EFFECTS OF TOURISM ON RURAL ROADS & RURAL DELIVERY WITH CAV

FINAL PROJECT REPORT
by

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16. Abstract While some congestion is expected at rural attractions such as national parks, theme parks, special sporting events, scenic points and the like, there are locations along the rural highway network that nearby attractions cause substantial congestion and/or unusually elevated traffic safety risk. This paper presents the case of two very popular tourist attractions on the North Shore of the Island of Oahu in the State of Hawaii: Laniakea Beach and Shark's Cove. These locations are within five miles of each other and are served solely by the 2-lane rural Kamehameha Highway. These two locations have been congestion black spots for over a decade, and local opposition to more development and tourism has been substantial. A team of students in civil engineering at the University of Hawaii at Manoa has been meeting with the local communities and has collected sample data to substantiate the extent of the problem. Several discussions were completed, where mitigation proposals were presented and discussed. This paper summarizes both the history of this problem, and the various data collected such as vehicular and pedestrian volumes, travel times and queue lengths. It also presents a list of proposed mitigations. There is a multitude of problems with most of the proposals including cost, appeal (they are not context sensitive), difficulty with agency jurisdictional bounds, community acceptance and risk from waves and long-term sea level rise.			
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SI* (Modern Metric) Conversion Factors

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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Executive Summary

While some congestion is expected at rural attractions such as national parks, theme parks, special sporting events, scenic points and the like, there are locations along the rural highway network where nearby attractions cause substantial congestion and/or unusually elevated traffic safety risk. This paper presents the case of two very popular tourist attractions on the North Shore of the Island of Oahu in the State of Hawaii: Laniakea Beach and Shark's Cove. These locations are within five miles of each other and are served solely by the 2-lane rural Kamehameha Highway. These two locations have been congestion black spots for over a decade, and local opposition to more development and tourism has been substantial. A team of students in civil engineering at the University of Hawaii at Manoa has been meeting with the local communities and has collected sample data to substantiate the extent of the problem. Several discussions were completed, where mitigation proposals were presented and discussed. This paper summarizes both the history of this problem, and the various data collected such as vehicular and pedestrian volumes, travel times and queue lengths. It also presents a list of proposed mitigations. There is a multitude of problems with most of the proposals including cost, appeal (they are not context sensitive), difficulty with agency jurisdictional bounds, community acceptance and risk from waves and long-term sea level rise. Finally, we also investigate the impacts of autonomous vehicles (AVs) on household travel-activity patterns in the Oahu MPO study area. Through this study, we address the following broad question: "Which households will benefit from AVs, with respect to their travel patterns?" With respect to regional travel patterns, while the regional benefits from AVs have been broadly envisioned and discussed, the impacts to households or other decision makers are less clear. This study begins to address the question of who potentially benefits, while recognizing that these impacts are contingent on future conditions which face varying uncertainties. In this study, we adopt the perspective of households as service providers that dispatch a vehicle fleet to service out-of-home activities. Analogous service systems include delivery logistics providers (e.g. FedEx, UPS, USPS, DHL, etc.), rideshare TNCs (e.g. Uber, Lyft, etc.) and emergency service providers (EMS, Municipal Fire Departments, etc.). From this perspective, households have a set of out-of-home activities that need to be completed; they must decide how many household vehicles to dispatch, their routing and their scheduling of stops (timing and sequencing). The status quo travel-activity pattern, for each household, is assumed to be their observed travel-activity patterns from the 2012 Oahu Household Travel Survey. Their AV scenario patterns were the final solutions solving their respective Household VRP with each heuristic. Performance metrics considered include the total travel time across all household vehicles and the total number of vehicles required to complete the set of out-of-home activities.

CHAPTER 1. History of the Problem

The turn of the new millennium brought with it the widespread usage of social media platforms on the Internet and smart phones. These, in combination, propelled several lesser-known tourist locations to a much higher level of awareness, which created a much larger number of visitors to these locations, most tourists arriving there by private transportation such as cars, vans and recreational vehicles. Both Laniakea Beach (due to its large sea turtles frequenting the shore and sandy areas) and Shark's Cove (due to its expansive, family-friendly ponds with a variety of sea life) received much additional attention and progressively traffic volume and parking problems reached levels that often are intolerable in both terms of level of service (several miles of queued traffic) and safety (hundreds of crossings per hour of a state highway and erratic parking maneuvers).

There are five major tourist attractions on The North Shore of Oahu: Sunset Beach, Shark's Cove, Waimea Bay, Laniakea Beach and Haleiwa town. Kamehameha Highway is a rural, typical 35 and 45 mph speed-limited 2-lane highway; it is the sole connector of all five sights, except Haleiwa town that got so congested in the 1990s that a road bypassing it and leading straight to Laniakea Beach was constructed. The focus of this field research project was on Laniakea Beach and Shark's Cove. This stretch of Kamehameha Highway (locally called Kam Hwy) is a rural, one-lane-per-direction facility and the only road that connects the entire North Shore of Oahu to destinations on Windward Oahu north of Kaneohe (Kahalu'u, Ka'a'awa, Punalu'u, Laie, and Kahuku). The segment of Kam Hwy between Haleiwa and the north tip of Oahu connects many popular attractions. Starting from Haleiwa, it connects Laniakea Beach, Waimea Bay, Waimea Valley, Pupukea and Shark's Cove. Ocean surfing championship locations like Banzai Pipeline and Sunset Beach, and the large and expanding Turtle Bay resort are also located in close vicinity of Kam Hwy. The multiple traffic bottlenecks along the eight-mile stretch of Kamehameha Highway (see Table 1) provide a poor level of service for locals and tourists. Typically, the worst bottleneck is Laniakea Beach (perennial), followed by Sunset Beach (seasonal) and Shark's Cove (warmer months, March to December) which is slated for more commercial development for tourism.

Table 1. Approximate Roadway Distances in the Area of Study

Dist.	Location
0.00	Weed Circle/Haleiwa Bypass
1.20	Haleiwa town
2.20	Laniakea Beach
2.20	Waimea Bay/Pu'u O Mahuka Heiau
0.85	Shark's Cove
1.25	Sunset Beach
7.70	(miles) 12.4 km

An improvised unimproved parking lot is located at the side of the road opposite Laniakea Beach. Visitors must cross the highway to access the beach. Cars and buses maneuver to get in and out of the parking lot. Some vehicles slow down or stop so that the occupants can cross the road to see the turtles. Surfers drive by to check the waves; Laniakea Beach is one of the few beaches in North Shore with unobstructed views to ocean conditions. All these motorist and pedestrian behaviors cause frequent slowdowns and stoppages; when the amount of traffic is substantial (e.g., holidays, weekdays and other tourism peaks,) these worsen to substantial traffic congestion that extends for miles. About 15 years ago, the community began logging objections and demands for mitigation actions as summarized below.

2004

- In August, a Draft Environmental Assessment (EA), prepared by Oceanit for the C&C of Honolulu Department of Design and Construction, for Laniakea Beach Support Park became available for review and comments.

2005

- The Final EA declared FONSI (Finding of No Significant Impact) for Laniakea Beach Support Park, that is, no significant impacts were anticipated from the construction and operation of the proposed improvements associated with the Laniakea Beach Support Park.
- The Final EA included:
    - Site location and history.
    - Project description such as infrastructure improvements, landscaping, drainage and security.
    - Proposed action and alternatives (three options + no action alternative).
    - Affected environment: geology and topography, land use, soils, climate, air quality, water resources, flood hazard, flora, fauna, cultural and historical resources, archaeological resources, traffic, noise, utilities, socio-economic benefits, environmental justice, and relationship to government regulations and permitting requirements.
    - Determination and conclusions.
- OMPO (Oahu Metropolitan Planning Organization) Citizens Advisory Committee:
    - Antya Miller represents NSNB (North Shore Neighborhood Board).
    - Gil Riviere represents NSCOC (NS Chamber of Commerce) until end of 2010.
- In July, the Traffic and Transportation Committee was created by NSNB.
- In November, the Committee suggested a model concept of realignment of Kam Hwy to HDOT.
- The HDOT clarified that the best-case scenario would take seven years (3-yr for the study of alternative, 2-yr for design and 2-yr for construction).

2006

- HDOT did not approve funding in 2006-2008 Transportation Improvement Program.
- HDOT stated that a road and parking project for Laniakea Beach would be very expensive and that they need $1.2 million for a Traffic Alternatives Study.

2007

- HDOT did not approve a traffic study for Laniakea Beach proposed by OMPO.
- Legislature funds $1.2 million of CIP funds for Laniakea Beach study.

- Project is delayed for two years because the HDOT decided to enlarge the study from Haleiwa Bypass to Waimea Bay. The community didn't agree to this expansion of scope and set up a meeting with the HDOT Director, to get the project back on track.

2008

- Nothing was done by HDOT.

2009

- CIP funds lapsed; then $1.7 million was reprogrammed for the Traffic Alternatives Study.

2010

- Pressure by Figueroa, Miller, Riviere et al. gets money released to hire consultant and start the study.

2011

- Public Scoping Meeting at Haleiwa Elementary School: project estimated to begin July 2011.

2012

- First and Second Laniakea Task Force Meeting: Community demands relief with short-term solutions.
- HDOT considers three study projects: no parking, and two versions of one-way in and one-way out.

2013

- Laniakea Beach traffic worsens as the 2008-2009 economic recession is followed by strong economic and tourism growth. The North Shore community becomes increasingly upset by government inaction.
- HDOT recommends the placement of barriers.
- A motion at NSNB to support the placement of barriers fails.
- Third Laniakea Task Force Meeting: The majority voted against the placement of barriers.
- In December 22, HDOT installed portable concrete barriers blocking all parking across Laniakea Beach.

2014

- HDOT is sued over restricting access to city park land with the barriers; the parking space is a City park.
- Fourth Laniakea Task Force Meeting: Discussion of five possible realignment alternatives. Verbal estimation of $20-40 million.
- The barriers were in effect for the entire year and the majority of North Shore residents thought that the barriers improved the traffic flow adjacent to Laniakea Beach.

2015

- Court order to remove the barriers due to not getting a Shoreline Management Act (SMA) permit.
- On August 24 the barriers were removed and "No Parking" signs were installed (to no real effect.)
- First Laniakea Stakeholder Group Meeting: Several requests for meeting with the Governor had no response.
- December: Senator Riviere meets with HDOT Highways Division and reports on HDOT's plan to get a draft EA and SMA permit by July 2016.

- HDOT is planning a major Laniakea Beach realignment due to beach erosion/climate change concerns.

2016, 2017

- No obvious activity or action, but a consultant is conducting a study.

2018

- Two community meetings involving the UH team, city council candidate James, Senator Riviere and Representative Quinlan focused on likely feasible short term/immediate relief alternatives.
- Representative Quinlan states that HDOT will unveil the study after the elections.
- No updates or study from HDOT by year’s end.

CHAPTER 2. Background

Since 1989, the number of tourists arriving to Hawaii has increased which is in many ways a challenge because "all of the social costs associated with tourism are or are primarily associated with their physical presence" according to economist Paul Brewbaker (Lund 2018). The state and tourism industry created programs to attract people to these rural areas to help with the economy of the surrounding area.

The North Shore is a very heavily trafficked region of Oahu for locals and visitors to surf, snorkel, eat, spot marine life and all together enjoy the beauty that Oahu has to offer. There are approximately 11 miles of beaches on which commuters drive past daily. The issue at hand is the traffic problems in popular rural beach areas such as Laniakea Beach, Waimea Beach, and Pupukea Beach. This is the order of traffic study locations within a 5 mile stretch in which a typical commuter will experience stalled traffic when traveling east bound from Haleiwa to Pupukea. The surrounding community has reached out to the Department of Transportations with their concerns, but insufficient actions have been made over the past four decades (ETurboNews 2018; Daysog 2017; Lund 2018).

Figure 1: Laniakea Traffic Congestion - Cause and Effect

The goal of this project was to collect sample data, to inform and collaborate with the community about the multitude of problems, and to create mitigation strategies for the existing problems of acute traffic congestion, lack of parking, and pedestrian crossings. This project was conducted under the auspices of CSET, the Center for Safety Equity in Transportation (a Tier-1 UTC) which is focused on Rural, Isolated, Tribal and Indigenous (RITI) communities. The North Shore are of Oahu qualifies not only as a rural area but also an area of Hawaiian (indigenous) cultural life including surfing and historical artifacts at the Pu'u O Mahuka Heiau State Historic Site; this site is a 17th century heiau (an ancient Hawaiian temple or sacred site), one of the largest in Hawaii and is located about 0.4 miles from Waimea Bay.

CHAPTER 3. Field Data Collection and Analysis

This project was primarily concerned with the pedestrian crossings at Laniakea Beach and Shark's Cove location on the North Shore region of Oahu. In addition to pedestrian crossings, we collected volume data that are contemporaneous with the pedestrian crossings, to be used in a future conflict analysis and risk assessment, and for comparison with historical counts in the area. The data below clearly depicts a situation where a large number of unprotected pedestrian crossings take place along a busy 2-lane highway. Furthermore, at Laniakea Beach the situation is compounded by a dysfunctional, illegal and unimproved parking lot, and at Shark's Cove the situation is compounded by several busy driveways.

Pedestrian Crossing – Laniakea

Laniakea Beach Support Park is three acres of undeveloped land owned by the City and County of Honolulu on the land side of Kamehameha Highway at Laniakea. The sandy beach fronts the park but is lined with a rocky shelf. Seaweed growing on the shelf and the ocean bottom attracts turtles to the beach, many of them coming ashore to rest (Hawaii Beach Safety 2019, Best of Oahu 2016, Hawaii 2017). The sea turtles are protected under state and federal law requiring a minimum of 10 feet from any turtle (Hawaii DLNR 2018). Many tourism operators bring in large groups of tourists with the promise of seeing and swimming with turtles (Turtles of Hawaii 2019).

The shoulder dirt area that sits parallel to Laniakea beach is mainly occupied by parked tour buses and rental cars despite the "No Parking Signs" so use the word illegal to describe this parking activity. While police frequently patrol the area and respond to fairly frequent minor collisions (due to distraction and unexpected congestion, i.e., standing queue), no enforcement of the No Parking rule has occurred because it is deemed as undesirable to tourism and typically causes more localized congestion and infringement on adjacent local properties and road shoulders.

There is no pedestrian crosswalk at Laniakea Beach, therefore hundreds of pedestrians cross the street daily. At 2:00 PM – 3:00 PM there is a peak of around 300+ pedestrian crossings which indicates the typical Sunday arrival time for tour buses to reach Laniakea Beach. Within a seven-hour time-period, there was a total of 2,193 pedestrian crossings in March and 2,114 pedestrian crossings in May as shown in Table 2. By all accounts, this is a high volume of pedestrians crossing a rural 2-lane highway.

Table 2. Hourly Pedestrian Count at Laniakea Beach

End Time	**12 PM**	**1 PM**	**2 PM**	**3 PM**	**4 PM**	**5 PM**	**6 PM**	**7 PM**	**Total**
March	209	158	310	**397**	363	367	249	140	**2,193**
May	204	155	302	**388**	386	330	223	126	**2,114**

Pedestrian Crossing – Shark's Cove

The people who go to Shark's Cove can conveniently walk across Kam Hwy to the supermarket or the food vendor areas. There is a proper, market cross walk by the Pupukea Fire Station with pedestrian actuation buttons. The distance from the food vendor parking lot to the crosswalk to Shark's Cove is approximately 550 ft. whereas the direct link between Shark's Cove and the Vendor area is under 150 ft., which explains the preponderance for illegal crossings as shown in Figure 5.

The results show that the average percentage of pedestrians crossing illegally was 34% on a Sunday in March and 48% on a Sunday in May (Cinco de Mayo.) We defined an illegal crossing as a crossing occurring more than 20 ft. away from the marked crosswalk. Some of the illegal crossings did occur in parallel to the "Walk" display on the crosswalk, but most of them occurred randomly near the driveway to and from the food vendor area.

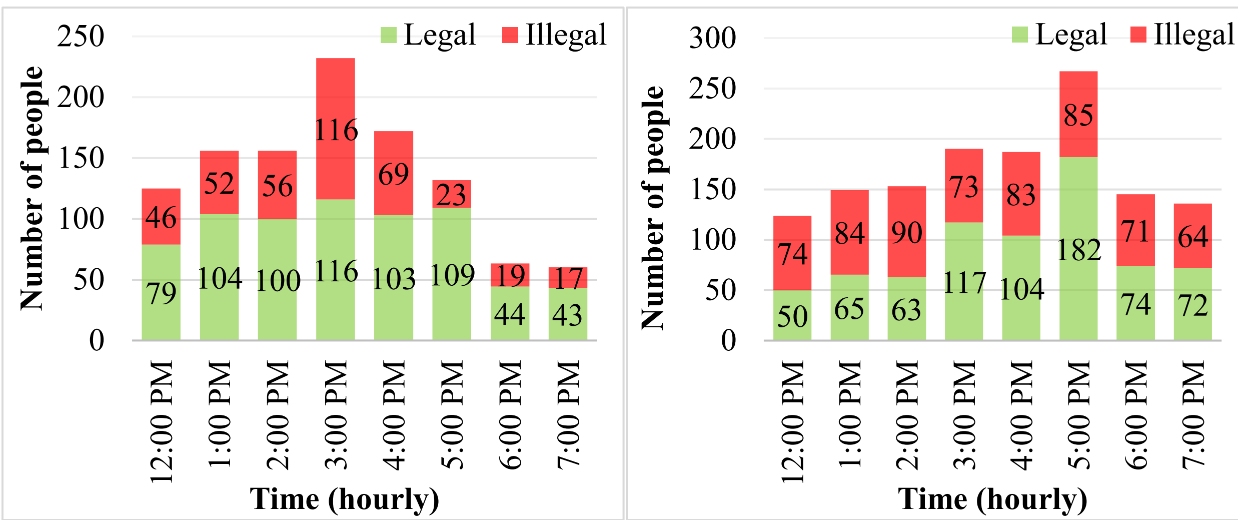

Figure 2: Pedestrian Crossing at Pupukea: (a) March 9, 2019; (b) May 5, 2019

Waimea Bay is a popular beach to visit on the North Shore during the summer and winter seasons for many reasons (Best of Oahu 2016). It is located just past Laniakea Beach and across the street from Waimea Falls Park. Near Waimea Bay is one of the most well preserved and largest Hawaiian heiau, the Pu'u O Mahaka State site, or "Hill of Escape" (Hawaii DLNR 2018, Prevedouros 2019). A major surfing competition is held at Waimea Bay: the "Eddie Aikau Big Wave International" or "The Eddie" in honor of Edward "Eddie" Aikau who lost his life to help fellow travelers on a capsized sailing boat in 1978. This surf competition brings in thousands of spectators from around the world. This world renown competition occurs only if conditions of wave heights meet a minimum of 20 feet (Historic Mysteries 2016, Star-Advertiser 2018, Honolulu Magazine 2016, Prevedouros et al. 2019).

Waimea Bay has 86 parking stalls at its parking lot where five stalls are reserved for lifeguards and four are handicap stalls. When parking stall availability runs low, many people park their cars alongside the shoulder of the access road and ticketing of parking violators is frequent. Table 3 shows the traffic volume counts per hour at Waimea Bay during the month of March when there were no special events happening to cause additional demand. Within a four-hour time-period, 3,135 cars traveled east bound towards Shark's Cove and 3,093 cars traveled west bound towards Laniakea. A total of 574 cars driving into Waimea Bay and an average of 115 cars entering every hour (Prevedouros 2019). On average, there are at least 1,200 vehicles traveling on Kam Hwy per hour. This amount of traffic conflicts with the illegal crossings of pedestrians at Laniakea Beach, as shown earlier in this section.

Table 3. Traffic Volume at Waimea Bay Beach Driveway

Location	**Parking Lot**		**Laniakea**		**Shark's Cove**		**Thru Traffic**
Time	**South Bound, Right**	**South Bound, Left**	**East Bound, Left**	**East Bound**	**West Bound, Right**	**West Bound**	**East – West**
12:00 PM	49	49	61	636	48	616	1252
1:00 PM	64	62	64	626	56	662	1288
2:00 PM	53	64	59	631	39	604	1235
3:00 PM	68	59	74	584	72	652	1236
4:00 PM	65	45	47	658	54	559	1217
Total	**299**	**279**	**305**	**3135**	**269**	**3093**	**6228**

Traffic Volume – Shark's Cove

Pupukea Beach Park is a Marine Life Conservation District, about 80-acres of lava rock with small sandy beaches, and home to the well-known Shark's Cove. Shark's Cove has been rated as one of the top twelve shore dives in the world due to the underwater caves and the diverse marine life that inhabits this shark shaped reef cove (Hawaii 2017).

The traffic volume analysis was conducted at the intersection of Kamehameha Highway and Pupukea Road. Adjacent to this intersection is the only major supermarket in a radius of over 40 miles and a host of local vendors, mostly the type that is called "food trucks" who cater to both tourists and the surrounding local community. This is the only signalized intersection on a rural coastal highway stretch of 20 miles (i.e., between Laie and Kahuhu.) Table 4 shows the traffic volume at the Kamehameha Highway and Pupukea Road intersection during peak hours during Cinco De Mayo 2019 (Prevedouros et al. 2019). The total traffic volume in all directions are as follows: 1,821 east bound, 2,053 west bound, 571 south bound, and 55 north bound. East-west is the through traffic on Kam Hwy. South bound enters into the residential area. North bound is the Pupukea Fire Station and beach parking lot. On average, there are about 1,000 vehicles traveling on Kam Hwy per hour. This amount of traffic conflicts with the illegal crossings of pedestrians at Shark's Cove, as shown in this section.

Table 4. Traffic Volume at Kamehameha Highway and Pupukea Road

	Pupukea			**Fire Station**			**Shark's Cove**			**Laniakea**		
Direction / Time	**NB,R**	**NB**	**NB,L**	**SB, L**	**SB**	**SB, R**	**WB, L**	**WB**	**WB, R**	**EB,R**	**EB**	**EB,L**
3:00 PM	41	4	87	8	4	12	57	512	18	88	474	4
4:00 PM	48	3	97	4	1	12	52	516	9	92	505	0
5:00 PM	54	2	82	0	1	4	66	397	1	109	416	1
6:00 PM	43	3	58	5	0	5	32	271	6	69	223	4

Driveway Traffic – Shark's Cove

There are three driveways across from Shark's Cove and along Kamehameha Highway. Two driveways (one for entering and one for exiting) serve a major local grocery store (Foodland, Hawaii's largest locally owned and operated grocery store chain dating back to 1948.) This is the only sizeable grocery story outside Haleiwa Town (5.5 miles, westbound) and Kahuku (9.5 miles, eastbound). The entire parcel of land across from Shark's Cove that encompasses the supermarket and food trucks and other vendors is owned by Hanapohaku LLC. This parcel of land which consists of 2.7 acres is a community area which is leased to local small businesses to sell goods and services. Currently, there are plans in reconstructing this parcel of land into a community commercial center (Hawaii DLR 2019). The operational hours of this leased parcel of land is from 8:30 AM – 8:30 PM.

The count of vehicles using the three driveways is displayed in Table 5 (Prevedouros et al. 2019). The counts reflect a moderately busy level of driveway operations next to a rural 2-lane highway. The turning movement split on the three driveways along Kam Hwy is 59% right turns and 41% left turns, partly reflecting the congested nature of the operation which impedes mostly left turns.

Table 5. Hourly Driveway Traffic

	Food Venue Parking Lot				**Super Market Parking Lot**				**Pupukea Rd. Access**	
	OUT		**IN**		**OUT**		**IN**			
Time	**NB,R**	**NB, L**	**WB, L**	**EB, R**	**NB, R**	**NB, L**	**EB, L**	**WB, R**	**IN**	**OUT**
3:30 PM	17	23	18	6	71	22	64	57	49	51
4:30 PM	11	13	12	14	71	25	48	46	72	81
5:30 PM	7	23	14	18	85	24	47	54	62	78
6:30 PM	3	6	2	3	22	0	10	10	6	18

Waze, a GPS navigation software app, shows traffic conditions and uses colors to represent traffic condition including red to represent slow traffic or queues. WAZE snapshots were recorded every 15 minutes on Sunday, March 3 and Sunday, May 5, 2019, then manually queue lengths were recorded separately for each direction on Kam Hwy. (Pupukea is the same as Shark's Cove.) Figure 3 shows that queues often exceed one mile in length which is a highly unusual condition for a rural highway. Notably peak queues are realized at 3 PM which coincides with the peak in pedestrian crossings at Laniakea Beach, as shown in Table 2. A normal speed average on between Laniakea Beach and Shark's Cove is about 30 mph in daytime, and about 40 mph at night. Normal daytime travel time between Laniakea Beach and Shark's Cove is about 5 minutes and actual travel time was 35 minutes or more.

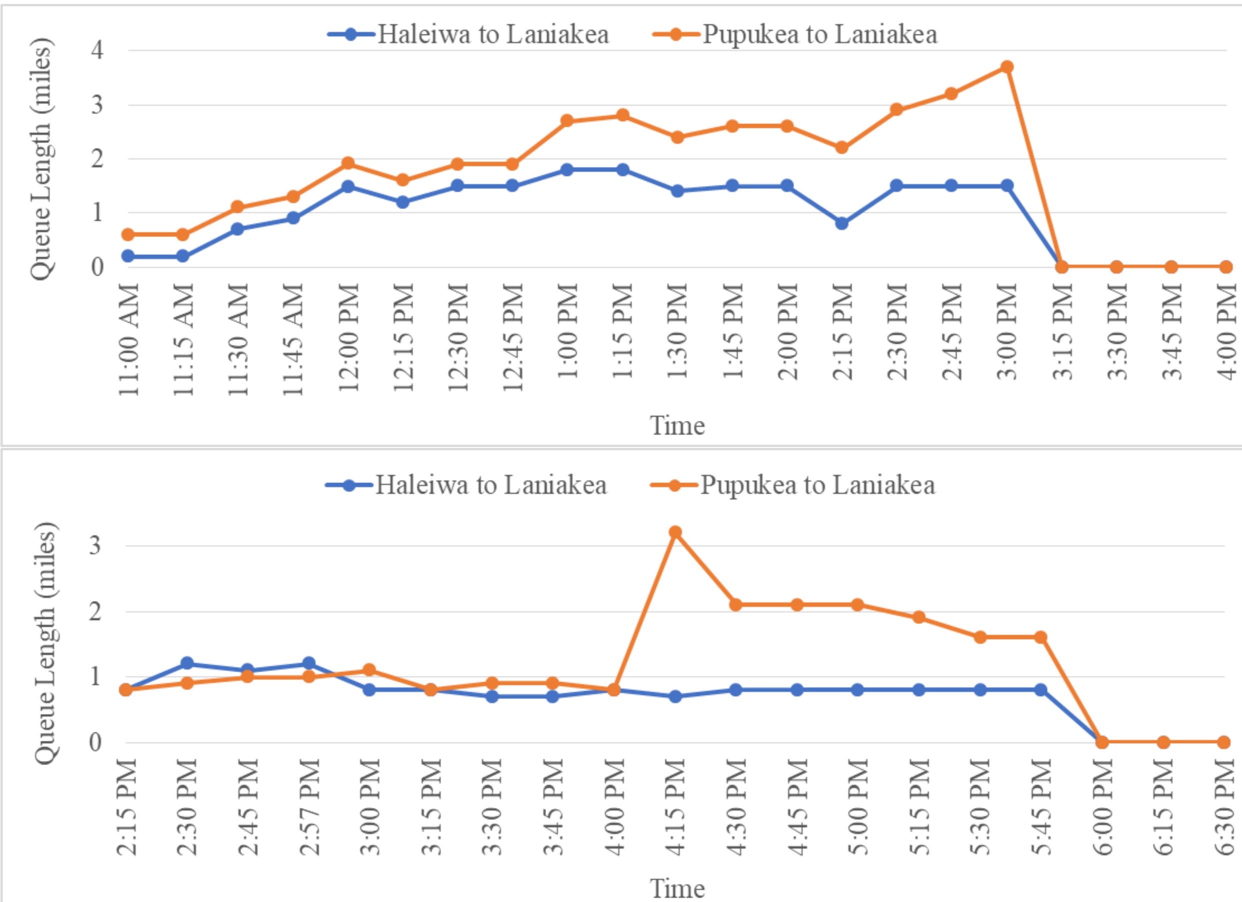

Figure 3: WAZE Estimated Queue Length: (a) March; (b) May

Mitigation Proposals

A few mitigation proposals that combine old and new ideas are shown in Table 6 along with their advantages and disadvantages, and the agencies responsible for the implementation of the project. In the table, DLNR stands for Hawaii State Department of Land and Natural Resources, HDOT stands for Hawaii State Department of Transportation, and C&C stands for the City and County of Honolulu. Additional proposals as well schematic depictions of the proposed mitigations are detailed in (Prevedouros et al. 2019). Most actions require the cooperation of at least two agencies, which makes the deployment of actions more complex and time-consuming.

Table 6. Sample Mitigation Proposals for Laniakea Beach

	PROPOSAL	ADVANTAGES	DISADVANTAGES	RESPONSIBLE AGENCY
1	**Close the parking lot with barriers.**	(a) Tourists would stop parking at the parking opposite the beach and consequently stop crossing the highway. (b) Immediate implementation. (c) Can be used as a pilot project.	1) Parking will relocate to nearby places and some illegal crossings will continue to occur. 2) Prohibited parking for tourists is less desirable.	DLNR, HDOT, C&C
2	**Partially close the parking lot leaving an opening for entrance and exit of the cars. Also add a traffic signal to control walk and don't walk times.**	(a) Organizing a temporary parking lot withan one-way entrance and exit and limited space for parking maneuvers. (b) Temporary traffic signal would regulate the crossing of the pedestrians. (c) Capacity during peak visitation periods will improve from 300 vph to 1,000 vph per direction. (d) Proposal 1 (b) and (c).	1) Cost of installing a temporary semi-portable traffic signal 2) Cost of developing the currently unimproved parking lot.	DLNR, HDOT, C&C
3	**Close the beach as a "turtle sanctuary" and enforce this rule.**	(a) No tourism and parking. (b) No traffic congestion at this location.	(a) Surfers are against it. (b) Environmental study needed to prove this need. (c) Problematic transition period after closure and likely violations. (d) Some loss of tourism appeal; opposition from tourism industry.	DLNR
4	**Temporary, portable traffic signal.**	(a) Regulates pedestrian crossing time. (b) Improves the traffic flow. (c) Quick implementation.	(a) Cost of installing a semi-portable traffic signal. (b) Police presence may still be needed to discourage jay walking.	HDOT
5	**Realigned Kamehameha Hwy. with ocean side parking lot.**	(a) Organizes a parking lot on the ocean side. (b) Tourists wouldn't have to cross the highway. (c) Improved safety and traffic flow.	(a) Environmental impact; vehicles too close to shoreline. (b) Damage from high wave action. (c) Costly due to road realignment. (d) High risk "chicane" realignment at night at high speed. (e HDOT did not approve of this short realignment as too close to wave action.	DLNR, HDOT
6	**Enact parking fee.**	Fewer people parking and crossing.	(a) Need to purchase, install, maintain a machine that collects the parking fee. Plus enforcement. (b) Some may relocate to free parking openings nearby. (c) May not reduce jaywalking at peak hours.	C&C
7	**Pedestrian Crosswalk.**	(a) Pedestrians would cross at a specific location. (b) Traffic flow may be better due to less spread out jaywalking. (c) Proper sidewalk on both sides of the street will enhance experience and pedestrian safety; make beach more accessible to handicapped people.	(a) Install crosswalk and easements to it. (b) Not all pedestrians will comply without enforcement. (c) May not be acceptable to install a crosswalk without ADA compliance at both ends of it. (d) Costly to provide ADA compliant crosswalk and sidewalks on both sides of the street.	HDOT
8	**Cross under the nearby bridge.**	1) Relocation of pedestrian crossing. 2) The structure and passage are already there. 3) Eliminates interference with traffic flow.	1) Unpredictable and unsafe passage: The typically dry channel can flood from both ocean and land sides. 2) It increases walking distance; less desirable for accessing the beach. 3) Barriers are needed to channel people to the under-bridge crossing. 4) Bridge is susceptible to sand plugging and low clearance. The passage needs regular clearing.	DLNR, HDOT

CHAPTER 4. Discussion

This report presented the case of two very popular tourist attractions on the North Shore of the Island of Oahu in the State of Hawaii: Laniakea Beach and Shark's Cove. These locations are within a couple of miles of each other and are served solely by the 2-lane coastal rural Kamehameha Highway. The locations have been a congestion black spot for over a decade and local opposition to more development and tourism has been substantial. A team of students in civil engineering at the University of Hawaii at Manoa has been meeting with the local communities and has collected a few sample data to substantiate the extent of the problem. Several meetings and discussions were had where mitigation proposals have been presented and discussed. This study summarizes both the history of this problem, and the various data collected such as vehicle and pedestrian volumes, travel times and queue lengths. It also presented a list of proposed mitigations. There is a multitude of problems with most of the proposals including cost, appeal (they are not context-sensitive), difficulty with agency jurisdictional bounds, community acceptance and risk from waves and long-term sea level rise. Both the North Shore communities and tourists will benefit greatly from the quick action of the responsible agencies to lessen the current levels of traffic congestion and safety risk. Additional development at Shark's Cove should be delayed until (i) a regional study on Kamehameha Hwy. can be completed, and (ii) a plan to provide a reasonable and dependable level of service, are set in motion. Meanwhile, the Laniakea Beach location would benefit greatly from an improved and managed parking lot with fencing to discourage arbitrary crossings, along with a temporary, pedestrian- actuated traffic signal to provide for a safe crossing at a single cross section.

CHAPTER 5. Mobility in Honolulu

In the Oahu MPO study area, 70 percent of households are within one-quarter mile of a bus stop, and approximately two-thirds of residents drive alone to work. Additionally, the average commute time by public transportation takes approximately twice as long as the average commute time by car. Many residents state that public transportation services average between 30 minutes to an hour, and they need to make multiple transfers to reach a destination only a few miles from their household origins (OMPO 2021; Lyte 2018). Those who live in the rural and urban fringe areas of Oahu expressed that public transportation services, such as *TheBus* and *TheHandi-Van*, are limited compared to urban Honolulu. These issues are documented in the Mobility Report for the Oahu MPO area (OMPO, 2021). Within this mobility context, Honolulu households have witnessed several emerging mobility options for travelers. These range from *Biki* bikeshare in 2011, Lime e-scooters in 2018 and the opening of the *Honolulu Authority on Rapid Transportation Rail System (HART)*, set for 2023. In the future, autonomous vehicles are also expected to weave into the set of mobility options. Forecasting for regional scenarios characterized by these mobility options begins with understanding the potential shifts they bring to household travel-activity patterns, including the scheduling of out-of-home activities.

The overarching goal of this study is to understand how the introduction of AVs and the HART system to Oahu could potentially change household travel patterns. Through this study, we address the following broad questions:

A) *Which households will benefit from AVs, with respect to their travel patterns?* With respect to regional travel patterns, while the regional benefits from AVs have broadly envisioned and discussed, the impacts to households or other decision makers are less clear. This study begins to address the question of *who* potentially benefits, while recognizing that these impacts are contingent on future conditions which face varying uncertainties.

B) *How will the HART rail system affect AV impacts on households?* Parallel to the expectation of AVs is the opening of the HART rail system. This study also considers how to account for the impacts from the availability of the rail.

The remainder of this section presents background literature on the definitions and concepts related to autonomous vehicles and modeling their impacts on travel-activity behaviors. This is followed by sections on the presentation of the analysis framework and results.

CHAPTER 6. Autonomous Vehicles (AVs): Definitions and Concepts

Significant improvements in vehicle communication and sensor technologies have resulted in an increasing interest in estimating the potential benefits of autonomous vehicles (AVs) among transportation planners and policymakers (Anderson et al. 2014). The National Highway Traffic Safety Administration (NHSTA) proposed characterizing AVs on a scale from level 0 to 4, where level 0 refers to complete driver control and level 4 refers to vehicles that perform all safety-critical functions for the entire trip with no expected control from drivers (USDOT 2015). Less attention has been paid to how travelers will eventually use AV for completing activity programs, especially given a household fleet of other mobility resources. In comparison to other emerging vehicle technologies in the past, such as electric vehicles (EVs), AVs present a wider latitude of operational characteristics that differ from conventional vehicles.

6.1 Autonomous Vehicles (AVs): Modeling Travel/Activity Patterns

Investigating the behavioral implications of AV on household travel and activity patterns opens the door to a wide range of methodological directions under the umbrella of activity-based approaches to travel analysis. Under this approach, travel is a derived demand from the need to participate in activities, subject to space-time constraints. Recognizing that individual trips are components integrated into a more complex travel and activity pattern, an impressive body of research work has been produced that model and operationalize this perspective (Rindt and McNally, 2007; Timmermans and Zhang, 2009; Pinjari and Bhat, 2011). Within this literature, four main directions have emerged for modeling travel and activity patterns.

Constraint-Based: One direction witnessing considerably contribution from geographers, planners and engineers focuses on the space-time constraints of activities (Hägerstraand 1970). Using an activity program as input, these models consider the feasibility of a set of patterns with respect to a set of constraints, such as business hours for commercial or retail organizations. An activity program characterizes a set of activities and their associated durations and time windows. The number of feasible activity schedules, subject to these constraints, is often used as a measure of flexibility in space-time environments faced by travelers (Ettema and Timmermans, 2007, Lee et al. 2009). These space-time constraints are usually characterized by (a) potential activity locations; (b) travel mode and accessibility; and (c) network travel times and costs between locations per travel mode. Additionally, these constraints reflect (i) the sufficiency of time duration between the end time of the previous activity and start time of the next activity; (ii) the earliest possible start time and latest end time; and (iii) activity sequencing conditions.

Implemented constraint-based models have been produced since the inception of the activity-based approach, which include PESASP (Program Evaluating the Set of Alternative Sample Paths) (Lenntorp 1979) and CARLA (Combinatorial Algorithm for Rescheduling Lists of Activities) (Jones et al. 1983), and more recent ones including MASTIC (Model of Action Space in Time Intervals and Clusters) (Dijst and Vidakovic 1995) and GISICAS (Geographic Information System-based Integrated Computational Activity Scheduling) (Kwan 1997). An advantage of constraint-based models is the ability to determine a feasible set of potential activity patterns versus a single preferred path from a pre-defined set of alternatives. However, with respect to forecasting and prediction, these models currently cannot easily account for adjustment and/or rescheduling which are likely caused by changes in space-time constraints (Lee and McNally 2003, Roorda and Miller 2005, Joh et al. 2008).

Econometric: A second approach views activity patterns as the outcome of utility-maximizing decisions or choices, which serve as a theoretical foundation of econometric models of discrete choice. Given a choice set of activity patterns, each alternative is assumed to be adequately represented as bundles of attribute levels, each contributing to the overall utility of the alternative. The body of research work on discrete choice modeling and travel and activity patterns is vast and intellectually rich, examining a broad range of dimensions, from in-home vs. out-of-home (Akar et al. 2011), to choices among complete activity-travel patterns (Bowman and Ben-Akiva 2001) and rescheduling adjustments (Sun et al. 2005). These econometric approaches capture preferences for one single pattern over another with respect to combinations of attributes levels.

Simulation and Process – A third approach conceptualizes activity scheduling as a process that can be modeled and simulated through computational methods, such as agent-based modeling and other simulation approaches. As a basis for the decision models and their associated behavioral parameters, several of these models incorporate econometric discrete choice models of scheduling decisions (Recker et al. 1986; Kitamura Fujii 1998, Arentze and Timmermans 2009). Validating the decision rules used is a major hurdle for these models. These approaches explicitly recognize and embrace the complexity in modeling travelers' scheduling process, in contrast to oversimplifying through a trip-based model system. These decision process models represent one distinct promising direction for operational models, but, perhaps more importantly, they easily provide a testbed for alternative activity scheduling behavior conceptual frameworks.

Mathematical Programming or Vehicle Routing Problem (VRP) Approaches: A fourth approach considers household activity patterns as an outcome or solution to optimizing an objective function in the form of a generalized cost function with a set of space-time constraints. From this perspective, these models share the ability to consider feasible space-time activity patterns like constraint-based approaches and have the potential for capturing utility-maximizing decision rules like discrete choice models. Within the transportation analysis literature, one example is the Household Activity Pattern Problem (HAPP) formulation developed by Recker

(1995) in response to limitations in the STARCHILD model (Recker et al. 1986). The HAPP model is a variation of the "pick-up and delivery problem with time windows" (PDPTW) common in operations research. Households will "pick-up" activities at various locations, accessing these locations using household transportation resources and reflecting interpersonal and temporal constraints, and "deliver" these activities by completing a tour and returning home. HAPP is constructed as a mixed-integer mathematical program and explicitly reflects a full range of travel and activity constraints. Since its introduction, the HAPP model has been extended to account for rescheduling, stochastic activity completion (Gan and Recker, 2013) and locations (Kang and Recker 2013). A recent application also integrates HAPP with the network design problem (Kang et al. 2013). Additionally, HAPP has been applied to a wide range of contexts, such as traffic control for vehicle emissions (Recker and Parimi 1999) and refueling hydrogen fuel vehicles (Kang and Recker 2014). An important methodological issue is the estimation of parameters in the objective function in HAPP, which would interest many in the travel analysis community concerned with operationalizing HAPP with travel-activity data from conventional datasets. Two main approaches have surfaced in response to this need. The first uses similarity metrics to infer the relative importance of spatial and temporal factors associated with out-of-home activities. A more recent effort to calibrate HAPP with larger datasets approaches the problem as an inverse optimization problem, where the decision variables are the coefficients of the cost function, given an optimal path (Chow and Recker 2012). HAPP holds great potential for extensions, both as a pure activity-based framework and as a bridge to conventional discrete choice models of travel behavior.

6.2 Synthesis

Autonomous vehicles are considered in the range of emerging mobility options for metropolitan regions, such as Oahu. While their real-world adoption at the consumer level is beyond the near future, forecasting for long-range transportation planning scenarios will require considering their impacts on household travel patterns. Several methods exist in the literature for modeling these impacts. The next section describes the modeling approach taken in this study based on literature.

CHAPTER 7. Analysis and Modeling Framework

Forecasting regional travel-activity patterns requires a *crystal ball*, conventionally accomplished with methods such as computer simulations, data-driven econometric or machine learning approaches, synthesizing case studies, or a combination of the above. Developing forecasting tools that are sensitive and responsive to future contexts with new mobility options, begins with developing models that reflect travel pattern changes in response to difference contexts, such as adoption of AVs. This requires understanding these changes and their directions. The analysis and modeling framework for this study is summarized in Figure 4 below. The framework begins with the perspective of households as vehicle fleet dispatchers with out-of-home activities that need to be completed. Data on the scheduling constraints and transportation system performance levels (travel times, etc.) are assembled for each household's individual VRP.

In this framework, we view households as analogous to service systems such as delivery logistics providers (e.g. FedEx, UPS, USPS, etc.), rideshare TNCs (e.g. Uber, Lyft, etc.) and emergency response services (EMS, Municipal Fire Departments, etc.). *From this perspective, households have a set of out-of-home activities that need to be completed; they must decide how many household vehicles to dispatch, their routing and their scheduling of stops (timing and sequencing).* This decision problem is known in the literature as the *Vehicle Routing Problem (VRP)* and its variations. These include VRPs with (a) pick-up and deliveries; (b) time windows and schedule constraints; (c) others operational constraints of the decision context. Conventionally, these decisions are driven by the objective of optimizing along dimensions, such as travel time, travel cost and other performance metrics.

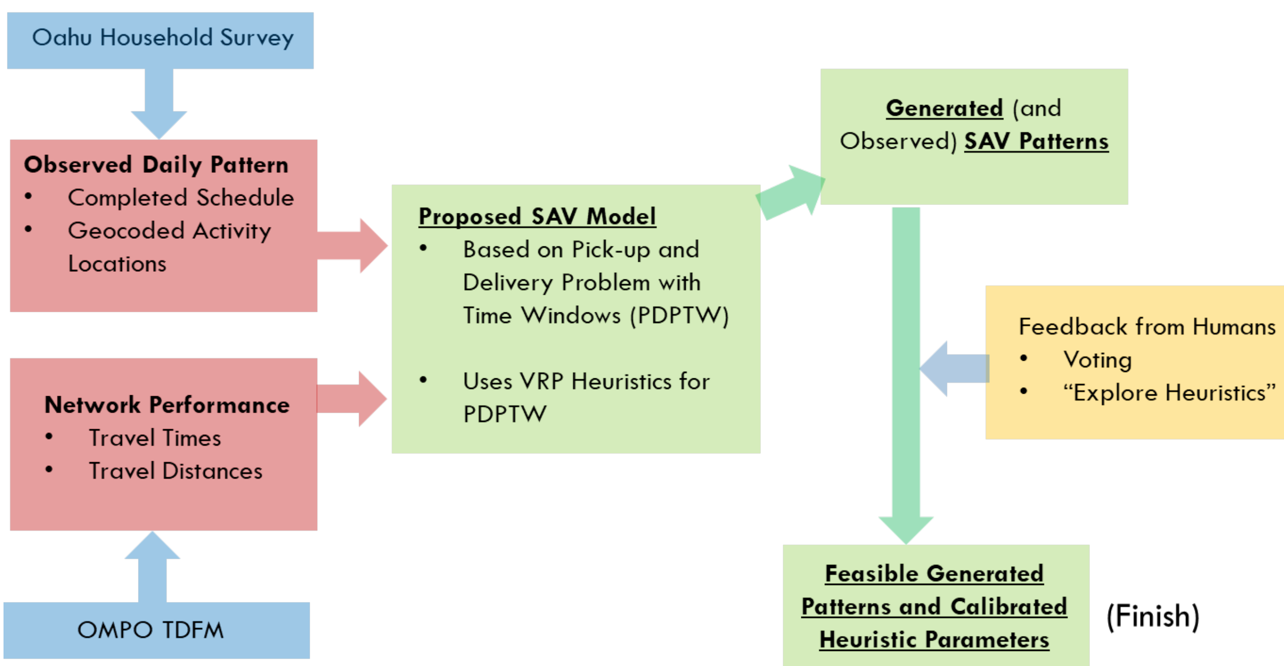

Figure 4: Study Modeling Approach and Framework

After the assembly of network performance and schedule constraint data from the 2012 Oahu Household Travel Survey and the OMPO Travel Demand Forecasting Model (TDFM), respectively, we solve each household's individual VRP. Specifically, we solve the VRP for the set of out-of-home activities in their daily observed pattern. We consider a decision context with "pick-up/delivery of activities" and the objective of minimizing travel time and idle time of the vehicle. AVs are assumed to be *Level 4*, with full autonomy and other operational characteristics derived from the literature. For example, these include AVs picking up groceries or completing other services without human intervention. This also includes the envisioned function as a taxi service dropping-off/picking-up human passengers with no parking (Cusack 2021).

7.1 Activity Scheduling Constraints

To operationalize the household VRP (described in the following section), schedule constraints faced by household activities requiring completion need to be defined. The literature provides little guidance on how to determine these schedule constraints. While there is a sizeable amount of literature on travel time and cost budgets faced by individual and households, operationalizing a household VRP also requires acceptable time windows for activity start times. For example, we may observe a household with a grocery shopping activity beginning at 4:35PM in the Oahu Household Survey. However, from a scheduling perspective, the time window may be as wide as the store hours or as narrow as a 30-minute time window, due to other constraints faced by the households. Without further study, knowing the scheduling constraints faced by specific households is difficult to determine. Regardless, we assume schedule constraints based on the type of activity to operationalize the household VRP. An example of the reasoning that underlies our assumptions are school and work activities, which are assumed to have a very narrow time window reflective of their mandatory nature. Once again, while these assumed schedule constraints will likely differ from real-world constraints faced by each individual traveler, to operationalize the modeling approach, they were necessary. The assumed schedule constraints on start times are presented below in Table 7.

Table 7. Assumed Activity Start Time Constraints

Activity Type	**Rule**
Mandatory with "hard" Start Times	Within 30 mins +/- of observed start time
Maintenance Shopping	Published Store Hours
Government Office Visits or Services	Published Service Hours
Social and Recreational	Within 60 mins +/- of observed start time
All Other Activities	5AM-10PM (feasible day)

Additionally, activity finish time constraints were also assumed, but with less restrictiveness than activity start times. Activity durations were taken from Oahu Survey Sample. For example, if households observed eating for 1.5 hours, then the eating activity was assumed to require 1.5

hours in duration in subsequent analysis. Given the set of out-of-home activities with their schedule constraints (activity start/finish time windows and durations), for our household sample, a VRP is solved for each household.

7.2 Household Vehicle Routing Problem (VRP)

The mathematical programming approach is adopted for its ability to account for sequencing and timing of activities and/or location visits relative to an objective function of generalized costs and space-time constraints. Additionally, this approach easily allows for the exploration of alternative scenarios characterized by varying constraints and objective function specifications. While several extensions have been made since the first introduction, to provide a foundation from which to make extensions to in-vehicle activities the original HAPP formulation (Recker 1995) was used as the starting point. To take advantage of previous work, a deliberate attempt was made to maintain, to every extent possible, both the notation and structure of the original HAPP model. While many AV operations could be considered, such as dropping off one passenger at one location then picking-up a second passenger at a second location, this study only examines extensions dealing with in-vehicle activities, which are impossible or very difficult for drivers of conventional vehicles for safety reasons.

Consider the activity program where a set of mandatory activities n and a set of IV activities can be completed in-vehicle in an autonomous vehicle or similar mobility service. An activity program characterizes a set of activities and their associated durations and time windows. The following notation is adopted:

$A = \{1,2, \dots , n, n + 1, \dots , n + IV\}$	Set of $n + IV$ out-of-home activities scheduled for completion by household travelers; a total of n mandatory activities can only occur out-of-vehicle; a total of IV activities can only occur in-vehicle (this is relaxed in a later extension);
$V = \{1,2, \dots , \vert V\vert\}$	Set of autonomous or conventional vehicles used by travelers in the household to complete their scheduled activities;
$P^+ = \{1, .., n\}$	Set designating the locations for mandatory activities that can only be completed at these locations;
$P^+_{IV} = \{n + 1, \dots , n + IV\}$	Set of in-vehicle activities that can *only* be completed in-vehicle;

$\bar{P}^{+} = P^{+} \cup P_{IV}^{+}$	Set of all activity pickups;
$P^{-} = \{n + IV + 1, n + IV + 2, \dots, 2n + IV\}$	Set designating the ultimate destinations of return-to-home trips for each pickup in P^{+};
$P_{IV}^{-} = \{2n + IV + 1, \dots, 2n + 2IV\}$	Set designating the ultimate locations for in-vehicle activities in P_{IV}^{+};
$\bar{P}^{-} = P^{-} \cup P_{IV}^{-}$	Set of all activity drop-offs;
$P = \bar{P}^{+} \cup \bar{P}^{-}$	Set of all pick-up and drop-off nodes;
$N = \{0, P, 2(n + IV) + 1\}$	Set of all nodes, including those associated with the initial and final departure from home;
$[a_i, b_i]$	The time window for the available start times for activity *i*;
s_i	The duration of activity *i*;
t_{uw}	The travel time from the location of activity *u* to activity *w*;
c_{uw}^{v}	The travel cost from location of activity *u* to *w* for vehicle *v*;
B_c	The household travel cost budget;
B_t^{v}	The household travel time budget for vehicle *v*;

This formulation implies that different elements of $\bar{P}^{+}$ can potentially correspond to the same physical location. All elements of $\bar{P}^{-}$ correspond to the same physical location (home).

Consequently, the travel time and costs between all drop-off nodes are assumed to be zero: $t_{u,w}^{v} = c_{u,w} \equiv 0 \;\; \forall \;\; u,w \in \bar{P}^{-}, \;\; v \in V$.

Consistent with the HAPP formulation (Recker 1995), activities are viewed as being 'picked up' for mathematical purposes by a particular household member at the location where they are performed. Once completed with a service duration s_i, these activities are 'dropped-off' or 'delivered' on the return trip home. Multiple pick-ups are analogous to multiple sojourns or sub-tours for any given tour.

Given a household's objective function, the routing and scheduling policy generated represents a space-time diagram conventional to the travel behavior analysis literature. Additionally, demand functions and vehicle capacity (D) ensure that the schedule of pickups and deliveries do not violate any vehicle capacity constraints. For this study, define the capacity D as the maximum number of activities serviced within a tour, with demand function: $d_u = 1, u \in \bar{P}^{+}$.

The decision variables in this formulation are directly analogous to those of the HAPP and PDPTW formulations and are defined as follows:

$X_{uw}^{u}, u, w \in N, v \in V, u \neq w$	Binary decision variable equal to one if vehicle *v* travels from activity u to w and zero otherwise;
$T_u, u \in P$	The time at which participation in activity *u* begins;
$T_0^{v}, T_{2(n+IV)+1}^{v}$	The time at which vehicle v first departs from home and last returns to home, respectively;
$Y_u, u \in P$	The total accumulation of demand or loads (activities) immediately following the completion of activity *u*;

A generalized cost or disutility function representing costs for households is minimized with respect to a set of constraints that capture the space-time constraints of activities that need to be performed. The formulation presented as follows:

$$\text{Minimize } Z = \text{Household Travel Disutility} \qquad (1)$$

Subject to:

$$\sum_{v \in V} \sum_{w \in N} X_{uw}^{v} = 1, u \in \bar{P}^{+} \quad (2)$$

$$\sum_{w \in N} X_{uw}^{v} - \sum_{w \in N} X_{wu}^{v} = 0, u \in P, v \in V \quad (3)$$

$$\sum_{w \in \bar{P}^{+}} X_{0,w}^{v} = 1, v \in V \quad (4)$$

$$\sum_{u \in \bar{P}^{-}} X_{u,2(n+IV)+1}^{v} = 1, v \in V \quad (5)$$

$$\sum_{w \in N} X_{uw}^{v} - \sum_{w \in N} X_{w,u+(n+IV)}^{v} = 0, u \in \bar{P}^{+}, v \in V \quad (6)$$

$$T_u + s_u + t_{u,(n+IV)+u} \leq T_{(n+IV)+u}, u \in P \quad (7)$$

$$X_{uw}^{v} = 1 \Rightarrow T_u + s_u + t_{uw} \leq T_w, u, w \in P, v \in V \quad (8)$$

$$X_{0,w}^{v} = 1 \Rightarrow T_0 + t_{0,w} \leq T_w, u, w \in P, v \in V \quad (9)$$

$$X_{u,2(n+IV)+1}^{v} = 1 \Rightarrow T_u + t_{u,2(n+IV)+1} \leq T_w, u, w \in P, v \in V \quad (10)$$

Constraints 2-10 are identical to those in the original HAPP formulation (*1*) with updated node sets to accommodate in-vehicle activities. Constraints 2-6 form a multi-commodity minimum cost flow problem. Constraint 7 forces node *u* (pick-up) to be visited before node $(n + IV) + u$ (drop-off). Constraints 8-10 describe the compatibility between routes and schedules.

7.3 Solving the Household VRP

Solving the Household VRP: Given this definition of the VRP faced by households, solving this class of problems is known to be NP-hard, indicating that the computational time to reach a solution increases infeasibly as the size of the problem increases. A set of VRP heuristics were used to feasibly solve the Household VRPs in the analysis sample. Heuristics used in this study include: (a) Clark-Wright Savings (CW) and (b) the Node Insertion family (N1, N2, N3) of heuristics (Solomon 1987). Each heuristic and their assumed set of parameter values result in solutions that favor different metrics, such as vehicle travel time and idle time. A comparison of these heuristics was completed. Table 8 provides a description of the heuristics used in this study. Table 9 provides the set of parameters used.

Table 8. VRP Heuristics Considered

Heuristic	Description
Clark-Wright Savings (CW)	Initialize with each activity in its own tour; Combine tours to give the largest savings in Cost (Distance or Travel Time)
Node Insertion 1 (N1)	Insert Nodes to Maximize Savings from Servicing each Activity Individually (**similar to C-W Savings**)
Node Insertion 2 (N2)	Insert Nodes to Minimize Total Route Distance and Time (Both)
Node Insertion 3 (N3)	Similar to Node Insertion 1; **Account for Schedule Urgency**

While other heuristics could also have been used, these two sets of heuristics were used due to their performance as documented in Solomon (1987). The results from previous studies indicate that Node Insertion 1 (N1) performed the best out of all the Node Insertion heuristics.

Table 9. VRP Heuristics Considered – Parameter Values Used

Heuristic Type ID	Heuristic Name	Parameter Values
11	Clark-Wright Savings (CW)	$\mu = 1.0$
12	Clark-Wright Savings (CW)	$\mu = 0.2$
1	Node Insertion 1 (N1)	$\mu = 1.0$; λ=1.0; $\alpha 1$=1.0; $\alpha 2$=0
2	Node Insertion 1 (N1)	$\mu = 1.0$; λ=2.0; $\alpha 1$=1.0; $\alpha 2$=0
3	Node Insertion 1 (N1)	$\mu = 1.0$; λ=1.0; $\alpha 1$=0; $\alpha 2$=1.0
4	Node Insertion 1 (N1)	$\mu = 1.0$; λ=2.0; $\alpha 1$=0; $\alpha 2$=1.0
5	Node Insertion 2 (N2)	$\mu = 1.0$; $\alpha 1$=0.5; $\alpha 2$=0.5; $\beta 1$=0.5; $\beta 2$=0.5
6	Node Insertion 2 (N2)	$\mu = 1.0$; $\alpha 1$=1.0; $\alpha 2$=0.0; $\beta 1$=0.5; $\beta 2$=0.5
7	Node Insertion 2 (N2)	$\mu = 1.0$; $\alpha 1$=0; $\alpha 2$=1.0; $\beta 1$=1.0; $\beta 2$=0
8	Node Insertion 3 (N3)	$\mu = 1.0$; $\alpha 1$=0.5; $\alpha 2$=0.5; $\alpha 3$=0
9	Node Insertion 3 (N3)	$\mu = 1.0$; $\alpha 1$=0.4; $\alpha 2$=0.4; $\alpha 3$=0.2
10	Node Insertion 3 (N3)	$\mu = 1.0$; $\alpha 1$=0; $\alpha 2$=1.0; $\alpha 3$=0

CHAPTER 8. Results and Discussion

This section presents the results of the analysis, including a discussion on implications. The next section describes the data preparation required, beginning with the 2012 Oahu Household Travel Survey to obtain the analysis sample.

8.1 Analysis Sample Preparation

This study is concerned with the impact of AVs on households. However, we address the adoption of AVs in only a limited manner. The analysis begins with the 2012 Oahu Household Travel Survey, which has 4,002 households. For this analysis we only consider households observed with vehicle-based travel patterns. Example patterns include households that carpool to work and those that drive to an express bus route and take the rest of the journey on express bus. The motivation is that households who regularly use vehicles are more likely to incorporate AVs into their household patterns when they become available. This resulted in 2,976 households being considered in our analysis of VRP Heuristics. A summary of these samples is provided below in Table 10.

Two alternative assumptions also considered on how to prepare the sample of households who would adopt and incorporate AVs in their travel-activity patterns would be (a) assuming all households will replace their current travel modes with AVs or (b) a proportion of households based on a decision mechanisms or stated-preference survey. Neither of these options were feasible given the scope of this project. Alternative (a) was infeasible because assuming all households will eventually use an AV in the future is extremely unlikely and unrealistic. Alternative (b), while appealing, would require more resources and effort to implement. Additionally, validating Alternative (b) would be extremely difficult. Therefore, the assumption that households observed to use vehicles in their observed patterns from the Oahu Survey was used.

8.1.1 HART System Scenarios

Given the interest in the HART rail system, a second analysis sample consisting of households that used vehicles in their observed patterns and used one of the express bus lines from *TheBus*, were assumed to be a target market segment for HART, when it opens. Assessing the ridership for HART is not an easy task; at the time of this study, HART was not open yet and there is no data on its ridership. If we require an additional level of assessment to also identify households likely to use HART, this further complicates the assessment. Therefore, analysis on the presence of the HART system and AVs was limited to considering households who used vehicles in their observed patterns and the express bus services; this was 56 households in total.

8.2 Comparison of Heuristics for the Household VRP

Given the household VRP defined by the schedule constraints derived from the Oahu Household Travel Survey and the network performance of the Oahu TDFM, heuristics were applied to solve the individual household VRPs. The results are summarized in Tables 11 to 13, which show relative differences with respect to the heuristics and their parameter value combinations. The following metrics were used to evaluate their performance:

A) *Number of Vehicles required to Complete the Activity Schedule (#vehicles)*: The number of vehicles required in the final solution from the heuristic; we hypothesize this would decrease relative to what households were observed to use in the survey;

B) *Total Travel Time of the Household Vehicle Fleet (mins):* The total travel time across all vehicles in the household fleet;

C) *Total Idle Time of the Household Vehicle Fleet (mins):* The total duration household vehicles were idle or "parked" during the day; and

D) *Total Duration Out-of-Home of the Household Vehicle Fleet (mins)*: The total duration vehicles spend away from the home location.

Looking at Table 11, the relative to the average performance for the heuristics were consistent with the relative performance of the heuristics reported in Solomon (1987). Overall, heuristic N1 was found to outperform N2 and N3 for Total Travel Time. However, for total vehicle idle time, N2 and N3 were relatively better.

To assess the potential improvements to households, the difference between the heuristic solutions and the observed travel-activity pattern was determined. These. A positive difference indicated the observed pattern had a metric value higher than the solution. For example, looking at Table 11, the first combination of parameters for Node 1 had a difference of 78 minutes, indicating on average household AV patterns had a little more than one hour savings relative to the observed travel-activity pattern. Looking at Table 12, Node Insertion Heuristic 1 (N1) and the Clarke-Wright Savings Heuristics (CW) saw positive improvements (lower travel times) on average for the total travel time of the household fleet. Node Insertion Heuristic 2 (N2) and 3 (N3) saw travel time increases, on average. All heuristics saw decreases in the number of vehicles each household required in their fleets, except for the CW heuristic. There was marginal difference between households who took the express bus and under the HART scenarios.

8.3 Assessing the Potential Impact of Autonomous Vehicles for Households

To assess the potential impacts of AVs, a regression model between the relative change in the performance metrics (A-D) from the previous section for N1 and household characteristics was estimated, including the planning district location of their residence. *Only heuristic N1 was further examined since it produced solutions with better total travel times and was comparable for total idle time.* The mean relative change in performance metrics between the status quo and our AV scenarios were shown in Tables 13 and 14 with respect to *total travel time* and *number of vehicles*. The status quo responses are assumed to be the observed travel patterns from the 2012 Oahu Household Travel Survey. Outcomes from AV scenarios were the final solutions from each heuristic.

Looking at Tables 14 to 17, with respect to AVs, households in Wai'anae and East Honolulu potentially stand to benefit in terms of travel time savings from the non-AV context (observed travel patterns), controlling for other household characteristics. Relative to other planning districts, the average marginal improvement from households in these two planning districts have the following ranges, depending on district: Wai'anae – 13.7 to 15.2 minutes; East Honolulu – 6.7 to 9.6 minutes. These two planning districts showed consistent marginal benefits from using AVs to complete their observed set of activities. Estimation results also showed that the Ewa district had a total travel time improvement of 11.9 minutes per household under an AV context, and the Ko'olau Loa district showed an increase of 21.4 minutes, but for one set of heuristic parameters. With respect to the number of vehicles required, under the AV scenario, all heuristic solutions produced a reduction, except for solutions from the Clark-Wright Savings (CW) heuristic. One explanation is that CW heuristic does not optimize fleet size. With respect to household characteristics, household size and number of workers consistently explained these differences, statistically.

For scenarios where the HART system was introduced, the change in impacts from AVs was marginal and statistically insignificant. However, this was under the conservative assumption that only the 56 households observed using both a vehicle and an express bus route on TheBus system would try to incorporate HART for at least a portion of their travel chain segment in combination with an AV. To fully understand the impact of the HART station, future ridership levels, including household demographics, would need to be determined.

Table 10. Analysis of Sample Characteristics

Variable	2012 Oahu Household Travel Survey (N = 4002 Households)							Analysis Sample (N = 2976 Households)						
	Mean	**Median**	**Std.Dev.**	**Min**	**25%**	**75%**	**Max**	**Mean**	**Median**	**Std.Dev.**	**Min**	**25%**	**75%**	**Max**
Household Size	2.2	2	1.2	1	1	3	10	2.4	2	1.3	1	2	3	10
Number of Employed Members	1.2	1	0.93	0	1	2	6	1.4	1	0.9	0	1	2	6
Number of Student Members	0.42	0	0.82	0	0	1	6	0.51	0	0.88	0	0	1	6
Number of Members with Driver's License	1.7	2	0.87	0	1	2	7	1.9	2	0.79	0	1	2	7
Number of Operating Vehicles	1.8	2	0.85	0	1	2	8	1.9	2	0.85	0	1	2	8
Number of Out-of-Home Activities Requiring AV	---	---	---	---	---	---	---	7.6	6	5.8	1	4	10	57
	Proportion of Sample (%)							**Proportion of Sample (%)**						
1= Less than $10,000	3.1%							1.3%						
2= $10,000 to $19,999	4.5%							1.9%						
3= $20,000 to $29,999	7.5%							4.9%						
4= $30,000 to $39,999	9.3%							7.7%						
5= $40,000 to $49,999	9.5%							9.5%						
6= $50,000 to $59,999	8.9%							9.3%						
7= $60,000 to $74,999	9.1%							9.7%						
8= $75,000 to $99,999	19.0%							22.0%						
9= $100,000 to $149,999	16.0%							20.0%						
10= $150,000 or more	7.9%							9.8%						
	Proportion of Sample (%): 2012 Oahu Survey							**Proportion of Sample (%): Analysis Sample**						
(1) Central Oahu	19.0%							21.0%						
(2) East Honolulu	6.8%							7.7%						
(3) Ewa	7.2%							7.7%						
(4) Ko'olau Loa	1.2%							1.2%						
(5) Ko'olau Poko	13.0%							14.0%						
(6) North Shore	1.7%							1.7%						
(7) PUC	47.0%							44.0%						
(8) Wai'anae	3.2%							3.0%						
TOTAL	**99%**							**100%**						

Table 11. Performance Metrics Across Heuristics – Analysis Sample

		NVEH	TT (min)	WT (min)	DOH (min)
Node Insertion 1	μ = 1.0; λ=1.0; α1=1.0; α2=0	1.2	78	507	584
Node Insertion 1	μ = 1.0; λ=2.0; α1=1.0; α2=0	1.2	70	512	582
Node Insertion 1	μ = 1.0; λ=1.0; α1=0; α2=1.0	1.1	75	504	579
Node Insertion 1	μ = 1.0; λ=2.0; α1=0; α2=1.0	1.1	74	504	578
Node Insertion 2	μ = 1.0; α1=0.5; α2=0.5; β1=0.5; β2=0.5	1.3	136	470	606
Node Insertion 2	μ = 1.0; α1=1.0; α2=0.0; β1=0.5; β2=0.5	1.3	136	470	606
Node Insertion 2	μ = 1.0; α1=0; α2=1.0; β1=1.0; β2=0	1.3	145	466	611
Node Insertion 3	μ = 1.0; α1=0.5; α2=0.5; α3=0	1.3	146	475	620
Node Insertion 3	μ = 1.0; α1=0.4; α2=0.4; α3=0.2	1.3	144	468	612
Node Insertion 3	μ = 1.0; α1=0; α2=1.0; α3=0	1.2	116	489	605
Clark-Wright Savings	μ = 1.0	1.9	64	817	881
Clark-Wright Savings	μ = 0.2	1.8	68	722	789

Table 12. Impact of AVs on the Average Total Household Vehicle Fleet Travel Time across Scenarios

Heuristic	Parameters	S0	S0 (EXP)	S1 (EXP)
Node Insertion 1	μ = 1.0; λ=1.0; α1=1.0; α2=0	0.74	7.7	6.4
Node Insertion 1	μ = 1.0; λ=2.0; α1=1.0; α2=0	9	17	15
Node Insertion 1	μ = 1.0; λ=1.0; α1=0; α2=1.0	4	7.2	5.7
Node Insertion 1	μ = 1.0; λ=2.0; α1=0; α2=1.0	4.6	7.7	6.3
Node Insertion 2	μ = 1.0; α1=0.5; α2=0.5; β1=0.5; β2=0.5	-57	-49	-51
Node Insertion 2	μ = 1.0; α1=1.0; α2=0.0; β1=0.5; β2=0.5	-57	-49	-51
Node Insertion 2	μ = 1.0; α1=0; α2=1.0; β1=1.0; β2=0	-66	-57	-59
Node Insertion 3	μ = 1.0; α1=0.5; α2=0.5; α3=0	-67	-61	-63
Node Insertion 3	μ = 1.0; α1=0.4; α2=0.4; α3=0.2	-65	-56	-59
Node Insertion 3	μ = 1.0; α1=0; α2=1.0; α3=0	-38	-25	-28
Clark-Wright Savings	μ = 1.0	21	30	27
Clark-Wright Savings	μ = 0.2	17	22	21
Sample Size (N)		**2976**	**56**	**56**

Table 13. Impact of AVs on the Average Number of Vehicles Required for Households Across Scenarios

Heuristic	Parameters	S0	S0	S1
Node Insertion 1	μ = 1.0; λ=1.0; α1=1.0; α2=0	0.28	0.45	0.45
Node Insertion 1	μ = 1.0; λ=2.0; α1=1.0; α2=0	0.29	0.38	0.38
Node Insertion 1	μ = 1.0; λ=1.0; α1=0; α2=1.0	0.34	0.51	0.51
Node Insertion 1	μ = 1.0; λ=2.0; α1=0; α2=1.0	0.34	0.49	0.49
Node Insertion 2	μ = 1.0; α1=0.5; α2=0.5; β1=0.5; β2=0.5	0.21	0.42	0.42
Node Insertion 2	μ = 1.0; α1=1.0; α2=0.0; β1=0.5; β2=0.5	0.21	0.42	0.42
Node Insertion 2	μ = 1.0; α1=0; α2=1.0; β1=1.0; β2=0	0.19	0.42	0.42
Node Insertion 3	μ = 1.0; α1=0.5; α2=0.5; α3=0	0.17	0.38	0.38
Node Insertion 3	μ = 1.0; α1=0.4; α2=0.4; α3=0.2	0.18	0.38	0.38
Node Insertion 3	μ = 1.0; α1=0; α2=1.0; α3=0	0.22	0.45	0.45
Clark-Wright Savings	μ = 1.0	-0.41	-0.32	-0.34
Clark-Wright Savings	μ = 0.2	-0.32	-0.3	-0.3
Sample Size (N)		**2976**	**56**	**56**

Table 14. Linear Regression of Marginal Impacts on HH Vehicle Fleet Travel Times – Type 1

Variable	**Coefficient**	**Std. Error**	**t-statistic**	**Coefficient**	**Std. Error**	**t-statistic**	**Coefficient**	**Std. Error**	**t-statistic**
Constant	7.203	3.635	1.981	6.622	3.764	1.760	4.247	2.311	1.838
HH Size	11.942	1.150	10.384	11.602	1.151	10.079	11.728	1.141	10.275
HH Students	-3.487	1.288	-2.708	-3.122	1.292	-2.416	-3.148	1.278	-2.463
HH Workers	-6.412	1.150	-5.577	-6.160	1.151	-5.354	-6.044	1.132	-5.341
HH Licensed Drivers	-5.281	1.634	-3.232	-5.187	1.634	-3.174	-5.270	1.624	-3.245
Duration at Current Home (yrs)	-0.163	0.058	-2.800	-0.147	0.060	-2.461	-0.177	0.054	-3.297
Operational Vehicles	-4.283	1.290	-3.319	-4.436	1.293	-3.430	-4.351	1.256	-3.465
Rent (1/0)	3.683	2.434	1.513	3.913	2.451	1.597	---	---	---
Single-Family Attached Unit (1/0)	-1.691	2.940	-0.575	-1.532	2.939	-0.521	---	---	---
Multi-Family Dwelling (1/0)	-2.878	2.443	-1.178	-2.425	2.533	-0.957	---	---	---
HH Income: Less than $10,000	-2.190	7.337	-0.298	-1.313	7.331	-0.179	---	---	---
HH Income: $10,000 to $19,999	-4.199	6.353	-0.661	-4.403	6.369	-0.691	---	---	---
HH Income: $20,000 to $29,999	3.390	4.331	0.783	3.278	4.358	0.752	---	---	---
HH Income: $30,000 to $39,999	-3.871	3.949	-0.980	-3.635	3.966	-0.917	---	---	---
HH Income: $40,000 to $49,999	-4.231	3.579	-1.182	-4.469	3.603	-1.240	---	---	---
HH Income: $50,000 to $59,999	-2.170	3.532	-0.614	-1.835	3.543	-0.518	---	---	---
HH Income: $60,000 to $74,999	-1.746	3.453	-0.506	-1.593	3.458	-0.461	---	---	---
HH Income: $75,000 to $99,999	-2.560	3.023	-0.847	-2.224	3.044	-0.731	---	---	---
HH Income: $100,000 to $149,999	-6.505	2.722	-2.390	-6.378	2.730	-2.336	-5.229	2.103	-2.487
HH Income: $150,000 or more	---	---	---	---	---	---	---	---	---
Central Oahu (1/0)	---	---	---	-3.377	2.478	-1.363	---	---	---
East Honolulu (1/0)	---	---	---	8.201	3.219	2.548	9.621	3.008	3.199
Ewa (1/0)	---	---	---	5.319	3.313	1.606	---	---	---
Ko'olau Loa (1/0)	---	---	---	-8.145	7.548	-1.079	---	---	---
Ko'olau Poko (1/0)	---	---	---	-3.674	2.815	-1.305	---	---	---
North Shore (1/0)	---	---	---	-9.772	7.856	-1.244	---	---	---
Primary Urban Center (1/0)	---	---	---	---	---	---	---	---	---
Wai'anae (1/0)	---	---	---	12.726	4.453	2.858	13.749	4.286	3.208
N		2976			2976			2976	
R^2		0.07523			0.08415			0.07873	
SSE		6355906			6294542			6331812	

Table 41. Linear Regression of Marginal Impacts on HH Vehicle Fleet Travel Times – Type 2

Variable	Coefficient	Std. Error	t-statistic	Coefficient	Std. Error	t-statistic	Coefficient	Std. Error	t-statistic
Constant	15.346	3.496	4.389	12.849	3.616	3.554	4.474	2.210	2.025
HH Size	10.331	1.106	9.340	10.029	1.106	9.069	9.760	0.729	13.392
HH Students	-0.732	1.239	-0.591	-0.458	1.242	-0.369	---	---	---
HH Workers	-5.299	1.106	-4.792	-5.055	1.105	-4.573	-4.731	1.078	-4.389
HH Licensed Drivers	-3.060	1.571	-1.947	-3.193	1.570	-2.034	-2.806	1.501	-1.870
Duration at Current Home (yrs)	-0.199	0.056	-3.545	-0.148	0.057	-2.590	-0.150	0.051	-2.944
Operational Vehicles	-4.112	1.241	-3.313	-4.380	1.243	-3.525	-3.375	1.205	-2.801
Rent (1/0)	0.668	2.341	0.285	1.739	2.354	0.739	---	---	---
Single-Family Attached Unit (1/0)	-1.213	2.828	-0.429	-1.046	2.823	-0.371	---	---	---
Multi-Family Dwelling (1/0)	-6.315	2.350	-2.687	-4.179	2.433	-1.718	---	---	---
HH Income: Less than $10,000	-7.062	7.057	-1.001	-7.337	7.043	-1.042	---	---	---
HH Income: $10,000 to $19,999	-8.977	6.110	-1.469	-10.928	6.119	-1.786	---	---	---
HH Income: $20,000 to $29,999	-2.484	4.165	-0.596	-3.987	4.187	-0.952	---	---	---
HH Income: $30,000 to $39,999	-8.587	3.798	-2.261	-9.444	3.810	-2.479	---	---	---
HH Income: $40,000 to $49,999	-7.654	3.442	-2.223	-9.166	3.462	-2.648	---	---	---
HH Income: $50,000 to $59,999	-4.495	3.397	-1.323	-5.262	3.404	-1.546	---	---	---
HH Income: $60,000 to $74,999	-5.216	3.321	-1.571	-5.848	3.322	-1.760	---	---	---
HH Income: $75,000 to $99,999	-3.072	2.908	-1.057	-3.905	2.924	-1.335	---	---	---
HH Income: $100,000 to $149,999	-5.466	2.618	-2.088	-6.189	2.623	-2.360	---	---	---
HH Income: $150,000 or more	---	---	---	---	---	---	---	---	---
Central Oahu (1/0)	---	---	---	2.561	2.380	1.076	---	---	---
East Honolulu (1/0)	---	---	---	7.960	3.092	2.574	8.715	2.900	3.005
Ewa (1/0)	---	---	---	12.393	3.182	3.894	11.925	2.966	4.021
Ko'olau Loa (1/0)	---	---	---	-11.637	7.252	-1.605	---	---	---
Ko'olau Poko (1/0)	---	---	---	-0.243	2.704	-0.090	---	---	---
North Shore (1/0)	---	---	---	4.352	7.548	0.577	---	---	---
Primary Urban Center (1/0)	---	---	---	---	---	---	---	---	---
Wai'anae (1/0)	---	---	---	15.909	4.278	3.719	15.154	4.122	3.677
N		2976			2976			2976	
R^2		0.08166			0.08415			0.08602	
SSE		5879397			5809308			5851441	

Table 67. Linear Regression of Marginal Impacts on HH Vehicle Fleet Travel Times – Type 3

Variable	Coefficient	Std. Error	t-statistic	Coefficient	Std. Error	t-statistic	Coefficient	Std. Error	t-statistic
Constant	15.946	3.585	4.447	15.336	3.711	4.132	9.317	2.316	4.024
HH Size	10.274	1.134	9.059	9.997	1.135	8.808	9.448	0.757	12.476
HH Students	-1.594	1.270	-1.255	-1.004	1.274	-0.788	---	---	---
HH Workers	-6.669	1.134	-5.881	-6.466	1.135	-5.699	-5.949	1.114	-5.338
HH Licensed Drivers	-4.249	1.611	-2.637	-4.245	1.611	-2.635	-3.972	1.544	-2.573
Duration at Current Home (yrs)	-0.238	0.058	-4.138	-0.211	0.059	-3.593	-0.229	0.052	-4.397
Operational Vehicles	-3.767	1.273	-2.960	-4.119	1.275	-3.230	-3.614	1.240	-2.915
Rent (1/0)	1.715	2.401	0.714	2.090	2.416	0.865	---	---	---
Single-Family Attached Unit (1/0)	-0.377	2.900	-0.130	-0.107	2.898	-0.037	---	---	---
Multi-Family Dwelling (1/0)	-2.389	2.410	-0.991	-1.643	2.497	-0.658	---	---	---
HH Income: Less than $10,000	-10.784	7.237	-1.490	-10.872	7.229	-1.504	---	---	---
HH Income: $10,000 to $19,999	-10.433	6.266	-1.665	-11.702	6.280	-1.863	---	---	---
HH Income: $20,000 to $29,999	-0.998	4.271	-0.234	-2.022	4.297	-0.471	---	---	---
HH Income: $30,000 to $39,999	-9.644	3.895	-2.476	-10.124	3.911	-2.589	---	---	---
HH Income: $40,000 to $49,999	-11.063	3.530	-3.134	-11.702	3.553	-3.294	-6.443	2.917	-2.209
HH Income: $50,000 to $59,999	-5.897	3.484	-1.693	-6.109	3.494	-1.749	---	---	---
HH Income: $60,000 to $74,999	-5.997	3.405	-1.761	-6.047	3.410	-1.774	---	---	---
HH Income: $75,000 to $99,999	-5.111	2.982	-1.714	-4.967	3.002	-1.655	---	---	---
HH Income: $100,000 to $149,999	-8.137	2.685	-3.031	-8.022	2.692	-2.980	-4.021	2.095	-1.919
HH Income: $150,000 or more	---	---	---	---	---	---	---	---	---
Central Oahu (1/0)	---	---	---	-0.124	2.443	-0.051	---	---	---
East Honolulu (1/0)	---	---	---	6.561	3.174	2.067	7.941	2.967	2.676
Ewa (1/0)	---	---	---	3.828	3.266	1.172	---	---	---
Ko'olau Loa (1/0)	---	---	---	-21.174	7.443	-2.845	-21.378	7.315	-2.923
Ko'olau Poko (1/0)	---	---	---	-3.845	2.775	-1.386	---	---	---
North Shore (1/0)	---	---	---	0.698	7.747	0.090	---	---	---
Primary Urban Center (1/0)	---	---	---	---	---	---	---	---	---
Wai'anae (1/0)	---	---	---	14.566	4.391	3.317	14.351	4.227	3.395
N		2976			2976.000			2976.000	
R^2		0.0746			0.084			0.079	
SSE		6182307			6120031			6154044	

Table 87. Linear Regression of Marginal Impacts on HH Vehicle Fleet Travel Times – Type 4

Variable	Coefficient	Std. Error	t-statistic	Coefficient	Std. Error	t-statistic	Coefficient	Std. Error	t-statistic
Constant	13.567	3.563	3.808	12.712	3.690	3.445	7.002	2.312	3.029
HH Size	10.493	1.127	9.310	10.143	1.129	8.988	9.799	0.745	13.146
HH Students	-0.630	1.262	-0.499	-0.242	1.267	-0.191	---	---	---
HH Workers	-6.552	1.127	-5.813	-6.401	1.128	-5.674	-6.106	1.107	-5.518
HH Licensed Drivers	-4.096	1.602	-2.557	-4.028	1.602	-2.514	-3.835	1.533	-2.501
Duration at Current Home (yrs)	-0.178	0.057	-3.114	-0.145	0.058	-2.484	-0.170	0.052	-3.272
Operational Vehicles	-3.913	1.265	-3.094	-4.111	1.268	-3.242	-3.247	1.227	-2.646
Rent (1/0)	1.218	2.386	0.510	1.828	2.403	0.761	---	---	---
Single-Family Attached Unit (1/0)	0.594	2.882	0.206	0.705	2.881	0.245	---	---	---
Multi-Family Dwelling (1/0)	-2.079	2.395	-0.868	-1.128	2.483	-0.454	---	---	---
HH Income: Less than $10,000	-10.761	7.192	-1.496	-10.883	7.188	-1.514	---	---	---
HH Income: $10,000 to $19,999	-10.468	6.227	-1.681	-12.021	6.244	-1.925	---	---	---
HH Income: $20,000 to $29,999	-0.916	4.245	-0.216	-2.185	4.273	-0.511	---	---	---
HH Income: $30,000 to $39,999	-8.955	3.871	-2.313	-9.622	3.888	-2.475	---	---	---
HH Income: $40,000 to $49,999	-9.759	3.508	-2.782	-10.859	3.533	-3.074	-5.918	2.905	-2.037
HH Income: $50,000 to $59,999	-4.921	3.462	-1.421	-5.433	3.474	-1.564	---	---	---
HH Income: $60,000 to $74,999	-6.249	3.384	-1.847	-6.515	3.390	-1.922	---	---	---
HH Income: $75,000 to $99,999	-4.733	2.963	-1.597	-5.083	2.985	-1.703	---	---	---
HH Income: $100,000 to $149,999	-7.937	2.668	-2.975	-8.125	2.677	-3.036	-4.057	2.082	-1.948
HH Income: $150,000 or more	---	---	---	---	---	---	---	---	---
Central Oahu (1/0)	---	---	---	0.265	2.429	0.109	---	---	---
East Honolulu (1/0)	---	---	---	5.588	3.156	1.770	6.667	3.017	2.210
Ewa (1/0)	---	---	---	6.818	3.248	2.099	---	---	---
Ko'olau Loa (1/0)	---	---	---	-11.553	7.401	-1.561	---	---	---
Ko'olau Poko (1/0)	---	---	---	-4.374	2.759	-1.585	---	---	---
North Shore (1/0)	---	---	---	2.827	7.703	0.367	---	---	---
Primary Urban Center (1/0)	---	---	---	---	---	---	---	---	---
Wai'anae (1/0)	---	---	---	15.032	4.366	3.443	14.579	4.205	3.467
N	2976			2976			2976		
R^2	0.07973			0.080			0.08114		
SSE	6106452			6050434			6097093		

CHAPTER 9. Conclusions

This study investigates the potential impacts of AVs on household vehicle fleet usage. The motivation is that households which potentially see an improvement in their experience performance metrics, such as total travel time across household vehicles and total number of vehicles needed to complete a set of activities, are more likely to use AVs in the future. While the results did indicate a certain market segment of households potentially see benefits from AVs, the assumption behind these estimates requires further investigation. These segments include East (Hawaii Kai), Central (Mililani/Waipio) and Ewa areas of Oahu. Interestingly, these are areas with significant economic activity but segmented from the urban core. The impact of the HART system was minimal, but the market segment potentially affected was a conservative estimate in this study. The rail was not open at the time of this study and data on ridership was unavailable. However, given a more robust estimate for the potential market of HART, the estimates for AV and HART scenarios could be revisited.

Future work includes incorporating the results into the existing Oahu TDFM. This study provided a method to generate potential household AV patterns. Given that the Oahu TDFM relies on the synthetic generation of a population and its travel-activity patterns, integrating the two would not present a serious issue, in principle.

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