Impact of Autonomous Ground Vehicles on Urban Air Mobility Operations

Final Presentation

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Motivation

In a 2018 survey of high-income commuters in five U.S. cities, we examined competition among exiting modes and eVTOL. However, the long-term viability of eVTOL may be impacted by the entry of other new modes in the market, most notably autonomous ground vehicles (AV).

Research Objectives

1. To understand how existing commute modes (e.g., autos, transit) will compete with autonomous ground vehicles and eVTOL
2. To understand how the ability to be productive and/or do other things in an AV or eVTOL influences commuters’ mode choices
3. To understand how ridesharing (traveling alone, with people you know, with strangers) influences commuters’ mode choices

Survey Design

1. Conduct a survey of 1,400 commuters in the same five U.S. cities used in the 2018 survey
2. Ask a mix of qualitative and quantitative (mode trade-off questions)
3. Use results from survey to predict market shares under different future scenarios

Survey instrument was published as AIAA paper, presentation covered descriptive statistics.

Garrow, L.A., Mokhtarian, P., German, B.J., Glodek, J. and Boddupalli S.-S. (2019). If you fly it, will commuters come? Predicting demand for eVTOL urban air trips. In proceedings from the American Institute of Aeronautics and Astronautics, Dallas, TX. pp. 1-45.

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Survey Instrument

1. IRB consent form and screening questions
2. Opinions about travel
3. Current commute information
4. Introduction to self-driving cars, design features
5. Introduction to air taxi service, design features
6. Discrete choice trade-offs
7. Personality and lifestyle questions
8. Socio-economic/socio-demographic information

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Screening Questions

1. Full-time worker
2. Travel to a work location outside the home at least twice per week
3. **Annual household income >$75K**
4. Average one-way commute of at least **30 minutes**
5. Live and work in one of the five target CSAs
6. Not an airline employee

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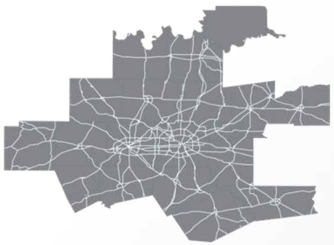
Cities Included in the Survey

Atlanta CSA

Boston CSA



Dallas/Ft Worth CSA

Los Angeles CSA

San Francisco Bay Area CSA

SOURCES:
[1] United States Census Bureau. (2017). US Counties and Primary and Secondary Roads. TIGER/Line® Shapefiles. Retrieved from https://www.census.gov/cgi-bin/geo/shapefiles/index.php
[2] United States Census Bureau. (2014). US Combined Statistical Area". TIGER/Line® Shapefiles. Retrieved from https://www.census.gov/cgi-bin/geo/shapefiles/index.php

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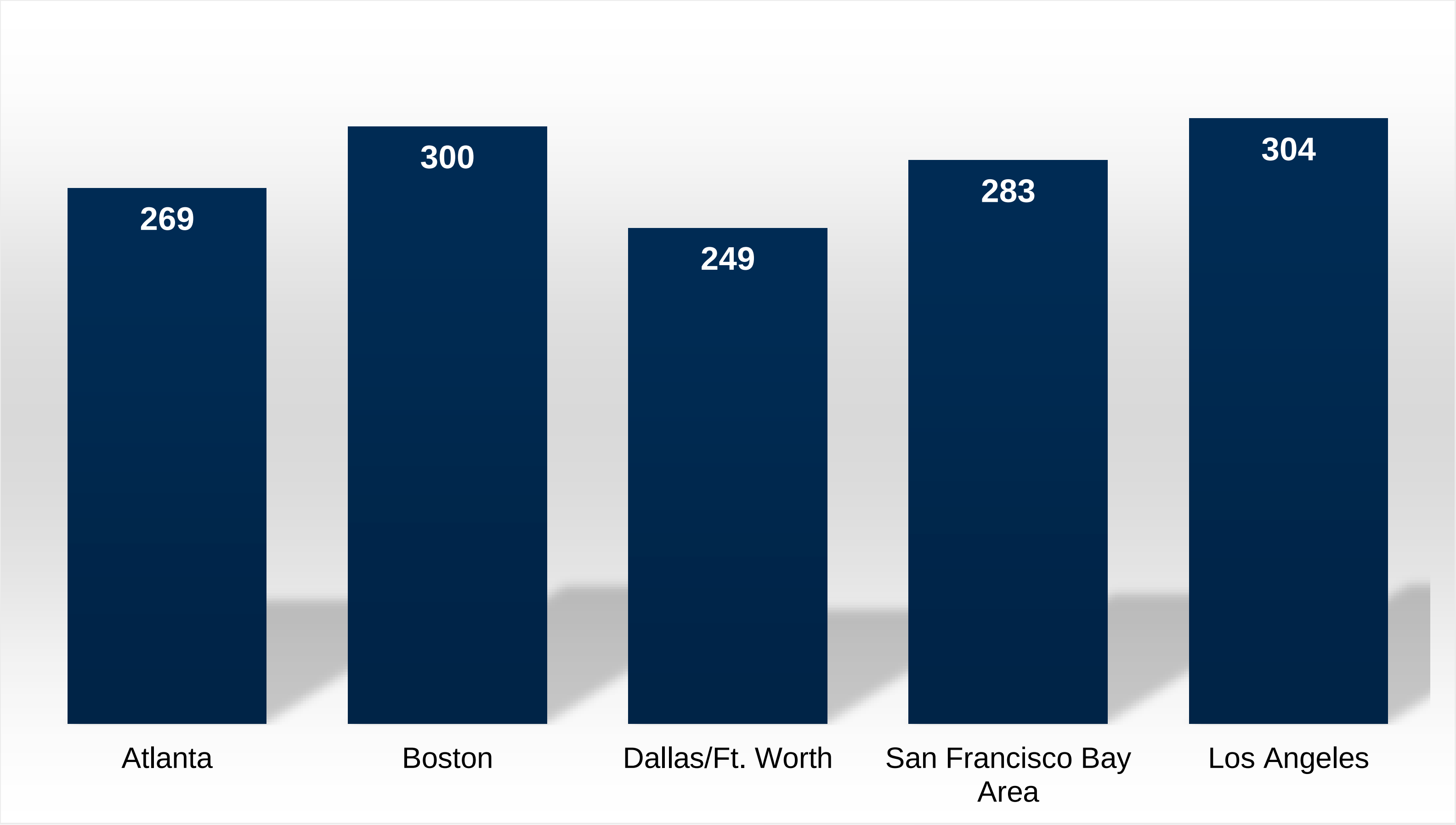
Survey execution (N=1405)



Annual Household Income

	75-99K	100-149K	150-199K	200+ K
Atlanta	74	66	64	65
Boston	71	84	68	77
Dallas/Ft. Worth	63	67	63	56
Los Angeles	67	78	82	77
San Francisco	71	67	76	69

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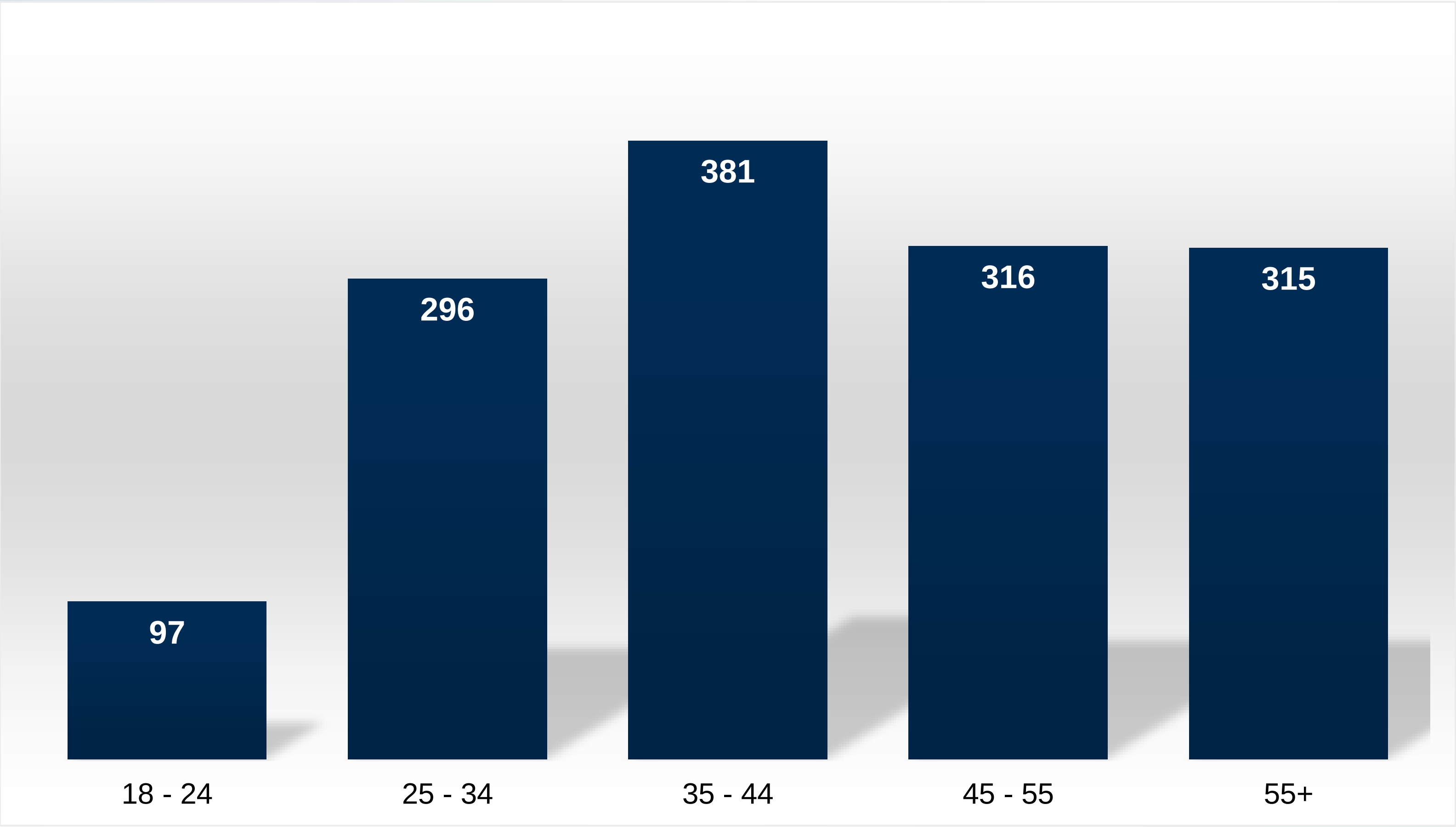
Age



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Introduction to Self-Driving Cars

Such vehicles drive themselves and control all operating and safety functions, and are even able to travel without a human inside. For our purposes, we want you to imagine a future where both conventional cars and self-driving cars (that do not need humans driving them) are available.

1. Driverless cars at least as safe as today‘s cars are, and generally affordable.
2. Cars equipped with services such as an office, a television, or a small fridge for snacks.
3. Power outlets for laptop and phone
4. Can send an empty self-driving car to pick up kids or groceries, or park after dropping you off.
5. You could let a self-driving car take you places while you sleep.

Several images of self-driving car concepts were shown on the survey.

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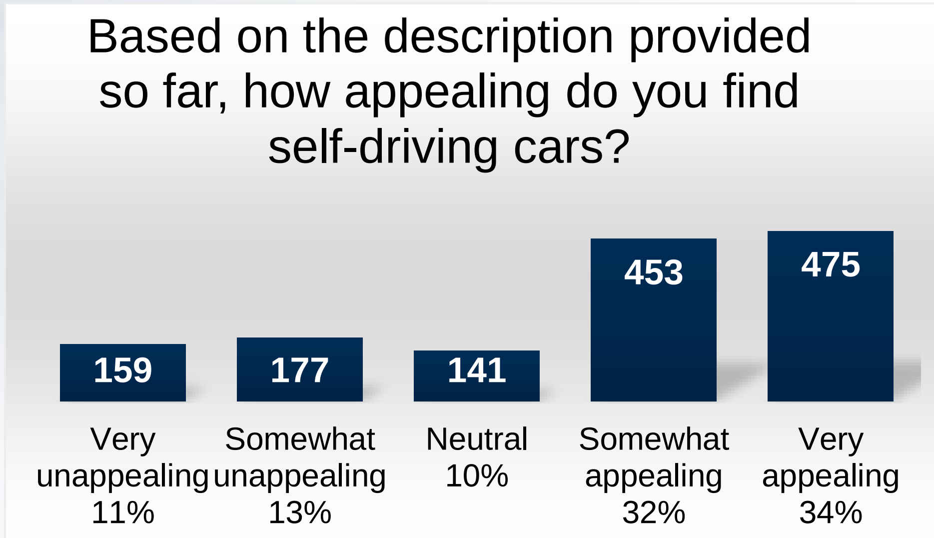
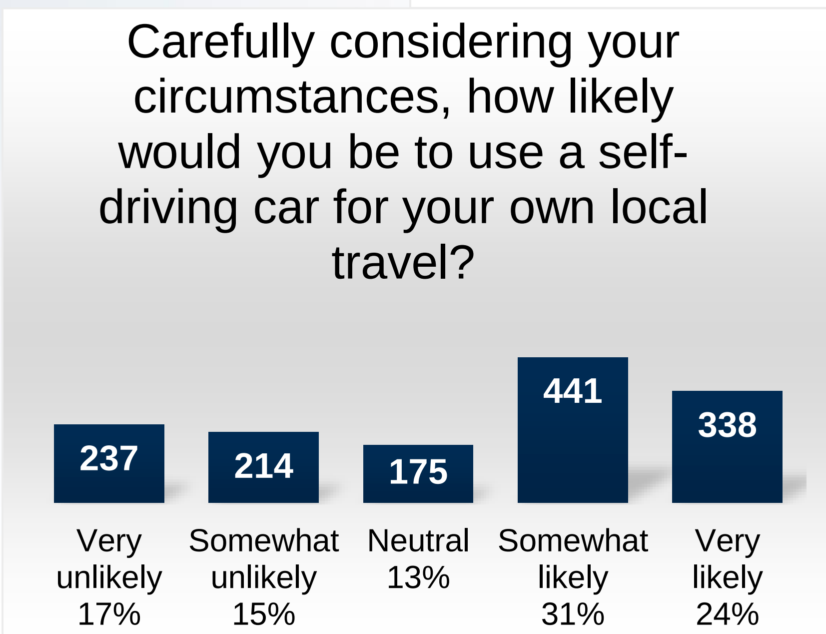
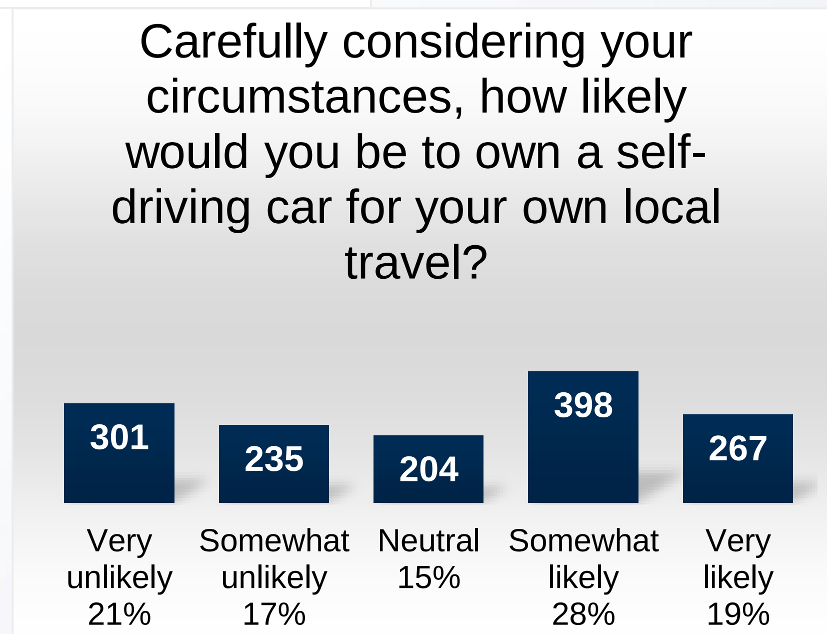
Initial Impressions of Self-Driving Cars

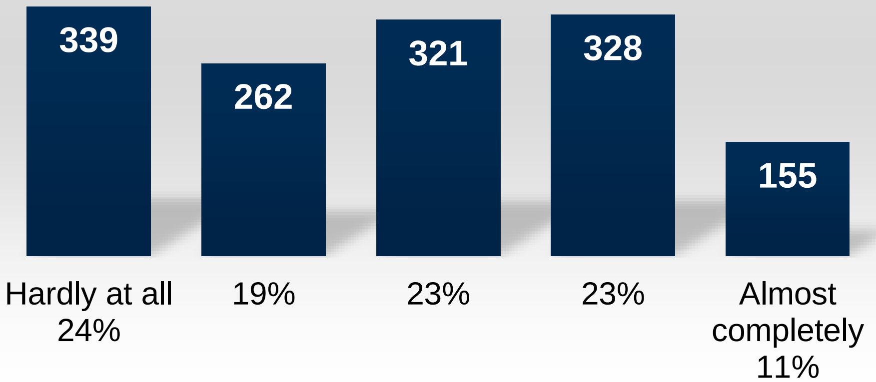




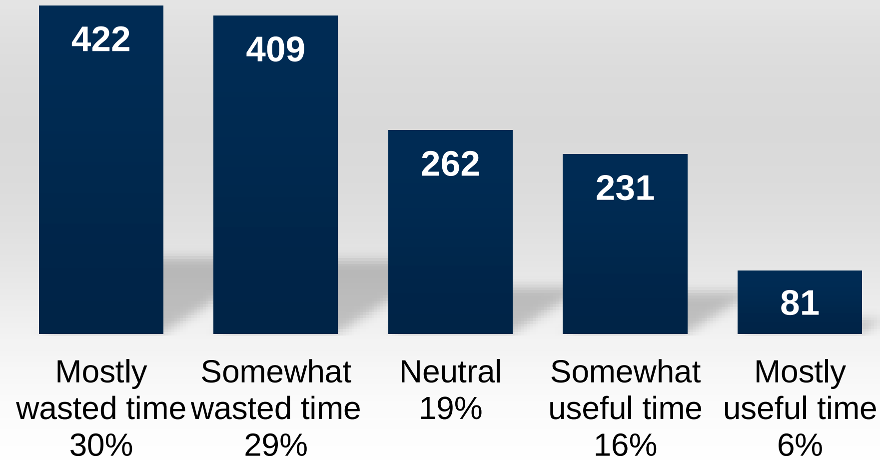


Current Commute Productivity

How much do conditions during your trip allow you to do the things you might want to do while traveling?



In terms of its value to you, how would you rate the time you now spend on your typical trip to work?



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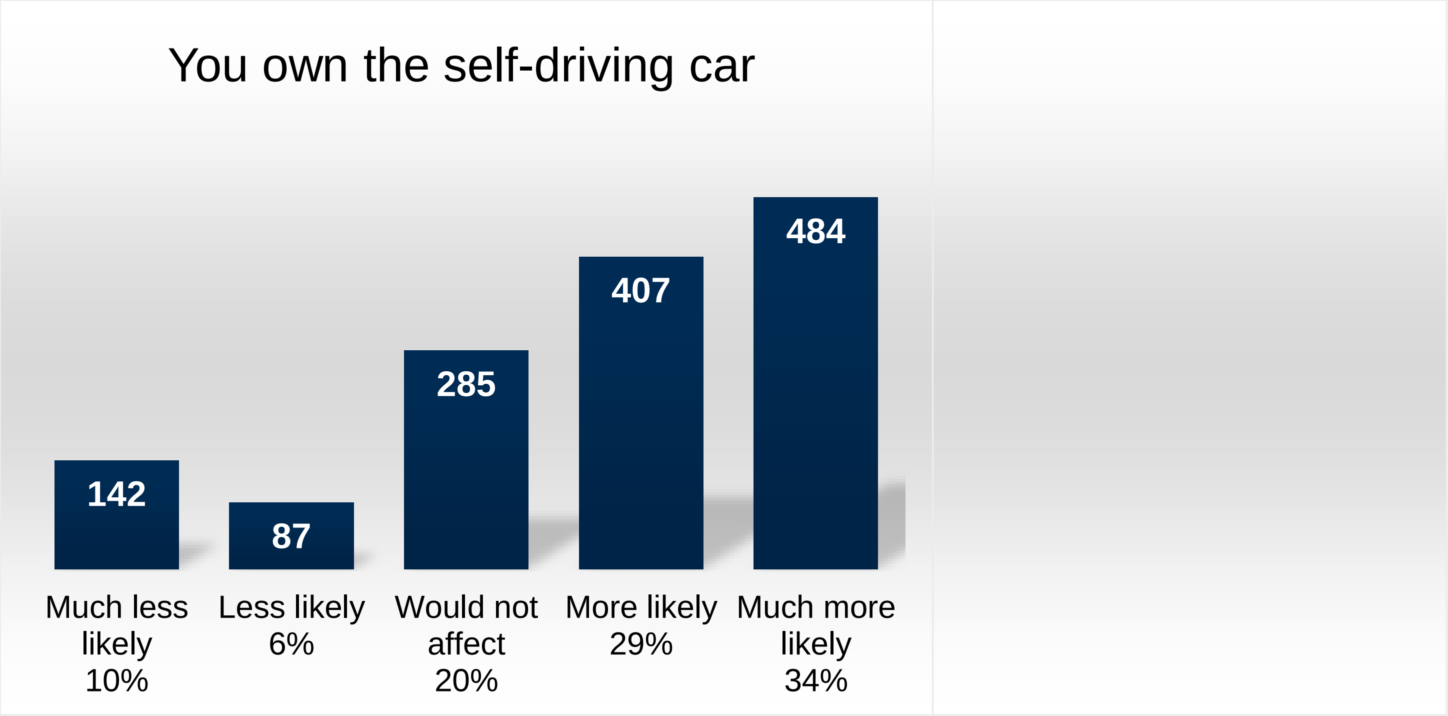
Potential Ownership Situations

For each feature, we are interested in knowing how much more or less likely you would be to travel in a self-driving car, compared to a traditional car



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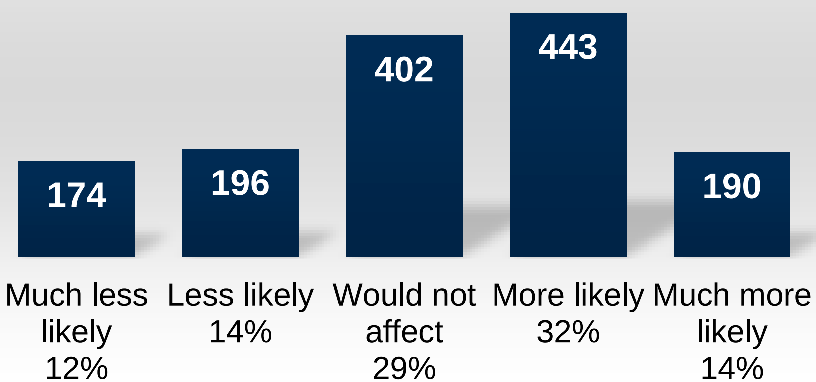
Potential RideShare Situations

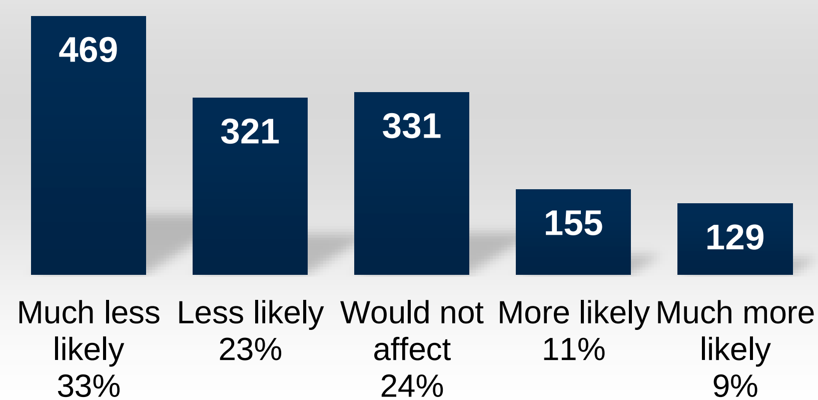
For each feature, we are interested in knowing how much more or less likely you would be to travel in a self-driving car, compared to a traditional car

You arrange for a pick-up from a rideshare company and travel alone

You arrange for a pick-up from a rideshare company and share with people you know



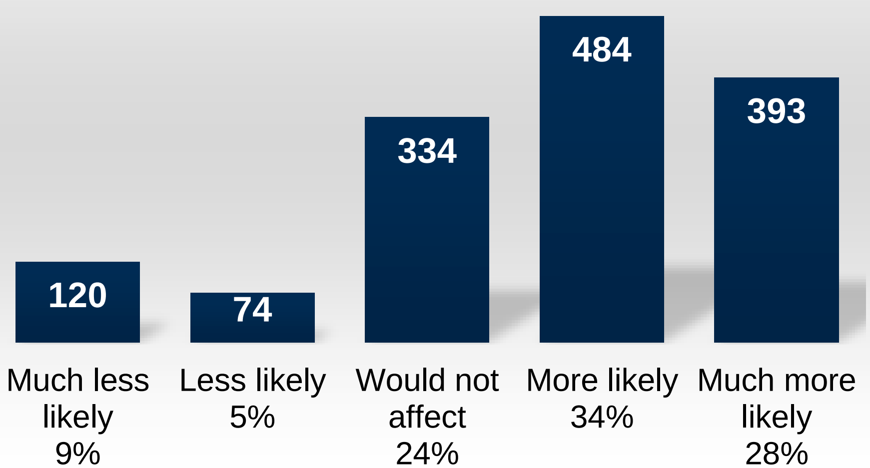
You arrange for a pick-up from a rideshare company and share with strangers



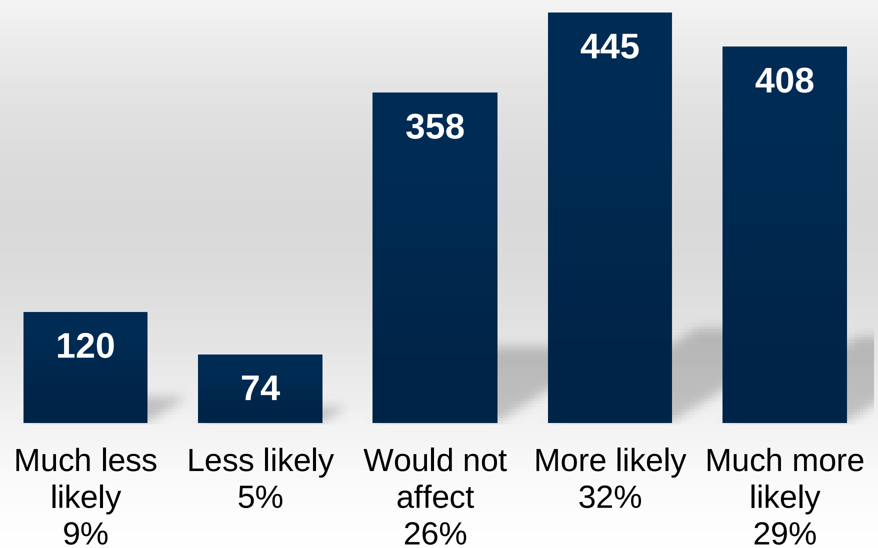
Potential Productivity Settings (1)

For each feature, we are interested in knowing how much more or less likely you would be to travel in a self-driving car, compared to a traditional car

You could use your phone to talk, text, and access the internet



You could do work on your laptop



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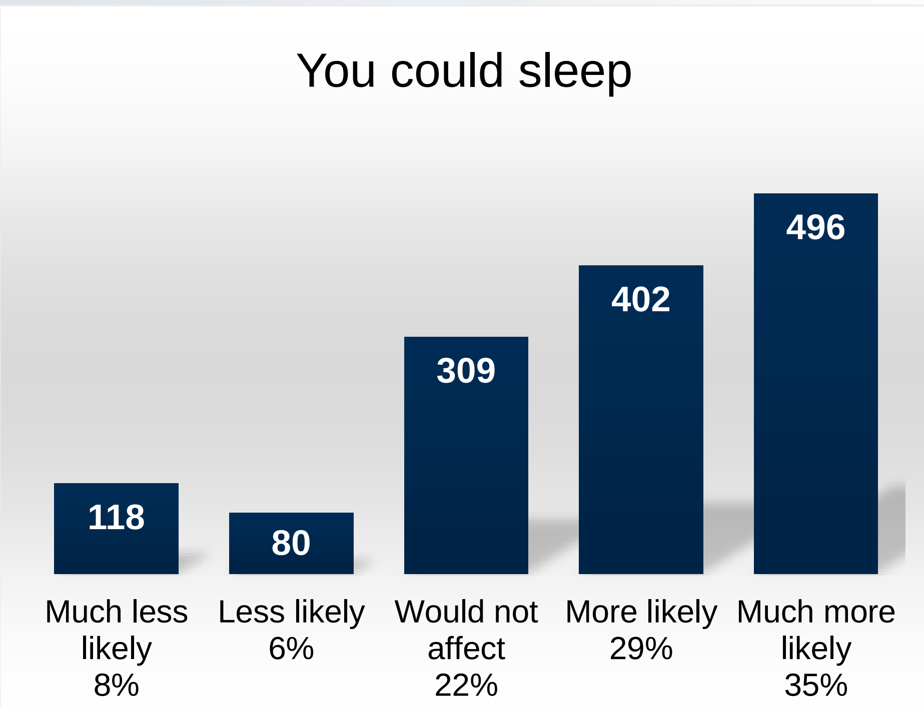
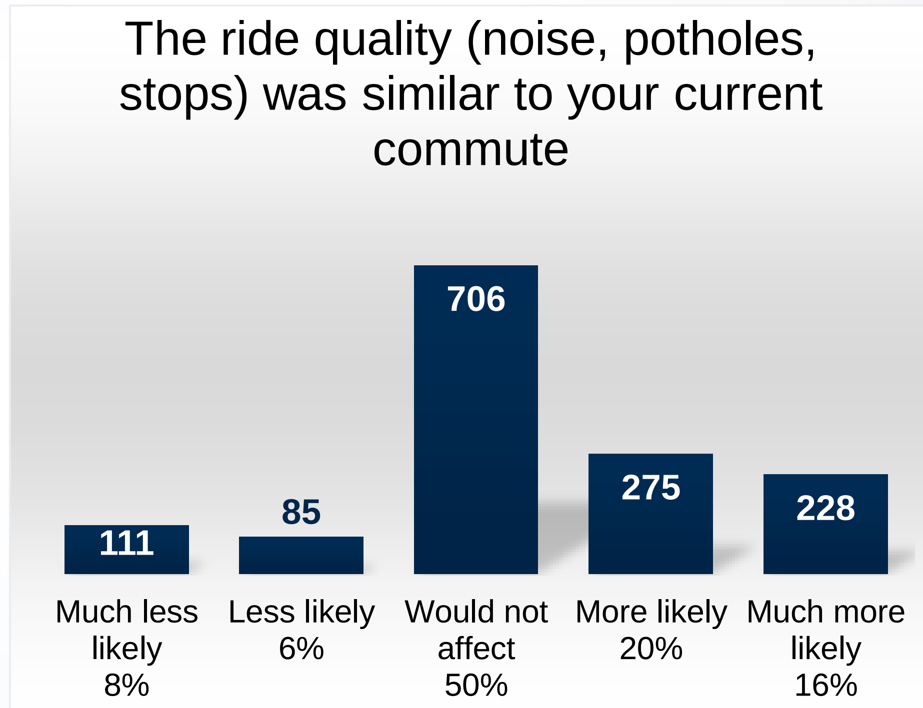
Potential Productivity Settings (2)

For each feature, we are interested in knowing how much more or less likely you would be to travel in a self-driving car, compared to a traditional car





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Introduction to Air Taxi Service

In this section, we ask you to imaging that you are flying in one of these new eVTOL aircraft.

- Battery powered
- Carry 2 – 4 passengers
- Travel within a city at cruise speeds of 150 mph
- Could be used for getting to and from work faster
- Have efficient security checks with no lines
- Have a ride quality and cabin noise level similar to large aircraft
- Are much quieter than helicopters, both for the community and for the occupants of the aircraft
- Travel at about the altitude where helicopters fly
- Are flown by certified pilots
- …

Several images of air taxis were shown on the survey.

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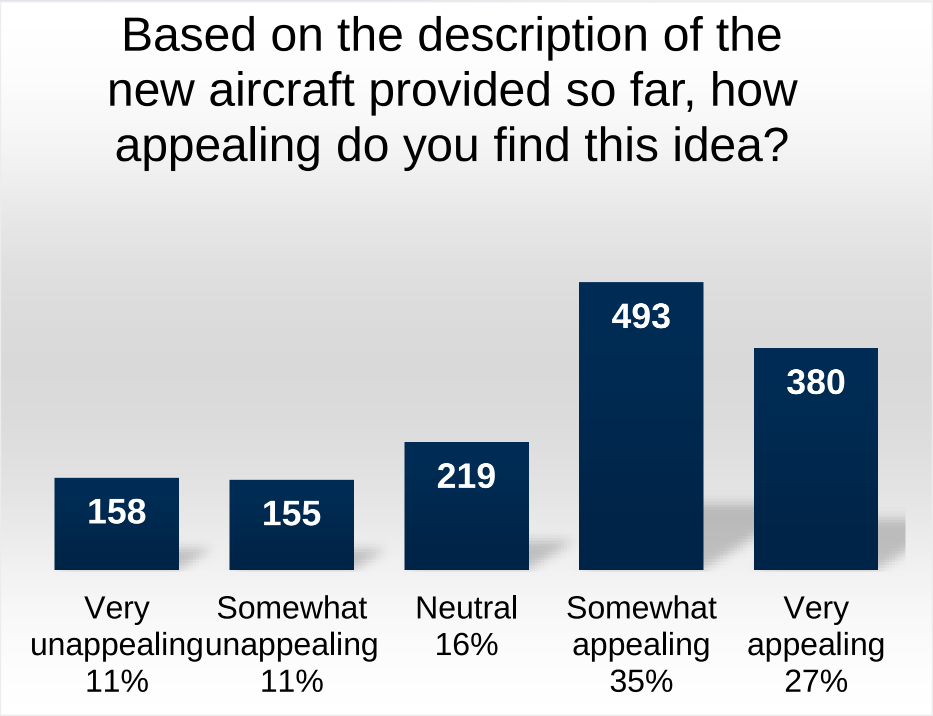
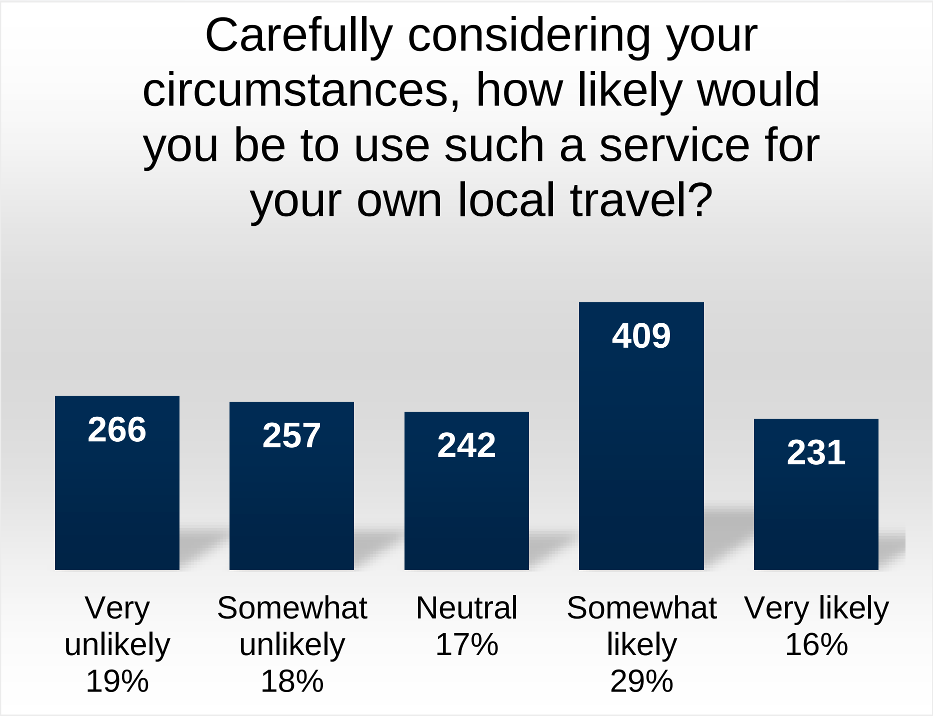
Initial eVTOL Impressions





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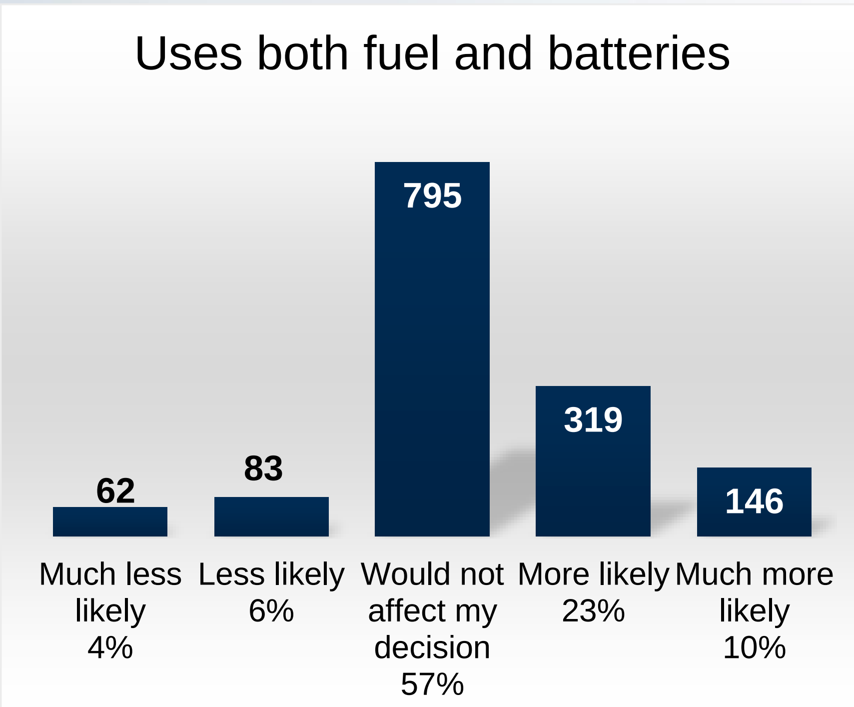
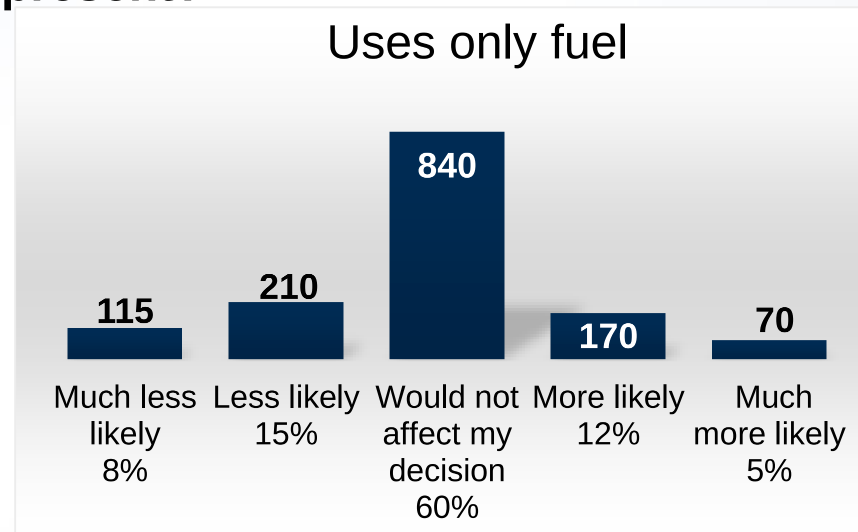
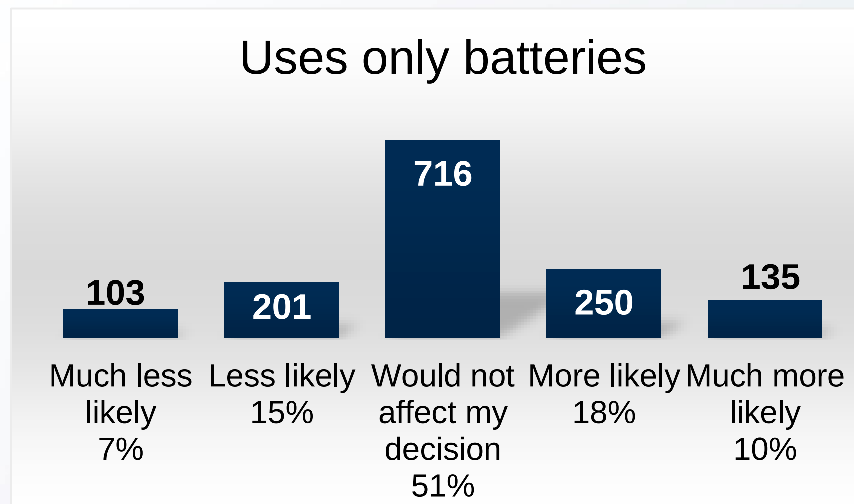
eVTOL Features (1)

How much more or less likely you would be to fly in an eVTOL aircraft if each feature were present?







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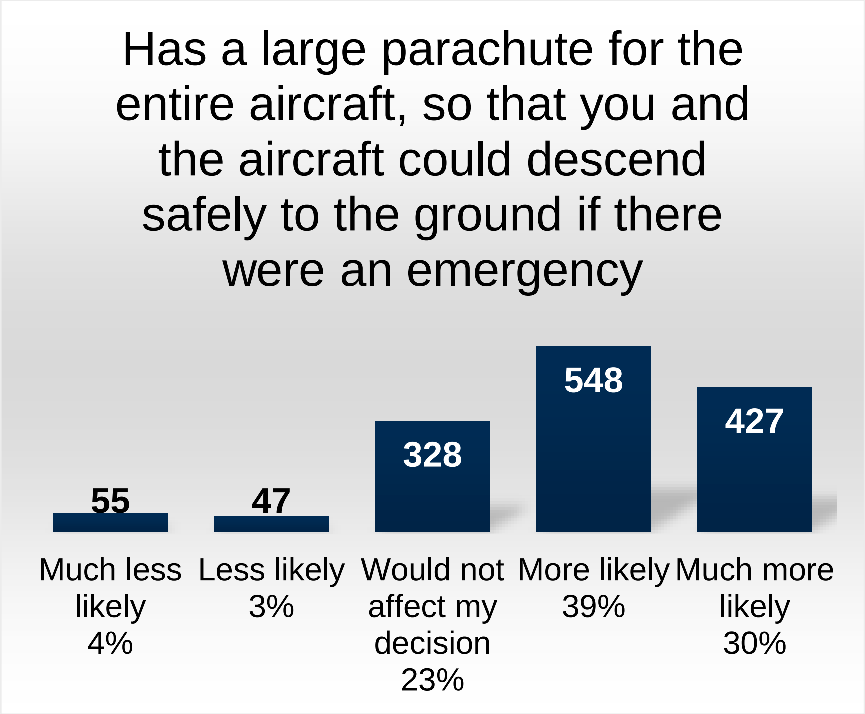

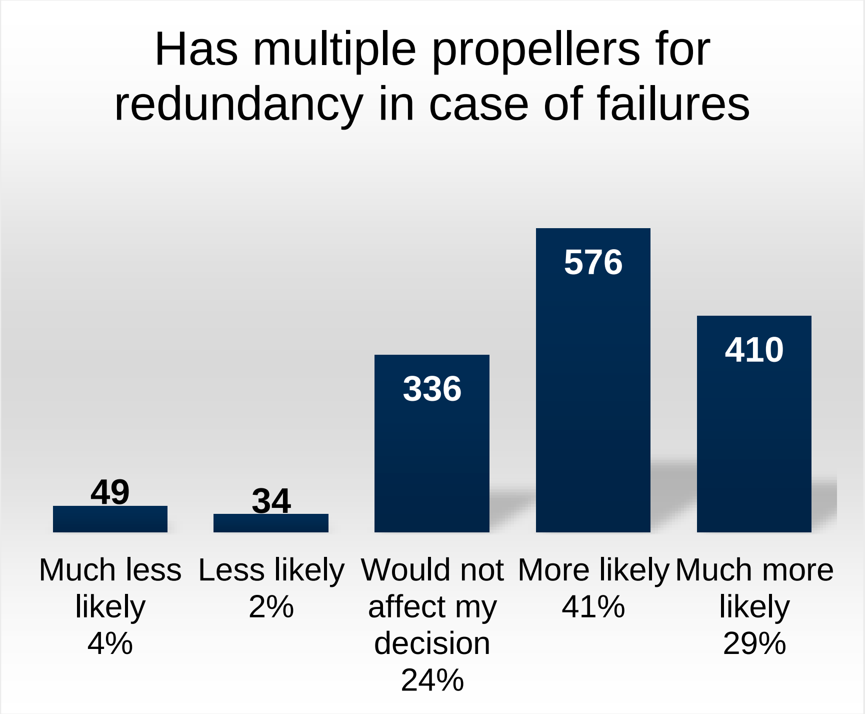

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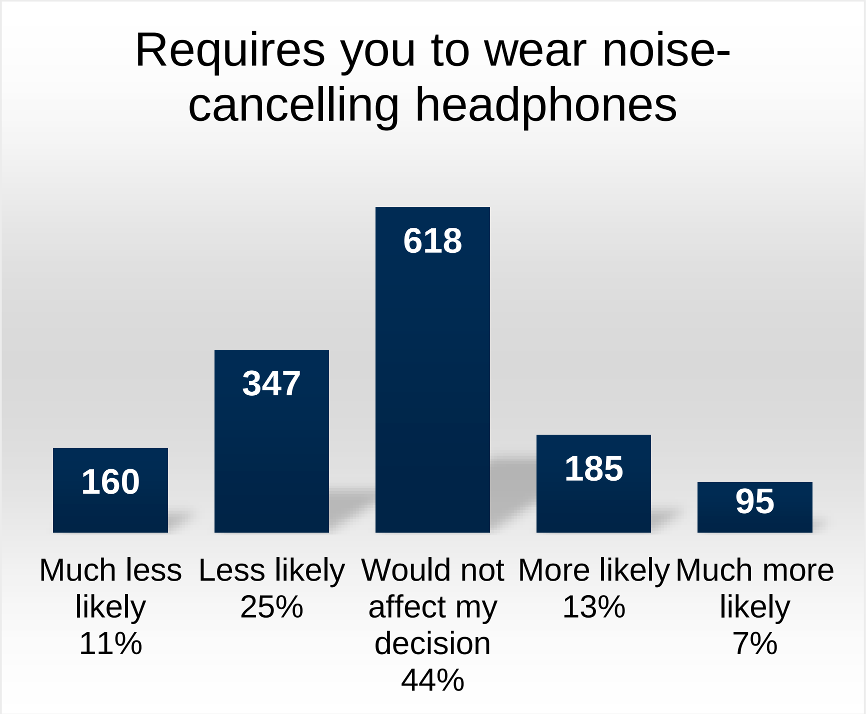
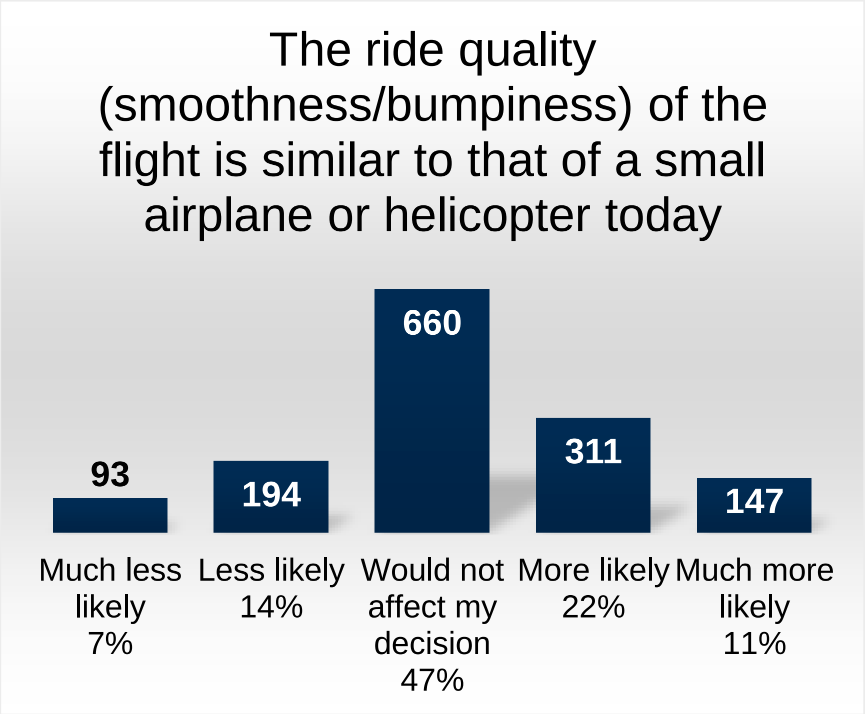
eVTOL Features (3)

How much more or less likely you would be to fly in an eVTOL aircraft if each feature were present?





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Discrete Choice: Auto vs. AV vs. eVTOL

Drive yourself in a traditional car with the following characteristics:	Travel by a self-driving car with the following characteristics:	Travel by a piloted air taxi with the following characteristics:
Cost: $5	**Cost:** $5	**Cost:** $5
Travel Time: 50 minutes	**Travel Time:** 50 minutes	**Flight Time:** 15 minutes
	Wait Time: 20 minutes	**Time To/From Aircraft:** 10 minutes
	Own Vehicle? No	**Guaranteed Lyft/Uber Ride:** No
	Travel Companions: None / alone	**Travel Companions:** Strangers

Levels for time, cost, other attributes set using design of experiment methods.

Images of a traditional car, self-driving car and air taxi were shown on survey.

Discrete Choice: Transit vs. AV vs. eVTOL

Travel by transit with the following characteristics:	Travel by a self-driving car with the following characteristics:	Travel by a piloted air taxi with the following characteristics:
Cost: $5	**Cost:** $5	**Cost:** $5
Travel Time: 50 minutes	**Travel Time:** 50 minutes	**Flight Time:** 15 minutes
Time To/From Transit: 20 minutes	**Wait Time:** 20 minutes	**Time To/From Aircraft:** 10 minutes
Guarenteed Lyft/Uber Ride: No	**Own Vehicle?** No	**Guaranteed Lyft/Uber Ride:** No
Transfer: Yes	**Travel Companions:** None / alone	**Travel Companions:** Strangers

Levels for time, cost, other attributes set using design of experiment methods.

Images of a transit vehicle, self-driving car and air taxi were shown on survey.

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Multinomial Logit (MNL) Probability

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_{j \in C_n} e^{V_{nj}}}$$

- Assuming ε's are iid extreme value gives MNL probability
- P_{ni} = probability of individual n choosing alternative i
- $j \in C_n$ = all alternatives (J) that belong to the choice set of individual n

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Overall Modeling Process

Discrete Choice Models

MNL

↓

NL*

↓

Mixed**

Estimation Software

- Stata (commercial)
- Larch (Newman/GT freeware)
- Biogeme (freeware)

*Can help determine if AV is going to compete more with eVTOL and/or traditional auto

**Computationally expensive, good for simulation environments and situations in which the "tail" of the distribution is important.

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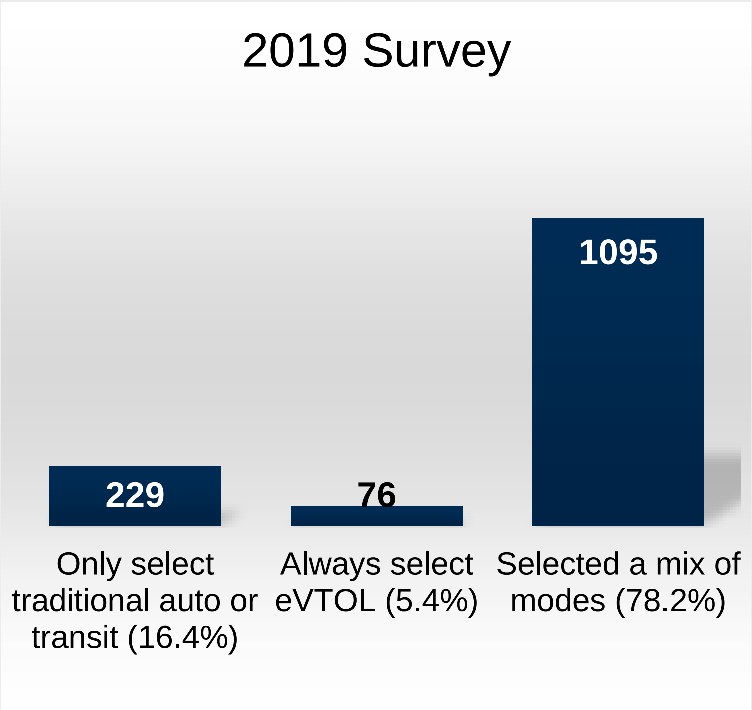
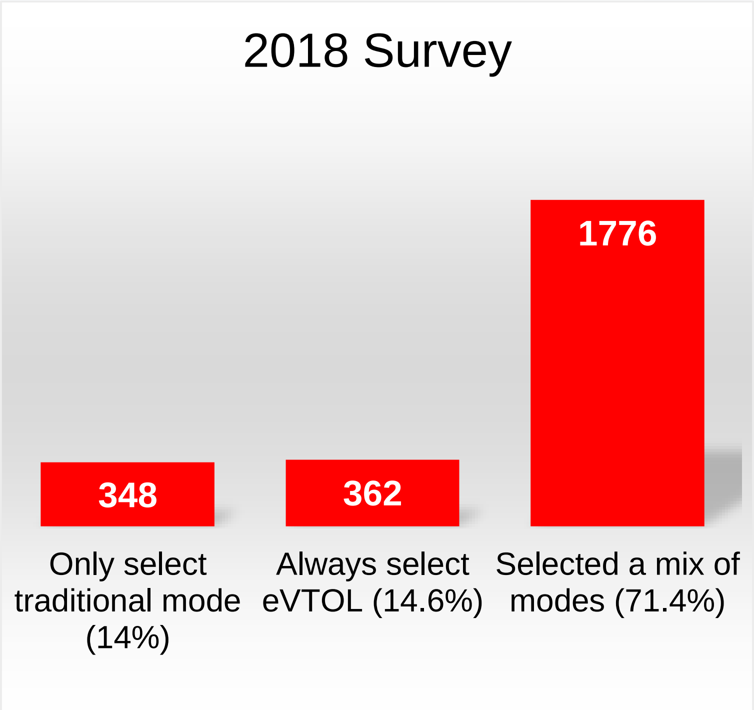
“I’ll never fly these things!”

You never selected the eVTOL aircraft option. Is there anything that would change your mind/any circumstances under which you would take an eVTOL aircraft?





We ran models with and without the “straight line” responses – defined as those individuals who always selected the same mode for all 8 trade-off scenarios.

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MNL Results

We expect OVT to be about 2.0-5.0 times higher than IVT and constrain this relationship (at 2.5) for mixed logit model

	Coefficient Estimate	T-stat	Odds Ratio	VOT
Cost [$]	-0.102	-21.8		
In-vehicle travel time [hr]	-2.488	-35.0		$24.52
Out-of-vehicle travel time [hr]	-1.167	-4.8		$11.50
Transfer	-0.340	-2.8	1.4 ↓	
Ride Guarantee	0.141	2.8	1.2 ↑	
Own AV – AV	0.864	8.6	2.4 ↑	
CPI adjusted income [Income [$]/(1000*CPI of the city)]				
Transit	-0.587	-1.8	1.8 ↓	
Autonomous ground vehicle	-0.003	0.0	1.0 ↓	
Traditional auto	0.350	2.3	1.4 ↑	
Air taxi (ref.)	0.0		1.0	

Excludes straight line data

MNL Results (Continued)

	Estimate	T-stat	Odds Ratio
Air Frequency			
Traditional auto	-0.377	-6.7	1.5 ↓
Transit, AV, and air taxi (ref.)	0.0		1.0
Uses Rideshare			
Transit	-0.652	-3.5	1.9 ↓
Traditional auto	-0.536	-8.4	1.7 ↓
AV and air taxi (ref.)	0.0		1.0
Female			
Traditional auto	0.083	1.5	1.1 ↑
Transit, AV, and air taxi (ref.)	0.0		1.0

Excludes straight line data

MNL Results – Companions by Age (OR)

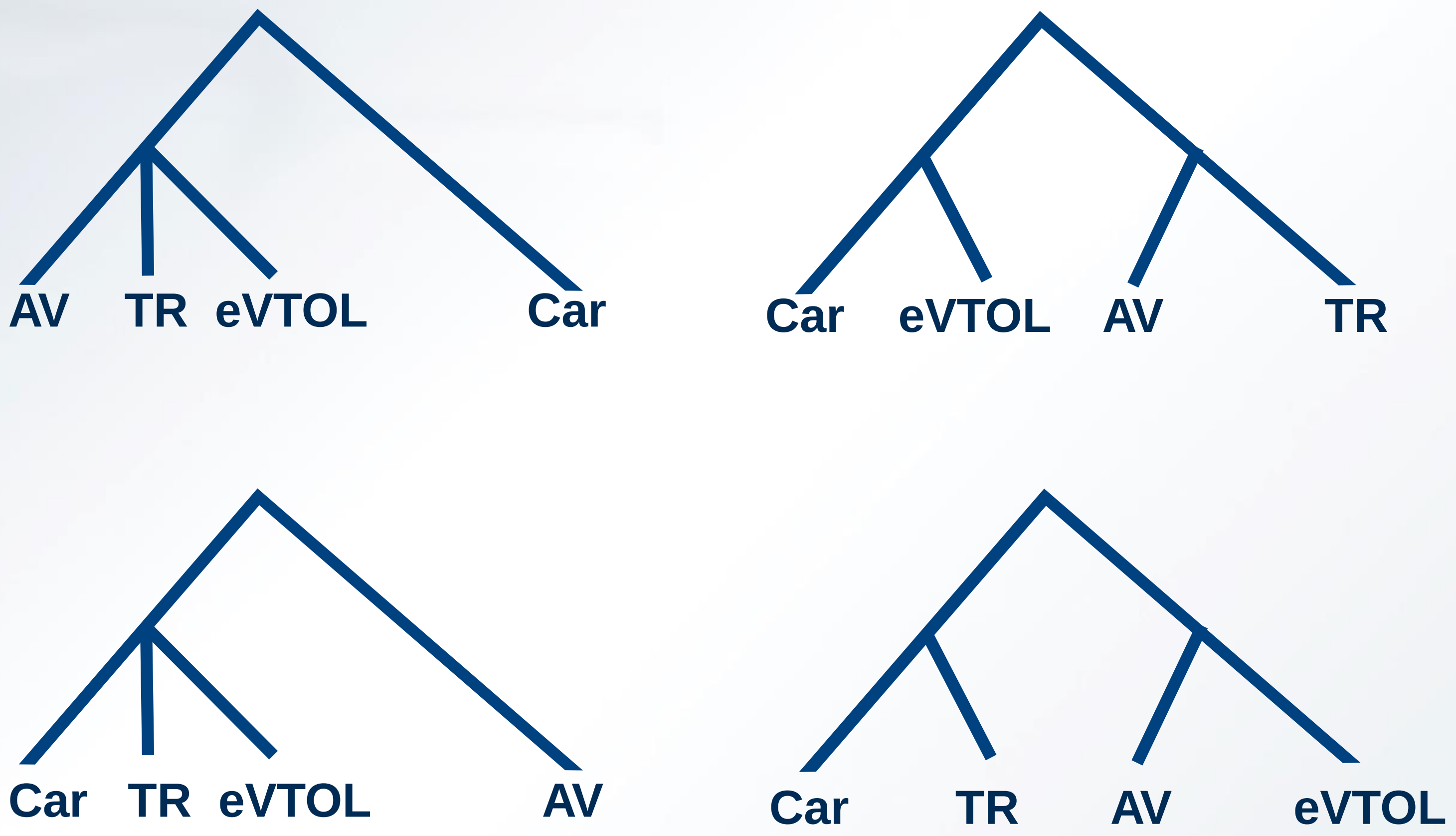
Age	Odds ratio: Travel alone or with people you know – AV*	Odds Ratio: Travel with people you know eVTOL
18-24	2.2	1.5
25-34	1.3	1.5
35-44	1.5	1.3
45-54	1.5	1.2
55-64	1.2	1.1
65+	1.0	1.0

*Statistically not much difference between travelling alone and people you know.

Excludes straight line data

Nested Logit Results

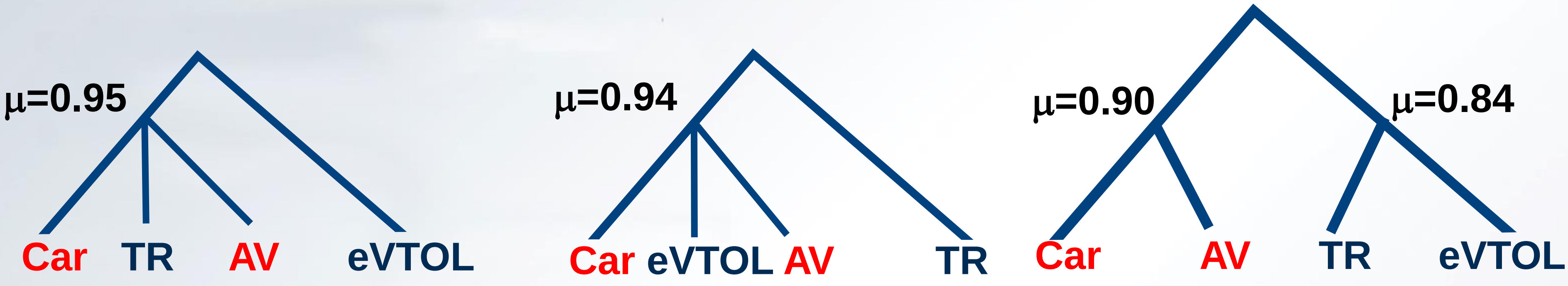
Tried out all possible one-level nest structures



These nests did not work

Excludes straight line data

NL Results – AV & Car Nests "worked"



Practical implications:

A value of **μ =** 1 is equivalent to a MNL model. **μ** ranges from 0 to 1. Values closer to 0 mean more correlation.

Increased substitution among ground modes, meaning that when AV is entered into the market it will draw proportionately more share from car than from eVTOL. There will still be share taken from eVTOL, but the NL suggests this will be slightly less share taken than with a MNL model.

Excludes straight line data

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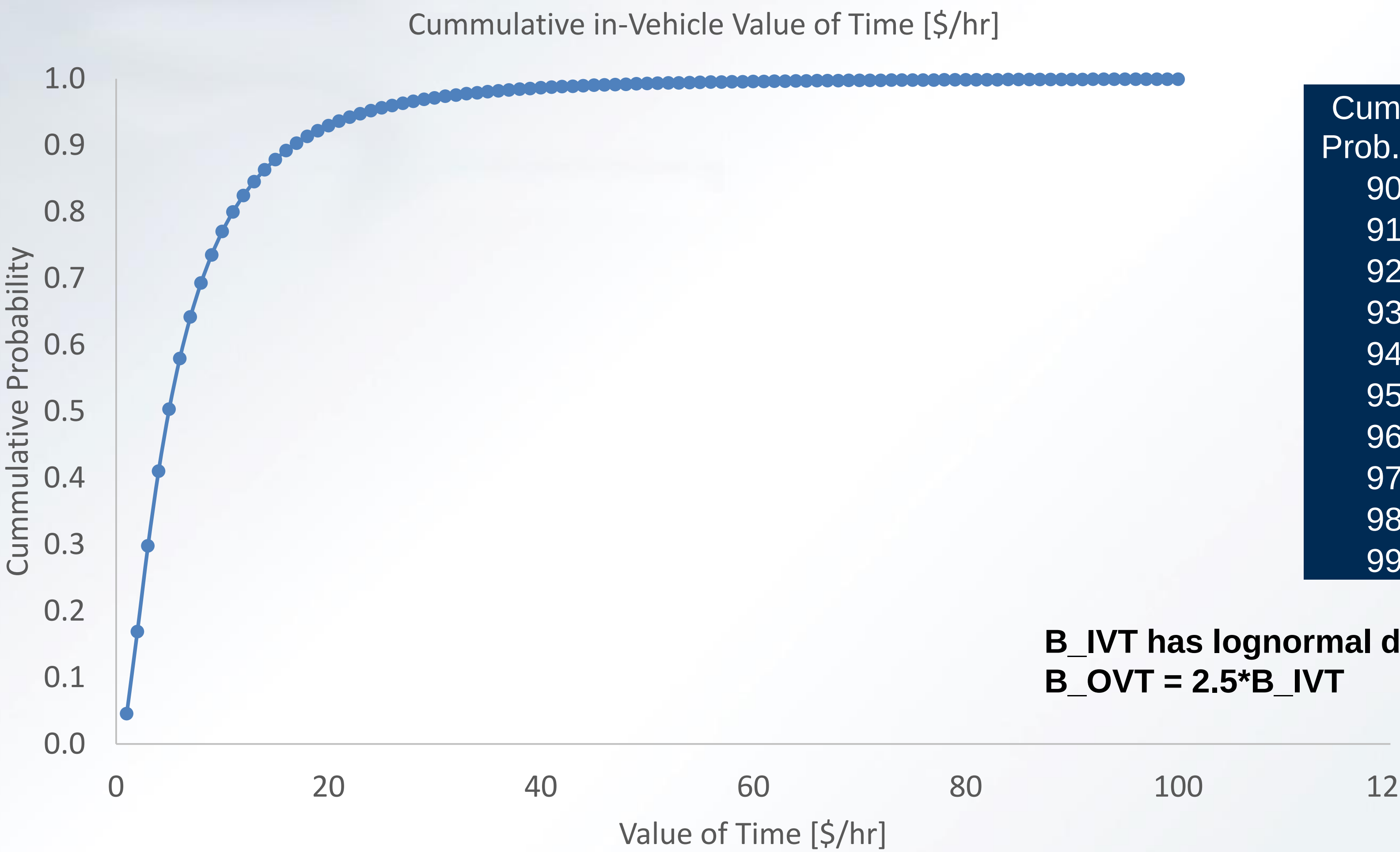
Mixed Results – Key Insight



Cumm. Prob.[%]	VoT [$/hr]
90	16.7
91	17.7
92	18.8
93	20.1
94	21.6
95	23.6
96	26.1
97	29.5
98	34.7
99	44.9

B_IVT has lognormal distribution
B_OVT = 2.5*B_IVT

Excludes straight line data

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Additional Materials

Literature Review of:

Synergies and Risks between Autonomous Ground Vehicles and UAM Service

Lessons to Be Learned from Transit Station Design and Planning

Alternate Future Scenarios

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Synergies and Risks between Autonomous Ground Vehicles and UAM Service

Problem Statement

- The rise of ground-based autonomous vehicles will coincide with/precede the rise of air-based autonomous vehicles
- What are potential synergies and risks between the two modes

Synergies and Risks between Autonomous Ground Vehicles and UAM Service

Synergies Associated with Autonomous Vehicles

- People are not willing to pay for personal ownership of autonomous cars may choose to share/take eVTOL instead (Richardson & Davies)
- Younger people are not as concerned with the safety of autonomous shared vehicles (will pave the way for acceptance of eVTOL) (Richardson & Davies)
- People generally think they are safe, but are not interested in owning autonomous cars (Richardson & Davies)
- Starting to combine the ground and air autonomous vehicles with detachable pods (Lambert)
- Cars are being tested as first/last mile connections (Scheltes & Correia)
- Personal ownership would be conducive to people living further away (therefore greater demand for eVTOL) (Gruel & Stanford)
- Seeing autonomous vehicles firsthand and confirming the safety benefits will lead to greater public acceptance of all types of AVs ("Public Perceptions…")

Synergies and Risks between Autonomous Ground Vehicles and UAM Service

Risks Associated with Autonomous Vehicles

- People will be more willing to spend time in cars because it will be less stressful and they will be able to do other things (Wadud et. al.)
- People may even prefer to spend more time in cars because they can get stuff done and be in a privately owned space (Wadud et. al.)
  - The value of commute time reduction changes… people don’t care if their commutes are shorter
  - The benefit of a shorter commute time with eVTOL will be unimportant
- AVs will reduce congestion, so there is less incentive to save time with eVTOL (Schrank, et. al)
- People who don’t have drivers license and other limited mobility users suddenly will be able to own cars and not use public transportation (Wadud et. al.)
- Sharing vehicles leads to less traveling overall (higher marginal cost vs private ownership) (Wadud et. al.)
- Sharing vehicles will lead to people living closer together… the need for eVTOL will decrease (Gruel & Stanford)
- Will make travel safer and therefore more people will use cars and reduce commute times (Gruel & Stanford)
- There is greater comfort with AVs that are personally owned (compared to shuttles, taxis, shared, etc.) (Bloomberg)

Lessons to Be Learned from Transit Station Design and Planning

Problem Statement

- eVTOL bears similarities to transit
- What are the lessons we can learn from station planning that is designed to attract ridership, and can we use that and apply it to eVTOL vertiport planning
- How does the advent of AVs spell out the future for transit – competition or supplement

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Lessons to Be Learned from Transit Station Design and Planning

TOD Practices

- Mixed land use; housing near transit increases chances of ridership - “A California study found that, among those who drove to work when they lived away from transit, 52.3% switched to transit commuting upon moving within a half-mile walking distance of a rail station” (Cervero).
- Mixed-use should be located such that ridership is ensured at all times, all days of the week. Linear corridors of varying land use helps produce balanced bi-directional flows
- Another important ridership dimension of TODs is their mixed-use attributes. (Cervero)
- More pedestrian activity (circulation) around a station encourages walking and in turn, transit (Loutzenheiser)
- OVTT is a significant variable as a deterrent to transit ridership
  - Activities around the station to distract / occupy riders in the OVTT helps
  - Retail, Restaurants and Entertainment

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Lessons to Be Learned from Transit Station Design and Planning

Relationship between infra, design, circulation and ridership

- Station design influences how people interact with the station and its surroundings (Voulgaris et. al)
- Location of stops (including distance between stops), based on land use (Reconnecting America)
  - Suburban areas have more spaced out stations
  - Dense land uses have closer stations
  - Vertiports can be located similarly
- Connection time / access between modes (bus-train interchanges) (Litman)
  - Encourage multimodality
  - Cars can drive up into the station
  - Exciting attractions in the terminal
  - Design the station like an airport terminal

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Lessons to Be Learned from Transit Station Design and Planning

Impact of AVs on transit ridership

- General disagreement / uncertainty on the impacts
- Paratransit would definitely take a blow, as AVs provide comfort and mobility to the elderly and disabled (Kockelman)
- Reduced vehicle ownership numbers, but overall increase in travel because of SAVs (Kockelman)
- Promised decrease in congestion and travel time could be in the long run; no immediate elasticity against transit (Childress et. al)
- Autonomous buses - Transit agencies would look at autonomous buses to operate in BRT lanes, to create Heavy Rail levels of efficiency (Guerra)

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Lessons to Be Learned from Transit Station Design and Planning

Similarities & differences between eVTOL and Transit

- By default, the fall-back option for failure of eVTOL (in case of bad weather) is rideshare - we can't talk about competition when it is a component of it
- Similarities: Ferrying people together; not demand responsive, fixed schedule, route
- Differences: Ownership (public vs. corporate), funding structure

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Alternate Future Scenarios

Congestion reduction based on Market Penetration (Schrank, et al., 2012)

- Assumptions:
- AVs are equipped with adaptive cruise control, traffic flow smoothing capabilities
- Actual Congestion reduction is offset by increase in induced trips (i.e. VMT)
- Reduction in crashes and the associated first response time is included in reduced congestion time
- 40% of roadway congestion occurs on freeways, and the numbers below are representative of only the delay reduction predictions on freeways
- 10% MP, 15% reduction in delay
- 50% MP, 35% reduction in delay
- 90% MP, 60% reduction in delay (along with a doubling of roadway capacity)

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Alternate Future Scenarios

Based on Ownership and Behavior

Gruel and Stanford then go into possible implications for AVs which can be extrapolated into implications for eVTOL for each scenario in their paper.

- There is no change in behavior or ownership of vehicles. AVs are used in the same way cars are used today and vehicles are privately owned (Gruel & Stanford).
- There is a change in behaviour but not in ownership. People conduct new travel patterns, but still own their own vehicles (Gruel & Stanford).
- There is a change in behaviour and in ownership. People both have new travel patterns and now share AVs with the masses (Gruel & Stanford).

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Alternate Future Scenarios

Potential Dichotomies (That We've Noted)

- Private vs. shared AVs (no consensus)
- Autonomous vs. piloted eVTOL (short-term piloted, long-term autonomous)
- More sprawl vs. more density (no consensus)
- Ground VMT increase vs. decrease (increase more likely)
- Decrease vs. increase of transit usage (decrease more likely)

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