HAWAII OPERATIONAL KNOWLEDGE UTILITY (HOKU) PROJECT

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IN REPLY REFER TO:

DEP-HWY 7.2019

March 20, 2019

The Honorable Elaine Chao
Secretary of Transportation
U.S. Department of Transportation, Office of the Secretary
West Building—1200 New Jersey Avenue, S.E.
Washington, D.C. 20590

Dear Secretary Chao:

RE: Submission of the Project Proposal "Hawaii Operational Knowledge Utility (HOKU) ADS Transit EV Deployment Project" in Response to the funding opportunity "Automated Driving Systems (ADS) Demonstration Grants (NOFO 693JJ319NF00001)"

This letter serves to confirm that Hawaii Department of Transportation (HDOT) submits this project entitled HOKU ADS Transit EV Deployment Project for the funding opportunity titled ADS Demonstration Grants (NOFO 693JJ319NF00001). We will work collaboratively with the University of Hawaii, City and County of Honolulu, and relevant private sectors nationwide to ensure the success of this project. As detailed in the attached support letter, should this proposal be awarded, HDOT and City & County of Honolulu will provide cash or in-kind support for $13,000,000 USD for the purposes of meeting the local match commitment to the U.S. Department of Transportation.

If you have any questions or concerns, please feel free to contact me at (808) 587-2156. We look forward to working with you on this effort.

Sincerely,

EDWIN H. SNIFFEN
Deputy Director, Highways Division

Summary Table

Project Name/Title	Hawaii Operational Knowledge Utility (HOKU) ADS Transit EV Deployment Project
Eligible Entity Applying to Receive Federal Funding	Hawaii State Department of Transportation 869 Punchbowl Street Honolulu, HI 96816
Point of Contact	Edwin Sniffen, Highways Deputy Director
Proposed Location for the Demonstration	Hawaii and the City and County of Honolulu
Proposed Technologies for the Demonstration	• 5 transit EVs with L3+ ADS including operating using modular AV stacks with open source software, white boxes, and incorporating HAD Maps for multiple routes • A scalable system of fixed and mobile-location sensor deployments and telematics to provide for real-time safety redundancy, particularly for vulnerable users, at all intersections and for vehicle location, condition & performance monitoring with reporting to the USDOT's Controlled-Access, Collaborative Data System • Integrated V2I/V2X framework incorporating FHWA's CARMA platform to support SPAT and MAP messages with the ADS, and an intelligent infrastructure system with enhanced data fusion capabilities to locate, identify, connect, and safely broker all users' demands efficiently. • Simulation environment where insight gained from the project data provides knowledge for predictions on similar networks in improving mobility, traffic conditions and infrastructure improvements requirements for a range of events when CAV operations are introduced, from short-term and long-term perspectives, and provide tools for training and public outreach • Data fusion environment for real-time safety warnings and wayfinding/FMLM recommendations for transit and all travelers, including visually disabled and non-English speakers who provide input such as their Origin-Destination (OD) pair information through connected vehicle based applications, web-kiosk and –smartphone-based software devices.
Proposed duration of the Demonstration	4 years
Federal Funding Amount Requested	$ 6 million
Non-Federal Cost Share Amount	$ 13 million
Total Project Cost	$ 19 million

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1. Executive Summary

This Hawaii Operational Knowledge Utility (HOKU) project proposes a four year transit EV demonstration of SAE Level 3+ Automated Driving Systems (ADS) that utilize advanced wayfinding technologies to obtain the knowledge needed, combined with an intelligent and connected infrastructure, to safely provide integrated mobility services with the intermodal and multi-modal transportation system of an area. Specifically, these handicap accessible buses will provide First Mile Last Mile (FMLM) mobility services for two distinct populations at different termini of the Honolulu Authority for Rapid Transit (HART) project, the nation's first autonomous rail transit system when it opens next year. HOKU will build on its partners' knowledge of sensors and data by employing integrated data fusion techniques with software to focus on providing safe systems for all users, particularly the disabled and disadvantaged. HOKU is requesting $6 million in ADS grant monies to support these ADS demonstrations.

HOKU will be managed by HDOT, which is responsible for the state airports, harbors, and highways systems. The overall HOKU demonstration project is a collaborative effort that will build on existing State and City and County of Honolulu autonomous vehicle (AV) initiatives, pilot projects and infrastructure; therefore, HDOT is prepared to implement a project valued at over $19.1 million. HDOT is requesting about 30% of this in federal funding ($6 million) through the ADS program. All other project costs will come from non-federal sources, totaling about 70% ($13.1 million). HDOT will provide $10 million of this, with the City and County of Honolulu also committing $3 million, and the non-profit Ulupono Initiative contributing up to $150,000.

HOKU will also be part of the Hawaii Autonomous Vehicles Institute (HAVI), a collaborative institutional framework, to build bridges across currently disparate communities. HDOT, the City and County of Honolulu agencies of the Department of Transportation Services (DTS) and HART, the University of Hawaii (UH), and private partners will collaborate under the HAVI umbrella to demonstrate safe strategies for addressing rapidly changing environments and technologies, specifically in relation to connected and autonomous vehicles (CAVs). CAVs are bringing more complexity to the already large challenges of planning, prioritizing, constructing, maintaining, and operating transportation infrastructure that need to be addressed systematically. HOKU strategies will focus on developing the potential safety, mobility and accessibility improvements to the transportation system that are inherent in CAVs. The Research and Development data requirements for the USDOT will be coordinated by the UH. HDOT has the following vision for the Hawaii Operational Knowledge Utility (HOKU) project. Hawaii is a knowledge center of safe and useful CAV technology building on its traditions of Polynesian voyaging whose expertise in wayfinding and celestial navigation spanned the Pacific.

2. Background Information

Over 1,000 years ago, Polynesian voyagers on large double-hulled sailing canoes utilized their advanced wayfinding and celestial navigation skills to cross long distances against the trade winds to find the Hawaiian archipelago, the most remote island chain in the world, as they had colonized many of the islands throughout the large expanse of the Pacific Ocean. Polynesian voyaging involved a collaborative effort with everyone working together to discover and reach an unknown final destination suitable for building a sustainable environment. Wayfinding involved the expert use of knowledge gained from insight on patterns of wind, waves, current, and other available information from the environment. The navigators often relied on a guiding star or “Hoku” in Hawaiian, and for the discovery of the Hawaiian archipelago it was Arcturus or “Hokulea.”

HOKU is intended to build a bridge to the future on the foundations of knowledge from the past and some basic Hawaiian principles. Specifically, this year marks the 200th anniversary of the passing of King Kamehameha the Great who united all the islands and originated the law, Kanawai Mamalahoe, or the Law of the Splintered Paddle. The law states, "Let every elderly person, woman and child lie by the roadside in safety," and is enshrined in the state constitution. This year will mark the 60th anniversary of Hawaii becoming the 50th state and the opening of the Hawaii Department of Transportation (HDOT) building. The law is represented as a symbol of crossed paddles in the center with the shield on the HDOT building as shown in Figure 1 below.

Develop a data driven ADS framework to assist with the good stewardship of CAVS for creating a smart and sustainable intermodal and multimodal transportation system for Hawaii.

- Safety: protect vulnerable users by preventing crashes and providing positive guidance to minimize the number and severity of crashes as part for a safe transportation system.
- Sustainability: introduce zero emissions accessible smart transit EVs to replace diesel and other fossil fuel vehicles along with a smart infrastructure to improve the overall system efficiency in terms of time and congestion.
- Mobility: address first mile/last mile (FMLM) transportation needs, especially for the transportation challenged such as people with disabilities.

Since Captain Cook’s death 240 years ago, witnessed by Kamehameha the Great, Hawaii has gone through tremendous changes and challenges with the introduction of guns, germs, and steel from those events. Hawaii would like to be more proactive and to correctly steer the inevitable progression towards smart cars with smart infrastructure. Moreover, Hawaii would like to take part in this progress to help build a more sustainable environment for its future. To reflect this mission, Governor David Ige issued Executive Order No. 17-07 on Autonomous Vehicle Testing (https://governor.hawaii.gov/wp-content/uploads/2017/11/EO-17-07.pdf).

This March 15th, the 50th state celebrated the 50th anniversary of the building of The Hawaii State Capitol, judged by many to be a Modernist masterpiece. The building was opened to the legislature on March 15, 1969 on the tenth anniversary of the passage of the Statehood bill by Congress. The first state Governor, John Burns, used his opening address to the legislature that day to expound on the openness and spirit of Hawaiʻi:

“The open sea, the open sky, the open doorway, open arms and open hearts—these are the symbols of our Hawaiian heritage…It is by means of this striking architecture of this new structure that Hawaiʻi cries out to the nations of the Pacific and of the world this message: `We are a free people…we are an open society…we welcome all visitors to our Island home.’

Figure 1. A symbol of Crossed Paddles in the Center with the Shield on HDOT Building

3. Goals and Objectives

The HOKU project will build on this message and can be encapsulated by the Hawaiian word “imua” that means forward progress as shown in Table 1 below.

Table 1. IMUA Interpretation of the HOKU Project

I	Ike means knowledge. Alakai ka ike are guides of learning, teachers & a key project value
M	Malu means safe, both a project goal and value
U	Uila means electric as the project will be utilizing transit EVs to move to zero emissions
A	Alawa maka means to diagnose by insight

In terms of specific safety, data for safety analysis and rulemaking, and collaboration, the goals of this HOKU project include

Table 2. The Goals of the HOKU Project

Safety	HOKU goal is to systematically deploy technologies that can be used to create a safe system with redundancies. The test deployments will facilitate the safe integration of AVs through a comprehensive approach to assess and establish safe operating conditions, to ensure compliance with best practices for safety operations, monitor and evaluate autonomous system and vehicle performance including following rules of the road, including negotiating signalized intersections.
Data for Safety Analysis and Rulemaking	HOKU framework is an open research data, evidence based approach to gain and share knowledge and insight. The UH will gather data and share it in near real-time and retain it securely for US DOT regulatory analysis. The suite of analytical tools proposed are capable of integrating data including conventional data regarding safety incidents, operational (vehicle and ecosystem data), and to assess risks and offer mitigation strategies. The data and related analytics could be the basis for performance-based compliance tools, risk-based rather than specification-based standards, and guidance on best practices for state and manufacturers. These tools and associated data will enable continuous improvement of the

	safety of ADS in a variety of operating conditions.
Collaboration	HOKU involves partnerships across government agencies, universities, and private partners across the nation. As it deploys it will tap the insights of state and local governments, university and nonprofit research communities, manufacturers, insurance, national testing facilities and non-profit safety organizations.

The objectives of the HOKU project are based on the following four demonstration components that comprise a safe system environment:

1) Smart transit EVs (and routes)
2) Smart infrastructure (and communications)
3) Data (management and analytics)
4) People (user interfaces and acceptance)

They include:

- Test two types of 20+ passenger EVs, one that is sold commercially for L3+ ADS operations, and a standard accessible bus, later modified to L3+ ADS, by incorporating a modular AV kit with open source software, white box, and incorporating HAD Maps developed by the HOKU partners for true research and development.
- Test an integrated V2I/V2X framework incorporating FHWA's CARMA open platform to support SPaT and MAP messages with the ADS, and an intelligent infrastructure system with enhanced data fusion capabilities to locate, identify, connect, and safely broker all users' demands efficiently.
- Test a modular and scalable system of fixed and mobile-location sensor deployments and telematics to provide for real-time safety redundancy, particularly for vulnerable users, at all intersections and for vehicle location, condition & performance monitoring with reporting to the USDOT's Controlled-Access, Collaborative Data System
- Test a data fusion environment for real-time safety warnings and wayfinding/FMLM recommendations for transit and all travelers, including visually disabled and non-English speakers who provide input such as their Origin-Destination (OD) pair information through connected vehicle based applications, web-kiosk and –smartphone-based software devices.
- Test a simulation environment where insight gained from the project data provides knowledge for predictions on similar networks in improving mobility, traffic conditions and infrastructure improvements requirements for a range of events when CAV operations are introduced, from short-term and long-term perspectives, and that can provide tools for training and public outreach

4. Geographic Area

Since Hawaii became a state 60 years ago, the population has grown by roughly 230 percent with more than 70 percent of the almost 1.5 million people residing in the City and County (C&C) of Honolulu, the state capital and proposed initial deployment area for the HOKU project. Tourism has become the largest industry with annual visitor arrivals now reaching 10 million annually, or over 80 million person-days, up from around only 3 million in the 1990s. At any given time, there are over 200,000 visitors on the islands, nearly 15% of the resident population. Almost 80 percent of these tourists visit Honolulu with the majority of those staying in the tourist area of Waikiki next to Central Honolulu. Government is the next largest employer, and the federal government is the largest landowner in the state. Joint Base Pearl Harbor-Hickam (JBPHH) in Honolulu is among the largest military bases in the world, and there are over 70 military bases and facilities in the state.

Similar growth has been experienced by Honolulu's transportation system, which carries more than 70 percent of all the people and goods movements statewide. Almost 20 million passengers annually fly through the main international airport in Honolulu (HNL), adjacent to JBPHH, making it one of the busiest in the nation. HNL also handles about 500,000 tons of cargo annually. About 80 percent of all the state's goods consumed are imported, and about 70 percent of these imported goods go through the adjacent Honolulu Harbor. This harbor handles over 1.2 million TEU freight containers annually, which is comparable to the Port of Seattle. Most of the state's energy and transportation are fuel oil dependent, which also comes into this harbor.

Most of HDOT's major systems development projects ended in the late 1970s. Since then, the entire transportation system has gone through a prolonged period of decline under multiple pressures from growing traffic congestion, aging infrastructure, and declining funding resources. However, similar to the recent revival of Polynesian navigation in Hawaii, there has been a growing movement to modernize the entire transportation system given the critical role these infrastructure lifelines play in sustaining our modern society.

Honolulu on the island of Oahu is the most remote city in the world with a population over 500,000. The next most remote city is on another Polynesian discovered island, Auckland, New Zealand. Natural disasters such as hurricanes and tsunamis have occurred on the Oahu in the past and potential emergency evacuation services could be incorporated into the HOKU framework.

Honolulu is the fourth densest urban area in the U.S. Urban development has primarily been confined to a narrow strip between the mountains and the ocean as shown on the Figure 2 that also graphically shows the Primary Urban Center (PUC) of Honolulu. More affordable housing lies to the west of the PUC; whereas, 60 percent of the jobs are in the lower eastern quadrant of the PUC.

Commuters from the economically disadvantaged and transit dependent areas to the west of Central Honolulu, routinely describe commutes in excess of an hour, and the farther west they go, two hours is not uncommon. These workers make the commute from the more affordable housing in the west to often the lower paying tourist industry jobs in Waikiki, east of Central Honolulu. To help alleviate this situation, voters in 2005 approved the creation of HART to build a roughly $10 billion, 20-mile long, autonomous rail transit system along the corridor from West to East where nearly 70 percent of Oahu's population and more than 80 percent of the island's jobs will be located by 2030. The first phase will open at the end of 2020 with the full system projected to be operational by 2025. Travel time from west to east along the complete line is projected to take 42 minutes.

Figure 2. Geographic Area

HART's elevated rail construction project has proceeded from the western termini in Kapolei and recently reached HNL. It provides a good opportunity for HDOT now to coordinate with the City and County of Honolulu DTS and HART on the development of a plan for incorporating CAVs in a multi-modal and inter-model integration of this nation's first driverless train system.

Besides the HART project, given the impact of 20 million passengers a year, a $750 million HNL modernization plan broke ground in May 2013. Vehicle miles of travel (VMT) by visitors in Hawaii as a proportion of total VMT is among the highest in the nation, but almost entirely in rental cars (there are over 17 million rental car-days per year statewide). To serve over 10,000 rental cars a day, $330 million of these modernization funds went for a new consolidated rental car facility (CONRAC). Construction for the HNL CONRAC started in November 2017 and is scheduled for completion in 2020.

5. AV Deployment and Test Sites

HOKU proposes to test five smart buses for at least two demonstrations of different FMLM transit EV services operating with Level 3+ ADS on public state and city roads in urban environments with a wide mixture of traffic, including pedestrians. HOKU proposes to test modular and scalable V2X smart infrastructure solutions building on the current systems deployed by HART for its rail construction project. The data and software requirements will be managed by UH.

5.1 HDOT HNL CONRAC Demonstration Testbed

The first test and deployment of driverless vehicles/CAVs in the state were planned to begin with a pilot project for the new shuttle buses to serve the new HNL CONRAC with the Governor's Executive Order 17-07 on AV testing. The Governor in his FY 19 Supplemental budget committed $7 million for a two part pilot project out of some $39 million budgeted for the CONRAC shuttle bus program. The first part of the pilot project was to evaluate various alternative fuel powertrain vehicles for their performance along the shuttle loop as shown in Figure 3. After 6 months of operation, the first part of the pilot tests ended at the end of February 2019 with a 40 foot, 40 passenger transit EV manufactured by Proterra being determined to be the best choice. The new CONRAC transit EV bus procurement is currently underway.

The second part of the pilot project was to concurrently solicit for a total solution provider to test an autonomous shuttle service for CONRAC during the powertrain tests; however the solicitation was unsuccessful. This proposed HOKU project intends to succeed the uncompleted second part of the pilot project by integrating an open ADS in a modular AV stack from a total solution provider to three of the accessible transit EVs purchased for the new CONRAC shuttle service after factory delivery. These vehicles will be augmented with additional camera, radar, and lidar sensors, and provided with HAD Maps developed by Mandli from their lidar surveys in 2019. The shuttles will be operational after testing them on new connected scalable smart infrastructure solutions that extend throughout HNL, adding safety systems redundancy and also as part of the HOKU demo.

After testing, each L3+ transit EV will be operated by the HNL CONRAC transit services contractor, Roberts, for a total of eight hours every day, with over 40 miles driven, and with over 400 passengers carried. Over the course of the two year operational shuttle pilot services, it is estimated that these CAVs will have driven approximately 90,000 miles and carried 900,000 passengers in total.

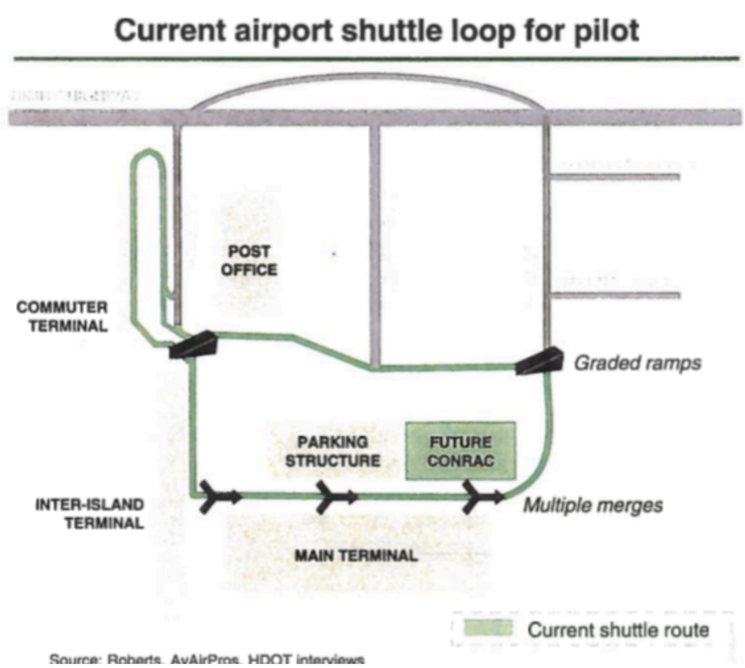

Figure 3. Honolulu Airport Test Site Layout

5.2 Kapolei HART Demonstration Testbed

The dense built urban environment in Honolulu precludes the building of numerous transit stations with parking facilities. With the assistance of the Ulupono Initiative, work on CAVs as a potential solution to address the FMLM needs of the transit dependent populations, especially the disabled and disadvantaged, has been conducted involving many stakeholders in the City. DTS proposes to build on this work by deploying two transit L4 CAVs for a route connecting HART 's west termini in Kapolei to an underserved disabled veterans housing project.

Specifically, the proposed AV shuttle service will operate daily to and from US VETS at Barber's Point and the East Kapolei rail station on a This 5.2-mile (10.4-mile round-trip) route will operate on public streets and will be served by two 20+ passenger automated shuttle buses operating from 5am to 8pm. The infrastructure will be enhanced through striping and lane barriers, as well as the installation of communications and sensors that will allow the vehicle to communicate with the infrastructure and even pedestrians. Sensors may also be embedded outside the vehicle to provide redundant obstacle detection.

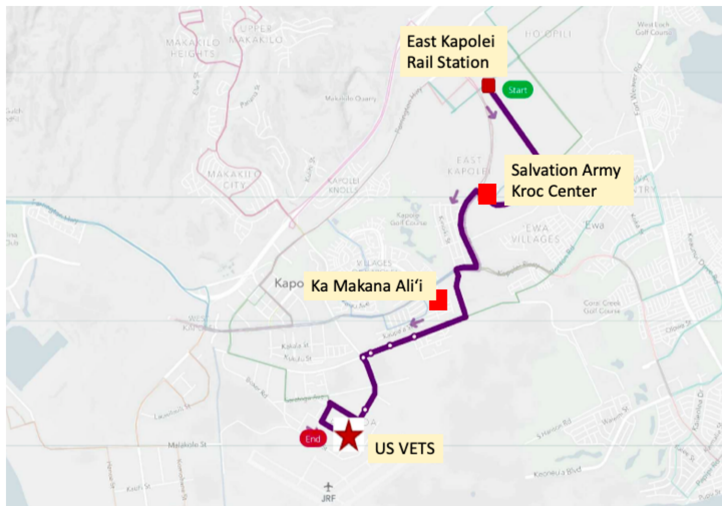

Figure 4. Kapolei Test Site Layout

5.3 AV Deployment

The new AV service would operate two 100% electric Motive shuttle buses on a route to and from US VETS to the Ka Makana Ali'i Mall, Salvation Army's Kroc Center, and, by the end of 2020, to East Kapolei Rail Station. People living at Barbers Point will have "door to door" service to and from home to community services, shopping, health services, and jobs. All vehicles will be accessible to those in wheelchairs and those with limited ability to communicate.

Figure 5. AV Deployment and Service

Before passenger service, the safety of each vehicle will be confirmed. Using the risk assessment tool, dRISK, the team will conduct a hazard assessment of the route and take steps to minimize or eliminate hazards. Over the course of the demonstration, the team will use data-based tools such as Icarus (a digital checklist), dRISK (risk mapping), and nSight (an AV data recorder and data analytics program) to gather data, share it in near real time, and analyze it in relation to safety operations compliance and performance of the vehicle and autonomy, as well as to understand the vehicles interaction with others sharing the road.

5.4 Smart Infrastructure

5.4.1 TrafficCast System

New V2X connected scalable smart infrastructure solutions are also part of the proposed HOKU demo. The initial plan is to deploy a TrafficCast Transit Signal and Pedestrian Priority System so that it extends throughout HNL, adding safety systems redundancy. This system would build on the existing TrafficCast system shown in Figure 3 that the HART rail construction project has currently deployed in Honolulu. This system uses TrafficCast's BlueTOAD Spectra Roadside Unit (RSU) that incorporates the highly-advanced DSRC technology and hardware, Signal Phase and Timing (SPaT), intersection geometry (MAP), Signal Request Message (SRM), Traveler Information Message (TIM) and connected vehicle Basic Safety Messages (BSM). The BlueTOAD Spectra RSU is a highly accurate lane-by-lane GPS-based system providing an advanced Connected Vehicle solution to effectively set the foundation to manage and access the full range of required Connected Vehicle applications, including Transit Signal Priority and Emergency Preemption System services. In this project, TrafficCast will use an in-cabinet "processor" based on an open-source and industry-standard Linux® based processor to manage message translator applications as well as Connected Vehicle applications as developed by the USDOT.

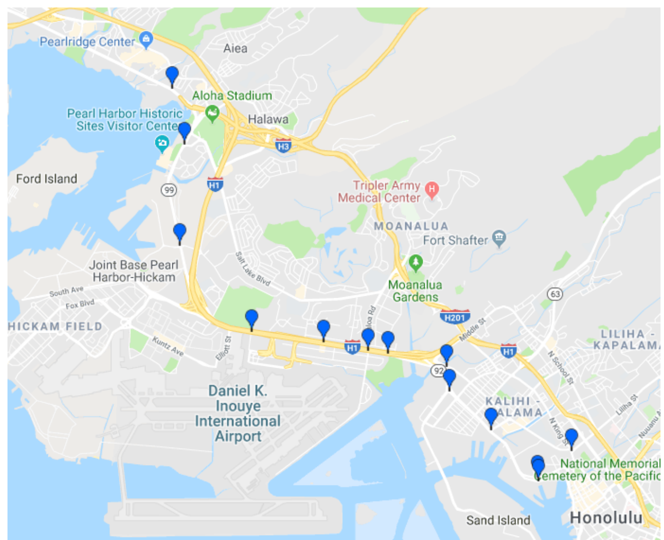

Figure 6. TrafficCast System Deployment in Honolulu, HI

The BlueARGUS traffic data and hardware management system will be used to provide a Vehicle to Everything (V2X) Operational Data Environment (ODE). This V2X Operational Data Environment provides the option to deploy the BlueTOAD Spectra RSU, a combined Bluetooth® and DSRC roadside transceiver and TrafficCarma, an advanced mobile application that leverages big data and a widely-deployed commuter application platform. This advanced Connected Vehicle system will be used to share, manage and process travel and signal priority system data across a single platform. The BlueARGUS system serves as the Graphical User Interface (GUI) and software foundation for the overall Signal Priority and Preemption system providing an expandable platform to manage Roadside devices, authorized service vehicles and the data that is collected for this project managed at UH.

5.4.2 SAFES System

Safe Access to Future Exchanges System (SAFES) is a Cooperative Vehicle Intersection Control System (CVICS) designed by the Hawaii DOT and its partner network to: 1) to safely guide a CAV through a signalized intersection, and 2) provide a mechanism for capturing innovative data sources that allow authorities to measure safety and support future rulemaking.

The cornerstone of SAFES is data. In order for SAFES to deliver on the promise of safe signalized intersection navigation, the system will collect key data elements from both the vehicle and infrastructure and leverage innovative rulemaking to ensure that AVs traverse signalized intersections without incident. For a given intersection, SAFES is currently made up of 3 additional systems: 1) the ADS Vision and Control System, 2) the Infrastructure Vision and Control system, and 3) the Communication System that connects the ADS and the infrastructure.

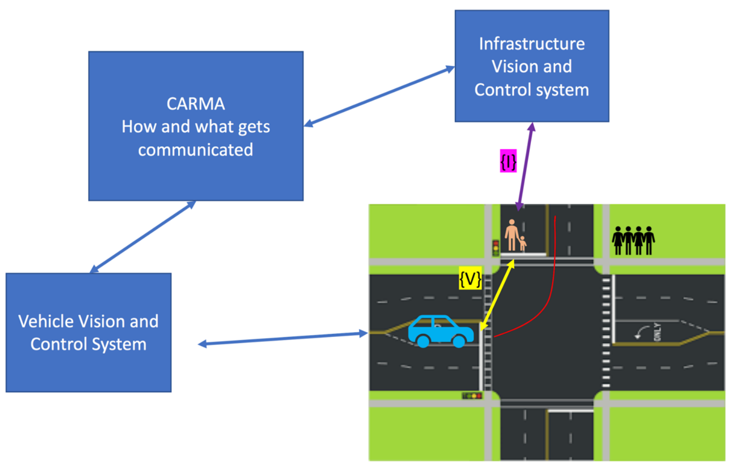

Figure 7. SAFES System

HOKU will equip 3 transit EV buses from Proterra with an autonomous drive-by-wire kit and sensors to enable Level 3+ autonomy. Each of these components plays a critical role in ensuring that the ADS is able to sense, interact with, and respond to its environment. The components that will be added include a drive-by-wire kit, a Delphi radar sensor, an Allied Vision machine vision camera, a rugged NovAtel GNSS receiver and tactical grade IMU, Velodyne LiDAR sensors, and an AStuff Spectra autonomous driving computer.

A part of this study will include the utilization of Open Source Autonomous Driving Software to cultivate reduced cost ADS research that is available to everyone. The ADS Vision and Control System will leverage Autoware for perception, localization, and motion planning, and Robot Operating System (ROS) for middleware functions, debug, and data viewing.

As part of our study of ADS Bus Transit, we will learn about how advanced infrastructure at intersections and crosswalks can enhance the performance of an ADS Bus, potentially decreasing the time required for safe ADS Bus technology to be developed and deployed at scale. Scanning Lidars and a Lidar Processing Compute Module will be integrated at select crosswalks and intersections. All detections from the SAFES compute module will be transmitted in real time via 4G or DSRC communication to the ADS bus and fused into the ADS bus' existing perception and decision-making flow. The Lidar processing software in the ADS Bus and SAFES locations will be developed by separate engineering teams using separate algorithms/SW. This will reduce the odds of systematic failures in the overall transit system.

The SAFES ADS buses will drive the Honolulu airport route with an HD Map provided by Mandli Communications, Inc., and integrated by AutonomouStuff into the ADS Vision and Control System. The HD Map will be used for preemptive knowledge of road semantics and enhanced localization on city and urban route portions. The HD Maps for the airport route will be partially validated in simulation ahead of arrival in Honolulu. Final validation of the HD Map, the ADS buses, and their integration will occur on site at Honolulu airport.

To create the HD Map, Mandli Communications will use a Maverick Mobile Mapping System to collect LiDAR, 360º Imaging, and NovAtel-based GNSS data with IMU-supported solution for the airport route. Mandli will then leverage its in-house LiDAR processing teams and software to create an open-source HD Map.

5.4.3 ADS Vehicle Validation at AutonomouStuff

Each ADS Bus will go through full system validation at AutonomouStuff technical center in Morton, IL before being shipped to Honolulu airport. Both Simulation of the Honolulu Airport Route and ADS Bus, and HD Maps at AutonomouStuff facilities, will be used to verify ADS system performance on the Honolulu airport route as much as possible prior to shipment. Testing at the AutonomouStuff tech center will enable us to resolve many issues ahead of shipment, leaving mostly site specific issues to resolve at Honolulu Airport, and reducing the cost of AutonomouStuff on-site support.

AutonomouStuff engineers will validate the ADS Buses and SAFES system on site at Honolulu Airport. We will validate performance for all complex traffic scenarios on the route including crosswalks, merging, and intersections. We plan to use 3 AutonomouStuff engineers to complete the validation process over the course of 5 months. The AutonomouStuff on-site team will include 2 Algorithm/Software Engineers and 1 System Engineer. Site Specific validations will include HD Map Accuracy and Proper Integration, Localization Performance, and SAFES and ADS Bus integration and communication. Our goal in the first 5 months will be to have achieved adequate performance for the ADS buses to be driven daily with minimal safety driver takeovers.

6. Technical Approach and Data Analytics

6.1 Vision for AV Data System Establishment

Through the deployment of two AV operational demonstration testbeds detailed in the previous sections, various testing data will be collected and analyzed to establish our AV data analytics and management system. These data will be stored in the data hub hosted at the University of Hawaii as well as shared with the USDOT periodically through the remote controlled-access, collaborative data station at https://its.dot.gov/data/secure/, the Secure Data Commons Proof of Concept (SDC POC) is an online cloud-based analytic sandbox that provides us access to data sets and programming environments for this project. It can be envisioned that establishing the shared, secured AV data exchange system will greatly enhance our understanding and readiness to utilize advanced AV technologies to provide safe, efficient, and reliable travel for people and goods in Hawaii. To establish the prototype AV testing system and conduct the relevant safety performance analysis will help prepare state-wide infrastructure, policy, regulation, and operations for near-future AV-penetrated transportation systems.

6.2 Objectives of AV Data System

Specially, the AV data system aims to achieve the following objectives:

- Provide in-depth data analytics and safety pattern knowledge for the AV demonstration projects in terms of AV operation efficiency and safety performance in Hawaii
- Provide critical inputs to test and deploy AV technology in its close loop of machine learning processes and gain experience through pilot projects and engage in national efforts
- Establish foundational shared data analytics and management systems with USDOT to support future AV deployment to enable sustained deployment activities
- Develop safety data metrics to characterize AV benefits and potential challenges for agencies and travelers by adapting our infrastructure to future transportation systems during the current transitional timeframe of AV on our roadways.
- Seek for opportunities to leverage CAV technologies to support existing performance based planning and maximize operational benefits.

6.3 Data Collection

Based on the AV sensor systems enabled by the Autonomous Stuff Autoware Kit, and the infrastructure control and surveillance system deployed at the airport testbed and the Kapolei Street testbed, AV operational safety performance will be tested and examined under various scenarios considering prevailing traffic, geometry, and control conditions.

Various data will be collected at sufficient resolutions. Cooperative Automation Research Mobility Applications (CARMA) 2.0 developed by the Federal Highway Administration (FHWA) will be adopted as an open source software platform in this project to enable control coordination and safety performance testing through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. CARMA facilitates the research and development of cooperative interactions by infrastructure and AVs. Various data will used to communicate and inform connected vehicles of what's ahead and what to expect to enable the safer and more efficient movement of the entire traffic systems. CARMA2 runs on a Linux computer within an AV interacting with the vehicle's devices and microcontrollers via the vehicle's Controller Area Network (CAN bus). The onboard unit (OBU) will communicate with other vehicles and infrastructure through dedicated short-range communications (DSRC). The CARMA2 software platform can perform the following functions.

- Cruising—recognize and follow speed limit.
- Yield—slow down vehicle to avoid a collision.
- Lane change and merge—coordinate with vehicle in a lane to the left or right to make space to merge and change lanes.
- Platooning—enable collaboration between vehicles at close range in a single lane to save fuel and reduce roadway usage.
- Speed harmonization—Follow dynamic speed commands from a cloud server that is measuring traffic and determining upstream speeds to minimize traffic jams and limit back-end congestion.

Therefore, the related data will be collected including

- Speed limits
- Real-time vehicle speed, acceleration/deceleration rates
- Lane changing decisions
- Vehicle platooning coordination decisions
- Speed control and coordination

In addition to these interconnecting data transmission and collection, the additional data will be collected though AV sensors including

- AV GPS trajectory data,
- AV Lidar data,
- AV radar,
- AV video data,
- AV Origin Destination (OD) pairs and turning movement data,
- AV-Human Dirven Vehicle (HDV) interaction data,
    - ➢ time headway,
    - ➢ spacing,
    - ➢ speed variances, etc.
- AV-infrastructure interaction data,

    - distance between AV to land shoulder,
    - roadway curb,
    - roadside utility structure, etc.
- AV-pedestrian/passenger interaction data,
    - AV reaction time and distance to dynamic pedestrian/passenger crossing,
    - AV-response to customized passengers' destination requirements through unified user interface applications, etc.

Various sensors deployed in the infrastructure system will provide another set of data to quantify the AV system safety performance and operation efficiency. These data include:

- Traffic flow characteristic data,
    - flow rate,
    - space-mean speed,
    - lane occupancy, etc.
- Traffic signal control data,
    - phase structure,
    - timing parameter,
    - progression green wave, etc.
- Traffic system performance evaluation data,
    - travel time,
    - control delay,
    - crash rate,
    - crash injury severity outcomes ,
- Simulation data,
- Infrastructure sensor data,
    - High resolution Lidar data for infrastructure profile and roadway conditions,
    - loop data
    - surveillance video data

6.4 Test Scenarios

The testing scenarios will be designed and examined under prevailing traffic, geometric, and control conditions as well as hypothetical conditions. Specially, the following AV safety performance tests will be emphasized at both the airport and Kapolei test sites.

- AV-enabled collision avoidance performance impacted by dynamically movable objects (such as pedestrians, HDVs) and enhanced marking and signing infrastructure improvements
- AV coordination and communication controlled by signalized intersections along arterials
- AV/Infrastructure/HDV Interactions
- AV collision avoidance under extreme conditions, such as windy, dusty, limited visibility, inferior lighting, strong sunshine reflection, etc.
- AV-enabled routing and destination optimization for customized requests

- AV response and safety buffer zone establishment under hacked, misleading guidance for Cyber security checking

For example, at the airport test site, the AV shuttle buses are used to carry passengers from terminals to parking lots following the routine routes guided by specific infrastructure. In order to enhance AV shuttle bus safety performance, enhanced illumination guidance lighting systems can be used and tested to guide vehicles and people to better utilize the facilities. Smart Road Sticker developed by the Smart Transportation Application and Research Lab (STAR Lab) at the University of Washington can be used on the road shoulder/lane to promote the lane visibility significantly compared with traditional lane markers. Each smart road sticker utilizes two sets of high brightness LEDs with 2000mcd with different colors on both sides in order to meet different illumination requirements. With LoRa communication technology, stickers can achieve long-distance communication in flexible network structure. The project team can control the light color remotely through LoRa dynamically based on the real-time traffic situation and communicate its operation status with AVs and pedestrians. The sticker can receive remote commands every minute sent by AV and infrastructure management centers. The project team will test AV-infrastructure interoperability in terms of AVs' and pedestrians' safety performance based on these innovative signing and marking improvements under different scenarios.

6.5 Safety Data Metrics Development and Safety Performance Modeling

AV technologies represent near-future transportation systems and enable many advanced applications for safety and mobility enhancement to improve our energy, infrastructure, and environmental impacts. As the first priority for transportation system operations, safety performance measurement is complex. In order to complement traditional safety performance assessments, safety data metrics should be developed considering AV high-resolution operation data. Based on the various data measured by AV sensors and infrastructure sensing systems, the data processing will be conducted and the following safety data metrics are proposed to monitor and quality the effectiveness of AV-penetrated traffic systems.

- AV-induced crashes and injuries during the project periods,
- Backup drivers' interventions in case of an emergency,
- AV malfunction warnings during autonomous driving,
- Hazardous distance records between AV and HDVs, pedestrians, curbs, lane shoulders,
- AV speed variations and fluctuations on arterials,
- AV-involved signal control violations,
- AV safety buffer distance and time headways
- Traffic flow progression interruptions due to AV operations

These safety data metrics can be obtained from various raw data collected by AV and sensing systems, and will be monitored and examined statistically. These safety data metrics will be further analyzed for safety performance classification and quantification based on a multinomial Logit model-Bayesian network hybrid approach, which will be developed to discover the underlying AV safety patterns behind safety data metrics and investigate the impacts of significant contributing attributes on AV-enabled traffic system safety performance. Bayesian networks have emerged as a powerful framework to extract expert knowledge and patterns hidden behind data through combining graph theory and probability theory. Graphical representations of Bayesian networks visualize complicated relationships and interactions among independent and dependent variables for constructing probabilistic inference and diagnosis. Therefore, Bayesian networks are capable of modeling inter-correlated independent variables to better interpret heterogeneous influence on AV-penetrated traffic crash injury outcoems from attribute changes. However, Bayesian network structure optimization in the global space is extremely computation-intensive considering a large amount of independent variables. The search space increases as a super-exponential function of the number of variables.

To achieve feasible and efficient network structure estimation, the significant variables must be selected to reduce the search space. Variable selection is very important to find a set of significant contributing variables and screen out variables that do not influence model performance. Many different variable selection criteria and methods have been used, such as the most commonly used correlation-based variable selection. During this process, a set of variables are selected due to their strong correlations with the output outcomes but low inter-correlations with each other. Such correlation-based variable examination may not produce statistically stable results regarding variable predictive ability and redundancy reduction among variables. In this study, a multinomial Logit model is used to select significant variables to comprehensively screen out unnecessary and redundant attributes and increase optimal Bayesian network structure search efficiency.

- Multinomial Logit Model-based Variable Selection

Based on the safety data metrics, multinomial Logit models are developed to estimate the probability of three categorized safety outcomes in AV-related crashes: Property Damage Only, Possible Pedestrian/Passenger Injury, and Incapacitating Pedestrian/Passenger Injury/Fatality. It is assumed that for any AV attribute changes, the marginal costs for each safety outcome (Property Damage Only, Possible Passenger Injury, and Incapacitating Passenger Injury/Fatality) are different. P_{is}, the probability of AV, *s*, being involved in a crash with severity level, *i*, is determined by the utility function U_{is}:

$$P_{is} = P\big(U_{is} \geq U_{js}, \forall i,j \in C, i \neq j\big) = P(u_{is} + \varepsilon_{is} \geq u_{js} + \varepsilon_{js}, \forall i,j \in C, i \neq j) \qquad (1)$$

where u_{is} is the deterministic component that is only modeled by significant safety metric variables describing the instance; ε_{is} is the random component representing the hidden effect on pedestrian/passenger injury severity; *C* is the choice set of possible safety outcomes. u_{is} is defined as a linear function for driver *s*,

$$u_{is} = \boldsymbol{\beta_i} \times \boldsymbol{V_{is}} + \alpha_{is} \qquad (2)$$

where V_{is} is the exogenous variable vector influencing safety outcome, *i*, for AV, *s*, and β_i is a coefficient vector to be estimated for measuring the influence of V_{is} on safety outcome, *i*; α_{is} is the constant term. ε_{is} is normally assumed to follow a Generalized Extreme Value (GEV) distribution, and a multinomial Logit model can be derived as

$$P_{is} = \frac{e^{u_{is}}}{\sum_{j \in C} e^{u_{js}}} = \frac{e^{\beta_i \times V_{is} + \alpha_{is}}}{\sum_{j \in C} e^{\beta_j \times V_{js} + \alpha_{js}}} \quad (3)$$

where, P_{is} is the probability of driver, *s,* suffering injury outcome, *i,* in a crash. The coefficients $\boldsymbol{\beta_i}$ and α_{is} are estimated via maximum likelihood estimation methods. All the variables are used for multinomial Logit model development and significant ones are identified based on their T-ratios and P-values at the confidence level of p=0.01. These identified significant variables will be used for Bayesian network structure establishment and probabilistic parameter learning to explicitly formulate cause-effect relationships between injury severity outcomes and explanatory attributes.

- Bayesian Network Definition

Bayesian network will be employed as a classifier to analyze AV-related injury outcomes in traffic crashes based on the significant safety data metrics identified in the multinomial Logit model in this study. Bayesian network is capable of quantifying conditional probability relationships among variables via graphic presentation, known as a Directed Acyclic Graph (DAG). A BN can be represented by a network structure B_s over a set of variables, $V = \{x_1, x_2, \ldots, x_v\}, v > 1$. The DAG topology is portrayed to show cause-effect relationships among variables. A set of probability tables $B_p = \{p(x_i|pr(x_i)), x_i \in V\}$ are provided to quantitatively interpret these cause-effect relationships depicted by the graphical structure, B_s, where $pr(x_i)$ is the set of parent variables of x_i in B_s and i=1,2,…,*v*. Technically speaking, A BN over a set of variables, *V*, represents joint probability distributions, $P(V) = \prod_{x_i \in V} p(x_i|pr(x_i))$ for $i=1,2,\ldots, v$. Using BN to analyze crash injury severities is to classify a potential driver injury outcome, $y = y_0$ (e.g. no injury, injury, fatality), given a set of significant attribute variables identified, $X = \{x_1, x_2, \ldots, x_k\}, k = v - 1$. The driver injury outcome, *y*, and the attribute variables, *X*, constitute the overall variable set *V*=(*X*, *y*). The classifier is a function mapping a case of *X* to an outcome of *y*, which could be trained from a given dataset *D* that contains sample instances of (*X*, *y*). To use BN as a classifier, we need to calculate $argmax_y P(y|X)$, the value of *y* that maximizes $P(y|X)$, using the distribution *P(V)*, where

$$P(y|X) = \frac{P(X,y)}{P(X)} = \frac{P(V)}{P(X)} \propto P(V) = \prod_{x_i \in V} p(x_i|pr(x_i)) \quad (4)$$

The Bayesian network structure graphically represents various intersections among safety data metrics. The variables are denoted as nodes and their interactions are represented by directional arcs and edges between two nodes. Unconnected nodes signify direct independence between the variables represented by the corresponding nodes. The optimal network structure, DAG, can be examined based on the prior knowledge constraints and predefined scoring metrics. Prior knowledge and network structure score will be combined to achieve an efficient network structure estimation. The structure scoring metrics, Minimum Description Length (MDL) and Akaike information criterion (AIC), will be used as structure quality measurements.

- Bayesian Learning and Model Specification

Supervised Bayesian network learning will be conducted to find an appropriate network structure and estimate the corresponding parameters based on the scoring metrics and prior expert knowledge to identify the best Bayesian network structure given a data set. Through training processes for both network structures and parameters, a

Bayesian network is able to interpret observed crash injury severity data based on their probabilistic relationships and predicting unobserved crash injury outcomes based on attribute variables. An improved *K2* searching algorithm will be applied. A *K2* algorithm is a type of greedy hill climbing search algorithm, and based on this staring point, all the neighboring DAGs are established by adding, removing, and reversing an existing arc of the initial DAG. The scoring metrics are used to evaluate each DAG performance. A DAG with the highest score is the optimal network structure. The identified optimal BN structure presents the dependence relationships among the variables in the model based on the data set. The conditional probability tables can be estimated by maximum likelihood estimation methods during the parameter estimation process.

7. Schedule

The overall schedule for major tasks is listed as follows over the four years. Year One focuses on system integration planning, design, procurement of the transit CAVs for Kapolei, and starting integration for the CONRAC transit EV's ADS system in the modular AV stack, data recording systems, and smart infrastructure system deployments and software application development. Year Two focuses on the piloting of the Kapolei transit service program and development and testing of AV stack integration with the CONRAC shuttle buses. In Year Three, all systems will be fully functional, operational, and monitored continuously for improvement and optimization. Kapolei demonstration finishes at end of the year. Year Four CONRAC performance monitoring, reporting, and documentation will be conducted regularly and end of the year findings reported and shared with USDOT and the HAVI Advisory Panel. The annual review meetings allow the USDOT and the HAVI Advisory Panel members to provide feedback and comments to guide the subsequent year's activities.

8. Reemphasis on Focus Areas

Table 3. Focus Area Interpretations

1. Significant Public Benefits	Human errors are factors in most vehicle crashes, and crash related injuries are a significant public health issue in many communities. By verifying the safety improvements from the deployment of ADS and collecting and analyzing related data, communities can begin to have access to technologies to reduce the deaths and injuries caused by vehicle crashes.
2. Addressing Market Failure and Other Compelling Public Needs	To date the market has failed to develop accessible vehicles for shared mobility for people who use wheelchairs or who have limited ability to communicate. The Kapolei deployment will connect

	disabled veterans and retirees to jobs, shopping, and health services. The project will demonstrate the value of such service to other transportation challenged populations and will extend the reach of the autonomous rail system to underserved communities.
3. Economic Vitality	The funds will be expended in accordance with the Buy America Act. HOKU will support the development of regional and national electric automated vehicle industry through use of U.S. manufactured vehicles and technology. Tourism is the largest industry in Hawaii, and the HNL rental car shuttles will help serve thousands of tourists daily.
4. Complexity of Technology	The project will demonstrate the safety of level-3+ electric shuttle buses with V2X infrastructure improvements.
5. Diversity of Projects	The project will test transit services in both high and low volume environments with a mix of traffic and road conditions. Insights from this project could also be of value in many communities from retirement, employment campus, college settings, and residential facilities for adults with disabilities.
6. Transportation-challenged Populations	The project includes the development of 20+ passenger automated electric buses with automated wheel chair ramp and automated securement device. The proposed Kapolei route will provide accessible service to disabled veterans and seniors who now must walk or use wheelchairs to travel about a mile to a bus stop. The airport ADS demonstration will operate a 40-passenger accessible automated electric bus.
7. Prototypes	The vehicles in the demonstration will be electric vehicles that are fully compliant with FMVSS requirements and therefore will not require for federal exemptions. Further, it is expected that these vehicles will be eligible under state law to operate as a pilot.

9. Requirement Satisfactions

1. Demonstration will include
    a. the operation of L3+ shuttles on public roads. Shuttle will include
        i. a multi-passenger vehicle,
        ii. multiple vision sensors (cameras, radar, lidar),
        iii. a gps system,
        iv. and an AV software stack including
    b. perception system software (sensor fusion, and object detection),
    c. control system software (all human interface components traditionally found in vehicles),
    d. and navigation system software (route planning), and
    e. the addition of several custom capabilities into the AV software stack including
        i. Integration of an externally managed/updated HD map into the perception system software,
        ii. Integration of a new AV module focused on producing critical operational safety measures,
        iii. Development of a new user interface for communicating the critical operational safety measures to users of the shuttle, and
        iv. A communications system to transmit the critical operational safety measures to a remote location for additional analysis, and for near real-time distribution to the public
2. Shuttle operates on one of many possible locations
3. UH will host a distributed/scalable database in order to support additional data processing/analysis, and distribution to public-facing dashboards/information systems.
4. Several user interfaces will be provided to communicate relevant information to stakeholders:
    a. UH will develop an integrated UI showing route information, and status of critical operational safety measures to shuttle passengers.
    b. TrafficCast will provide mobile device-enabled applications for the public to interact with the data provided
    c. HOKU Autonomous Assistant (AA)

HOKU will experiment with different autonomous user interfaces to enhance the user experience at the proposed HNL airport CONRAC site. Fixed and mobile (robotic) interfaces will be tested, and feedback will be gathered to evaluate the benefits and disadvantages of such a system. The robotic interface will be connected with the V2I communications network and will be able to inform users of shuttle arrival times and will be able to direct or escort the users to the pick-up locations. In addition, the autonomous platforms will be able to provide information on airport services in multiple languages. Powered with Oceanit's VIPA protocol running machine-vision algorithms, it will be able to recognize gestures, voice commands, and even perform facial recognition.

As an example, a non-English-speaking visitor has arrived at HNL airport and needs to rent a car, but does not speak or read English. He gestures to the HOKU AA. The robot meets the traveler and is able to recognize the language that he is speaking. The HOKU AA is able to direct him in his native language to the shuttle stop location, informs him of the time of the next shuttle arrival, and is able to show him where the nearest restroom is. If the HOKU AA encounters him again, he will recognize his face and ask him if he needs any additional assistance. Oceanit is currently developing a personal robot assistant for the elderly in collaboration with a startup company, using the Temi robot platform. The assistant will recognize gestures, perform facial recognition (including identifying pain), and detect falls and injuries.

5. Technologies will be provided by key partners that are capable of scaling their operations. New systems will be developed with scalability/elasticity in mind from the beginning. The combination of these items will ensure the technical aspects are scalable.

Simulation environment where insight gained from the project data provides knowledge for predictions on similar networks in improving mobility, traffic conditions and infrastructure improvements requirements for a range of events when CAV operations are introduced, from short-term and long-term perspectives, and provide tools for training and public outreach.

Develop an accurate photo realistic virtual-reality model of the transit routes, its street furniture, its existing signage, its surrounding infrastructure and the built environment from the Mandli lidar surveys in 2019 as shown in Figure. Populate the virtual 3D environment with pedestrians, bicycles, motorcycles, appropriate vehicles, and trucks from actual data from real time monitoring sites. Simulate the construction of future improvement plans and the incorporation of CAVs. Set up a cloud environment so that users could drive in both directions on the facilities, either as driver or passengers – by means of a low cost Logitec Steering Rack - and thereby assess the conditions such as driving in the contra flow lanes and the changeable message signs that could be programmed by the user of the interactive 3D model.