverless car, or robotic car) is defined as a motor vehicle capable of automated driving and navigating entirely without direct human input. Self-driving cars sense their surroundings with techniques such as radar, GPS, and computer vision. Advanced control systems interpret electronic sensor information to identify appropriate navigation paths, as well as obstacles and relevant signage (*4*, *5*).

Self-driving vehicle technology has origins as early as the 1920s, when Achen Motor Company demonstrated a phantom motor car in Milwaukee (*6*). Other car companies, as well as electronics companies and universities, experimented with self-driving cars with limited success (*7*, *8*). Advancements in self-driving vehicle technology accelerated in the 2000s with the US government sponsored Defense Advanced Research Projects Agency (DARPA) Grand Challenge in 2004. The DARPA Challenge was the first long distance competition for driverless cars and attracted more than one hundred teams in its first year (*9*). The winning robot of the second Grand Challenge, led by Sebastian Thrun's team at Stanford, sparked the development of Google's self-driving cars (*10*). As of 2013, many automotive manufacturers are testing driverless car systems, including Audi, BMW, Ford, General Motors, Mercedes-Benz, Nissan, Toyota (*11*, *12*, *13*, *14*). Based on their perceptions of the desires of potential customers, many of these systems are not fully autonomous, requiring no driver input, but are rather a form of 'autopilot' that can be switched on and off by the driver.

Opportunities for self-driving cars

Self-driving vehicles and allied technologies such as connected vehicles, ITS, and electric drive vehicles have the power to change modern transportation to become more sustainable, safer, and convenient compared to today's system. Driverless vehicles can allow people to travel on demand and benefit from the economies of scale that come with being part of a larger transportation network. Self-driving cars can address issues of safety, congestion, fuel efficiency, and equity.

Improvements in safety could be realized soon after widespread adoption of self-driving vehicles. Self-driving car sensors can follow traffic rules and be more alert and responsive than drivers today. In 2010, there were approximately 35,000 vehicle fatalities in the U.S.; many of these fatalities were caused by distracted driving, drunk driving, and other impairments (*3*). Research on connected vehicles has shown that vehicle-to-vehicle communication systems potentially address 81% of all police-reported vehicle target crashes annually (*15*). Self-driving technology includes elements of connected vehicle technology and is likely to gain these safety benefits as well.

Adoption of self-driving vehicles at the city or regional level is likely to result in reduced congestion across the network once the market penetration of these vehicles passes a certain threshold. As self-driving vehicles have not been deployed on such a scale, empirically determined values for optimum market penetration do not exist. However, one can imagine centralized, demand responsive routing will enable self-driving vehicles to choose a route that minimizes delay for all users in the system and "reserve" a spot in the network. These vehicles would then be able to avoid bottlenecks and congestion prone areas before they begin to slow down traffic. Additionally, forming cars into eight car platoons potentially increases the capacity of freeway lanes about 367% at 45 mph, according to a computer simulation of the effects of platooning (*20*). These capacity improvements would be achieved without having to add lanes, which uses existing roads more efficiently. Likewise, this will increase the overall throughput in areas where highway expansion is not possible due to physical characteristics of the site (bridges, hillsides, etc), as well as reduce the amount of land that must be ceded to transportation at the expense of other open space and developments.

Another opportunity for self-driving cars lies with fuel efficiency and environmental benefits. Platooning vehicles offers immediate benefits to efficiency, regardless of fuel type. The cars behind the lead vehicle reap aerodynamic benefits and reduce their energy consumption by up to 25% (*18*). A 2013 Japanese study showed truck platooning improved fuel economy by 15% for heavy commercial vehicles (*19*). Since self-driving cars can navigate along a highway with a precision that human drivers cannot, it can enable vehicles to be powered in non-conventional ways that can reduce the energy consumption of the transportation sector. Self-driving vehicles can adopt features of On Line Electric Vehicles (OLEVs), electric vehicles that receive their power from the roadway using inductive power transfers. According to a 2007 IEEE paper, "roadway vehicles driven by human operators cannot meet the tolerance demanded by [the] present [OLEV] system, consequently, system performance is compromised" (*17*). Self-driving cars enable these benefits and other technologies through their ability to precisely position themselves in the roadway or relative to similarly equipped cars.

Self-driving cars can also positively address issues of equity. Historically, several groups have been excluded from the flexible, convenient and speedy travel provided by automobiles (*21*, *22*, *23*). The upfront cost of an automobile is high, preventing economically disadvantaged groups from the benefits of a car. Those who do own cars are likely to spend a disproportionate part of their household expenses on auto ownership. Additionally, people younger than the legal driving age, or those who do not have the physical or mental capabilities to drive a car, are restricted from the benefits of automobile use. With self-driving vehicles, these barriers can be lessened as one does not necessarily have to know or be able to drive to reap the benefits.

From a social perspective, shared driverless vehicles represent the most affordable way for people to access self-driving technology and its associated benefits. Opening the market for self-driving cars to those who have been excluded from the automobile market could encourage adoption, lower the price of the technology, and enhance network benefits. From an environmental perspective, shared driverless vehicles are a way to reduce the amount of land consumed for parking, as well as the amount of energy and resources into building vehicles. Finally, shared self-driving cars potentially could reduce VMT since their presence in the market will change the way in which people pay for transportation by translating sunk costs into up-front costs to consumers, discouraging needless trips, encouraging trip-chaining, and sharing of rides. Shared driverless cars or self-driving taxis have the greatest potential environmental benefits and their adoption should be particularly targeted.

Challenges to adoption of self-driving cars

Google's co-founder Sergey Brin says that autonomous vehicles will be available to the public by 2017 (*26*). While self-driving cars are technologically feasible, significant challenges remain with the legal framework, regulatory changes, cost of technology, and issues of control and trust.

As of 2013, California, Nevada, Florida, and the District of Columbia have passed laws authorizing companies to test self-driving cars on private and public roads; nine other states have debated similar bills (*27*). Yet, the legal and regulatory framework still needs work (*4*). “If the driver, by design, is no longer in control, what happens if the vehicle crashes? The ‘driver’ could well be an innocent bystander or might at least bear lesser liability than drivers do today” (*3*). Additionally, self-driving vehicles will likely be connected through V2V (Vehicle to Vehicle) or V2I (Vehicle to Infrastructure) technology (*3*). Such connectivity will require a large investment in infrastructure that will either have to be provided by the public sector, or made profitable enough that a private entity will be able to provide this service. Regulatory changes must be adopted at the state and local levels to address these issues. The National Highway Traffic Safety Administration has begun efforts, having defined five levels of vehicle automation and announced a policy to address safety of self-driving cars (*28*).

Cost of the technology is also a significant barrier to many, and without enough of these vehicles on the roads, the network benefits will not be achieved. “The LIDAR system used in the Google car, for example, costs $70,000” (*3*). As of 2013, the autonomous driving system costs about $150,000 (*27*). This is more than the average vehicle purchase and illustrates the need to find technological solutions that the market will bear. Since the success of self-driving vehicles depends on the widespread adoption of this technology as a replacement to the automobile, ascertaining public attitudes towards these vehicles is extremely important since it will affect public support for regulation or expenditures, as well as influence demand for a product introduced into the market.

Control and trust of the technology is also expected to be a significant issue with the public. The technology is very new and its safety record unproven. Few people feel comfortable using an unproven transportation technology on a regular basis, as one can learn from a study of the history of air travel. Although the Wright Brothers flew at Kitty Hawk in 1903, it was not until the 1920s that the United States had a significant passenger airline network (*29*). Similar concerns about the safety and reliability of self-driving technology have been expressed (*4*, *12*, *13*, *14*). Moreover, people have expressed concerns about giving up control of the car to a machine, and general beliefs that the car is unsafe. Such concerns about safety and reliability of a nascent technology are natural, and we intend to study their effect on the enthusiasm for self-driving vehicles.

Self-driving cars are in development and are not yet fully accessible to the public; as such, limited research about public attitudes toward the technology exists. As of 2013, there have been two significant public opinion surveys conducted by private firms. In 2011, Accenture surveyed 2,006 consumers in the US and UK. Nearly half of respondents indicated they would be comfortable with using driverless cars, and the other half was more likely to use the technology if they could take back control if needed (*24*). In 2012, J.D. Power and Associates conducted a survey of 17,400 vehicle owners; 37% said they would be interested in purchasing a fully autonomous car, but the figure dropped to 20% with the introduction of added costs (*25*). Since the existing literature on self-driving cars is limited, and the data on public attitudes are proprietary, this study collects and contributes new data to the autonomous vehicle discussion.

METHODOLOGY

Public attitudes toward self-driving cars become increasingly important as the public shapes the demand and market for the cars, the policies that govern them, and future investments in infrastructure. Our guiding research questions are:

- What does the public find most attractive and least attractive about self-driving technology?
- How does the public envision the inclusion of this technology in today's network?
- Would the public adopt self-driving technology, and in what form?
- Do an individual's existing travel behavior, relationship to cars, and relationship to technology affect his or her opinion about self-driving cars?

Data & approach

To understand public perceptions of self-driving vehicle technology, public opinion data is needed. Limited research currently exists, so we developed and implemented surveys for new data. One of the main obstacles to collecting valid data we encountered was that many people did not have enough information about self-driving cars to offer a fully formed opinion. To help control for differences in background knowledge of the subject, we targeted science museum visitors in Berkeley, California. This group was chosen because they were likely adopters, more willing to listen to an informational video designed to ensure all participates had similar information, and the location was accessible to the authors of this unfunded study. We were then able to focus on the effects that differences in demographics and attitudes towards technology and vehicles have on shaping opinion to these cars.

We administered the study to visitors at the Lawrence Hall of Science in Berkeley, California in spring 2013. The Lawrence Hall of Science is a public science museum and research center that offers hands-on science exhibits, student workshops, professional development seminars, and other educational opportunities. The research study was advertised to visitors at time of admission, and candy was used as an incentive and reward for participation. The study was administered in a group classroom setting, took approximately 15-20 minutes, and included a survey and 10-minute video. The survey has five sections, and the video was shown after the second section.

Section A asked questions about an individual's travel behavior and household characteristics. How do you usually commute to work? How do you usually travel for leisure? How many people live in your household? Do you own or lease a vehicle? Do you or anyone in your household expect to purchase a vehicle before 2020? Section B included two questions asking participants to describe their relationship to technology and relationship to cars. For example, do you consider yourself an early adopter, eager to try new technologies, or do you have little or no interest in new technologies? Do you view cars as basic transport, or do you want cars with luxury, style, and energy saving technology? The purpose of these questions was to see whether travel behavior, household characteristics, and one's self-identified relationship to technology and cars might affect one's opinion about self-driving cars. For example, we hypothesized that early adopters of new technologies might be more willing to adopt self-driving cars.

After the first two sections, participants were shown a video. As self-driving technology is fairly new and not well understood, a video was critical so participants understand how the technology works. Various videos were considered, and the one selected was the most impartial video found, highlighting both benefits and drawbacks of the technology. The video can be found here: http://youtu.be/65QoObF5ft4.

After the video, participants were asked a series of questions about their perceptions of self-driving cars. In this section, participants were asked to select up to three aspects of self-driving technology they found most and least attractive. Additionally, they were asked two questions about the inclusion of this technology in today's transportation network. Would they prefer if self-driving cars operated in the same lanes as normal traffic, or should self-driving cars be separated from other modes of transportation? Would they be willing to support a public bond measure to build new infrastructure, such as special lanes or traffic signals for self-driving cars? In Section D, participants were asked to consider three scenarios in a future of self-driving cars and their willingness to adopt the technology. A total of 107 survey responses were collected along with voluntary demographic information respondents chose to provide.

Many measures were taken to ensure a quality research approach. First, the study received Institutional Review Board approval to ensure proper human subjects treatment. We vetted the survey with transportation professionals and members of the UC Berkeley faculty, and pretested the survey before data collection. During administration of the study, we were available to clarify any questions and ensure completion of the surveys. While participants were free to decline to answer any question, we followed up with participants who left questions blank to ensure they purposely left the question blank; this ensured accuracy of our responses. Finally, we ensured impartiality as best we could during administration of the surveys by refraining from discussion until after the respondents had completed the survey.

We analyzed the data collected in the surveys using a logit model for most questions. The frequency with which respondents indicated they would use a self-driving taxi is analyzed using a log-linear regression. The independent variables are dummy coded compared to a control group with the following attributes: Married, white males with a bachelor's degree and an income between $50,000 and $75,000. The control group had a moderate relationship to technology and valued automobiles with green technology, luxury, and style. We selected this control group because it is strongly represented in the sample and provides a good base with which to compare the responses of those with different attitudes and demographic characteristics.

Limitations

The future is difficult to predict. Self-driving technology is not widely adopted and how this technology unfolds is still unknown. Self-driving technology may take an entirely different shape than what is familiar to the public, and more information or future events may change people's attitudes. Stated preferences may change depending on new information and other factors.

While many efforts were made to ensure impartial data collection, there was still bias with survey distribution, self-selection, and non-response. We intercepted visitors at the Lawrence

Hall of Science in Berkeley, and because the population shares certain characteristics, the sample skewed towards wealthy, educated families with cars. People who are interested in technology and self-driving cars may self-select into the study. People may answer differently in a group-administered survey setting as opposed to a close online survey or other settings. Additionally, the study was constrained by time and resources. A larger survey sample from many locations would strengthen future research on self-driving technology. In many cases, although our sample size was large enough to determine meaningful correlations using a logit model, we were prevented from obtaining correlations on questions where a large number of people answered 'maybe,' reducing that question's effective sample size.

RESULTS & ANALYSIS

We advertised our study at the ticket admissions desk, and intercepted about 200 visitors outside the study classroom. We received 107 survey responses from 47 males and 60 females. The respondents were racially diverse: 52% identified as white, 28% as Asian, 14% as Hispanic, 5% as Black, and 1% as other. The respondents were educated, with 75% of participants having at least a Bachelor's degree. Income varied as well, with 23% of participants making less than 50k, 32% making between 50-100k, and 45% making more than 100k. The age of respondents ranged from 19 to 84, with the majority of respondents (43%) in the 35-44 age bracket. In our sample, 70% of respondents are married, 20% are single, 6% are partnered, and 4% chose other.

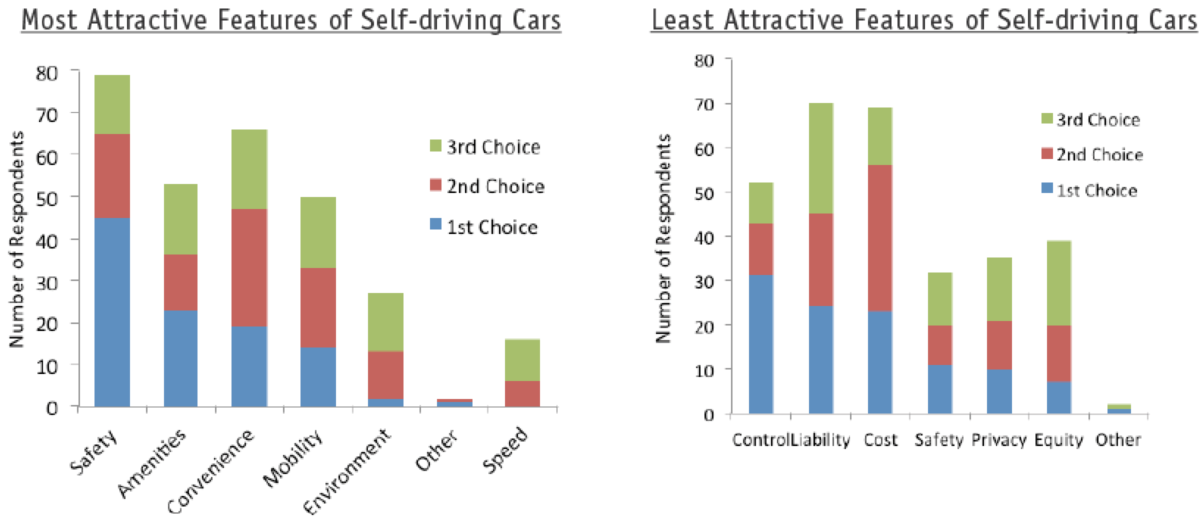
This results and analysis section is organized by our guiding research questions:

- What does the public find most attractive and least attractive about self-driving technology?
- How does the public envision the inclusion of this technology in today's network?
- Would the public adopt self-driving technology, and in what form?
- Do an individual's existing travel behavior, relationship to cars, and relationship to technology affect his or her opinion about self-driving cars?

What does the public find most and least attractive about self-driving technology?

From the literature, we identified six attractive features to self-driving cars: amenities (e.g. ability to text message or multitask while driving), convenience (e.g. not having to find parking), environmental friendliness, increased mobility, safety, and speed. We identified five concerns to self-driving technology: lack of control, costs and equity, liability, privacy, and safety. We listed these factors and asked respondents to select up to three aspects of the technology they found most and least attractive, and to rank their choices. Participants also had an option of writing in another factor.

FIGURE 1 Most and Least Attractive Elements of Self-Driving Cars



Respondents found increased safety, amenities like multitasking, and convenience to be the most attractive features of self-driving cars. These findings reflect current marketing efforts, which often tout safety as the greatest benefit to self-driving cars. Many people are aware of high death rates in the United States due to vehicle accidents. The findings also reveal that people are interested in self-driving cars as an improvement to their lives, and value personal amenities and convenience higher than societal benefits like environmental friendliness and reduced travel times.

Respondents were most concerned with liability, costs and control. A number of people feel very strongly about lack of control, but the majority of respondents do not share their concern. With respect to liability, many cite unreliable technology at work and home as evidence that self-driving car technology may also be unreliable. The concern over liability seems to contrast with safety as the greatest benefit. This suggests that most respondents believe that self-driving cars represent a net safety improvement over the status quo, but a driverless future is not an accident-free future. A driverless car network may resemble today's air network, where there are few accidents, but those that do occur are more catastrophic and visible than auto accidents today.

These findings reflect key challenges that industry professionals and policymakers must address: ensuring quality technology, addressing who is at fault should a vehicle malfunction, and appropriately pricing the technology. With respect to costs and equity, people view self-driving cars as potentially exclusive and cost-prohibitive. A significant minority of respondents felt strongly about loss of control of the vehicle. Education, exposure, and time may persuade those to embrace the technology, but we hypothesize that those who are most concerned about control will take the longest to accept self-driving cars.

How does the public envision the inclusion of this technology in today's network?

To test this research question, we asked participants where they think self-driving cars should operate: 1) in same lanes as normal car traffic; 2) separated from other modes of transportation through dedicated lanes, like carpool lanes on freeways; 3) operate on a new network created solely for self-driving cars, like a separate rail system; or 4) no opinion. Participants were also asked whether they would support a bond measure to build infrastructure for self-driving cars.

Of the 107 responses, 46% believe that self-driving cars should operate with normal traffic, 38% in separate lanes, and 11% had no opinion. With regards to support of a bond measure for self-driving cars, 43% of the participants said maybe, 35% favored a bond measure, and 22% opposed. Responses to these questions suggest that the public needs more information about self-driving cars before making a decision of how self-driving cars would integrate in today's network. There is an opportunity to influence public opinion in this realm.

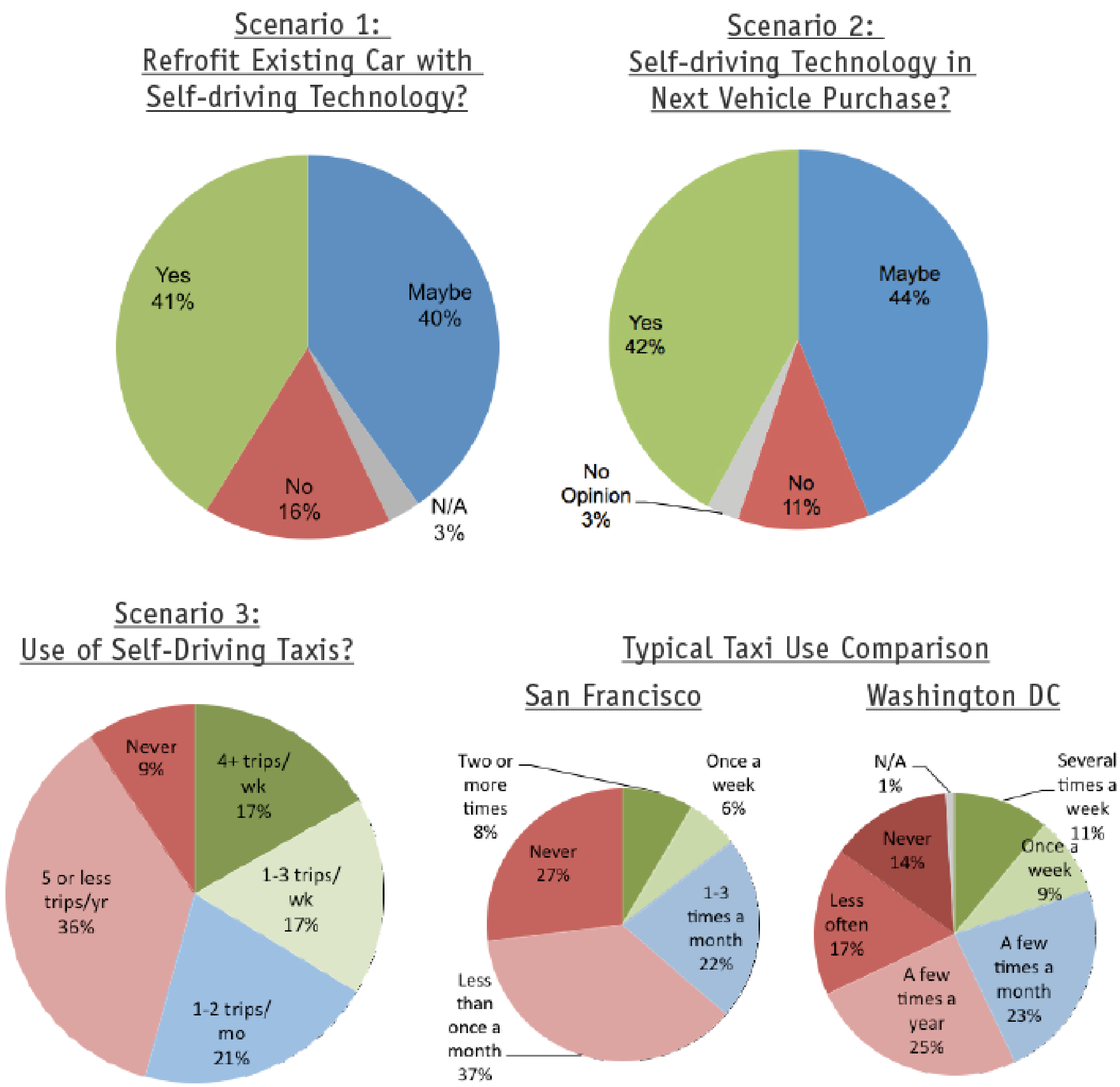
Would the public adopt self-driving technology, and in what form?

Participants were given three scenarios in a future world of self-driving cars: 1) retrofitting existing cars with self-driving technology, 2) buying a new self-driving car, or 3) using self-driving cars as a public transit/taxi service. While the adoption of self-driving cars could be a transformative event, we framed the scenarios in terms of transportation currently understood: traditional car ownership and pay-per-use (taxi) service. Responses are reflected in Figure 2.

The benefits of self-driving technology depend on vehicle adoption and use en masse. The first scenario asks respondents if they would retrofit their existing car with self-driving technology. Assuming retrofits are more affordable than buying new equipment, this option could facilitate seamless adoption of self-driving technology, as well as accelerate adoption rates. In the second scenario, respondents are asked whether they would purchase self-driving technology as optional equipment for their next car. A small percentage of our sample did not want to retrofit their car, nor had an interest in buying self-driving technology, suggesting people are mostly receptive to self-driving technology.

In the third scenario, we asked participants their willingness to take self-driving cars as a taxi service. Introducing the phrase "self-driving taxi" proved problematic, as many associate taxis with high-cost point-to-point travel. While we included language to discourage people from thinking about costs, it was evident that respondents were curious about cost and this influenced their responses. Respondents' willingness to use self-driving cars as taxis was not high. However, self-driving taxis still seem more popular than traditional taxis, when we compare our data with data from a March 2013 telephone survey of San Francisco residents' use of taxis *(34)* and a July 2012 poll of Washington DC residents' use of taxis *(33)*.

FIGURE 2 Self-driving Car Scenario Planning Responses



Do an individual's demographic characteristics, existing travel behavior, relationship to cars, and relationship to technology affect his or her opinion about self-driving cars?

The results of the logit model (Table 1) show that the men surveyed are more likely to be concerned with liability and less likely to be concerned with control than women. Married people value amenities such as multitasking less, but place a high importance on the safety improvements offered by the technology. Married people are also less concerned with cost. People coming from larger households, as well as those of Hispanic and Asian decent highly value the potential of the technology to improve mobility for the impaired.

Income also plays a significant role in shaping a person's attitude. Those with higher income are most concerned with liability, and less concerned with giving up control. Lower income households appear to be more concerned with safety, and control. People of all income groups had concerns about cost.

Single-occupancy vehicle (SOV) commuters and cyclists are most concerned with giving up control of the car, while those who primarily carpool or walk are not. Frequent technology users are less likely to be concerned with the cost of the technology than those who interact with technology less frequently. Those who use technology less frequently are much more concerned about control than frequent users.

Those who value a car for luxury, image, and prestige are more concerned about giving up control, revealing that car enthusiasts would be ambivalent towards the technology because they enjoy driving. Conversely who place a higher importance on a car's fuel economy do not see giving up control as a major issue.

TABLE 1 Most and Least Attractive Aspects of Self-driving Cars vs Respondent Characteristics

Most Attractive Elements

	Control		Cost		Equity		Liability		Privacy		Safety	
	N	*Chi sq*	*N*	*Chi sq*	*N*	*Chi sq*	*N*	*Chi sq*	*N*	*Chi sq*	*N*	*Chi sq*
	101	0.0174	96	0.0271	24	0.2465	88	0.6139	10 pos. response		101	0.3848
Variable	*Coeff*	*P-value*	*Coeff*	*P-value*	*Coeff*	*P-value*	*Coeff*	*P-value*	*Coeff*	*P-value*	*Coeff*	*P-value*
Intercept	-1.77	0.28	-13.56	0.99	12.74	1.00	-4.44	0.99			0.56	0.83
Female	1.39	0.12	0.19	0.82	61.74	0.99	-1.52	0.03	Not enough pos. responses to determine correlation		-1.16	0.34
Not Married	-0.32	0.70	3.65	0.00	neg.	(om)	-0.78	0.38			-1.52	0.37
HH Size	0.14	0.66	0.32	0.39	-31.19	0.99	0.17	0.63			-0.78	0.22
Black	0.97	0.50	neg.	(om)	neg.	(om)	neg.	(om)			7.03	0.02
Hispanic	1.88	0.08	-0.63	0.63	neg.	(om)	0.38	0.74			-16.15	1.00
Asian	-1.64	0.11	-1.28	0.20	47.22	0.99	0.78	0.29			2.45	0.08
Under 25K	0.86	0.43	-2.91	0.10	0.21	1.00	0.33	0.83			1.76	0.37
25K-50K	-4.99	0.01	2.32	0.17	neg.	(om)	0.04	0.98			4.15	0.10
75K-100K	-0.61	0.57	2.38	0.15	0.13	1.00	-0.16	0.90			-0.13	0.95
100K-125K	1.79	0.22	1.48	0.34	30.42	0.99	-0.20	0.88			-0.81	0.71
125K +	-1.90	0.10	1.90	0.16	-0.39	0.89	0.81	0.45			-0.20	0.92
HS or Less	-0.16	0.94	0.23	0.92	col.	(om)	neg.	(om)			20.68	0.99
Some Col	1.52	0.10	-2.10	0.14	neg.	(om)	0.56	0.52			-2.57	0.21
Masters	0.60	0.54	-1.65	0.07	46.25	0.99	0.98	0.28			-1.78	0.25
PhD	2.52	0.09	0.13	0.94	-0.78	1.00	0.81	0.49			-2.28	0.23
SOV	-1.68	0.03	8.09	1.00	pos.	(om)	-0.66	0.28			col.	(om)
HOV	0.98	0.45	-7.99	1.00	col.	(om)	0.44	0.74			col.	(om)
Transit	-0.78	0.50	8.48	1.00	col.	(om)	-0.77	0.41			col.	(om)
Bike	-1.30	0.35	-7.62	1.00	col.	(om)	-0.71	0.59			col.	(om)
Walk	2.44	0.14	-9.19	1.00	col.	(om)	1.57	0.35			col.	(om)
Limited	3.65	0.05	-0.50	0.77	neg.	(om)	neg.	(om)			-0.77	0.71
Heavy	2.45	0.02	-2.45	0.05	61.42	0.99	0.13	0.87			-0.55	0.69
Early-Adopter	-0.11	0.95	-2.28	0.05	neg.	(om)	0.57	0.54			-0.96	0.53
Basic	0.48	0.59	-13.98	0.99	19.51	1.00	3.71	0.99			0.14	0.93
Comfort	-0.55	0.41	2.69	0.99	-27.26	0.99	3.21	0.99			-2.58	0.12
Fuel Econ	-2.58	0.02	4.05	0.99	-57.87	0.99	2.28	0.99			1.71	0.27
Luxury	3.53	0.03	3.38	0.99	79.50	0.99	-12.28	0.99			0.11	0.98

Notes

[1] neg. = neg.; (om) = omitted; pos. = positive; col. = collinear

[2] the first-choice/top ranked feature was used in regression analysis

[3] Variable categories (top to bottom): gender, marital status, household size, ethnicity, income, education, typical commute, relationship to technology, & relationship to cars

Least Attractive Elements

	Amenities (Multitasking)		Convenience		Environment		Mobility		Safety	
	N	*Chi sq*	*N*	*Chi sq*	*N*	*Chi sq*	*N*	*Chi sq*	*N*	*Chi Sq*
	94	0.1394	86	0.6368	2 positive response		88	0.8561	98	0.6954
Variable	*Coeff*	*P-value*	*Coeff*	*P-value*	*Coeff*	*P-value*	*Coeff*	*P-value*	*Coeff*	*P-value*
Intercept	-10.11	1.00	-8.26	0.99			-10.13	0.99	-2.24	0.99
Female	-1.54	0.07	0.94	0.27	Not enough positive responses to determine correlation		-0.21	0.84	0.00	1.00
Not Married	1.56	0.07	-0.10	0.93			0.03	0.98	-0.97	0.16
HH Size	-0.02	0.94	-0.21	0.56			0.94	0.04	-0.16	0.57
Black	neg.	(om)	2.85	0.12			neg.	(om)	1.23	0.39
Hispanic	-2.80	0.08	1.54	0.23			1.70	0.19	-0.11	0.91
Asian	-0.40	0.67	0.49	0.55			1.52	0.14	-0.29	0.66
Under 25K	-1.15	0.31	-0.78	0.58			1.65	0.21	0.36	0.71
25K-50K	2.20	0.29	neg.	(om)			-1.67	0.32	1.22	0.30
75K-100K	-0.92	0.49	0.13	0.92			-2.29	0.27	0.50	0.61
100K-125K	-0.40	0.77	1.33	0.31			-1.15	0.48	-0.73	0.49
125K +	-0.54	0.61	-0.54	0.66			0.11	0.93	0.55	0.50
HS or Less	0.77	0.73	neg.	(om)			-1.01	0.63	0.57	0.74
Some Col	0.71	0.43	-1.00	0.38			-1.08	0.34	0.14	0.85
Masters	-0.24	0.78	-0.67	0.51			-1.24	0.32	0.42	0.55
PhD	0.81	0.57	-0.94	0.54			neg.	(om)	0.43	0.70
SOV	6.34	1.00	4.28	0.99			2.00	1.00	2.58	0.99
HOV	-10.06	1.00	5.55	0.99			1.26	1.00	2.85	0.99
Transit	6.59	1.00	5.75	0.99			0.47	1.00	1.48	1.00
Bike	5.75	1.00	-10.40	1.00			-11.05	1.00	3.82	0.99
Walk	6.71	1.00	-10.58	1.00			6.23	0.99	-12.53	0.99
Limited	-1.29	0.44	0.11	0.95			-0.01	0.99	-1.57	0.24
Heavy	-0.43	0.65	-0.35	0.69			0.65	0.48	0.18	0.77
Early-Adopter	-1.05	0.41	-0.26	0.83			-0.48	0.74	0.22	0.79
Basic	2.90	1.00	4.23	0.99			2.83	1.00	-0.72	0.36
Comfort	4.57	0.99	2.76	1.00			2.43	1.00	-0.53	0.27
Fuel Econ	4.76	0.99	1.24	1.00			3.73	0.99	-0.26	0.65
Luxury	4.00	0.99	-10.89	1.00			-11.24	1.00	0.52	0.67

Notes

[1] neg. = neg.; (om) = omitted

[2] the first-choice/top ranked feature was used in regression analysis

[3] Variable categories (top to bottom): gender, marital status, household size, ethnicity, income, education, typical commute, relationship to technology, & relationship to cars

TABLE 2 Opinions on Self-Driving Cars vs. Respondent Characteristics

	Where should self driving cars operate?		Would you support a bond for self driving car infrastructure?		Would you retrofit your car with self-driving technology?		Would you buy a self-driving car?		How often would you use a self driving taxi?	
	N	*Chi sq*	*N*	*Chi sq*	*N*	*Chi sq*	*N*	*Chi sq*	*N*	*Signifce F*
	87	0.1847	52	0.811	59	0.06	36	0.829	101	0.2272
Variable	*Coeff*	*P-value*	*Coeff*	*P-value*	*Coeff*	*P-value*	*Coeff*	*P-value*	*Coeff*	*P-value*
Intercept	0.20	1.00	3.18	0.99	-4.25	1.00	1.54	0.42	2.58	0.01
Female	0.79	0.25	-1.41	0.18	2.59	0.11	(om)	(om)	-0.18	0.68
Not Married	-1.83	0.03	-0.69	0.56	-0.14	0.91	(om)	(om)	0.07	0.89
HH Size	0.57	0.07	0.36	0.44	-0.57	0.35	(om)	(om)	0.02	0.93
Black	1.19	0.42	-2.05	0.30	-0.84	0.92	(om)	(om)	-0.20	0.84
Hispanic	-1.74	0.22	-2.93	0.10	0.70	0.64	(om)	(om)	0.74	0.27
Asian	0.25	0.71	-0.30	0.82	-0.49	0.77	(om)	(om)	-0.32	0.51
Under 25K	0.67	0.56	-1.01	0.48	1.20	0.44	-0.71	0.64	-0.35	0.64
25K-50K	1.81	0.21	-0.17	0.93	1.26	0.55	-2.26	0.34	-0.76	0.36
75K-100K	0.69	0.57	-1.65	0.31	2.23	0.29	-1.38	0.39	-0.40	0.57
100K-125K	-0.26	0.83	(om)	(om)	5.73	0.05	-0.67	0.63	1.08	0.18
Over 125K	-1.00	0.31	-3.19	0.06	2.76	0.24	(om)	(om)	0.61	0.33
HS or less	(om)	(om)	2.69	0.30	2.82	0.32	(om)	(om)	-1.21	0.37
Some Col	-0.31	0.71	0.93	0.43	0.60	0.68	-1.27	0.34	0.71	0.20
Masters	-0.79	0.32	-0.64	0.63	1.21	0.49	-0.43	0.79	0.48	0.37
PhD	1.89	0.16	(om)	(om)	-34.27	0.99	(om)	(om)	0.92	0.25
Limited	0.12	0.93	-1.07	0.58	-2.87	0.19	(om)	(om)	0.27	0.77
Heavy	-0.13	0.86	0.88	0.51	3.33	0.03	1.10	0.33	0.24	0.62
Early-Adopter	1.92	0.08	2.34	0.17	32.10	0.99	0.02	0.99	0.47	0.45
Basic	1.78	0.06	1.64	0.29	-0.45	1.00	-1.55	0.28	-1.51	0.01
Fuel Economy	-0.40	0.46	-1.18	0.25	2.14	1.00	0.29	0.80	-0.48	0.20
Comfort	-0.04	0.95	0.57	0.55	1.23	1.00	-0.47	0.72	-0.54	0.23
Luxury	0.45	0.73	-0.52	0.77	-9.89	1.00	0.22	0.92	1.87	0.06

Notes
[1] (om) = omitted
[2] Variable categories (top to bottom): gender, marital status, household size, ethnicity, income, education, relationship to technology, & relationship to cars

Table 2 summarizes the results of a logit model (for the first 4 questions) and a log-linear regression (for the taxi question) connecting respondents' personal traits with their responses to the questions related to adoption. We were not able to determine a relationship between positive responses to "Would you buy a self-driving car" and a respondent's personal characteristics. This is because a large number of people responded "Maybe" to this question.

Income level and the relationship of people to technology are correlated to positive responses regarding the adoption of self-driving technology. Early adopters of technology are more likely to desire separate infrastructure for self-driving cars and support public financing of this infrastructure using bonds. Limited users of technology are much less likely to want to retrofit their vehicle with self-driving technology. Wealthier people also would retrofit their car and use a self-driving taxi more often that those with lower income. As mentioned earlier, use of the word 'taxi' seems to connote high expense and luxury, with people valuing luxury strongly favoring self-driving taxis and people interested in bare bones transportation rejecting a potential self-driving taxi service.

TABLE 3 Opinions on Self-Driving Cars vs Positive and Negative Aspects

	Where should self driving cars operate?		Would you support a bond for self driving car infrastructure?		Would you retrofit your car with self-driving technology?		Would you buy a self-driving car?		How often would you use a self driving taxi?	
	N	*Chi sq*	*N*	*Chi sq*	*N*	*Chi sq*	*N*	*Chi sq*	*N*	*Signifce F*
	99	0.0015	57	0.5527	60	0.8083	49	0.206	104	0.2822
Variable	*Coeff*	*P-value*	*Coeff*	*P-value*	*Coeff*	*P-value*	*Coeff*	*P-value*	*Coeff*	*P-value*
Intercept	1.87	0.10	0.27	0.74	0.30	0.78	1.60	0.15	0.79	0.59
Amenities	-0.95	0.18	-0.34	0.65	0.18	0.84	0.33	0.71	2.07	0.13
Convenience	0.79	0.27	0.88	0.35	0.08	0.93	0.86	0.39	1.65	0.24
Mobility	-0.37	0.64	-0.64	0.45	-0.45	0.63	(om)	(om)	1.35	0.34
Safety	(om)	(om)	(om)	(om)	(om)	(om)	(om)	(om)	2.21	0.10
Environment	(om)	(om)	(om)	(om)	(om)	(om)	(om)	(om)	(om)	(om)
Cost	-3.27	0.01	-0.22	0.82	1.16	0.33	0.73	0.63	0.60	0.45
Liability	-2.58	0.04	0.08	0.94	-0.04	0.97	-0.67	0.60	0.01	0.99
Control	-1.26	0.30	1.10	0.29	0.02	0.98	-2.08	0.12	-0.06	0.94
Safety	0.33	0.84	-0.05	0.97	(om)	(om)	-2.06	0.15	-0.60	0.51
Privacy	-2.28	0.09	(om)	(om)	(om)	(om)	(om)	(om)	0.82	0.37
Equity	(om)	(om)	(om)	(om)	(om)	(om)	(om)	(om)	(om)	(om)

Notes
[1] (om) = omitted
[2] Variable categories (top to bottom): positive attitudes, negative attitudes

Table 3 displays the results of a logit model (for the first 4 questions) and a log-linear regression (for the taxi question) connecting respondents' attitudes towards self-driving cars with their responses to the questions related to adoption. Although buying a self-driving car could not be connected to any of the personal traits, it is clear from these data that people with serious concerns about control or safety are not likely to purchase a self-driving car until their concerns are addressed. Those who value safety and amenities indicated a preference for self-driving taxis. Finally those who have concerns about the privacy, cost, or liability issues with the technology were not interested in government support for the technology through separate infrastructure.

CONCLUSION & RECOMMENDATIONS

Self-driving cars represent a leap forward for personal transportation with numerous social, environmental, political, and economic implications. As this technology is in its infancy, public perceptions of self-driving cars are increasingly important as the public shapes the demand for the technology, the policies that govern them, and future investments in infrastructure. This technology could transform the very interaction between society and its transportation system in ways that are scarcely imagined. Or, this technology could simply become a better cruise control for private autos or support current auto-oriented transportation and land use trends. Self-driving technology will likely be brought to market in the near future. How we choose to implement this technology will make the difference, and that largely depends on the views of political and market actors.

This study attempts to ascertain these views as they exist today. An understanding of the factors that play a role in such decision making can help the industry tailor its product and marketing to appeal to the greatest number people, and can help proponents of this technology frame their message. From our study, we conclude with a few salient points that must be addressed.

Cost

Although we made efforts to keep costs out of the study, it is clear that respondents are concerned about the price of the technology. Wealthier people are more likely to be interested in self-driving cars than those with lower income. Over two-thirds of respondents of all demographic groups cite costs as a concern, and likely contributes to why many respondents are unsure about buying a car in the future. The retrofitting option seems to be a successful technique for expanding the number of self-driving cars on the roads, as it enjoys support from those who are concerned about cost. Issues with cost are shared strongly by people of all incomes. This indicates that reductions in the cost of this technology may increase demand roughly uniformly over all income groups. We recommend further study quantifying the demand for self-driving vehicles, estimating people's willingness to pay or other econometric analysis.

Safety and Control

Our regressions reveal that safety plays an important role in adoption, and influences people's willingness to adopt self-driving cars. Most participants are also concerned with liability. Although most respondents view self-driving cars as an improvement in safety over the status quo, they are concerned with the technology malfunctioning. People who enjoy cars and driving (those who identified as driving alone for most trips, as well as those who value a car for its image or luxury) are more likely to desire greater control of the car, and those who cite safety or control as a major factor are much less likely to want to buy a self-driving car than others.

Convenience, Amenities, and Multitasking

The convenience of a self-driving car is widely cited by study participants as major benefit of the technology and is not correlated to any specific group. Based on these results, self-driving technology manufacturers and advocates should emphasize the convenience and amenities that driverless cars offer in order to ensure widespread adoption.

Self-driving Taxis

Self-driving taxis appeal more to individuals with higher income than those with lower income. Additionally, those who view a car as basic transport were less likely to use a self-driving taxi. This survey question was hampered by the association of taxis with cost, and we believe that self-driving taxis or shared driverless cars can be the most affordable option for many. Interestingly, self-driving taxis appear to be more popular than conventional taxis when compared to data from San Francisco and Washington D.C. residents, suggesting that self-driving taxis can still play an important role as public transit. We recommend further study on self-driving taxis with cost considerations included. Self-driving taxis or shared driverless cars have great potential to create a sustainable transportation system that is more efficient and convenient than today's system.

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