Evaluation of Delivery Service in Rural Areas with CAV

FINAL PROJECT REPORT

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16. Abstract

Urban areas have been experiencing automated delivery technology for several servings of food or a few bags of groceries, with automated (robotic) mini vehicles. The benefits of such automated delivery may be much more significant for rural areas with long distances due to the large potential savings in travel time, travel cost, and crash risk. Compared to urban areas, rural areas have older and more disabled residents, longer distances, higher traffic fatality rates, and high ownership of less fuel-efficient vehicles such as pickup trucks. An evaluation of connected autonomous vehicle (CAV) delivery service in rural areas was conducted. A detailed methodology was developed and applied to two case studies: One for deliveries between Hilo and Volcano Village in Hawaii as a case of deliveries over a moderate distance (~50-mile roundtrip) in a high-energy-cost environment, and another for deliveries between Spokane and Sprague in Washington State as a case of deliveries over a longer distance (~80-mile roundtrip) in a low-energy-cost environment. The delivery vehicles were based on the same compact van: A person-driven gasoline-powered van, a person-driven electric-powered van, and a CAV electric-powered van. The case study results suggest that the CAV van can be a viable option for implementing a delivery business for rural areas based on the evaluation results that accounted for a large number of location-specific costs and benefits and the number of orders served per trip.

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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

Urban areas have been experiencing automated delivery technology for several servings of food or a few bags of groceries, with automated (robotic) mini vehicles. The benefits of such automated delivery may be much more significant for rural areas with long distances due to the large potential savings in travel time, travel cost, and crash risk. Compared to urban areas, rural areas have older and more disabled residents, longer distances, higher traffic fatality rates, and high ownership of less fuel-efficient vehicles such as pickup trucks. An evaluation of connected autonomous vehicle (CAV) delivery service in rural areas was conducted. A detailed methodology was developed and applied to two case studies: One for deliveries between Hilo and Volcano Village in Hawaii as a case of deliveries over a moderate distance (~50-mile roundtrip) in a high-energy-cost environment, and another for deliveries between Spokane and Sprague in Washington State as a case of deliveries over a longer distance (~80-mile roundtrip) in a low-energy-cost environment. The delivery vehicles were based on the same compact van: A person-driven gasoline-powered van, a person-driven electric-powered van, and a CAV electric-powered van. The case study results suggest that the CAV van can be a viable option for implementing a delivery business for rural areas based on the evaluation results that accounted for a large number of location-specific costs and benefits and the number of orders served per trip.

Rural deliveries by CAV will reduce the number of the elderly on rural roads making it safer and reliable for them to access food and supplies from stores. While 100% substitution of trips for groceries and household goods by deliveries is unlikely, because the households likely chain several trip purposes for their (long) trips to the city, lower substitution rates are possible and all of them confer benefits.

Additional potential benefits include lower pollution and lower crash risk on rural roads. Human factors cause approximately 94% of crashes and an additional 2% of crashes are due to issues with the vehicle. About 96% of crashes can be attributed to the responsibility of the driver or the vehicle. This represents a very high potential for crash reduction by Level 4 and 5 CAV which operate within the limits of the law and have the ability to reduce at-fault crashes substantially.

There are positive implications of the COVID-19 pandemic (and similar future threats) in the development and deployment of CAVs. The combination of distancing requirements at crowded stores along with the substantial sensitivity to the disease by the elderly and those with a variety of health conditions provide additional impetus for contactless delivery of goods. This bodes well for urban delivery with mini CAVs and rural delivery with Level 4 and 5 van CAVs.

CHAPTER 1. INTRODUCTION

Since the 2007 DARPA driverless competitions, vigorous research and development have resulted in the advancement of connected and automated vehicles (CAV) to the point of using CAV technology on public roads. While most CAV development is focused on urban passenger transportation and freight truck convoying, other CAV initiatives aim to automate the delivery of personal items such as mail and packages, food orders, and household goods and supplies. A significant expected payoff of these efforts is a crash reduction based on the ability of CAV to obey the law and their inability to get distracted.

Motor vehicle fatalities are one of the five leading causes of death in the U.S. and the leading cause of death among people aged 1 to 44 years [1]. Rural areas have a higher rate of motor vehicle fatalities than urban areas [1]. In 2019, 15,565 fatal motor vehicle traffic crashed resulted in 16,340 fatalities in rural areas [2]. Rural areas accounted for 45% of the country's traffic fatalities in 2019, but only 19% of the population [2]. Based on the Fatality Analysis Reporting System (FARS), human error caused approximately 90% of those crashes in rural areas [3]. Major driver errors include speeding and alcohol-impaired driving. In 2019, approximately 30% of pedestrians died in rural areas [2]. Also, 30% of the total vehicle miles traveled (VMT) in 2019 were in rural areas [2].

The National Highway Traffic Safety Administration (NHTSA) reported that in 2019, the fatality rate per 100 million VMT was two times higher in rural areas than in urban areas (1.66 and 0.86, respectively) [2]. Furthermore, the median population age in rural areas is 44, whereas in urban areas it is 37. About 18.4% of residents in rural areas are 65 or older, compared to 14.5% in urban areas, and 15% of the population in rural areas has some form of recorded disability compared with 12% in urban areas [4]. All these suggest that the mobility challenges in rural areas, where public transportation is also practically nonexistent, are far greater than in urban areas. CAV deliveries could mitigate some of the transportation challenges of older and disabled rural residents.

Rural households tend to drive longer distances per trip, which leads to high VMT and longer driving times. Rural residents commonly drive larger, less fuel-efficient vehicles such as full-size pickup trucks. These increase gas costs and carbon dioxide emissions [5, 6]. Some deliveries to rural areas done in fuel efficient CAVs could meet rural residents' needs and reduce transportation costs for residents, emissions to the environment, and crashes on rural roads.

The objective of this research was to investigate delivery services in rural areas with CAVs in order to establish whether such services given the related costs of today's technology can be offered at a total cost that could be attractive for enacting such services. The costs were estimated from a business stand point, such as a big box retailer initiating a CAV delivery service from an urban center to rural areas, or an independent delivery business collecting items from various stores and delivering them to urban areas. Using this perspective, potential reductions in pollution and road crashes were not included in the analysis because these are social benefits, not provider monetary benefits. These benefits can be included in the future, once such savings have actually materialized. The social benefits can be monetized in various ways that would affect the provider's costs, e.g., as reduction in vehicle registration and other fees, as government subsidy for each rural delivery, etc.

Our investigation on CAV rural delivery agrees with the current shift in CAV priorities, as reported in the World Economic Forum [7]. "The market is shifting from robo-taxis to automated trucks and delivery vehicles: Increasingly, companies have begun to pivot their development and resourcing efforts towards delivery vehicles and automated trucks amid difficulties in commercializing Mobility as a Service (MaaS).

The vision of go-anywhere robo-taxis has proved to be more challenging than expected, caused by market demand and technological hurdles."

This introduction is followed by a literature review which covers characteristics of rural areas, driving costs, delivery costs, relevant features of CAVs, and existing delivery services using CAV. It is followed by the methodology which presents the elements for comprehensive feasibility analysis. The cost analysis was applied to two substantially different rural delivery areas, in Hawaii and Washington State, to obtain estimates, present comparisons and develop conclusions.

CHAPTER 2. LITERATURE

2.1. Characteristics of Rural Areas in the US

According to the U.S. Census Bureau, “rural" refers to a territory, housing, or population outside urban areas. The Census Bureau refers to urbanized areas as those containing 50,000 or more people, and urban clusters with population between 2,500 and 50,000 people. Other than population, rural and urban areas differ significantly in terms of population density, demographics, economic activities, climate, and topography [8].

Data from the National Household Travel Survey (NHTS), the Federal Highway Administration (FHWA), and American Housing Survey (AHS) show there are variations in transportation and travel behavior between rural and urban areas [5]. Two large differences are that rural counties have a low percentage (4.2%) of households without vehicles, and only 0.4% trips are made by public transportation. Rural households tend to make fewer trips than urban households. Urban households make more trips over short distances, whereas rural households drive more miles than their urban counterparts. In rural areas, more than 20% of the trips are for shopping, including grocery shopping. Most of those trips (90.3%) are made by personal vehicles [5].

Whereas accessing a grocery store in an urban setting is an easy task regardless of the time of the day as some grocery stores operate for 24 hours a day, accessing a grocery store in rural areas is a time consuming, expensive, and often inconvenient task [9,10]. The ease of accessing goods and groceries in a rural setting is further dependent on the household's financial status, the number of people residing in the household, and their age [10]. In rural areas, some households have resorted to producing their own food; however, this is both labor and time-intensive, especially for people without a farming background or the required expertise and resources. Access of goods and groceries in rural areas is more dependent on transportation, making it more difficult for the elderly and people with disabilities to access grocery and supplies from big box stores conveniently [11].

2.2. Transportation Availability

Approximately 95% of rural households in the U.S. had access to a vehicle, whereas 89% of urban households access to a vehicle. The disparity between the two can be attributed to the lack of reliable public transportation in rural areas compared to urban areas. However, a significant proportion of rural counties still register at least double the average rate of no auto availability compared to urban counties. The Economic Research Service reports that more than 1.6 million households in rural America, especially in Alaska, Appalachia, the Southwest, and in the South, do not have cars due to persistent poverty and high concentration of low-income earners. People in high poverty areas tend to rely on scarce public transportation service [6, 12].

2.3. Driving Cost

In 2017, the total expenditure for personal vehicles was $1.1 trillion, including purchasing, operating, and maintaining the cars; the purchasing of new and used vehicles amounted to $425.4 billion [13]. In rural areas, households buy big and relatively less fuel-efficient vehicles to help them navigate the country gravel roads during all seasons [14]. Owning a private vehicle comes with fixed and variable costs, which except for parking and registration, tend to be higher in rural areas than in urban areas; these include financing, depreciation, fuel costs, insurance, licenses and taxes, and maintenance.

Private vehicles depreciate with both rate of usage and passage of time. According to the National Automobile Dealers Association (NADA) Official Used Car Guide [15], a car with 5,000 fewer miles than the standard is worth $200 more during resale. Vehicles in rural areas are more likely to depreciate faster due to longer distances that cause higher mileage. Another reason that causes vehicles in rural areas to depreciate faster is the poor condition of roads. According to a TRIP report [16], rural America struggles with road and bridge deficiency, inadequate connectivity and capacity, and high crash rates because of dilapidated roads.

Finance is proportional to the loan costs for the acquisition of a car or truck. The borrower pays the lender interest and possibly a fee over a specific number of months in exchange for the loan. The interest rate that the bank applies to the purchaser represents the finance costs of purchase. According to *Experian*, the average auto loan interest rate in the last quarter of 2019 was 5.76% for a new vehicle and 9.49% for a used vehicle [17, 18].

Fuel is the cost of the energy used to operate the vehicle, including fossil fuels and electricity [19]. In the case of fossil fuels, the average U.S. regular gasoline price was $2.506/gal, as of January 27, 2020 [20]. On January 29, 2020, Hawaii had the highest gas price, at $3.658/gal, and Missouri had the lowest cost at $2.148/gal [21]. In November 2019, the national average cost of electricity was 13.04 cents per Kilowatt-hour (KWh). In November 2019, Hawaii had the highest price, at 30.99 cents per KWh, and Washington State had the lowest average cost at 9.54 cents per KWh [22].

State legislation typically requires a private vehicle owner to purchase annual insurance coverage for potential crashes and a host of other losses. The average cost of minimum coverage car insurance is $78 per month or $937 per year. For full coverage, the average is $200 per month or $2,390 per year. Insurance companies consider several factors, such as State, population density, vehicle type, age, gender, crime in the area, and the situation of local roads. Rural areas are at an advantage when population density and crime are considered, as these are more intense in urban areas; however, rural areas may pay higher premiums due to poorly maintained roads, longer commutes, and poorer weather conditions than urban areas [23, 24].

License, registration, and taxes are costs that depend on local governmental rates and taxes for cars, trucks, and drivers. Those fees are paid typically on an annual frequency or at the pump [25].

Vehicle owners in rural America spend more on maintenance than their counterparts in suburban and urban areas [26]. More rural residents have trained themselves to repair their cars; “many men were excellent auto repairmen, and there was hardly a man in the community who could not perform an impressive range of auto repair and maintenance activities” [26]. The distance to a suitable repair shop and the charge for towing in a rural area are disproportionally large. According to Liberty Mutual, the average American household spends approximately 1.5% of its annual income, about $817, on car repairs and maintenance [27].

2.4. Delivery Cost in Rural Areas

Delivery in rural areas is the most inefficient portion for all businesses in the logistics and delivery industry because customers tend to be far apart from the store, depot or warehouse. In some cases, carriers charge customers who live in rural areas more due to the extra fuel and travel time required for deliveries. Costly deliveries are an additional impediment to the access of goods for rural communities considering that as of 2017, the rural poverty rate was 16.4% compared with 12.9% for urban areas [12, 28].

2.5. Connected and Autonomous Vehicles

Connected and Autonomous Vehicles are driverless cars or vehicles that use public roadways and do not rely on human drivers for any of the routing and driving decisions and actions [29]. The National Conference of State Legislatures defines a self-driving vehicle as a "vehicle capable of navigating roadways and interpreting traffic control devices without a driver operating any of the vehicle's control systems" [30]. CAVs require the combination of other technologies, such as Global Positioning System, electric drive, fast computer processing, artificial intelligence, and a variety of sensors. CAVs also use communication technology to communicate with nearby vehicles and the roadside infrastructure as well as communication links to a supervisory center and data storage depositories [31].

The Society of Automotive Engineers (SAE) has classified all road-going vehicles into six levels of CAV capability, as follows [32]:

- Level 0 (No automation): Corresponds to a vehicle where the human driver performs all driving tasks.
- Level 1 (Driver Assistance): a driver controls the vehicle with a few driving assistance features. The vehicle contains at least one driver-assistance feature, such as lane-keeping technology or intelligent cruise control. (Currently many inexpensive vehicles have several advanced driver assistance systems, ADAS.)
- Level 2 (Partial Automation): The vehicle contains automated functions; however, the human driver must be engaged throughout the drive and monitor the environment. The vehicle automatically steers, brakes, and accelerates while the human driver stays as a backup. (Currently, the majority of light duty vehicles on sale, with automation systems, fall in this level.)
- Level 3 (Conditional Automation): A human driver is not required to monitor the environment as the automated system executes all driving tasks. The CAVs has a human driver who should be ready to take back control of the vehicle immediately. (Currently, there are several light duty vehicles on sale, with optional automation systems, that fall in this level.)
- Level 4 (High Automation): CAVs perform all driving functions without a human driver's intervention. However, the vehicle could be limited to a certain speed and geographical areas. (Currently at testing stage; no vehicles for sale.)
- Level 5 (Full Automation): CAVs can drive on any road and through all environmental conditions without human intervention. (Currently no CAVs in development claim this status.)

2.6. Existing Delivery Service with CAV Technology

Logistics and deliveries were among the first industries to benefit from CAVs, partly because the liability and risk in transporting goods are lower than transporting people. Autonomous mobility stands to play a crucial role in the transformation of these transportation-intensive industries [33]. While the use of CAVs to transport people is still under development, there are already numerous applications of CAVs in logistics and deliveries. Companies such as Airbus, WAYMO, Volvo, and Volkswagen have deployed models of autonomous vehicles ranging from pods to trucks (as well as aerial drones of various sizes) in the delivery of food, medicine, packages, and goods [34].

In Houston, San Francisco, Pittsburgh, Michigan, and Phoenix, companies have demonstrated deliveries with CAVs [35]. The Coronavirus pandemic in 2020 increased the use of CAVs to deliver goods as people avoided physical contact [36]. A sample of existing CAV delivery companies and their locations is given below:

- (China) 5G delivery vehicle was unveiled at an intelligent transport forum in Beijing.
- (China) Neolix is a CAV delivery service in Beijing.
- (USA) Nuro has partnered with Fry’s Food, Domino’s Pizza, Kroger, and Walmart to launch a delivery service.
- (USA) Udelv has partnered with Draeger's Market, and Walmart.
- (USA) Ford and Waymo have partnered with Walmart.
- (UK) Kar-go unveiled mini-CAV at the Goodwood Festival of Speed, hosted in the south of England; it is Europe’s first CAV delivery service.

CAVs deliveries are yet to be deployed in rural areas. CAVs are sensitive to environmental conditions and complex geography, making rural areas a challenging environment for their deployment. Other challenges impeding the deployment of CAVs include government regulations, reliability of CAV software and hardware, roadside and telecom infrastructure, public trust, and impacts on labor.

CHAPTER 3. METHODOLOGY

The research process started with a literature review on the topics of rural area definition, comprehensive vehicle costs, rural delivery service, and current characteristics of CAVs.. The next major portion was the development of case studies including location selection, vehicle selection, comprehensive vehicle costs by vehicle type and characteristics of deliveries including value of time and other benefits from trip avoidance. The investigation concluded with a break-even analysis based on the cost of various scenarios. The overall methodology is illustrated in Figure 3.1.

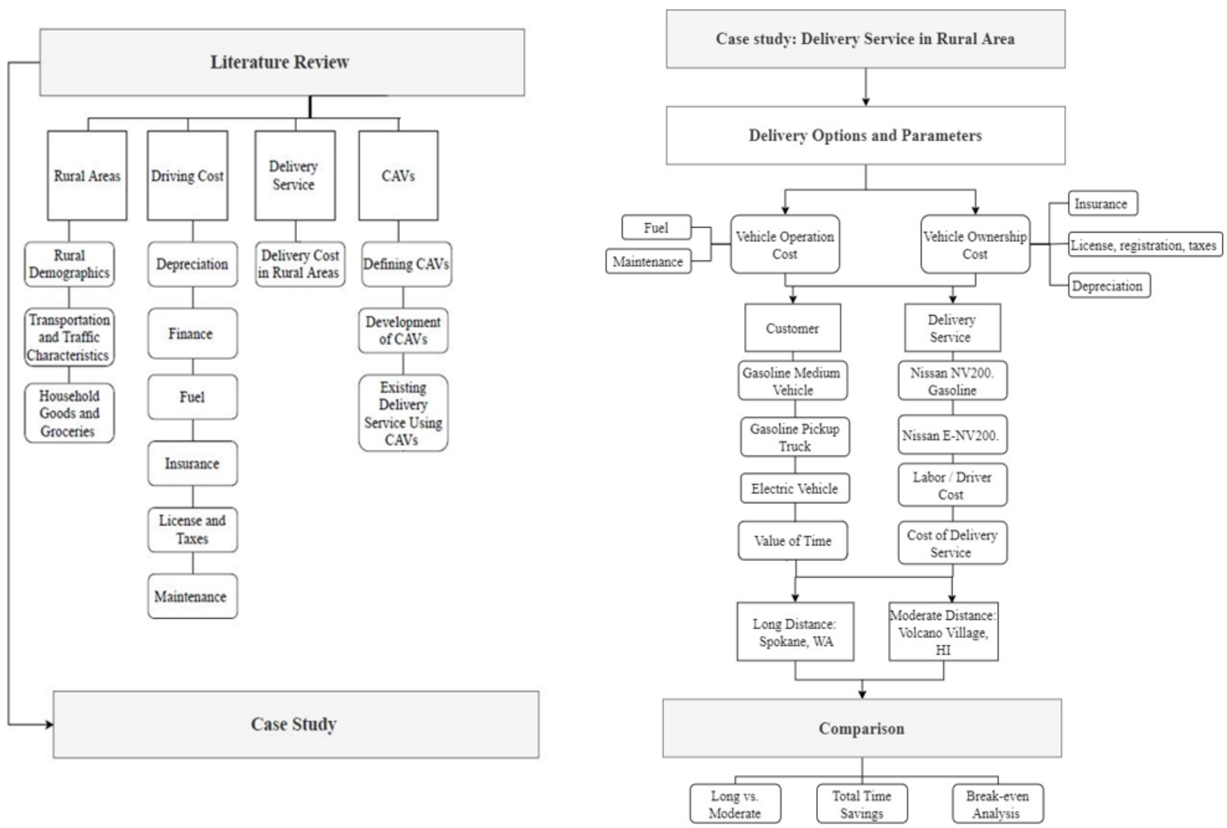


Figure 3.1 Methodology Diagram

Two rural areas with substantially different distances and costs were selected: Sprague in Washington State was selected as a long-distance area (~ 80 miles roundtrip from the nearest urban area of Spokane, population ~217,000 in 2019) with moderate gasoline cost, and low electricity cost; and, Volcano Village in Hawaii was selected as a moderate distance area (~ 50 miles roundtrip from the nearest urban area of Hilo, population ~45,000 in 2019) with high costs for both gasoline and electricity.

The case study included a detailed analysis of vehicle operating costs and vehicle ownership costs obtained for both customer and delivery service providers. The customer is a rural household that goes to the nearest city to buy groceries and household goods. The delivery service provider is a courier service where an independent company or branch of major retailer/grocer delivers groceries and household goods to customers.

The customer side of cost estimates accounts for the cost avoided by having a delivery made to their home. The delivery side of cost estimates accounts for the cost of making the delivery to a number of rural households. The number of households needed to break even is a decision variable that reveals whether rural deliveries make sense (i.e., will lead to a profit) for a given rural market.

The vehicle ownership and operating costs are detailed in the case studies in Chapter 4. The case studies also include a fringe rate or benefit rate for the delivery drivers; it is the rate of an employee's benefits multiplied by the total payroll and added to base salary. The base salary per hour for a delivery driver is $20.36 and $46.09 for a Field Autonomy Engineer (FAE) who supervises the CAV delivery vehicles [37]. After including the fringe rate of pension accumulation, pension administration, retiree health insurance, employees' health insurance, workers' compensation, unemployment compensation, social security, and Medicare, the total hourly rate for a delivery driver becomes $32.39 and $73.32 for the FAE [38].

Two types of vehicles were selected: customer and delivery vehicles. Customer vehicles that rural residents use to get their groceries, and delivery service vehicles which deliver groceries to rural households.

For the customers, three types of popular vehicles, 2015 models, were used to form the basis of their costs. We opted to use popular six-year-old household vehicles as a more realistic basis of transportation costs as opposed to using late model vehicles. The average age of the light duty vehicles in the U.S. was about 12 years in 2020 and we used the half point as a representative age of vehicles in this analysis. All three were chosen as the most popular (highest sales) in their class: sedan (2015 Toyota Camry LE), pickup truck (2015 Ford F-150 XLT) and EV (2015 Nissan Leaf S.)

For the delivery service providers, all vehicles were based on the 2020 model compact van NV200 made by Nissan: driver driven NV200 running on gasoline, driver driven e-NV200 running on electricity, and Level 4 or 5 CAV e-NV200 running on electricity.

The data for the chosen vehicles as applicable to the Hawaii and Washington locations we studied were analyzed to compare the total time saved, total operating costs, ownership costs, and break-even points. Operational data were used to compare the time and cost implications for long and moderate distances, e.g., one vehicle can make many deliveries in a day over moderate distances, but fewer deliveries over long distances.

3.1. Assumptions

Given that none of the "full size" delivery service analyzed herein exist, a number of important assumptions were made, as follows:

1- The value of time a customer spends getting goods came from their discretionary time multiplied by their median household income. Discretionary time was determined by subtracting the number of work hours, sleep hours, and eat/travel/other mandatory hours per year, as a total of 2,912 hours annually. The value of time varies by household.

2- Vehicle ownership cost was based on 15,000 miles driven annually for customers driving themselves to the stores, and 32,500 miles driven annually for delivery service providers.

3- The delivery fee was based on the Uber Eats method, which includes pickup fees of $2.5, drop-off fees of $3, and a per-mile rate [39]. The per-mile rate was set at $0.58 based on the IRS mileage method [40]. The basic distance chosen was 26 miles (it is the average distance of the two case studies examined) and was multiplied by the per-mile rate to have a delivery charge for both areas at $20.58.

4- A rural household drives to the grocery store once per week, for a total of 52 trips per year; this was varied as part of the analysis.

5- The annual savings were based on four options for getting groceries and households supplies as listed below:
    - 0% delivery-order option, 100% driving option (current situation).
    - 25% delivery-order option, 75% driving option.
    - 50% delivery-order option, 50% driving option.
    - 100% delivery-order option, 0% driving option.

6- The delivery vehicles were purchased at a 3% interest over 60 months and a compounding period of 12 months, as shown in Table 3.1.

7- A CAV delivery fleet consists of five vehicles, which are controlled by one FAE. The FAE's base salary was divided by five to yield the base salary per vehicle per hour of $12.22.

8- Autonomous driving technology has a significant cost component, making CAVs much more expensive than regular vehicles. The average costs for autonomous driving hardware, including LIDAR (LIght Detection And Ranging) sensors, cameras, a processing unit, and V2X equipment, are around $37,000 [40]. The Transport Systems Catapult study estimates the autonomy package costs at $7,454 for the year 2025. The study mentioned above also expects a learning rate of 90–95% for autonomy packages based on the observed economies of scale, which would cause costs to drop down to a range between $3,467 and $6,067 by the year 2035 [41]. Bansal and Kockelman [42] estimated a cost of $25,360 for a Level 4 autonomy package assuming an annual price reduction rate of 5%. Based on [42], the CAV add-on cost was set at $25,360.

Table 3.1 Delivery Van Cost to Own

Parameter	**Nissan NV200**	**Nissan e-NV200**	**Nissan e-NV200 (CAV)**
Purchase price [43,44]	$24,512	$27,802	$27,802
CAV cost	0	0	$25,360
Loan amount	$24,512	$27,802	$50,302
Interest rate	3%	3%	3%
Periods (months)	60	60	60
Compounding periods/year	12	12	12
Monthly payment	**$440.45**	**$499.57**	**$903.56**

CHAPTER 4. CASE STUDIES AND COST ANALYSIS

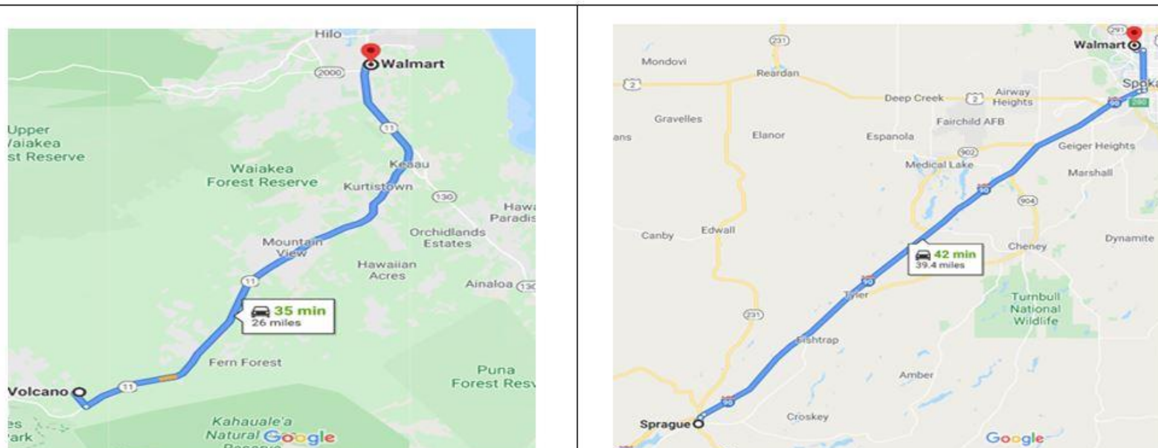
4.1. Selected Locations

This analysis was conducted with support from the Center for Safety Equity in Transportation (CSET), a Tier-1 UTC, which has four partners including the University of Alaska Fairbanks (UAF), the University of Hawaii at Manoa (UHM), the University of Idaho (UI) and the University of Washington (UW). Two locations from several candidate locations in these four partner states were selected for developing detailed case study costs, with three main parameters: Comparable average incomes, a reasonable distance between the rural area and an urban hub with big box stores (given the current range and charging limitations of EVs), and energy costs.

Sprague, WA, was selected as a long-distance, moderate gasoline cost, and low electricity cost location. Sprague is a rural village in Washington State with a population of approximately 452 people in the 2010 census, 128 families, and 197 households [45]; 15.2% of all households had someone aged 65 years or older living alone. Sprague's population density is 707.9 people per square mile [45]. The median household income in Sprague is $30,833 [45]. In March 2020, the price of gasoline per gallon was $2.70, and the electricity cost was $0.09 per KWh [46, 47]. The corresponding hub city is Spokane, WA.

Volcano Village, HI, was selected as a moderate distance and high gasoline and electricity cost location. Volcano village is a census-designated place in Hawaii County on the Big Island (Hawaii County) in Hawaii. The population of Volcano village was 2,575 in 2019 [48]. Volcano Village has 1,340 total housing units with a median household income of $30,639 [48]. In March 2020, the price of gasoline per gallon was $3.24, and the electricity cost was $0.32 per KWh [49, 32]. The corresponding hub city is Hilo, HI.

The basic routes are depicted in Figure XXX. While one sample route is displayed and analyzed, in reality there may be several routes for rural delivery centered at a big box store, i.e., hub and spokes. The analysis includes three different estimations. First is the customer cost for getting the groceries using their existing vehicle. Second is cost saving if they have a portion of all of their groceries delivered. Both of these are covered in Section 4.2. Third is the costs of the provider to provide deliveries, in Section 4.3. The last section presents a break-even analysis for the delivery provider in Section 4.4.



(a) Distance from Volcano to the Shopping Center of Hilo (b) Distance from Sprague to the Shopping Center of Spokane

Figure 4.1 Sample rural delivery routes in Hawaii and Washington State

4.2. Analysis of Customer Cost

Table shows the value of the discretionary time of customers. Regional incomes may produce substantially different results, but in our analysis, both rural communities have, by design, comparable incomes so the main difference is caused by travel time.

Table 4.1 Value of Time a Customer Spends

Parameter	Unit	Value	
		WA	HI
Time spent inside the store	Hour	0.72	0.72
Time spent on round-trip	Hour	1.28	1.12
Median household income	$/year	30,833	30,639
Discretionary income	$/year	10,278	10,213
Discretionary income	$/hour	3.53	3.51
Value of time per trip	**$**	**7.06**	**6.45**

The operating costs for the three representative customer vehicles are shown in Table 4.2. Fuel consumption and mileage, as well as the expected average maintenance and repairs, were analyzed to arrive at a value that reflects the total operating cost per mile. Table 4.2 shows that the 2015 Ford F-150 has the highest operating cost per mile of $0.268 for Sprague, WA and $0.300 for Volcano village, HI. The 2015 Nissan Leaf S has the lowest operating cost per mile.

Table 4.2 Rural Customer Vehicle Operating and Ownership Costs

Parameter	**2015 Camry** [50]		**2015 F-150** [51]		**2015 Leaf** [52]	
	WA	HI	WA	HI	WA	HI
Operating Cost						
Fuel	0.096	0.116	0.135	0.162	0.028	0.095
Maintenance	0.061	0.063	0.093	0.095	0.058	0.046
Repairs	0.030	0.032	0.040	0.043	0.042	0.032
Total cost per mile, $	**0.187**	**0.211**	**0.268**	**0.300**	**0.128**	**0.173**
Ownership Cost						
Insurance	2.189	2.900	2.367	3.061	2.324	2.932
Taxes and Fees	0.799	0.628	1.450	0.966	0.539	0.497
Depreciation	4.419	4.580	8.048	8.313	3.363	3.828
Total cost per day, $	**7.407**	**8.108**	**11.865**	**12.340**	**6.497**	**7.257**

Table 4.2 also presents the ownership costs associated with each of these vehicles. Ownership costs such as insurance, taxes, fees, and depreciation value have been factored into the operation of these

vehicles on a per-day basis. The 2015 Ford F-150 has the highest depreciation, while the 2015 Nissan Leaf S depreciated the least.

Table 4.1 summarizes the cost per mile for using the three representative customer vehicles. The average round trip distance for a customer in Sprague, WA who went to shop in Spokane, WA is 79 miles. The average round trip distance for a customer in Volcano village, HI who went to shop in Hilo, HI is 52 miles. The distances are multiplied by the operating cost per mile that incorporates the fuel consumption, maintenance, and repairs for each of the three vehicles. Finally, the total operating cost is added to the ownership cost and discretionary time value to arrive at the total cost per trip to a grocery store in Washington and Hawaii. The results show that the 2015 F-150 has the highest cost per trip at $40.13 and $34.41 in Washington and Hawaii, respectively. The 2015 Leaf has the least operating cost per trip to the grocery store at $23.72 and $22.73, respectively.

Table 4.1 Total Cost Per Mile

Parameter	2015 Camry		2015 F-150		2015 Leaf	
	WA	HI	WA	HI	WA	HI
Round-trip distance to store (mi)	79	52	79	52	79	52
Operating cost, $	14.75	10.97	21.20	15.62	10.16	9.02
Ownership cost, $	7.41	8.11	11.87	12.34	6.50	7.26
Value of Time, $	7.06	6.45	7.06	6.45	7.06	6.45
Total cost per mile, $	**29.22**	**25.53**	**40.13**	**34.41**	**23.72**	**22.73**

Table compares the annual savings of the customer vehicles for four different options of getting their groceries in Washington and Hawaii. These four options vary the percentages of delivery-order options with corresponding percentages for driving options to estimate customer total savings per year. The first option is the current situation with a 0% delivery option and a 100% (52 times a year) diving. No delivery service fee was recorded for these services and no savings were realized. The second option compares each customer vehicle savings with a 25% (13 times a year) delivery and 75% (39 times a year) driving. For this option, the highest amount of savings at $254 was estimated for a household using a 2015 F-150 pickup truck in Washington; the corresponding estimate for Hawaii is $180. The modest sedan (Camry) and the EV (Leaf) had much lower savings, but they are less typical choices for rural households.

Table continues with the 50%, 75% and 100% delivery option; the latter yields the highest potential savings. Avoiding 100% of the usage of a 2015 F-150 pickup truck for grocery and household supplies produced a savings of $1,016 in Washington and $719 in Hawaii. The savings are also substantial if the household uses a 2015 Camry for these trips, but the savings dwindle to under $200 for the Leaf.

Table 4.4 Annual Savings of the Four Options for Getting Groceries

Parameter	2015 Camry		2015 F-150		2015 Leaf	
	WA	HI	WA	HI	WA	HI
0% delivery-order option, 100% driving option (current situation)						
Total cost	1,519	1,328	2,086	1,789	1,233	1,182
Cost of driving option	(1,519)	(1,328)	(2,086)	(1,789)	(1,233)	(1,182)
Delivery service fee	-	-	-	-	-	-
Total annual savings, $	**-**	**-**	**-**	**-**	**-**	**-**
25% delivery-order option, 75% driving option						
Total cost	1,519	1,328	2,086	1,789	1,233	1,182
Cost of driving option	(1,139)	(996)	(1,565)	(1,342)	(925)	(886)
Delivery service fee	(268)	(268)	(268)	(268)	(268)	(268)
Total annual savings, $	**112**	**64**	**254**	**180**	**41**	**28**
50% delivery-order option, 50% driving option						
Total cost	1,519	1,328	2,086	1,789	1,233	1,182
Cost of driving option	(760)	(664)	(1,043)	(895)	(617)	(591)
Delivery service fee	(535)	(535)	(535)	(535)	(535)	(535)
Total annual savings, $	**224**	**129**	**508**	**360**	**81**	**56**
100% delivery-order option, 0% driving option						
Total cost	1,519	1,328	2,086	1,789	1,233	1,182
Cost of driving option	-	-	-	-	-	-
Delivery service fee	(1070)	(1070)	(1070)	(1070)	(1070)	(1070)
Total annual savings, $	**449**	**258**	**1,016**	**719**	**163**	**112**

4.3. Analysis of Delivery Service Provider Costs

Table shows the value of the discretionary time of customers. Regional incomes may produce substantially different results, but in our analysis, both rural communities have, by design, comparable incomes so the main difference is caused by travel time.

Table 4.5 Value of Trip Time

Parameter	Unit	Value	
		WA	HI
Time spent inside the store	Hour	0.72	0.72
Time spent on round-trip	Hour	1.28	1.12
Median household income	$/year	30,833	30,639
Discretionary income	$/year	10,278	10,213
Discretionary income	$/hour	3.53	3.51
Value of time per trip	**$**	**7.06**	**6.45**

The operating costs for the three representative customer vehicles are shown in Table 6. Fuel consumption and mileage, as well as the expected average maintenance and repairs, were analyzed to arrive at a value that reflects the total operating cost per mile. Table 6 shows that the 2015 Ford F-150 has the highest operating cost per mile of $0.268 for Sprague, WA and $0.300 for Volcano village, HI. The 2015 Nissan Leaf S has the lowest operating cost per mile.

Table 6 also presents the ownership costs associated with each of these vehicles. Ownership costs such as insurance, taxes, fees, and depreciation value have been factored into the operation of these vehicles on a per-day basis. The 2015 Ford F-150 has the highest depreciation, while the 2015 Nissan Leaf S depreciated the least.

Table 4.6 Rural Customer Vehicle Operating and Ownership Costs

Parameter	**2015 Camry** [50]		**2015 F-150** [51]		**2015 Leaf** [52]	
	WA	HI	WA	HI	WA	HI
Operating Cost						
Fuel	0.096	0.116	0.135	0.162	0.028	0.095
Maintenance	0.061	0.063	0.093	0.095	0.058	0.046
Repairs	0.030	0.032	0.040	0.043	0.042	0.032
Total cost per mile, $	**0.187**	**0.211**	**0.268**	**0.300**	**0.128**	**0.173**
Ownership Cost						
Insurance	2.189	2.900	2.367	3.061	2.324	2.932
Taxes and Fees	0.799	0.628	1.450	0.966	0.539	0.497
Depreciation	4.419	4.580	8.048	8.313	3.363	3.828
Total cost per day, $	**7.407**	**8.108**	**11.865**	**12.340**	**6.497**	**7.257**

Table 7 summarizes the cost per mile for using the three representative customer vehicles. The average round trip distance for a customer in Sprague, WA who went to shop in Spokane, WA is 79 miles. The average round trip distance for a customer in Volcano village, HI who went to shop in Hilo, HI is 52 miles. The distances are multiplied by the operating cost per mile that incorporates fuel consumption, maintenance, and repairs of each vehicle. Finally, the total operating cost is added to the ownership cost and discretionary time value (in dollars) to arrive at the total cost per trip to a grocery store in Washington and Hawaii. The results show that the 2015 F-150 has the highest cost per trip at $40.13 and $34.41 in Washington and Hawaii, respectively, while the 2015 Leaf had the least operating cost per trip to the grocery store at $23.72 and $22.73 respectively.

Table 4.7 Total Cost Per Mile

Parameter	2015 Camry		2015 F-150		2015 Leaf	
	WA	HI	WA	HI	WA	HI
Round-trip distance to store (mi)	79	52	79	52	79	52
Operating cost, $	14.75	10.97	21.20	15.62	10.16	9.02
Ownership cost, $	7.41	8.11	11.87	12.34	6.50	7.26
Value of Time, $	7.06	6.45	7.06	6.45	7.06	6.45
Total cost per mile, $	**29.22**	**25.53**	**40.13**	**34.41**	**23.72**	**22.73**

Table 4.8 compares the annual savings of the customer vehicles for four different options of getting groceries in Washington and Hawaii. These four options vary the percentages of delivery-order options with corresponding percentages for driving options to estimate customer total savings per year. The first option is the current situation with a 0% delivery option and a 100% (52 times a year) diving. No delivery service fee was recorded for these services and no savings were realized. The second option compares each customer vehicle savings with a 25% (13 times a year) delivery and 75% (39 times a year) driving. For this option, the highest amount of savings at $254 was estimated for a household using a 2015 F-150 pickup truck in Washington; the corresponding estimate for Hawaii is $180. The modest sedan (Camry) and the EV (Leaf) had much lower savings, but they are also less typical rural household vehicles.

Table 4.8 continues with the 50%, 75% and 100% delivery option; the latter yields the highest potential savings. Avoiding 100% of the usage of a 2015 F-150 pickup truck for grocery and household supplies produced a savings of $1,016 in Washington and $719 in Hawaii. The savings are also substantial if the household uses a 2015 Camry for these trips, but the savings dwindle to under $200 for the Leaf.

Table 4.8 Annual Savings of the Four Options for Getting Groceries

Parameter	2015 Camry		2015 F-150		2015 Leaf	
	WA	HI	WA	HI	WA	HI
0% delivery-order option, 100% driving option (current situation)						
Total cost	1,519	1,328	2,086	1,789	1,233	1,182
Cost of driving option	(1,519)	(1,328)	(2,086)	(1,789)	(1,233)	(1,182)
Delivery service fee	-	-	-	-	-	-
Total annual savings, $	**-**	**-**	**-**	**-**	**-**	**-**
25% delivery-order option, 75% driving option						
Total cost	1,519	1,328	2,086	1,789	1,233	1,182
Cost of driving option	(1,139)	(996)	(1,565)	(1,342)	(925)	(886)
Delivery service fee	(268)	(268)	(268)	(268)	(268)	(268)
Total annual savings, $	**112**	**64**	**254**	**180**	**41**	**28**
50% delivery-order option, 50% driving option						
Total cost	1,519	1,328	2,086	1,789	1,233	1,182
Cost of driving option	(760)	(664)	(1,043)	(895)	(617)	(591)
Delivery service fee	(535)	(535)	(535)	(535)	(535)	(535)
Total annual savings, $	**224**	**129**	**508**	**360**	**81**	**56**
100% delivery-order option, 0% driving option						
Total cost	1,519	1,328	2,086	1,789	1,233	1,182
Cost of driving option	-	-	-	-	-	-
Delivery service fee	(1070)	(1070)	(1070)	(1070)	(1070)	(1070)
Total annual savings, $	**449**	**258**	**1,016**	**719**	**163**	**112**

4.4. Break-Even Analysis for the Provider

Table 4.99 provides a comparative analysis of the cost of operating three delivery vehicles. The first part of Table 4.99 details the operation cost of these vehicles. It shows that the electric drive version of the van has a much lower operating and maintenance cost compared to the gasoline powered van. Table 4.9 also covers the ownership cost of these delivery vehicles. The ownership cost includes insurance, taxes and fees on the vehicles, depreciation value, and vehicle loan payment. The e-NV200 (CAV) is the most expensive because CAV equipment was added on, as shown in Table 3.1.

Table 4.9 Delivery Van Operating and Ownership Costs

Parameter	Nissan NV200 (25 MPG) [43]		Nissan e-NV200 (124 MPGe) [44,52,53]		Nissan e-NV200 (124 MPGe) CAV [44,52,53]	
	WA	HI	WA	HI	WA	HI
Operating Cost						
Fuel	0.11	0.13	0.03	0.10	0.03	0.1
Maintenance	0.11	0.11	0.025	0.025	0.025	0.025
Total cost per mile, $	**0.22**	**0.24**	**0.055**	**0.126**	**0.055**	**0.126**
Ownership Cost						
Insurance	3.21	2.42	3.21	3.42	3.21	3.42
Taxes and Fees	1.46	0.76	1.46	0.76	1.46	0.76
Depreciation	10.92	10.92	12.39	12.39	12.39	12.39
Loan Payment	14.48	14.48	16.42	16.42	29.72	29.72
Total cost per day, $	**30.07**	**29.59**	**33.48**	**33**	**46.77**	**46.29**

Table 10 provides an analysis of the break-even point of the three delivery service options for both case study locations. A one-way trip from the store to the customer was factored in, and then an increment of one mile was added for each additional delivery at the rural location. The driver's cost was calculated per roundtrip (back and forth to the store). Using a Nissan NV-200, the delivery service for one delivery is $99.2, generating a revenue of $20.58, leading to a $78.68 loss. For a Nissan NV-200 EV, the delivery cost reduced to $90.38, resulting in a $69.80 loss. For the Nissan e-NV200 CAV, the delivery service cost reduces to $76.63, leading to a $56.06 loss. Clearly, one delivery per trip is not a viable option, regardless of the type of van. By progressively incrementing the number of deliveries we reach a point that the first positive amount of profit appears. This number is shown as the "number of deliveries" in Table 10. It represents the transition from loss to profit.

The driver labor on Nissan NV-200 and Nissan e-NV200 significantly increases the cost of operating these vehicles. The break-even point for NV-200 and e-NV200 is 6 and 5 for Sprague, WA and they both have a break-even of 5 trips for Volcano, HI. In both locations, the CAV van is the option that requires the lowest number of deliveries in order to turn a profit. Recall, that there is one fleet supervising engineer for every five CAV vans; the corresponding cost is shown under driver labor.

Table 4.10 Number of Deliveries Needed to Turn a Profit

Parameter	WA			HI		
	NV-200	e-NV200	e-NV200 CAV	NV-200	e-NV200	e-NV200 CAV
No. of Deliveries	**6**	**5**	**4**	**5**	**5**	**4**
Distance, mi	44.5	43.5	42.5	29	29	28
Time, min	1.70	1.65	1.60	1.58	1.58	1.50
Driver Labor, $	55.19	53.33	19.58	51.01	51.01	18.33
Operating Cost, $	19.39	4.80	4.69	13.90	7.33	1.08
Ownership Cost, $	35.06	39.04	54.54	34.51	38.49	53.99
Net Cost, $	(109.64)	(97.39)	(78.81)	(99.42)	(96.83)	(79.40)
Delivery Charges, $	123.48	102.90	82.32	102.90	102.90	82.32
Net Profit, $	**13.48**	**5.51**	**3.51**	**3.48**	**6.07**	**2.92**

4.5. Summary of Analysis

For customers dwelling in rural areas, owning a Nissan Leaf presents the most economical means to travel for obtaining household groceries and goods. However, pickup trucks are far more popular than EVs and sedans in rural areas, therefore, substitution of their trips by deliveries will yield the largest savings.

If a sufficient and fairly uniform demand over time can be established, then delivery services in rural areas can be a viable option no matter which type of van is chosen; rural households will save time and money, and reduce their crash risk. However, the profits will be larger or the break-even demand will be lower with CAV delivery, as shown in Figure . We examined the base case where only one rural area is anchored to a hub city, but various other rural areas around each city can be added, which will substantially enlarge the rural market and the overall demand for deliveries.

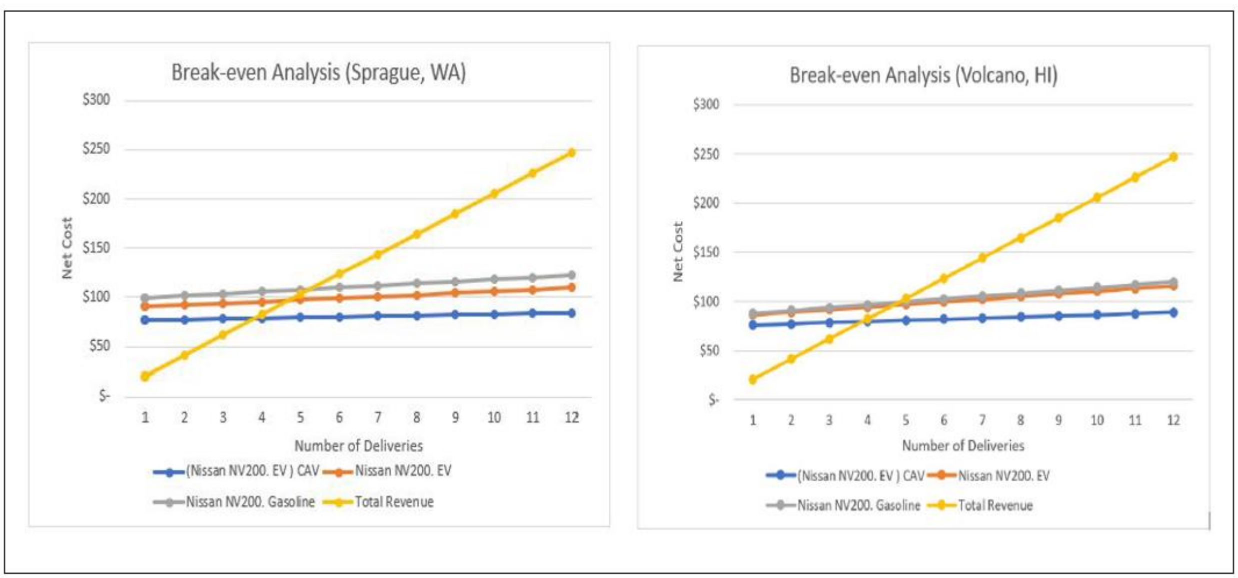


Figure 4.2 Delivery costs and revenues for three modes of delivery at two rural locations

CHAPTER 5. CONCLUSION

The objective of this research was to investigate delivery services in rural areas with CAVs in order to provide better access to goods to the large proportions of elderly and disabled people in rural areas, potentially reduce the disproportionally higher number of fatal crashes on rural highways, and reduce the transportation cost for obtaining goods for all types of rural households.

The objective was accomplished by conducting a two-fold analysis: The first part concentrated on the rural household and accounted for their costs for obtaining groceries and household goods. Rural delivery only makes sense if it saves them time and money. Additional benefits include pollution reduction and crash risk reduction. These were discussed but they were not monetized because these benefits are likely but premature to assume. More importantly, these environmental and safety benefits will be enjoyed at a societal level and are not a typical part of the decision making of households for choosing trip options.

The second part included detailed analysis for delivery by three modes based on an economical compact van (1) running with a driver and propelled by a gasoline internal propulsion engine; (2) running with a driver and propelled by an electric drive; and, (3) running as a Level 4 or 5 CAV and propelled by an electric drive. Two case studies were deployed in order to assess the impact of vehicle ownership and operating costs, distances, household incomes, and the value of time spent on obtaining household goods and groceries. The revenue streams were estimated based on the limited urban delivery information available. Again, environmental and safety benefits were not included in the provider's analysis of costs and revenues because these are social benefits. These social benefits can be monetized in various ways that would affect the provider's costs, e.g., as reduction in vehicle registration and other fees, as government subsidy for each rural delivery, etc. If enacted, the monetization of benefits will incentivize the deployment of rural delivery.

CAV delivery service can be more convenient, and result in reduced time, money, and effort that rural households spend to access a grocery store or big-box retailer. Rural deliveries by CAV will reduce the number of the elderly on rural roads making it safer and more reliable for them to access food and supplies from stores. While 100% substitution of trips for groceries and household goods by deliveries is unlikely, because the households likely chain several trip purposes for their (long) trips to the city, lower substitution rates are possible and all of them will benefit rural households.

Additional potential benefits include lower pollution and lower crash risk on rural roads. Human factors cause approximately 94% of crashes [54] and an additional 2% of crashes are due to issues with the vehicle; a CAV can assess itself and refuse operation if there are problems with itself (sensors, tires, headlights, etc.) Thus, about 96% of crashes can be attributed to the responsibility of the driver or the vehicle. This represents a very high potential for crash reduction by Level 4 and 5 CAV which operate within the limits of the law and have the ability to reduce at-fault crashes substantially.

Providing CAVs in rural areas faces several challenges. One of the challenges is the curviness and ruggedness of roads in rural areas due to the topography and climate. Some rural deliveries also involve driving on unpaved roads. In addition, CAVs have to overcome government regulations as there is no existing regulatory structure to oversee the safe introduction of CAVs in rural areas; current CAVs are taking place on geofenced urban and suburban environs, or on selected freeway corridors.

Finally, there are positive implications of the COVID-19 pandemic (and similar future threats) for the development and deployment of CAVs. The combination of distancing requirements at crowded stores along with the substantial sensitivity to the disease by older persons and persons with a variety of health conditions provide additional impetus for the contactless delivery of goods. This bodes well for urban delivery with mini CAVs and rural delivery with Level 4 and 5 van CAVs.

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