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Pilot Application of Biometric-Based Vehicle Occupancy Detection on Managed Lanes for Congestion Reduction

Sara J. Hendricks
Philip L. Winters
Poojitha Bolleni

National Institute for Congestion Reduction
University of South Florida
Center for Urban Transportation Research | University of South Florida

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Prepared by

Sara J. Hendricks
Philip L. Winters
Poojitha Bolleni

Center for Urban Transportation Research, USF

Prepared for

National Institute for Congestion Reduction
University of South Florida
Center for Urban Transportation Research

4202 E. Fowler Avenue, ENG030, Tampa, FL 33620-5375
nicr@usf.edu

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16. Abstract

This study tested the accuracy and reliability of a biometric vehicle occupancy detection technology. Downloaded onto a carpooler's mobile device, the app enables measuring the number of passengers in a vehicle for purposes of high occupancy vehicle (HOV) and high occupancy toll (HOT) lane management and incentivization. Volunteers recruited from South Florida, the Tampa Bay area, and Utah used the app to log carpool trips that were recorded and validated by the app. The data were compared against digital photos taken at the same time as the trip to verify that the carpool validation was correct. A survey was conducted to gather information about the user-friendliness of the app. Evaluators reviewed all 837 logged trips. Evaluators determined one False Positive among trips validated by the app, with a positive predictive value of 0.9803. Evaluators determined 13 False Negatives among trips unvalidated by the app, with a negative predictive value of 0.9030. Most of the False Negatives were due to occurrences of an overly high similarity threshold that can be adjusted. Evaluators also tested the app using single occupancy vehicles (SOV) for staged True Negative scenarios. After more than 30 attempts, evaluators failed to 'fool' the app into verifying an SOV as a carpool. During the pilot, the app continually improved performance, both in accuracy and in user experience. For the app to work as designed, carpoolers must remember to capture an initial snapshot with their mobile device, before the start of the carpool trip and revalidate at the end of the trip, if prompted. Carpoolers must look directly at their phone camera and wait for the verification signal to ensure sufficient biometric facial data has successfully been recorded. The app is configurable, thus requiring a policy decision regarding the balance between reducing the seconds required for trip validation, increasing convenience, versus heightened accuracy, by selected threshold for similarity. A soft launch of the app should provide an initial period for determining the acceptable balance of False Negatives and False Positives prior to a full deployment. There will be a need for customer support when deployed. Future research could focus on back-office integration with app functions, automated reward delivery, and testing the accuracy and reliability of counts for three or more vehicle occupants. Finally, social marketing research could provide insight into what would make the app more attractive than the alternatives for specific market segments, and what benefits would outweigh the barriers to using the app.

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Abbreviations and Acronyms

AI	Artificial Intelligence
CAP	Commuter Assistance Program
CUTR	Center for Urban Transportation Research
DOT	Department of Transportation
EL	Express Lanes
FN	False Negative
FDOT	Florida Department of Transportation
FP	False Positive
GPS	Global Positioning System
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
LPR	License Plate Recognition
MAP-21	Moving Ahead for Progress in the 21st Century
ML	Managed Lanes
NICR	National Institute for Congestion Reduction
NIR	Near Infrared
NPV	Negative Predictive Value
NSF I-Corps	National Science Foundation Innovation Corps
OCV	Occupancy Count Validation
PMT	Passenger Miles Traveled
PPV	Positive Predictive Value
RUC	Road Usage Charging
RFID	Radio Frequency Identification
SFCS	South Florida Commuter Services
SOV	Single Occupant Vehicle
SR	State Route
TBARTA	Tampa Bay Area Regional Transit Authority
TN	True Negative
TNC	Transportation Network Company
TP	True Positive
TSMO	Transportation Systems Management and Operations
USF	University of South Florida
VOD	Vehicle Occupancy Detection

Executive Summary

The purpose of this study was to field test an innovative smartphone application (app) developed by RideFlag Technologies, Inc. (herein referred to as RideFlag) and assess its ability to accurately detect faces and determine vehicle occupancy. The following research had two objectives: 1) independently establish the app's accuracy; and 2) test the app's ability to successfully deliver notification of rewards earned to app users who carpool.

The study, under the National Institute for Congestion Reduction (NICR), was sponsored by the Florida Department of Transportation (FDOT). To support managed lanes (ML) operations, the study sought to test RideFlag's biometric vehicle occupancy detection technology for the purposes of measuring its Occupancy Count Verification (OCV) accuracy. The ability to accurately distinguish between a single- occupant vehicle (SOV) and a high-occupancy vehicle (HOV) would allow ML facility operators to correctly charge the appropriate toll amount to the user's account, while also rewarding carpoolers with reduced or toll-free access to the ML facility.

The test began on July 20, 2022, and concluded February 28, 2023. A total of 29 carpoolers participated in the study, for a total of 837 logged trips using the app. Participants logged trips on geofenced segments of Interstate 95 (I-95) in South Florida, I-275 in the Tampa Bay region of Florida, and I-15 in the Salt Lake City region of Utah. A geofence is a digital boundary for a real-world geographic area, which is defined by using Global Positioning System (GPS) or radio frequency identification (RFID) technology. This boundary allows software applications, such as RideFlag's tool, to activate a specific action when a mobile device crosses into or out of the defined region. The app detects when a mobile device enters a highway, regardless of whether the app is running in the foreground or background of the phone.

Carpoolers who registered to participate in the pilot, downloaded the app and logged carpool trips. Each carpool trip required the use of just one mobile device per carpool. They were notified through the app when each carpool trip was verified. When a carpooler successfully completed a trip (i.e. they successfully verified occupancy at the beginning of the trip and reverified their carpool occupancy at the end of their trip), the app would display a tally of their total verified carpool trips. This information can also be accessed under the app menu tab, "Trip History". Carpoolers received $5.00 Amazon e-gift card value per successful carpool trip, for a maximum of 36 carpool trips. Back-office integration with a ML authority was not included in this study; rather, the study focused on gauging the app's accuracy of verifying vehicle occupancy. Furthermore, the app was configured to also record digital photos of participants when they verified and reverified their carpool occupancy. This configuration allowed independent evaluators to directly compare realness/facial geometry data and photo evidence of the carpool. This configuration is not necessary for deployment.

Realness is an artificial intelligence (AI)-trained model that looks for distinctions between a human face and an artificial/replica of one. Realness is configurable and determined based on what threshold is used in the region. When the app detects a face and assesses enough information, it will provide a percentage that it checks against the pre-determined threshold and then communicates that knowledge to the carpoolers (i.e., users) in real time. As the app is making determinations, the users will see a gray frame around each of their faces on the phone screen. If the app determines them to be real individuals, then they will receive a green frame.

A similarity score represents the relative similarity of the faces present during the initial verification and reverification. The app accomplishes this by assessing the facial geometry of a given face and temporarily storing that information locally on the user's smartphone. Facial geometry includes measurements between key landmarks of a person's face (e.g., distance from tip of nose to bottom lip). A similarity score's threshold can also be configured to be more or less strict, depending on the needs and goals of the ML authority.

Both realness and similarity scores were used to verify carpool occupancy in this study. Four outcomes of the vehicle occupancy detection (VOD) process were measured with each carpool trip. As illustrated in the confusion matrix shown in Figure 1, these included the following.

1. True Positive (TP) (i.e., occupancy accurately validated when HOV trip occurred).
2. True Negative (TN) (i.e., occupancy accurately validated when HOV trip did not occur).
3. False Positive (FP) (i.e., occupancy not accurately validated when HOV trip did not occur).
4. False Negative (FN) (i.e., occupancy not accurately validated when HOV trip did occur).

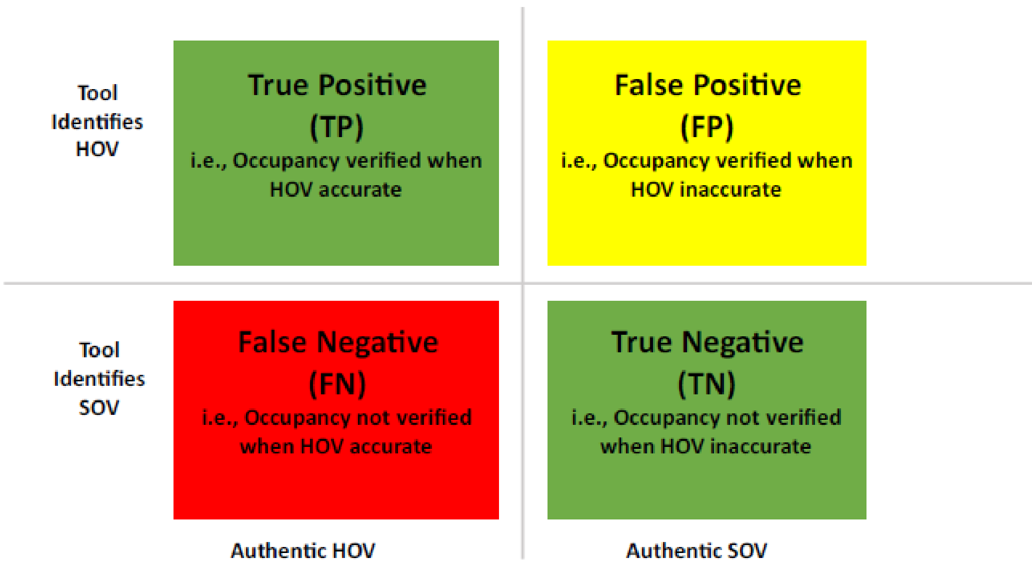

Figure 1. Confusion matrix as applied to the USF Carpool Study.

From the perspective of the volunteer carpoolers, their logged trips were determined to "pass", meaning their logged carpool trip was verified as a carpool for the purpose of earning the incentive, or "fail", meaning that the trip was not validated as a carpool. Figure 2 summarizes the breakdown of the number of trips that could be presented in the confusion matrix, describing the data collected and evaluated during the pilot.

It shows that 648 logged trips were identified to be TP trips. One trip was identified to be FP, and 13 trips were identified to be FN.

A total of 121 trips were identified to be TN. For purposes of this evaluation of the Ride Flag app, the category of TN includes not only the cases in which there was just one occupant detected in the vehicle, but also those logged trips in which the rules of app use were not followed or cases in which no trip was taken, as evidenced by the trip timestamp. Due to the unavailability of all data needed for independent verification of some logged trips, there also were a total of 54 trips deemed inconclusive. These trips are not included in the confusion matrix.

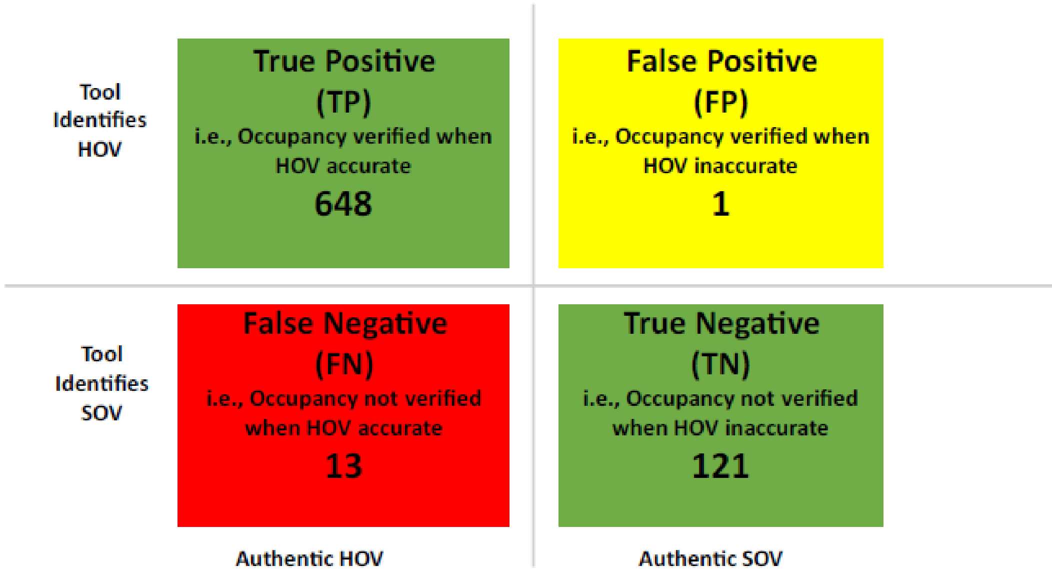

Figure 2. Confusion matrix showing results of USF Carpool Study.

There were many more validated carpool trips than unvalidated trips in the dataset of trips logged by the app testers. Instead of applying the metric of accuracy, the metrics of sensitivity and specificity were applied because these metrics are independent of prevalence. In the use of binary classification metrics, sensitivity is the proportion of HOVs that were correctly predicted as TPs.

Sensitivity = $TP/(TP + FN)$ = 648/(648 + 13) = 0.9803

Specificity is the proportion of TNs that were correctly predicted as TNs.

Specificity = $TN/(TN + FP)$ = 121/(121 + 1) = 0.9918

Informedness is a summary metric. It is sensitivity + specificity – 1 = 0.9721.

Positive predictive value (PPV) (precision) describes the proportion of positive predictions (TP) that were in fact TPs.

PPV = $TP/(TP + FP)$ = 648/(648 + 1) = 0.9985

Negative predictive value (NPV) describes the proportion of negative predictions (TN) that were in fact TNs.

NPV = $TN/(TN + FN)$ = 121/(121 + 13) = 0.9030

Nine of the FNs were due to an overly strict signature threshold. This threshold can be lowered.

It is recommended that prior to deployment of the app, a test period should be staged to determine the acceptable balance of FNs and FPs (i.e., signature threshold) based upon input from the ML authority.

Given the uncertainty of the app's accuracy before the project began, this USF Carpool Study did not automate the delivery of rewards ($5 Amazon egift card value per recorded trip, up to 36 trips) through the app. Future research may examine how to automate the process, whether it be gift cards or discounts or other types of incentives.

Another area of future research is to glean an understanding of the segments of the traveling public who see the benefits of the app. A social marketing approach could provide insight into what would make the app more attractive than the alternatives or what benefits would outweigh the barriers of using it.

The USF Carpool study did not focus on counting everyone in the vehicle, just whether there was more than one person. For areas that incentivize only carpools of three or more people, more testing would be necessary. Counting more occupants is a configurable option.

The technology RideFlag deployed in this study was the second version tested (i.e., v2). According to RideFlag, preliminary findings from this study were used to inform the third version of the app (v3) that was used in the Metropolitan Transportation Commission (MTC) Express Carpool Check Phase-1 Pilot program in the San Francisco area.

Chapter 1. Introduction

This research project, “Pilot Application of Biometric-Based Vehicle Occupancy Detection on Managed Lanes for Congestion Reduction” was conducted by the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF), as part of the Year 2 research program of the National Institute for Congestion Reduction (NICR). It was supported by the Florida Department of Transportation (FDOT). This final report represents the completion of the project. The participants who helped test the technology know this study as the USF Carpool Study.

Background

The 2012 federal transportation reauthorization, Moving Ahead for Progress in the 21st Century (MAP-21) focused on the establishment of performance measurement. MAP-21 ushered in a shift in emphasis from moving vehicles to moving people, measured as passenger throughput. This recognizes the underutilized capacity of empty seats in buses, vanpools, and single-occupant passenger cars on urban Interstate highways, even as these facilities experience peak period traffic congestion.

Gathering vehicle occupancy data has been used for various purposes including measurement of travel demand such as person throughput on highways. Promising uses of vehicle occupancy data are (1) to measure compliance with high occupancy vehicle (HOV) and high occupancy toll (HOT) operational rules for managed lanes (ML)[1] or express lanes (EL) and/or (2) to deliver rewards to travelers who choose HOV modes.

One approach to optimizing efficiency and reliability of travel for all transportation system users is to initiate programs to incentivize filling those empty seats, thereby reducing the number of peak period vehicles on the highway. Many high-occupancy vehicle/high-occupancy toll (HOV/HOT) lane programs enforce HOV rules through visual observation and highway traffic stops by law enforcement. This method of enforcement is inefficient, expensive, and unsafe (McDonald 2021, Morris et al. 2017, Carrick 2012). Other methods of verifying vehicle occupancy include the use of digital cameras and near infrared cameras attached to gantries or in fixed roadside locations. These methods of using equipment outside the vehicle, while providing improved enforcement over the honor system, require the installation and maintenance of equipment at multiple locations that are exposed to the elements.

Another method for managed lanes (ML) authorities to consider is the use of emerging in-vehicle occupancy detection technology. This enables measuring the number of passengers in a vehicle for purposes of HOV, ML, and HOT lane management and incentivization. In-vehicle methods have been proposed, including vehicle sensors, and detection of more than one Bluetooth signal within a vehicle. Detecting more than one Bluetooth signal from a vehicle is problematic for car passengers without phones and the method is easy to defeat by carrying multiple phones. The U.S. private vehicle fleet is years away from having vehicle sensors to detect vehicle occupancy as standard equipment.

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[1] The Federal Highway Administration defines HOV, HOT, and managed lanes thus:
HOV: High-occupancy vehicle (HOV) refers to a passenger vehicle transporting more than just the driver (e.g., carpool, vanpool, bus). Within the context of HOV lanes, these lanes require passenger vehicles to have a minimum number of passengers to be permitted to travel in them.
HOT: High-occupancy toll (HOT) lanes are HOV lanes that allow vehicles that do not meet occupancy requirements to pay a toll to use the lane. Variable pricing is used to manage the lane so that reliable performance is maintained at all times. HOT lanes encourage carpooling and other transit alternatives while offering travelers whose vehicles do not meet standard occupancy requirements another option. https://ops.fhwa.dot.gov/publications/fhwahop12031/fhwahop12027/index.htm
Managed lanes: Highway facilities or a set of lanes where operational strategies are proactively implemented in response to changing conditions. https://ops.fhwa.dot.gov/publications/managelanes_primer/

Where HOV/HOT lane incentivization policies presently exist, particularly on Express Lanes (EL), levels of HOV misdeclaration (corresponding to a false positive) can reach 50 percent or higher. A false positive (FP) is when an EL user declares the vehicle is an HOV when in fact it is a single occupant vehicle (SOV). The goal of vehicle occupancy detection is to eliminate HOV misdeclaration and confirm carpools that meet vehicle occupancy rules.

Problem Statement

Paired with the challenge of accurately verifying vehicle occupancy, commuter assistance programs (CAPs) in Florida and nationwide have relied on the honor system when commuters log their carpool trips to earn incentives and rewards for choosing to travel using HOV modes. Switchable transponders are honor-based and can be easy to defeat simply by setting the radio frequency identification (RFID) transponder to HOV, leading to lost revenue, and degraded managed lane performance. For example, studies that conducted manual observations to determine HOV rule compliance on HOV and HOT lane facilities, managed using the honor system, have measured violation rates ranging from 34-88 percent (Chimba and Camp 2018; Goodin 2005; Kurzhansky 2019). High rates of HOT lane violations have also been noticed by the public (Lazarus 2014). A more recent HOV enforcement campaign on State Route (SR) 99 near Sacramento by the California Highway Patrol aimed to reduce HOV violation rates of 47 percent on northbound SR 99 and 35 percent on southbound SR 99 (Caltrans 2022).

When enforcement of ELs is conducted by manual visual observations by highway law enforcement personnel directly interacting with motorists, evidence suggests roadside traffic stops slow traffic flow (Carrick 2012). Managed lanes often are not designed with adequate safe space for patrol officers to park and monitor traffic and for apprehended vehicles to be parked on the roadside, making it dangerous to conduct traffic stops for that purpose. Use of law enforcement personnel for HOV enforcement diverts them from higher priority safety regulation enforcement. One study conducted focus groups with officers with the Tennessee Highway Patrol who described the difficulties enforcing the HOV regulation (McDonald 2021).

Methods for Detecting Vehicle Occupancy

From the late 1990s through 2022, efforts have been undertaken to develop automated vehicle occupancy detection systems. These have included the development of either external cameras mounted overhead and roadside, in-vehicle camera systems or sensors, or app-based systems. These tools are commonly referred to as Vehicle Occupancy Detection (VOD) systems. Tolls are paid based upon an in-vehicle transponder set to single occupancy vehicle (SOV) or HOV by the motorist or a sticker tag, RFID to read the transponder setting and automated license plate recognition (LPR) to match the vehicle to the toll transaction. Some managed lane systems use camera systems with automated software that detects the number of vehicle occupants, and sometimes requires manual verification of photo images. These approaches can generate concern about quality control and privacy protection.

Earlier testing of a system in San Diego in 2011 featured two digital cameras that captured low intensity infrared wavelengths after infrared beams were cast upon passing vehicles, paired with an image processing unit to detect occupants. The system test evaluated all components, including power, camera alignment, trigger signal processing, data processing, image verification, digital video recording, and remote operation, including data upload and download capability. The test results indicated low accuracy; however, researchers noted that the identified technical issues would likely improve over time with improved image quality and image processing using state-of-the-art vision and camera technologies. Other identified future options included facial recognition using computer vision, and in- vehicle sensors (Chan et al. 2011).

Another out-of-vehicle occupancy detection technology test focused on the question of the variability in characteristics of vehicle glass and its impact on the capability of short-wave infrared image sensors and the

Honeywell tri-band infrared sensors to detect vehicle occupants. Problems arose in direct sunlight and in cases with reflective glare. Key questions included specifying illumination systems that both supply sufficient power at required spectral ranges while minimizing risk of eye safety hazard to motorists (Morris et al. 2017).

Other recent research on the use of out-of-vehicle technologies to detect vehicle occupancy has focused on computer vision and pattern recognition. One study has tested the combined use of LPR and Near Infrared (NIR) cameras. The NIR does not depend upon sufficient visible light, and it overcomes tinted windows. The images are captured from the front and side car windows and processed using computer vision and a deep neural network-based solution. Results appear to address the constraint of poor- quality low-resolution photos, with accuracy of detecting vehicle occupancy reported by the researchers at 94-96 percent. This method also requires installation of the imaging equipment at the site with a site- specific model trained to achieve best possible accuracy. There is the possibility of hardware failure and the periodic need for system upgrades at the local artificial intelligence (AI) processing station (Kumar et al. 2019).

Additional challenges include capturing backseat and rear-facing occupants and the effects that weather conditions have on camera image clarity. For any type of image processing approach, it is challenging to position the cameras to prevent or minimize occlusion. When completely built out, VOD system costs could reach hundreds of millions of dollars for some markets, plus maintenance and costs to conduct manual image checks as these systems can generate false negatives. A false negative (Type 2 error) result occurs when the vehicle occupancy of an authentic HOV is not validated because the technology misidentifies it as a SOV.

Other researchers have recently proposed and tested out-of-vehicle occupancy detection using a new data labeling method that detects passengers based on the number of occupants in each row of the vehicle instead of using human or face and window labeling. This method relies on two infrared cameras placed on the left and right sides of the passing vehicles, infrared ray illuminators and a laser trigger to acquire images that are sent to a server for training and testing. After testing and validation, the images can be used directly at the on-site system to determine vehicle occupancy. With use of both a left side and a right-side camera in tandem, the detection accuracy of the occupants in the proposed model is 97 percent for the binary case (i.e., more than two occupants or not more than two) and 91 percent for counting the actual number of occupants. In the case of using just a right-side camera the accuracy for the binary case was 94 percent and the accuracy for counting the actual number of occupants is 87 percent (Jooyoung Lee et al. 2020). Again, this method relies upon the installation and maintenance of external hardware. Another challenge is that these out-of-vehicle technologies are in fixed locations. Depending upon the configuration of managed lane entry and exit points, multiple sets of cameras, ray illuminators and laser triggers would be required in different locations, each requiring training, testing, validation, and maintenance.

Some transportation agencies and state departments of transportation (DOT) continue to monitor the progress of various technologies for HOV lane enforcement (Chamberlin and Haghighi 2020). Results from a 2018 pilot test sponsored by the Metropolitan Transportation Commission (MTC) using three different out-of-vehicle camera-based systems generating vehicle occupancy detection showed system accuracy of 77-89 percent based on manual image review and 37-75 percent based on controlled test runs. Pilot testers concluded that poor image quality results from dark conditions, glare, and tinted vehicle windows. A sufficiently large set of occupancy images must be collected for machine learning, with sufficient time for fine-tuning. The pilot required more power at the roadside test sites than portable generators could supply. There also was concern about the potential for vandalism of roadside system components (Lee, Rich and Burnworth 2021).

In-vehicle seat, camera, or radar-sensor data may be included in new vehicle manufacturing, providing real-time connected vehicle integration, and could potentially be adapted for counting vehicle occupants. These systems may not be feasible until most of the private vehicle fleet is equipped, and these raise privacy concerns.

App-to-app systems that count the number of device signals in proximity also exist and although they can declare the number of signals in proximity inside or near a vehicle, these tools require that all passengers have an app/device. These tools can be easy to defeat (driver using multiple phones) as well as disincentivize carpool occurrences (requiring all passengers to have an app/device).

Chapter 2. Purpose of Study

The purpose of this study was to field test an emerging mobile app technology to measure and document its ability to detect and record vehicle occupancy.

The first objective of this research is to independently establish accuracy. The second objective is to test the app's ability to successfully deliver notification of rewards to app users who carpool within predetermined geofenced highways. This is a simulation based upon the data collected by the app. This study did not test the technology's ability to communicate or integrate with a traffic management center or toll payment function of a managed lanes authority. Subsequent research could examine such integration. While the focus of this study is on potential use as a ML application, the app could also be used for other applications such as rewarding carpooling in general or incentivizing carpooling by providing preferential parking (e.g., discounts, parking spaces close to workplace). Another application would be tracking passenger miles traveled (PMT) as Road Usage Charging (RUC) becomes more prevalent.

The results of this research contribute toward the goal of reducing traffic congestion by applying technology that can reliably and systematically increase HOV incentivization effectiveness. The results of this study advance the mission of NICR by addressing the Year 2 Research Topic 1 to optimize efficiency and reliability of travel for highway system users, and Topic 3 to improve the effectiveness and attractiveness of carpooling and other high-occupancy modes of travel.

Description of VOD Technology that was Tested

RideFlag Technologies, Inc. holds several patents related to the app, including the following.

1. Papineau, M., Feltham, M. (2021a). Vehicle Occupancy Verification Utilizing Occupancy Confirmation. *U.S. Patent No. 11,003,930 B2.* Washington, D.C.: U.S. Patent and Trademark Office.
2. Papineau, M., Feltham, M. (2021b). Vehicle Parking Space Occupancy Verification and Use Authorization. *U.S. Patent No. 10,964,215 B2.* Washington, D.C.: U.S. Patent and Trademark Office.
3. Papineau, M., Feltham, M. (2021c). Vehicle Occupancy Multiple Verification Utilizing Proximity Confirmation. *U.S. Patent No. 10,922,703 B2.* Washington, D.C.: U.S. Patent and Trademark Office.
4. Papineau, M., Feltham, M. (2020). Streamlined Vehicle Occupancy Verification Using Confirmation. *U.S. Patent No. 10,628,691 B2.* Washington, D.C.: U.S. Patent and Trademark Office.
5. Papineau, M., Feltham, M. (2019). Vehicle Parking Space Occupancy Verification and Use Authorization. *U.S. Patent No. 10,490,076 B2.* Washington, D.C.: U.S. Patent and Trademark Office.

The technology tested as part of the USF Carpool Study was developed by RideFlag Technologies, Inc. (hereinafter referred to in this report as "RideFlag"). Described briefly below is an overview of the proprietary validation technology (RealFace), where it has been deployed, and features that have been tested and since been changed for testing in the USF Carpool Study.

According to RideFlag, the app takes the concept of roadside VOD camera technology and integrates it with modern smartphone capabilities to accurately verify vehicle occupants.They claim their tool offers all the advantages of both smartphone and VOD camera technologies without the costs (i.e., equipment purchase, installation, maintenance), operational constraints (i.e., location deployment) and validation challenges (i.e., false positives, counting nonvisible occupants). RideFlag lists the merits of the app to include ease of use, accuracy, elimination of expensive external equipment and enforcement, delivery of rewards, configurability across locations, facilities and pricing rules, and data collection.

RideFlag's technology is opt-in, meaning that those who wish to access HOV benefits must verify the required number of occupants using RideFlag's smartphone app for each HOV trip.

RideFlag's beta version of their app was first piloted on I-15 with the Utah Department of Transportation (UDOT) in 2019. RideFlag completed the pilot in February 2021 and reported recording 1,054 HOV trips validated on the I-15 EL, of which 999 (95 percent) were successful. When an end-of-trip reverification was introduced, this metric decreased as 200 end-of-trip reverifications were identified on the I-15 EL, of which 93 percent were validated successfully. After new upgrades to the app were released, the overall reverification success rate was 98 percent (Papineau 2021d).

During the Utah pilot, all passengers would use one smartphone to individually verify for each HOV trip. The driver had their image saved to their profile, so the driver did not need to verify for every trip. This method of verification is no longer used. Subsequent versions of the tool featured group verification where all occupants gather at the same time in the camera frame of one vehicle occupant's smartphone before starting the trip. Group verification is currently in use and was tested in the USF Carpool Study.

In addition to switching to group verification, other upgrades were made to the technology since the Utah pilot. These upgrades include proprietary technology that improved the camera's ability to verify occupants and passively determine that occupants are real (i.e., not a mannequin head or cardboard cutout of a facial image) with higher levels of certainty. The version of the tool used for the Utah pilot also used an active measure of realness that required occupants to change their facial expression when requested. The current version of the tool assesses realness without requiring the user to change their facial expression, which in turn enhances the app's ease of use.

In the configuration of the tool that was used for the initial Utah pilot, reverification was required every one in four trips at random. The purpose of reverifying vehicle occupancy at the end of the trip is to verify that the occupants of the vehicle at the end of the trip are the same individuals as those in the vehicle at the beginning of the trip. This ensures that an HOV trip took place. Because this early app configuration captured individual occupant reference images, one occupant could be selected at random for reverification by displaying their image for verification. Subsequent configurations require all occupants to reverify when required, as the tool is unable to pick a single occupant at random for reverification. This is because group verification requires all occupants to verify together in a single camera frame, so there are no individual reference images.

Even though the phone's camera feature is used to collect data verifying that multiple occupants are in the same vehicle, actual digital photos do not need to be taken while the app is used during an actual deployment. Other types of verification data are used instead, described later in this report. For this pilot, evaluators required verification of all trips and photographic reference images were used to help check the accuracy.

This USF Carpool Study was the first time that RideFlag had to test their single camera group verification. Aggregated results were used to inform and enhance the app that was used during the Metropolitan Transportation Commission (MTC) Phase-1 Pilot Program in the San Francisco area.

The technology has since been configured to also restrict app use while the vehicle is in-motion. Verification must now occur before entrance onto the geofenced portion of the managed lanes facility and while the vehicle is stopped. All changes described above were reflected in the version of the tool that was used for the USF Carpool Study.

Chapter 3. Study Process

This study began with initial kick-off meetings of key stakeholders and an Advisory Committee. These participants are listed in the Acknowledgements. The meetings were held via Microsoft Teams on August 13 and October 1, 2021. Evaluators introduced the study, presented information from a background scan about the South Florida area, established I-95 Express Lanes as a test corridor and discussed details of the study.

The discussion below describes the process used for testing the app. This included an initial application of a discovery process of the National Science Foundation Innovation Corps (NSF I-Corps). This process explored the merits of the innovative mobile app technology relative to the needs and preferences of identified markets. Locations for testing the app were selected. The evaluators developed a means to recruit volunteers to test the app and established an incentive to participate in the study. Evaluators coordinated with RideFlag that offered a beta version of the app for testing.

RideFlag devised the process by which volunteers would download and log in to the app. RideFlag also devised the carpool trip validation process for verifying vehicle occupancy. This discussion of the study process also includes a description of the alterations made to the app because of the testing process. This discussion also includes the results of an Exit Survey of the app testers.

Planning for Technology Transfer following I-Corps

There are two primary candidate customer groups for the vehicle occupancy detection capability. These are managed lanes authorities and the public that seeks to travel using the managed lanes if they get an incentive such as a discount based on vehicle occupancy. Not only must the app accurately and reliably detect the number of occupants in a vehicle but also managed lanes authorities must have confidence in the technology from the standpoint of ease of integration with managed lanes operations, risk management, and public acceptance, to name a few considerations. Travelers have modal choices and the decision to carpool may include perceived benefits of doing so. Carpoolers must feel comfortable using the app to validate their carpool occupancy without compromising their privacy.

To explore the business case for the vehicle occupancy detection capability, researchers participated in an I-Corps 3-seminar short course in Fall 2021. The NSF I-Corps Program is the NSF's signature effort to assist teams of university scientists and post-doctoral or graduate students to go outside of their laboratories and into the marketplace. This is where they can learn first-hand about entrepreneurship while they explore and validate the commercial landscape surrounding the innovation. NSF I-Corps provides the resources to investigate and validate the commercialization of science.

For this course, researchers interviewed customers and partners to discuss the utility of app-based vehicle occupancy detection. Researchers talked with vehicle drivers and passengers about the app, in addition to conducting interviews via Microsoft Teams with representatives of transportation systems management and operations (TSMO) offices of FDOT District Offices. These individuals are listed in the Acknowledgements. Appendix A contains pdfs of presentations developed for the course, which provide detailed findings. A summary of the process and findings is described below.

A small number of USF students who drive cars were interviewed face-to-face and asked how they felt about the benefits of carpooling, and whether they would use an app that would help keep scofflaws out of the HOV lane. The following paraphrased comments are representative of the feedback researchers heard from interviewees.

- It might be difficult to remember to verify occupancy before starting the carpool trip.
- Having to verify occupancy at the beginning of the ride is an added inconvenience.

- It would be difficult to take a snapshot while driving.
- Incentives and rewards to carpool are needed. Ideas include retail store and fuel discounts, free toll pass, free parking at destination.
- The app should be designed to provide for multiple uses.

Insights included the importance of emphasizing that the initial occupancy verification can only be done prior to entering the managed lane facility and only while stopped. An intensive public information effort would have to eliminate the impression that carpoolers must use their phones while driving, which is illegal in Florida.

Professionals in the TSMO field were interviewed. These professionals also are concerned about using the phone app while driving. Agencies are sensitive to customer perceptions, regardless of the capabilities of the app. There were many questions about safeguarding customer data security and privacy, and concern that the app might be recording and storing personal data. The professionals would need convincing that the app is accessible for use by all roadway travelers to satisfy policies of their public agencies.

TSMO professionals want proof that the user cannot trick the app and that it delivers a high rate of validation accuracy. Professionals expressed the sentiment that customers may grow weary of having to download yet another app. For this reason, some suggested app multifunctionality. There is concern that internal organizational lack of expertise regarding the app would put the operation of a managed lanes agency at risk if at any time there was insufficient technical support. Finally, one professional outside the South Florida region said that existing toll rates are not high enough for customers to seek toll credits by carpooling.

This study focuses upon the professional concerns about demonstrating that the app-based vehicle occupancy detection capability meets accuracy and reliability expectations. This study also addresses app user friendliness. Beyond this study, public information, outreach and marketing would be required to overcome the concerns of both the carpool user and the professional customer markets.

Location for the Study

USF evaluators tested the RideFlag app in a different setting from previous tests, to determine if these advantages can be replicated in a Florida context. With concurrence from stakeholders, the urban area corridor initially selected to test the app was I-95 from the Dolphin Expressway (SR 836)/I-395 in downtown Miami to Indiantown Road (SR 706) near Jupiter in Palm Beach County. As the study progressed and carpool testers signed up to participate, the corridor was extended along I-95 as far north as Stuart, FL in Martin County, for the purpose of enabling more carpoolers to participate in the testing. It is important to note that participation in testing the mobile app by carpoolers did not grant free access to the I-95 Express Lanes as part of this study.

Testing the app required traveling along any segment of I-95 within a polygon demarcated by GPS coordinates that contained the I-95 facility. This geofence enabled detection of the carpool passing into the highway polygon, then passing out of it, simulating the condition under which a carpool would be detected if the app were used for granting Express Lane toll free access or toll credits.[2]

To expand the pool of potential volunteers to test the app, evaluators began a similar test along I-275 in Hillsborough County, FL. A geofence was established along I-275 from Bearss Avenue to the north, to the interchange with SR 60 in Westshore to the south.

The volunteer pool was further expanded to include carpoolers who had previously volunteered to test the app for the Utah pilot along a geofenced portion of I-15 in the Salt Lake City area.

[2] A description of the overall I-95 Express Lanes system can be found at https://95express.com/related-information/south-florida-express-lanes-network/

Chronology of the Mobile App Testing Process

Evaluators met weekly via Microsoft Teams with the RideFlag app development staff to discuss the rollout of the test, the results of the carpool logging activity, and a review of the data as it was collected from the carpool trips.

Study Participant Recruitment

With collaborative support from South Florida Commuter Services (SFCS) and Commute Tampa Bay of the Tampa Bay Area Regional Transit Authority (TBARTA), volunteer carpoolers from ridematch databases received emailed invitations to volunteer to test the technology and provide their feedback on customer satisfaction and user-friendliness of the app. Interested carpoolers filled out and signed an Agreement to Participate, providing permission to collect data about their carpool trips, including digital photos for validation purposes. Contact information for the carpoolers, whose phones were used to test the app, was used to provide them app download information, password protected access to app usage, technical support to use the app, and a means to deliver an earned incentive. Identifying information of the volunteers was kept confidential. Data generated by the study has been kept on a secure server.

Evaluators actively recruited volunteer carpoolers from July 2022 through December 2022. Evaluators drafted three invitations that were emailed by South Florida Commuter Services (SFCS) to their ridematching database of over 3,900 recipients, on July 7, September 6, and November 14, 2022. With the assistance of the Commute Tampa Bay commuter assistance program of the Tampa Bay Area Regional Transit Authority (TBARTA), evaluators issued the invitation in August to carpoolers who travel along I-275 in the Tampa Bay region of Florida. At that time, an invitation was also extended to carpoolers using I-15 in Utah, through RideFlag's existing database of app testers.

In September, notifications were distributed to USF students, staff, and faculty, inviting them to test the app. An article in the Sunday, November 27, 2022 Tampa Bay Times and a news segment on WFLA Channel 8 News on December 5th describing the study also attracted more volunteers. The segment can be reviewed at this link.

https://www.wfla.com/news/traffic/use-i-275-get-paid-to-take-part-in-usf-carpool-study/

The invitations to carpoolers directed them to the study webpage at https://nicr.usf.edu/carpoolstudy, where interested carpoolers could learn more about the study. Figure 3 displays the USF Carpool Study webpage to which interested volunteers were directed via email invitation. They could click on a link found on the study webpage to find descriptive information and a set of 24 frequently asked questions that explained the testing process in detail, including the incentive for participation. They could choose to click on another link on the webpage to access an Agreement to Participate, created in Google Forms. A copy of the Agreement to Participate is in Appendix B.

Data collected on the Agreement to Participate included the following.

- Name
- Email to use to contact for sending beta app download instructions and to issue incentives
- Telephone number of mobile phone to be used in app testing
- U.S. citizen or permanent resident
- Age
- Statement of Agreement to Participate

Volunteer carpooler recruitment was more challenging than anticipated. This may be partly because earlier established carpools were broken up during the COVID-19 pandemic and never fully recovered as more employees continued to work from home or now work a hybrid schedule that makes it difficult to reestablish carpools.

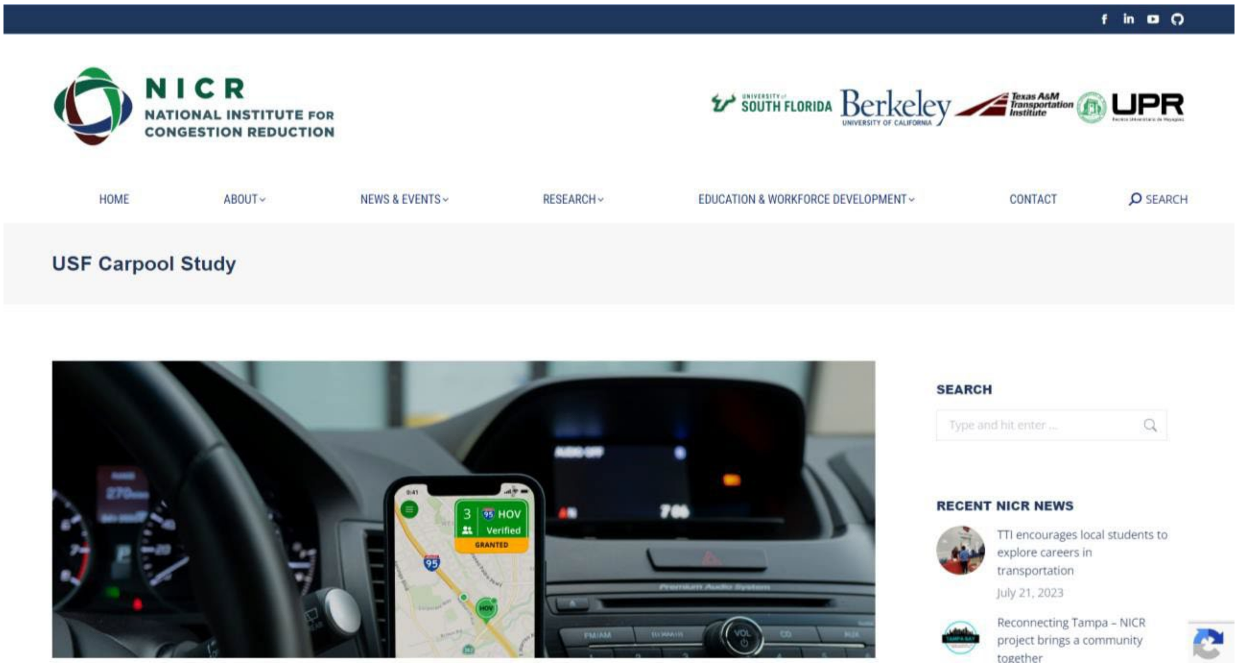

Figure 3. Carpoolers interested in volunteering were directed to the USF Carpool study webpage.
Source: Photo of car interior courtesy of RideFlag Technologies, Inc.

An email was distributed to those who signed the Agreement to Participate, with app download instructions to begin using the app to log carpool trips. Follow up emails were issued to study participants who signed up but who did not immediately download the app or log a trip, to find out that problems they might be experiencing and to encourage them to follow through in their participation.

As shown in Table 1, there was attrition in participation by the volunteers. There were many reasons. Some of it can be attributed to the complexity of study participation as a multi-step process. Evaluators attempted to measure the extent to which this result might have been due in part to the user- friendliness of the app, as addressed by questions in the Exit Survey.

Based upon follow-up email communication with some who signed up for the study, some volunteers misunderstood the intent of the study, thinking that RideFlag was like a transportation network company (TNC). This misunderstanding might be due in part to different meanings for the words 'carpool' and 'rideshare' after TNCs emerged and became popular. Ridesharing was originally used to mean carpooling that is not a vehicle for hire. At least one volunteer thought that he would be supplied with a carpool partner. Other volunteers indicated they no longer had time to participate, after evaluators followed up with them.

Study Incentive to Participate

Carpool participants received a monetary incentive for testing the app. The incentive was initially for downloading the app and logging up to 12 validated carpool trips on the geofenced facility for a maximum of $70.00 of earned incentives. This included $10.00 for downloading the app and logging the first validated carpool trip, then $5.00 per logged validated carpool trip thereafter, plus an extra $5.00 for filling out an Exit Survey. The Exit Survey and summary results for each question are contained in Appendix C.

Recruitment of participants was slow; however, evaluators noticed that a core group of volunteers quickly logged many carpool trips. To secure more logged carpool observations, evaluators expanded the maximum number of logged carpool trips per carpooler to 36, for a maximum potential incentive of $190 ($10 to download app and log first validated carpool trip, plus $5 per carpool trip thereafter up to 36, plus $5 for completing an Exit Survey.) The incentives were distributed in the form of Amazon egift card value coupon codes that could be emailed directly to the recipients. These recruitment efforts combined with altering the rules of study participation (e.g., expanding the test corridors) succeeded in almost doubling participation.

Carpool participants were required to abide by all existing operational rules of the I-95 Express Lanes, including advance registration if they were a three-person carpool seeking toll free access to the I-95 Express Lanes. These carpools could also participate in the mobile app testing and earn the incentive for participation. Most of the carpools that participated in the study were two-person carpools that traveled along I-95 and either paid the full toll for using the Express Lanes or used the General Purpose lanes on I-95 while testing the app. The USF Carpool Study did not focus on counting everyone in the vehicle, just whether there was more than one person.

Characteristics of Volunteer Participation

Table 1 summarizes characteristics of volunteer participation from the time of launch on July 7, 2022, through February 28, 2023. There were 12 individuals who were not accepted into the mobile app testing due to not meeting study inclusion criteria. The inclusion criteria included being age 18 or older, and U.S. citizenship or having permanent resident status. Some applicants were excluded due to submitting incomplete Agreements.

Table 1. Characteristics of Volunteer Participation through 2/28/23

Number of individuals who submitted Agreements to Participate	130
Number of individuals who were accepted to participate in mobile app testing	118
Number of individuals who downloaded the app	43
Number of carpoolers who attempted to log at least one carpool trip	29
Number of carpoolers who successfully logged at least one validated carpool trip using the app	25
Number of carpoolers who logged 35-36 (the maximum number of) carpool trips	17
Individuals who downloaded the app, logged no carpool trips but participated in the Exit Survey	3

The age breakdown of the 43 individuals who downloaded the app includes 29 individuals who were aged 25-44. That was over 67 percent of the participants. Five individuals were aged 18-24, six individuals were aged 45-59, and 3 individuals were aged 60 and over.

Of the 29 individuals who attempted to log at least one validated carpool trip, 16 were from South Florida, nine were from the Tampa Bay area and four were from Utah. These participants logged a total of 837 carpool trips.

Table 2 illustrates the percentage of the volunteers using iOS and Android phones for the USF Carpool Study. Comparatively in the United States, Android accounts for about 45 percent of the mobile phone operating system while iOS is about 55 percent (Statistica 2023).

Table 2. Mobile Phone Operating System Used by Volunteers

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	iPhone	36	83.7	83.7	83.7
	Android	7	16.3	16.3	100.0
	Total	43	100.0	100.0	

Exit Survey of App Testers

Evaluators developed and distributed a brief exit survey to the 29 participants who downloaded the app and attempted to log carpool trips in addition to 15 participants who downloaded the app but never attempted to log a carpool trip. They were asked questions about the ease of use of the app to log carpool trips. In addition, the survey asked their willingness to carpool using the app to register their carpool versus using an annual registration method currently used in South Florida. Evaluators received 24 responses to the exit survey, including from three who downloaded the app but logged no carpool trips. Evaluators compiled and analyzed the survey data. A copy of the Exit Survey is provided in Appendix C.

Because of the small number of responses received, despite repeated attempts to encourage participation, it is not possible to draw definitive conclusions.

See Table 3 for the survey responses about app download user experience. See Table 4 for survey responses about user experience logging first carpool trip using the app. See Table 5 for a cross tabulation of preference for method of gaining free access to the HOT lane based upon carpool size. Responses to this question may have been influenced by the fact that the recruited base of participants registering through the one-time registration system were already using the one-time annual carpool registration. However, the survey question provided participants who are experienced with both types of carpool validation—one-time annual pre-registration of carpool members versus the on-demand carpool validation through the app, the opportunity to compare both methods.

Table 3. User Experience Downloading the App

How did you find your experience downloading the USF Carpool Study app? * Mobile Phone Operating System Crosstabulation

Count

		Mobile Phone Operating System		
		iPhone	Android	Total
How did you find your experience downloading the USF Carpool Study app?	Very easy	13	0	13
	Easy	6	2	8
	Neither easy nor difficult	1	2	3
	Difficult	0	0	0
	Very difficult	0	0	0
Total		20	4	24

Table 4. User Experience Logging First Carpool Trip with App

How did you find your experience logging your first carpool trip using the app? * Mobile Phone Operating System Crosstabulation

Count

		Mobile Phone Operating System		
		iPhone	Android	Total
How did you find your experience logging your first carpool trip using the app?	Very easy	7	0	7
	Easy	8	0	8
	Neither easy nor difficult	3	1	4
	Difficult	2	2	4
	Very difficult	0	1	1
Total		20	4	24

Table 5. User Preference for HOV Validation by Carpool Size

If I wish to immediately gain free access to a high-occupancy toll lane, I would prefer… * How many people are in your carpool, on average, including yourself? Crosstabulation

Count

		How many people are in your carpool, on average, including yourself?			
		2 people (i.e., a 2-person carpool)	3 people	4 or more people	Total
If I wish to immediately gain free access to a high-occupancy toll lane, I would prefer…	...to use an app, such as the USF Carpool Study app, to verify anyone in my carpool each time.	4	2	1	7
	...a one-time annual pre-registration of each regular member of my carpool with a commuter assistance program.	9	2	1	12
	... either	3	2	0	5
Total		16	6	2	24

Description of the App Download Process

Prospective participants received an invitation that directed them to the study webpage where interested carpoolers could learn more. After learning more, they could click on a link embedded in the webpage to access the Agreement to Participate Google Form. For the purposes of this study, the app could only be downloaded through a private iOS App Store or Android Google Play link that was sent to them via email following registration.

This means that only those who were emailed the link were able to download the app. Apart from this, the download process would be the same as for app users outside the USF Carpool Study. Participants were also emailed a visual guide that helped to explain the app download process. The visual guides for both iOS and Android phones are contained in Appendix D.

After downloading the app, users were instructed to sign-in with their phone number and access a pre-set temporary password. Users were then prompted to create a new password. Next, they were prompted to select their app permissions, including allowing the app to track them via GPS to enable evaluators to verify where the carpool entered and exited the highway polygon.

Volunteers were encouraged to reach out by email if they had additional questions or were having difficulty downloading the app. RideFlag staff fielded these questions. Thereafter, during the testing of the app, volunteers were encouraged to use the Help feature in the app if they had any difficulties logging their carpool trip. Volunteers also were instructed to take a phone screenshot of the messaging from the app. This screenshot could be submitted directly to RideFlag staff for their inspection and determination if there was any issue or if the volunteer needed guidance on how to log their carpool trip. Volunteers with questions or concerns also could email the evaluators directly.

Some volunteers did have trouble downloading the app. Because this was a restricted app distribution for this pilot, it was important that the Google account on the volunteer's phone was associated with the email address the volunteer provided. Especially for the few that were using an Android phone, when this issue arose, evaluators had to determine if the volunteer was using a different Google account with their Android, and if so, then change the associated email to the list of authorized volunteers for download. There were 43 individuals who downloaded the app, of which seven were Android users and 36 were iOS users. Figure 4 describes the process of notification by an app user to RideFlag support staff for customer service or resolving issues.

Description of Process to Log and Validate a Carpool Trip Using the App

The eight screenshots in Figure 5 illustrate the sequence of app prompts, from left to right, which volunteer carpoolers for the USF Carpool Study would encounter when they used the app to verify their carpool. This includes before-trip verification and post-trip reverification. The Interstate symbol in Figure 5 is used for illustrative purposes only.

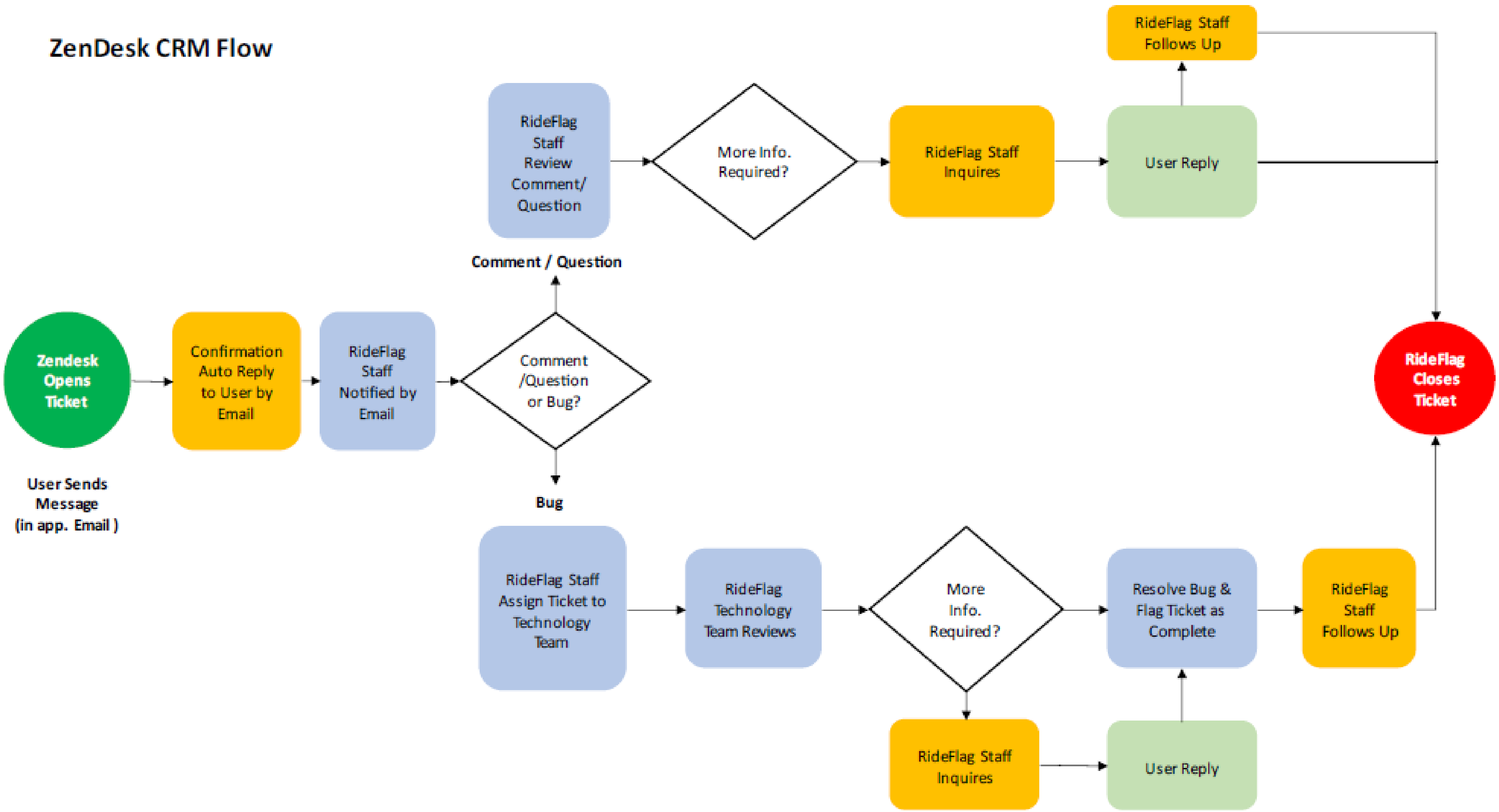

Figure 4. RideFlag process for responding to app user inquiries, using ZenDesk customer support software.

Source: Flow chart provided, courtesy of RideFlag Technologies, Inc.

Figure 5. A sequence of app screen shots illustrates prompts to verify vehicle occupancy.

Source: Screen shot illustration provided, courtesy of RideFlag Technologies, Inc.

Home: This is the Home screen. Users may tap on 'Verify Carpool' to commence carpool verification. The app has GPS enabled, which is evident by the green dot that represents the user's current location. Tapping the green circle in the upper-left corner is a menu that reveals other options, such as how many carpool credits a user has earned. The upper-right corner contains a grey '0' visual, indicating that a carpool trip has yet to be verified.

Verification: After tapping 'Verify Carpool', the camera opens, and the user begins to verify their occupancy. In this example, the user is attempting to verify three occupants in their carpool (i.e., HOV-3). If the app recognizes a human face, a gray box will appear around the occupant's face. The app is determining whether the face it detects is a real human, and not a fake face or a replica of a human face. After a moment, the gray frame around the occupant's face will turn green, indicating the occupant has been successfully verified. In this screenshot, all occupants have been successfully verified, which is reflected by the '3' located at the bottom of the screen. This number correlates with how many users receive a green frame.[3]

Trip Start: Following the verification process, the user is then brought back to the Home screen. What was once a green 'Verify Carpool' becomes an 'End trip'; however, when in motion, this button will become inactive to deter distracted driving. The once gray '0' indicating how many occupants have been verified has now changed to a green 'I-95 HOV Verified', indicating the carpool is eligible to earn a carpool credit while driving on I-95 Express Lanes. Within that same visual, the previous '0' has been changed to '3' indicating 3 occupants have been successfully verified. In this screenshot, the user is driving on I-95 and about to enter the Express Lanes, as indicated by the green 'HOV' pin.

User Enters Polygon: As the user enters the Express Lanes, they will be presented with a 'I-95 Credit Pending Reverification', reminding the user that their carpool credit is currently pending until they reconfirm their carpool occupancy once they leave the Express Lanes after they reach their destination. This notification will automatically disappear after a short duration.[4]

Credit Pending: Entering a designated Express Lane, as indicated by the HOV pin, will turn the once gray HOV pin a solid green, indicating the carpool credit for that Express Lane has been claimed. The HOV pin in the screenshot provided represents a geofenced facility that the carpoolers were approved for credit.

User Exits Polygon: Once the user has exited the Express Lane, the app will change screens and reveal a white pop-up drawer, reminding the user that they will need to reverify their occupancy when parked. Furthermore, the once labeled 'End Trip' will change to 'Reverify Carpool' following the user exiting the Express Lanes. In the screenshot provided, the user has safely parked at their destination after using I-95, which enables the 'Reverify Carpool' button (i.e., the button is no longer inactive), and is about to commence reverification.

Reverification: Tapping the red 'Reverify Carpool' opens the same camera sequence experienced during initial verification, allowing the user to reverify their occupancy. The app begins to find faces and make determinations on whether the same people it detects now (i.e., at the end of the carpool trip) were present at the beginning when verification first occurred. Once the app identifies a potential face (i.e., faces with gray frames), it will reference several metrics and determine if the occupant in question was indeed present during initial verification. Once the app confirms that the occupants during reverification are the same people during initial verification, their gray frame will turn green with a check mark in the upper-right corner of their frame.

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[3] Any of the vehicle occupants could have used their phone to verify occupancy; it does not have to be the driver. Additionally, this demonstrates that to verify the carpool, only one occupant must have the app on his or her phone and use it to verify the carpool. This means that carpoolers who do not have a phone also can participate in the carpool.

[4] This app message is shown here for illustrative purposes only, to show how the app could be used to award credits to carpoolers, such as a toll discount. Actual awards of toll credits by I-95 Express was not part of this research study.

Credit Granted: The app displays a confirmation message that the carpool has been reverified and carpool credit has been awarded. Following the display of this message, the user is brought back to the Home Screen where they may conduct another carpool trip using the app. The confirmation message can be tailored to suit any message relating to access or credits awarded to the carpool by a managed lanes authority. In this specific study, the "3/36" indicates that the carpoolers completed three verified carpools using the app, out of a possible maximum of 36 verified carpools for which the carpool volunteers could be awarded a small monetary incentive for each completed carpool in exchange for participating in the USF Carpool Study.

Definitions/Explanation of Data Types

Table 6 contains definitions for the types of data gathered through the VOD process. More definitions are found in Appendix E.

Table 6. Definitions of Data Gathered through the Verification Process

	Metric	Description
Unique Key	trip_id	trip_id for the occupants
Unique Key	rider_id	distinct name assigned to the occupant found in the camera
	average_real_score	the average realness from the sample images gathered
	average_Exit_score	The average realness from the sample images gathered on the Reverify occupant camera session
	similarity_score	This is the relative similarty of the matched faces between the signature gathered on the first camera session compared to the reverify occupants camera session

Source: RideFlag Technologies, Inc.

Reverification serves two purposes. The first purpose is to serve as a deterrence against the possibility that a driver verifies with an individual, only for that individual to exit the car. For example, a motorist can verify themselves and a friend at the beginning of the trip, but then the friend exits the vehicle while the motorist drives alone. Reverification ensures there are people/occupants at the end of the carpool (as opposed to a single occupant); otherwise, solo drivers will receive the benefit credit. The second purpose is to ensure that another individual does not enter the vehicle at the end of the trip, posing as a passenger with the intent of verifying a carpool that was really a solo. The app uses a patented technology that measures the distance between key facial landmarks to determine a probability that the individuals in the carpool at the beginning of the trip are the same individuals in the carpool at the end of the trip.

Realness uses a proprietary AI model to determine the probability of a real human face. A similarity score represents the relative similarity of the face(s) during initial verification and comparing those numbers during reverification. As such, realness and similarity are used to verify occupancy and to verify the carpool.

Lowering the realness threshold means that the app would grant vehicle occupancy verification using realness scores that represent a somewhat lower probability that the facial data captured in the camera screen was registering a face that was real.

Increasing the realness threshold to verify vehicle occupancy will result in the user needing ideal lighting conditions and be an appropriate distance from the camera when verifying and reverifying. By lowering the realness threshold, the data collected remains the same; however, the lower threshold allows for a better user experience by making the vehicle verification process easier to complete. For purposes of testing the app, switching to a lower realness threshold enhanced the evaluators' ability to test the accuracy and reliability of the app. This is because evaluators were able to check the app's verification using a lower realness threshold, against digital photos of the carpoolers taken concurrently during the carpool test trips. This would answer the question: How accurate and reliable is the app's ability to correctly verify a true carpool, even with a less strict realness threshold? The realness threshold can ultimately be configured to modify the strictness of the tool.

As with realness, facial geometry data also were collected to later determine the optimal facial geometry requirement. The purpose of including the facial geometry data is to determine the probability of the same people verifying and reverifying at the start and end of the trip, respectively.

The facial geometry similarity threshold would reflect a policy choice by decision makers about the desired degree of certainty that the app accurately identifies if the same people are present at the start and end of a carpool trip. The greater the facial geometry requirement, the more time it will take for the app to verify the carpool at both the beginning and end of each carpool trip. This time requirement seeks to balance the level of convenience and user-friendliness that carpoolers experience with the potential accuracy of the similarity determination.

Description of Alterations Made to App During the Testing Process

Testing of the app began July 20, 2022, and continued through February 28, 2023. As the pilot progressed, continual learning and collection of feedback from the testers led to some alterations of the app to increase participation and improve user experience of the tool. These changes to the app are described here.

The RideFlag staff incorporated changes to the app that allowed collecting actual digital photos, in addition to the facial dimension data. RideFlag staff worked on a new app build to include photos for each verification and reverification attempt. A forced app update was pushed to the private app store to ensure these changes were live among study participants.

Ordinarily, the app does not collect digital photos, but for the USF Carpool Study, the digital photos enabled the evaluators to visually verify the carpools, compared against the concurrently collected vehicle occupancy detection data to determine the accuracy and reliability of the app. Evaluators elected a Silent Photo Submission, in which digital photos are submitted upon successful reverification without the app users having to submit the photos themselves (i.e., Active Photo Submission). Photo submission was disclosed in the Agreement to Participate.

RideFlag staff also incorporated a map function as part of the trip details gathered by the RideFlag app for each carpool trip logged. The map function enabled evaluators to verify that the app registered whether and where the carpool traveled along the geofenced portion of the Interstate segments. The RideFlag app pinpoints locations of carpool start verification, entry into the Interstate polygon, exit from the Interstate polygon, and reverification at the end of the carpool trip.

At the end of August 2022, the 'Verify HOV' button was changed to 'Verify Carpool' based on confusion expressed by one participant.

Prior to the second (September 6) email invitation that SFCS issued through their Mail Chimp account, and prior to onboarding existing volunteer carpool testers from Utah, RideFlag completed a major upgrade to the realness technology and sent out an auto update to users on August 29, 2022. Utah testers received updates to their app to reflect the designs and flows of the Florida build.

The pilot boundaries were expanded after recruitment began to include additional participants. This included the northward and southward expansion of the original I-95 pilot corridor to include a length of approximately 120 miles, the addition of an I-275 corridor in Tampa Bay, extending from SR 60 in Westshore, approximately

18 miles to the Hillsborough County line, and the addition of a 48-mile segment of I-15 in Utah that allowed for testing by a small subset of participants from the 2019 UDOT pilot.

On September 29, there were carpools that were not being reverified at the end of the trip because the face similarity threshold was too high. Facial geometry, if turned on, will take more time due to a variety of reasons.

Facial geometry requirements at reverification were also later lowered during the later part of December 2022. The rationale for reducing similarity threshold is to enhance the overall user experience and encourage volunteers to continue logging trips.

A late October update of the app addressed the occurrence of a camera capture logic issue that started a carpool if two people were present, but if one person removed their face prior to the end of the camera validation process. This would result in data captured for just one person and no exit data for that person. The October update of the app addressed this issue.

At the beginning of December 2022, the realness threshold was lowered to allow for a quicker experience for participants as the tool's performance was maintaining a high level even when the thresholds were lowered. This resulted in a better user experience for participants, while maintaining accuracy of the HOV status.

Chapter 4. Data Collection

This section contains an explanation of possible outcomes of carpool validation accuracy as diagrammed by a Confusion Matrix, characteristics of the carpool trips logged, and a comparison of findings of degree of vehicle occupant detection accuracy.

Possible Outcomes of Carpool Validation Accuracy—Confusion Matrix

Figure 6 illustrates the four possible outcomes of the test of the RideFlag app. These include a True Positive in which a real carpool (high occupancy vehicle or HOV) is correctly identified as such. A True Negative is a single occupant vehicle (SOV) that is correctly identified as a SOV. A False Positive is an SOV that is incorrectly identified as a carpool. A False Negative is a carpool that is incorrectly identified as an SOV.

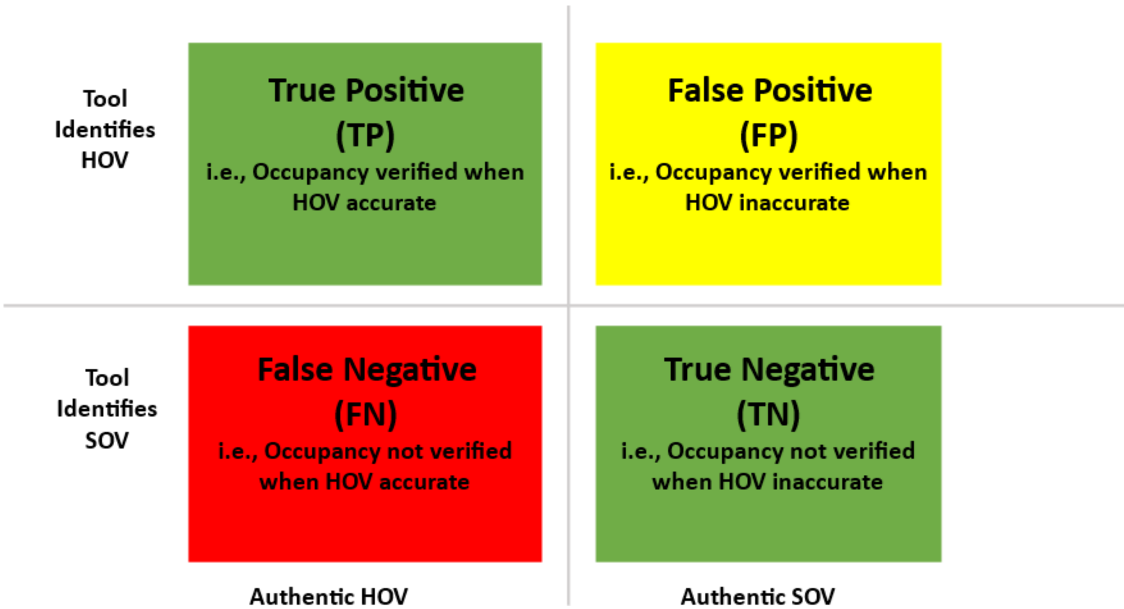

Figure 6. Possible HOV declaration outcomes using RideFlag.

For the version of the app used for this study, the accuracy of the app was reported by RideFlag as ≤2 percent incidence of False Positives (i.e., SOV misidentified as an HOV), and ≤1 percent incidence of False Negatives (i.e., HOV misidentified as an SOV). Evaluators independently tested these rates of accuracy.

Characteristics of the Logged Carpool Trips

The test was launched on July 7, 2022, with first carpool trip logged on July 20, 2022. Carpool trips were logged thereafter through February 28, 2023.

Table 7 provides the tally of total logged carpool trips from the test, indicating a determination of carpool validations by RideFlag. These trips totaled 837. Table 8 shows the total number of carpool trips that are the logged trips from which a determination could be made that these were either TP, TN, FP, or FN. These trips totaled 783. The remaining 54 trips represent those logged trips for which the data were inconclusive.

Table 7. Determination of Carpool Validations by RideFlag

Total Logged Carpool Trips	Percent of carpool trips	Number of carpool trips
Grand Total	100%	837
Those that were validated as True Positive	77.5%	649
Those that were not validated as True Positive	22.5%	188

Table 8. Inclusion of Carpool Trips in Confusion Matrix

Total Logged Carpool Trips	Percent of carpool trips	Number of carpool trips
Grand Total	100%	783
Those that were validated as True Positive or True Negative	98.2%	769
Those that were False Positive or False Negative	1.8%	14

Chapter 5. Evaluation of Logged Carpool Trips

The data for all 837 logged trips were manually reviewed by both RideFlag and by the evaluators. The app was set up to automatically allow verification on entry, regardless of realness, to collect the data, and so that at the end of the trip, the reverification process would insist on realness on exit, with the same faces as there were on entry. The app could deny validation to any true negatives (an SOV attempting validation as a carpool).

Using the 683 logged carpool trips that were initially validated by the app as True Positive (i.e., authenticated HOV, as initially reported in the MS Access database), evaluators compared the 'Pass' determination against the collected information. This inspection was to flag any logged carpool trips for which the evaluators had questions. These flagged trips were provided to RideFlag for their further inspection. This part of the evaluation would determine if there were any False Positives.

Likewise, the data generated from the remaining 154 logged carpool trips that were initially not validated by the app also were similarly studied to determine the reasons why these trips were not validated. This part of the evaluation would determine if there were any False Negatives (an HOV that was not validated by the app as such).

The carpool log data were transmitted from the mobile phones of app testers to the RideFlag secure server and stored in a Microsoft Access (MS) database. Table 9 lists the type of data in the database. The database provided four queries for which tables were developed, containing data that could be sorted in several ways.

Table 9. Data from Logged Carpool Trips Documented in a Microsoft Access Database

Queries	Data items
Trip counts by user	Name, user ID (mobile phone number), email address, number of unvalidated logged carpool trips, number of validated logged carpool trips.
Trip counts by date	Date, number of unvalidated carpool trips, number of validated carpool trips
Daily trips	Unique trip ID, passenger miles traveled, trip date and start time
Trip detail list by user	Name, unique trip ID, whether validated, whether award was granted, trip date and end time, occupancy

There were a series of forms in the database, including Trip Counts by User for which authorized team members could access details of all the carpool trips logged by that user. Details for each carpool trip by user were listed in a summary that included trip ID, trip start date and time, end date and end time, occupancy, cumulative carpool miles traveled, trip passenger miles traveled, whether the trip was validated, and whether the trip was rewarded.

The app ordinarily does not take photographs, nor does the app retain trip data after the trip is ended. However, for purposes of this pilot, digital photographs, using the app testers' camera function on their mobile phones, were taken for comparing the photos against the determination of carpool vehicle occupancy by the app. These photos were automatically taken by the app during both initial verification and reverification. All volunteers participating in the pilot signed the Agreement to Participate that explained that photographs would be collected. Photo comparisons enabled the evaluators to verify the accuracy of the mobile app's determinations.

For each trip by a user, evaluators could also access further details. These included a trip map, trip start photo and trip end photo, and a table showing realness and facial geometry scores used to determine vehicle occupancy. It is important to emphasize that the collection of verification and reverification photos were specific to this pilot for both quality assurance and research purposes.

Figure 7 illustrates a screenshot from the MS Access database containing calculations by the app for validating a 2-person carpool and showing some of the measurements of facial characteristics executed by the mobile app. These measurements are taken at the beginning of the carpool trip (i.e., entry or 'Ent') and then again at the end of the carpool trip (i.e., exit or 'Ext'). These metrics also are defined in Table 6. For safety purposes, the app was inactive while the user was driving/in motion. At no point were carpoolers required or encouraged to interact with the app while driving. The entry measurements are compared with the exit measurements to compute a score of facial geometry and similarity probability.   In this example, there are two occupants detected in the vehicle.

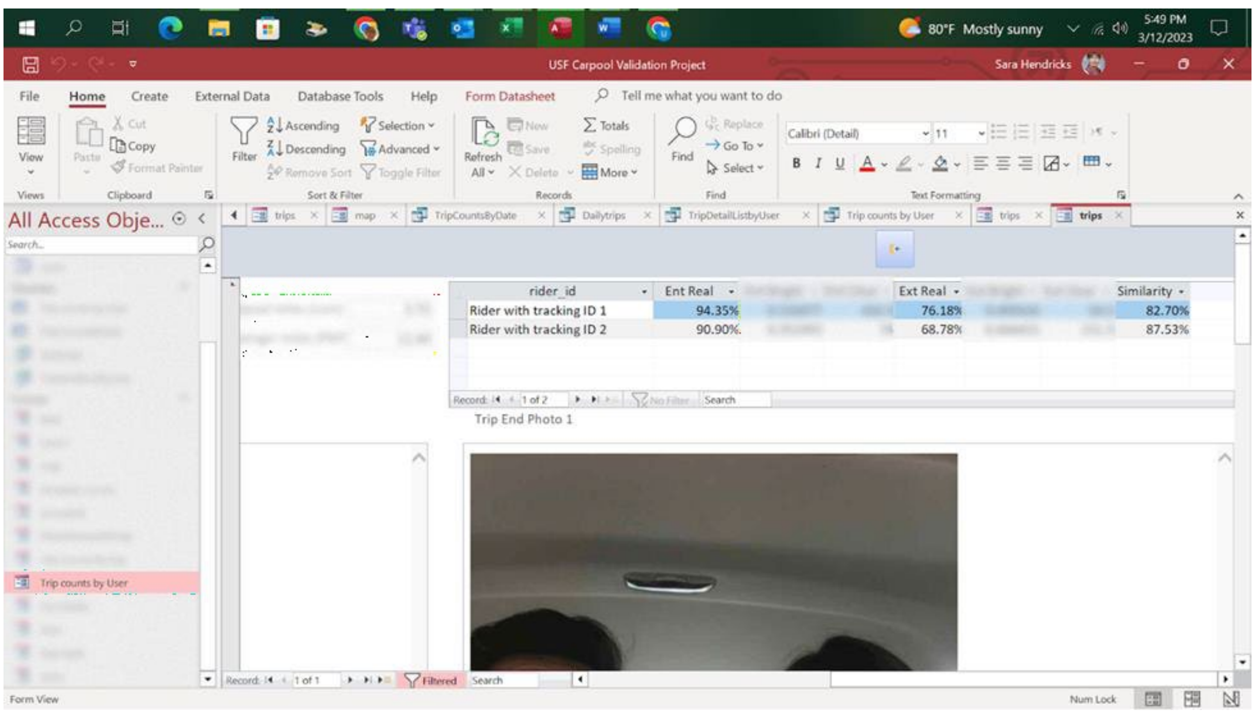

Figure 7. Example MS Access database screenshot for a validated 2-person carpool trip.

Example of a Carpool Trip Determined to be a True Positive

The MS Access database contained a Trip Counts by User form for each carpool, displaying trip characteristics and a 'Details' button to click on to retrieve more information about a specific trip.

Figure 8 is a screen shot from the MS Access database showing the details for one trip. Clicking on 'Details' opens this screen where there are digital photos taken concurrently with the biometric facial dimension data shown in the table and a link to a map of the trip. Figure 9 is a screen shot from the MS Access database after clicking on 'Map'. A screen opens that displays the carpool trip showing entry and exit points of travel within a geofenced segment of I-275 (i.e., highway polygon).

The trip log indicates that this carpool trip was granted entry onto the I-275 facility after successfully verifying occupancy at the beginning of the trip, then the carpool trip was recorded as valid at the end of the trip. These data displays are like those generated for each carpool trip logged through the app by each carpool volunteer.

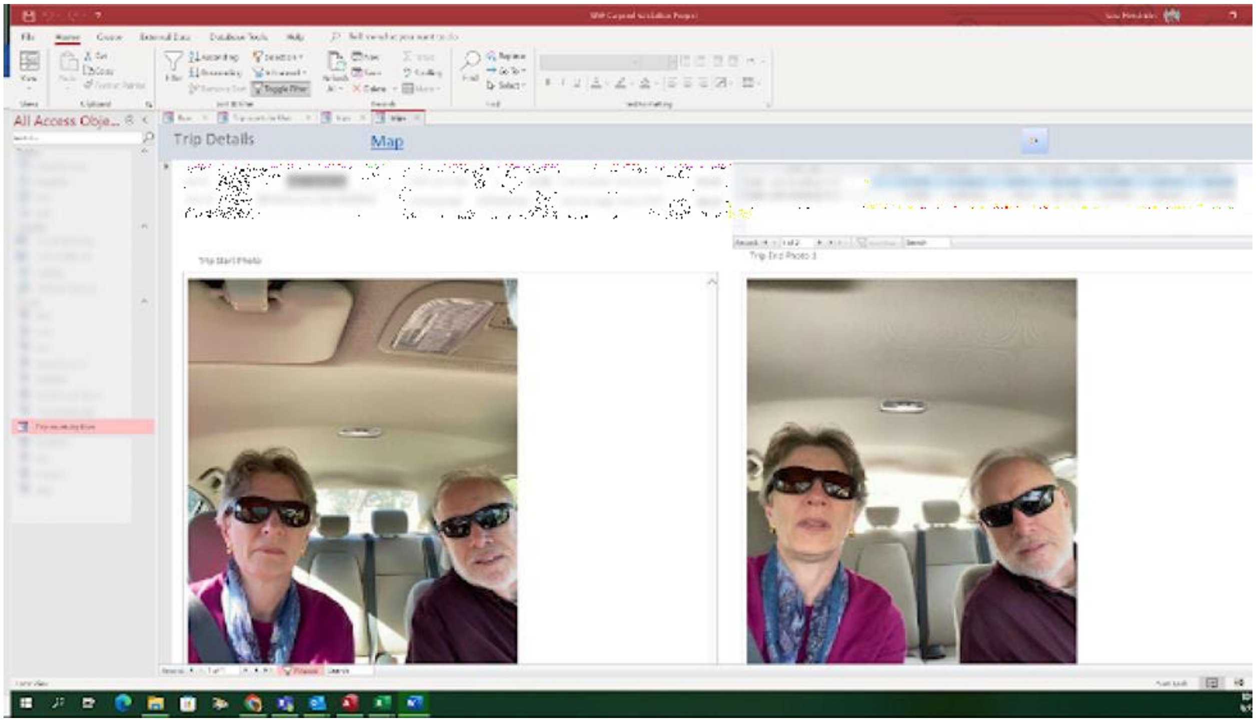

Figure 8. Screenshot from the MS Access database showing carpool trip details.

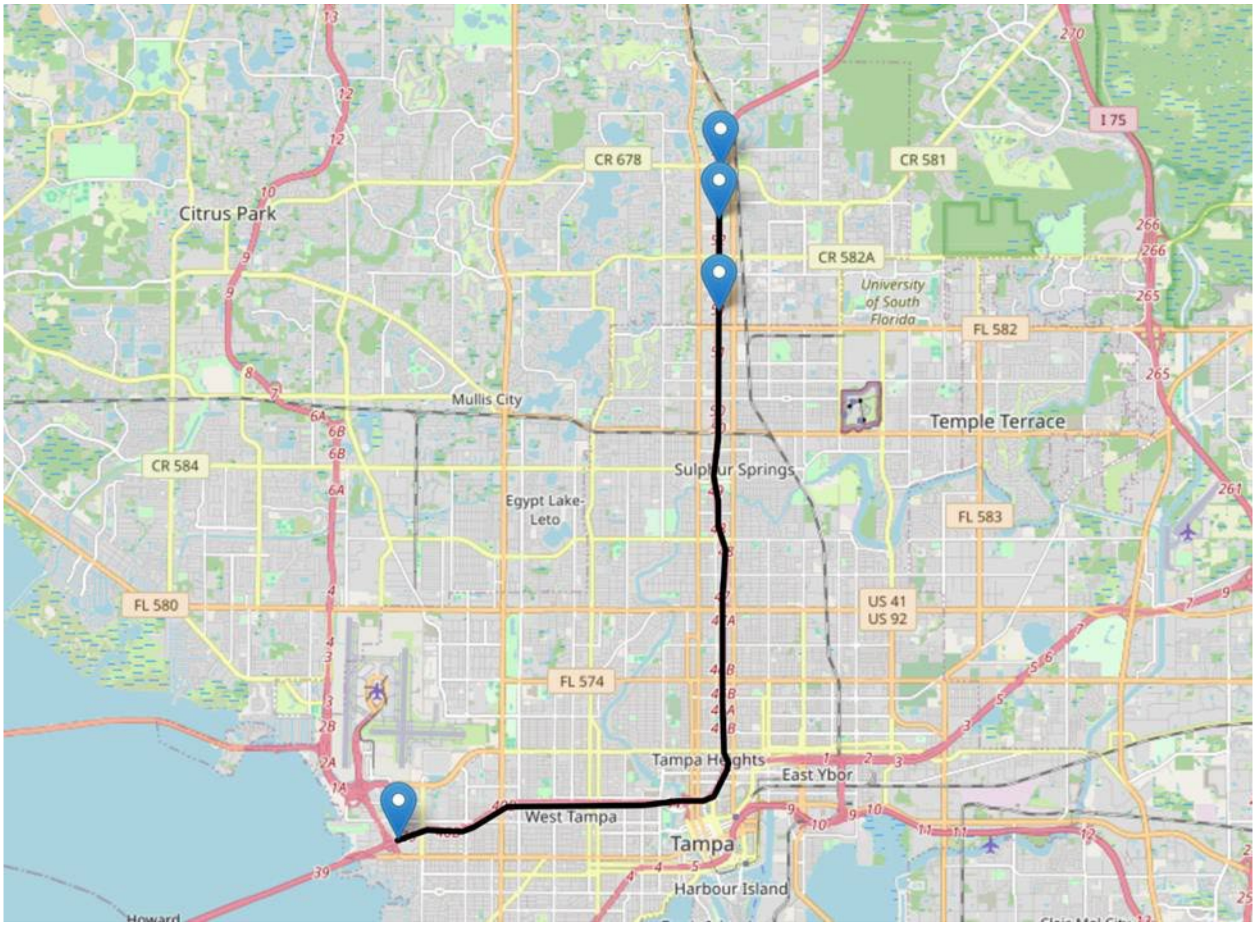

Figure 9. Screenshot from MS Access database showing mapped carpool route on I-275.

There is facial geometry created from facial characteristic measurements taken during the entrance verification, which the app compares with the measurements taken during the exit verification. Evaluators examined all records of logged carpool trips. Several examples of what appeared in the digital photos from other carpool trips are described in Table 10. The comparison of facial biometrics can determine that the faces measured prior to the start of the carpool trip are the same faces measured after the trip ends, even though there are variations in light and shadow, facial expression, angle of face, and other differences.

Table 10. Examples of Accurate Occupancy Validation of True Positives under Varying Conditions.

	Entrance verification	Exit verification	Trip ID, Date, trip start time
1	One face wearing sunglasses	Same face wearing no sunglasses	2/16/23 6:48am
2	One face with glare reflecting off eyeglasses	No glare on eyeglasses	2/7/23 5:22pm
3	Blurred image of both faces	Blurred image of both faces	1/23/23 5:22pm
4	Both faces can be seen easily	One face is more than half cut off by the frame of the image	12/9/23 4:53pm
5	Both faces with normal expression	One face with greatly exaggerated comical expression	1/3/22 7:20am
6	Unusual light and shadow patterns on faces	No shadow but low light	2/8/23 5:28pm
7	One face is lowered and looking downward	Both faces looking at phone, red light illuminating faces, perhaps taillights of vehicle ahead of them	1/23/23 6:24pm
8	No one wearing sunglasses	Both wearing sunglasses	1/15/23 1:24pm
9	One face obscured by passenger side light glare	Less glare on faces	1/11/23 4:03pm
10	Both wearing hats, and one face is wearing large sunglasses and there is a hand in front of this face	One occupant is wearing hat and the other occupant whose face was obscured in entrance verification is no longer wearing a hat or sunglasses	12/18/22 11:00am
11	One face is dim and partly cut off	Faces are reversed in order, the face that was partly cut off in entrance verification is now wearing eyeglasses and surprised face expression	12/27/22 6:28pm
12	One face wearing sunglasses	Same face now wearing sunglasses on his forehead and face is turned away from the camera	12/22/22 12:19pm

Reasons Why a Carpool Trip might not be Validated

In this pilot, some logged trips were invalidated. One might expect that an invalidated logged trip would represent a True Negative, or an SOV trip. During this pilot, there were just four SOVs. However, a true HOV would achieve carpool validation through successfully conducting a multi-step process. For purposes of testing the accuracy and reliability of the app, validation included three separate steps:

1. Carpoolers verify their vehicle occupancy prior to their carpool trip by gathering all faces in the camera frame;
2. Carpoolers enter the polygon defined by a geofenced portion of selected Interstate facility, and travel for at least some pre-set minimum distance (e.g., 1.0 mile), then exit the polygon; and
3. Carpoolers re-verify vehicle occupancy at the end of the carpool trip, which is reflective of what is done during the initial verification.

There were observed reasons for a carpool trip to fall short of achieving a successful verification. For some of the invalidated trips, the faces in the carpool were not reverified at the end of the trip. The app test was set up such that all carpool verification requests are accepted at the beginning of the trip, even if facial realness score is low, then during the reverification at the end of the trip, the app would insist on faces with higher realness score and both faces must be the same as the faces measured at the beginning of the trip (similarity score). Reasons carpools may not have succeeded in being reverified at the end of the trip include:

- Carpoolers may not have traveled in the highway test segment (geofenced polygon) that was specified by the study. A few of these types of trips were taken by volunteer carpool testers as the first few of their logged trips in the USF Carpool Study. They might not have completely understood initially that they had to travel along some portion of the geofenced highway test segment for the carpool trip to be validated. The app was set up to verify the number of occupants ***and also*** to verify that the carpool traveled on a specified highway facility. In the case of the USF Carpool Study, the designated facilities included segments of the I-95 Express Lanes in South Florida, the I-275 in Hillsborough County, and I-15 in Utah. Confirming that the carpool used a particular highway facility simulates the circumstance in which use of the facility could be awarded at a discount or toll free. This would result in the carpool trip to be validated.
- Carpoolers simply forgot to reverify at the end of their trip, despite receiving an audible prompt in addition to the app screen visual prompt to ‘Reverify HOV’. Forgetting to ‘Reverify HOV’ was easier to do than one might expect. The evaluators experienced forgetting to reverify. This might happen because arrival at the destination prompts travelers to think ahead about their next activities in their day. In some of the reverifications, the carpoolers had forgotten to reverify immediately after the trip, so the reverification was taken in a location outside the car. This was acceptable if the reverification was done within a reasonable amount of time at the end of the carpool, and the signature score verified that the faces at the end of the trip were the same as the faces at the beginning of the trip and would result in a True Positive.
- Thresholds set for realness and similarity may have been overly strict. These settings in the app can be adjusted for the optimum balance between accurately reverifying true carpools and accurately denying reverification to SOVs, based upon sponsor preferences.

Table 11 illustrates the conditions for carpool trips to be validated and why the process could fail.

Table 11. Conditions for Carpool Trips to be Validated

	Trip validated and rewarded	Trip not validated	Notes
Verify vehicle occupancy at beginning of trip, enter polygon, conduct reverification, **faces reverified**	X		
Verify vehicle occupancy at beginning of trip, enter polygon, conduct reverification, **faces fail reverification**		X	App prompts carpoolers to re-try to reverify if lighting is too dark
Verify vehicle occupancy at beginning of trip, enter polygon, **fail to conduct reverification**		X	
Verify vehicle occupancy at beginning of trip, **fail to enter polygon**		X	

Ideally, the volunteers would ordinarily travel along that portion of highway for their regular commute, such that participation in the app test would not require them to go out of their way. In some of these cases, carpoolers chose to alter their usual commute route to accommodate the study requirement. In a few cases, researchers enabled participation by lengthening the defined test segment to encompass carpoolers' normal commute route and make it convenient for them to participate. When this could not be done, some volunteers chose to stop participating.

The carpool also had to remain on the Interstate for a minimum distance before the app registered the carpool trip as validated. In a few cases, the logged carpool trip was not validated because the carpoolers exited the Interstate immediately after they entered. This minimum distance was later shortened by the RideFlag staff for purposes of validating carpool trips taken solely for purposes of testing the app. A real-life application of the app would specify a minimum distance driven on the facility to ensure the legitimacy of the carpool trips taken on the facility and eligibility for a toll credit or other reward.

One issue that was specific to GPS was identified during the study. Some devices received software updates that restricted GPS in very specific user scenarios. During the study, RideFlag implemented app enhancements to mitigate this issue. Regardless, the trips where GPS was not tracking are cases that were included in the 54 inconclusive trips.

RideFlag staff reviewed all trips that were flagged by the researchers and submitted comments and explanations about them. These comments provided further explanation about how the app works and addressed any misinterpretations of the results.

Evaluation of Results of the RideFlag App Test

Evaluators reviewed all logged trips, including the following data for each trip.

- Biometric data generated by the app during each logged trip
- Map generated from GPS tracking of each trip
- Entry photos taken by each carpooler's phone prior to entry onto the highway polygon
- Exit photos taken by each carpooler after exiting the highway polygon

A total of 837 trips were logged by the carpool testers. The app determined that 649 of these trips were validated and 188 trips were not validated.

There was one False Positive (FP) among the verified carpool trips. In this instance, the exit photo revealed that the second occupant was a different person from the two that were seen in the entry photo. The reason why the app verified this trip was because the app determined a high similarity between one of the occupants on entry and a different occupant on exit. This occurred because the similarity threshold to determine the likelihood that occupants are the same from beginning to end was set too low. This threshold can be re-set.

Among the 188 unvalidated trips, there were 121 True Negatives (TN). A TN can occur when the app correctly determines that the carpool is an SOV or if a trip did not have exit reverification data. This can happen if the app user opens the app to reverify, and only one face is detected, or they do not reverify. This also can happen if no trip was taken, as when the app user opens the app, then closes it moments thereafter. The trip was closed due to inactivity by the user or the server. A TN also can occur if the carpooler did not correctly use the app. The most common user error was not traveling for some portion of the carpool trip within the highway polygon or traveling for too short a distance in the polygon, such as using an on ramp then immediately exiting via an off-ramp (e.g., in attempt to secure reward).

There were 54 unvalidated trips marked as inconclusive. For 31 of the unvalidated trips evaluated as inconclusive, the trip log contains a map showing travel in the highway polygon, but no photos and no exit data; however, these trips were all rewarded. For most of them, the app did not validate the trip. This makes sense if there is no exit data. The study team unanimously agreed to grant carpool credits for trips that sometimes did not meet requirements, either based on in-app reports or user claims. This was done to encourage continued participation, thereby yielding additional data that was used to inform the study's research. For some of the trips, the app did validate the trip, but this would not make sense if there were no exit data. Without entry and exit photos, there is no way to independently confirm what happened. For another 23 unvalidated trips judged as inconclusive, GPS was not tracking or stopped tracking, so there is no way to verify if travel occurred within the polygon. For some but not all of these logged trips, the app did not validate the trip. These cases of GPS not tracking were likely the user's phone error. These cases were from multiple volunteer carpoolers, and these happened throughout the duration of the pilot. Because there is no way to know for sure what happened, these 23 cases were set aside as inconclusive.

Table 12 lists descriptions of trips where there was insufficient data to draw a conclusion verifying HOV and also different kinds of app user error.

Table 12. Description of Trips with Inconclusive Data or App User Error

Trip Category	Number of Occurrences	Description
True Negative (TN)	99	
Outside polygon	44	Users did not enter the polygon during the trip
Distance	7	Users did not travel the required minimum distance in the polygon
Other user error	7	User did not use the app correctly which resulted in error
No trip taken	41	The trip was closed by the user or the server due to inactivity
Inconclusive	54	Due to lack of data
No image	31	No image was available
No GPS	23	No GPS data was confirmed

There were 13 false negative trips found among the unvalidated trips. For nine of these trips, the threshold for the similarity score was set too high. This threshold can be lowered. For one FN, there was a data transfer issue and for three FNs, the issue is not known why the HOV was not validated.

There were many more validated carpool trips than unvalidated trips in the dataset of trips logged by the app testers. Instead of accuracy, the metrics of sensitivity and specificity were applied because these metrics are independent of prevalence. In the use of binary classification metrics, sensitivity is the proportion of HOVs that were correctly predicted as TPs.

Sensitivity = $TP/(TP + FN)$ = 648/(648 + 13) = 0.9803

Specificity is the proportion of TNs that were correctly predicted as TNs.

Specificity = $TN/(TN + FP)$ = 121/(121 + 1) = 0.9918

Informedness is a summary metric. It is sensitivity + specificity – 1 = 0.9721.

Positive predictive value (PPV) (precision) describes the proportion of positive predictions (TP) that were in fact TPs.

PPV = $TP/(TP + FP)$ = 648/(648 + 1) = 0.9803

Negative predictive value (NPV) describes the proportion of negative predictions (TN) that were in fact TNs.

NPV = $TN/(TN + FN)$ = 121/(121 + 13) = 0.9030

Figure 10 below summarizes the breakdown of the number of trips that could be presented in a confusion matrix, describing the data collected and evaluated during the pilot, as determined independently by the evaluators.

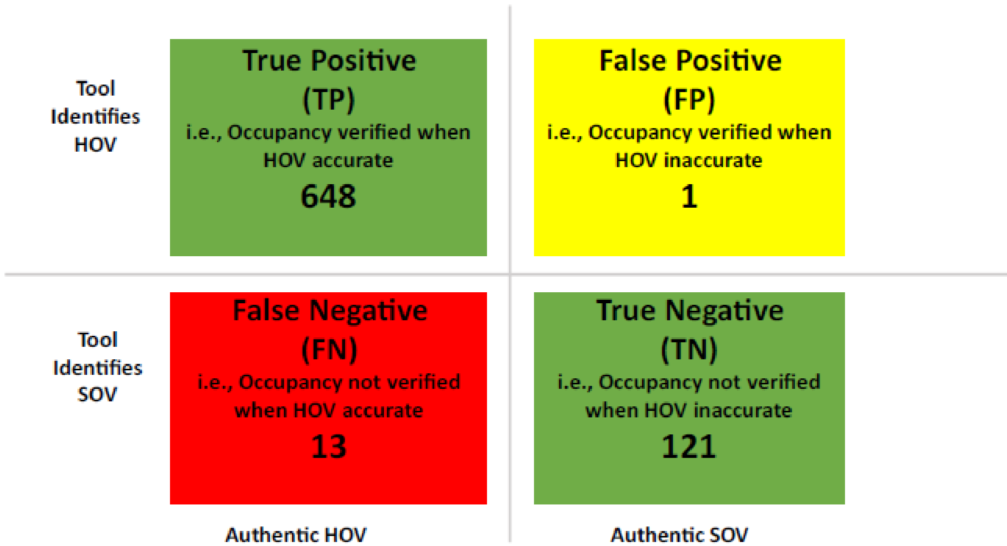

Figure 10. Confusion matrix with results of the USF Carpool Study

True Negatives

A True Negative determination by the app is when an SOV is accurately determined as such. One study participant used pictures of himself and his carpool partner, both printed images and digital images, to attempt a carpool validation. RideFlag's realness prevented the app from verifying the picture (i.e., fake face) as real. The app configuration at the time of the study allowed users to fail initial verification but permitted them to continue their carpool trip for research purposes, with the condition that they pass the reverification stage for the credit. This user did not pass the reverification. This rule was implemented to assess if users were having issues starting legitimate trips, as evidenced through image review.

Because the pilot was set up to test the app with volunteer carpoolers who were participating by logging carpool trips in good faith, there should not have been any true negatives. Evaluators also tested a different version of the RideFlag app that was configured not to automatically validate a carpool upon initial entry onto the geofenced highway. This app version was used by evaluators to test the app using SOVs for staged True Negative scenarios. After more than 30 attempts, evaluators failed to 'fool' the app into verifying an SOV as a carpool. Figure 11 below illustrates phone screen shots of the RideFlag app prompts that are displayed as an evaluator attempts to verify a carpool with just one vehicle occupant. She holds up a fake head and posters of faces. The app does not validate two faces as real.

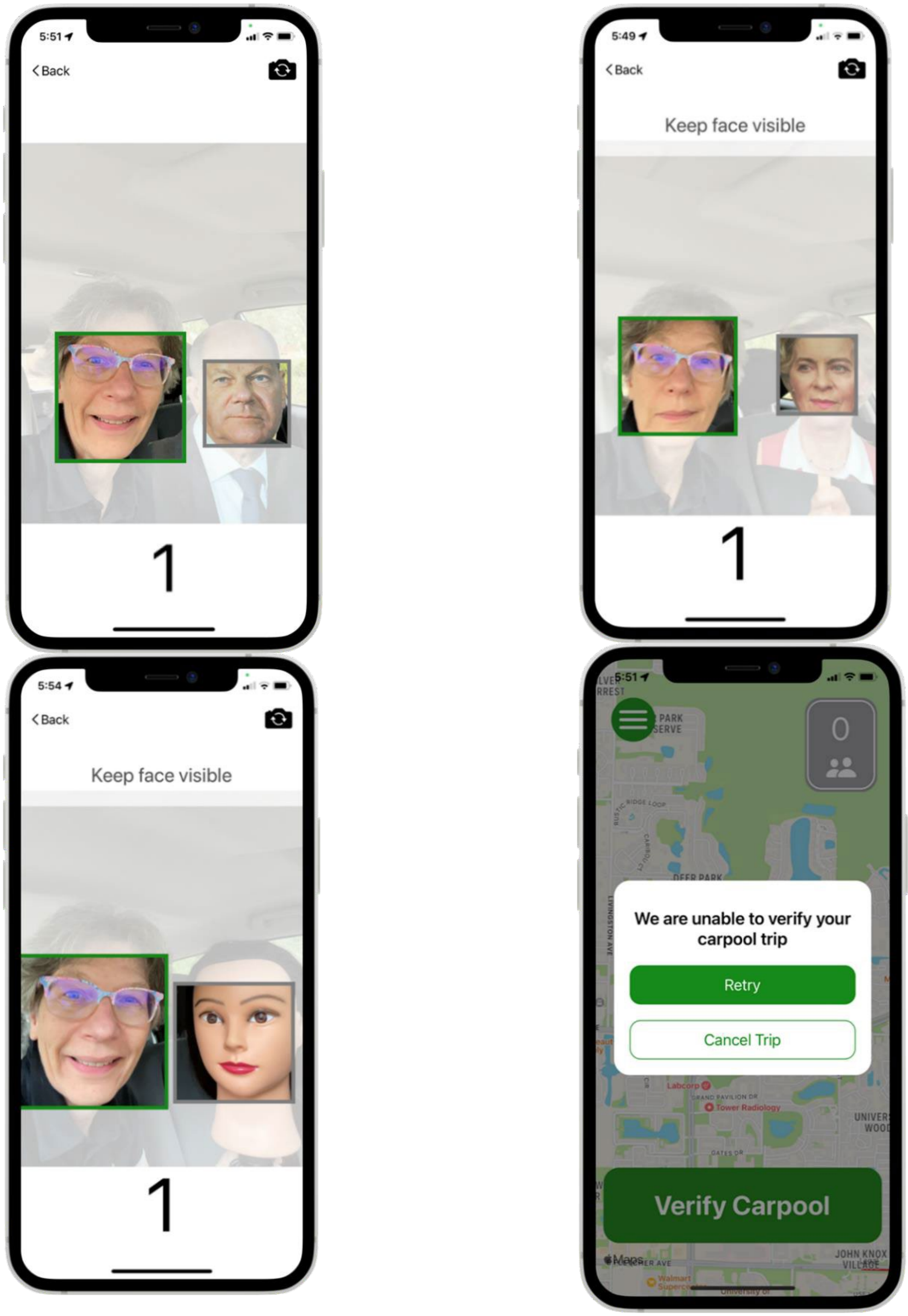

Figure 11. NICR evaluator attempts to validate an SOV as a carpool.

Chapter 6. Key Outcomes

During the pilot of the RideFlag vehicle occupancy detection app, 17 out of 25 individuals who successfully logged at least one validated carpool trip, went on to log the maximum number of trips allowed in the study. Most study participants used iOS phones; however, there were study participants that used Androids and successfully logged the maximum number of trips. The test demonstrated that 98.03 percent of the time, the app correctly determined TPs and 90.3 percent of the time, the app correctly determined TNs. The test demonstrated that the app could successfully be used to deliver notification of the delivery of an incentive or reward. The test also has demonstrated that the app can verify that faces are real under a variety of challenging circumstances, including changed lighting conditions.

During the pilot, from July 2022 through February 2023, continual learning from the collection of data enabled RideFlag to modify the app to improve its performance. These modifications included realness technology upgrades early in the pilot, adjusting the thresholds for realness and facial geometry, and addressing a camera capture logic issue.

Among the lessons learned, the settings in the app must be modifiable. The managed lanes authority may desire more or less strictness in how high the computed probability of realness and facial geometry must be for the carpool to be verified as valid. The greater the strictness, the higher the probability that a real carpool will be identified as such; however, it also may require more seconds for the carpoolers to hold their faces in the camera frame for verification to occur. This added time requirement might be experienced as an inconvenience to some carpoolers. This means that there is a trade-off between accuracy and user friendliness, or the degree to which the end user will be willing to use the app to verify their carpool. This suggests that the use of an app such as RideFlag for delivering incentives to validated carpools must be accompanied by policy decisions regarding the level of willingness to accept a certain amount of misdeclarations while maximizing user convenience and incentivizing carpooling. It also suggests that during early deployment of this type of vehicle occupancy detection, strictness thresholds for realness and similarity should be tested so that its application reflects the managed lanes authority’s preferences for balancing the rates of False Positives and False Negatives.

Chapter 7. Conclusions

For the app to work as it is designed, carpoolers are partly responsible for ensuring the validation of their carpool trip. As one might expect, there is a learning curve among users such as remembering to capture the initial photo before starting the trip and validating their vehicle occupancy at the end. Carpoolers also must look directly at the phone camera and wait for the verification signal, to ensure sufficient biometric facial data has successfully been recorded by the app, so that the carpool trip can be validated.

A sponsor of app implementation, such as a toll road authority or commuter assistance program, could choose to strike a different balance between shortening the time required for detection and heightened accuracy, which satisfies the minimum accuracy threshold to achieve the agency's goals. For example, the study team for this pilot elected to reverify every carpool at the end of each carpool trip, to establish false negative rates but other sponsors may prefer to reverify a smaller subset of carpool trips, selected at random, to reduce the burden on the user. Additionally, it is recommended that during a soft launch of the app, there should be a shakeout period for determining the acceptable balance of false negatives and false positives, by deciding on an appropriate signature threshold.

During the pilot, the app continually improved performance, both in accuracy and in user experience. This suggests that with added upgrades and adjustments, the accuracy of the app to detect vehicle occupancy, while improving user-friendliness, will continue to increase.

Future Research

The USF Carpool Study did not automate the delivery of the reward ($5 Amazon egift card per recorded trip up to 36 trips) through the app. Future research may examine how to automate the process whether it be gift cards or discounts or other types of incentives such as reserved carpool parking. Future research may also explore other elements of back-office integration with the app. In Utah, the vendor demonstrated on a limited scale the app's capability to connect to an agency's back-office system through secure API calls. They claim these calls can be completed in real time or can be matched during the trip building process. The initial Utah build used GPS to determine the location and time that users enter the highway. This information is reported to the server along with the occupancy status. The roadside system measures the location of the vehicle on the road and the app confirms the occupancy status of the vehicle.

Another area of research is to glean an understanding of the segments of the traveling public who see the benefits of the app. Some aspects of the app may cause hesitancy in adoption among some groups. The USF Carpool Study build included saving photos and a map of where they entered and exited the geofenced corridor in the database. These features were designed for verifying the accuracy for this USF Carpool Study. Other sponsors may wish to maintain those features for the same reasons. This could result in some consumer resistance to use the tool. A social marketing approach could provide insight into what would make the app more attractive than the alternatives or what benefits would outweigh the barriers of using it. Finally, the USF Carpool Study did not focus on counting everyone in the vehicle, just whether there was more than one person. For areas that incentivize only carpools of three or more people, more testing would be necessary. That being said, counting more occupants is a configurable option. At the time of this report, RideFlag has concluded a Phase-1 Pilot with the Metropolitan Transportation Commission in the San Francisco Bay Area and is preparing for a deployment with the State Road and Tollway Authority in Atlanta, Georgia.

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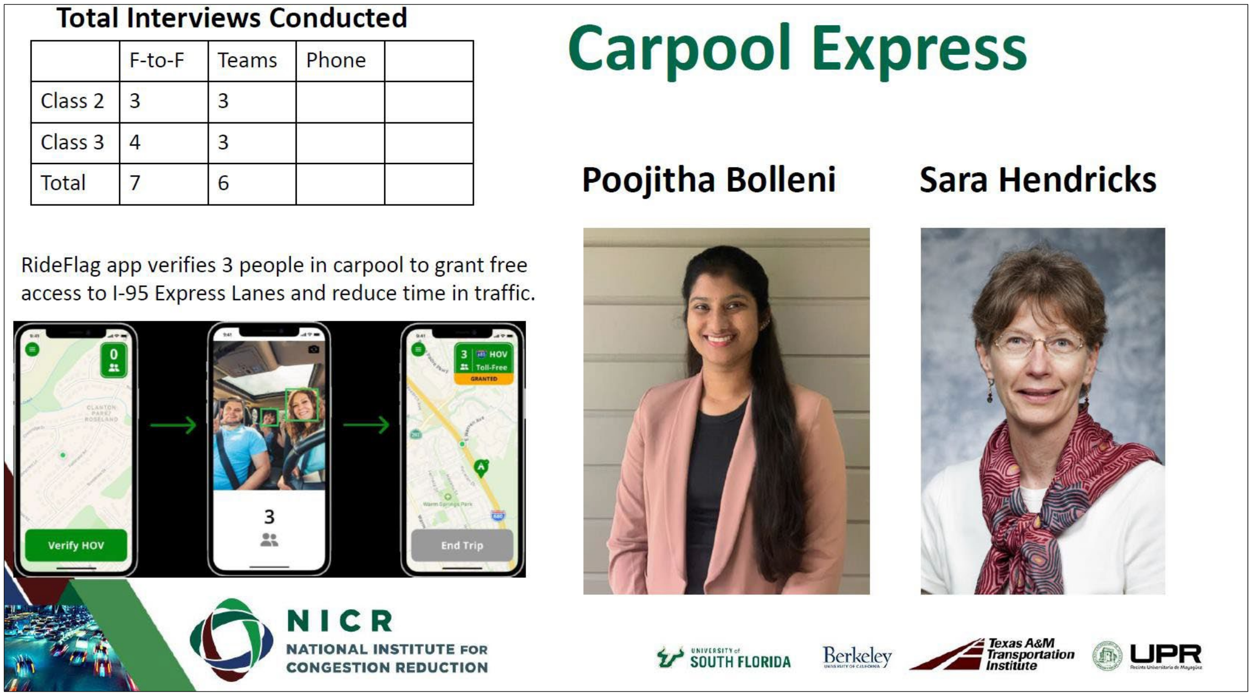
Appendix A

I-Corps Presentations Documenting Customer Discovery



Results of Customer Interviews

Customer Segment	Initial Hypothesis	Value Proposition to be tested
Motorists	Motorists will be glad that scofflaws are removed from the Express Lanes	✓ Receive incentives and rewards for carpooling. ✓ Enjoy faster speeds on the Express Lanes due to less vehicles using them.

- **Caitlin, motorist**
- **Danielle, motorist**
- **Evan, motorist**

1) **It might be a problem remembering to take a picture before starting the ride.**
2) **Taking a picture was an extra step.**
3) **Difficult to take a picture while driving.**
4) **People might not care enough to take this extra step or carpool.**

Danielle might not use RideFlag if there were no rewards or incentives. Danielle suggested the following: Rewards program. 10% off from any retail stores. Little incentives or small tokens.

1) **Evan said there is no point in developing the app if there is no law enforcement giving citations for vehicles with one passenger using the HOV lanes.**
2) **Evan said he would use the app only if the law requires it.**
3) **The app solves only one issue, would be great if it could have multiple usages.**

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Results of Customer Interviews

Customer Segment	Initial Hypothesis	Value Proposition to be tested
Managed lanes authorities	Primary concern is increasing toll collection	✓ Improve HOV lane enforceability ✓ Improve traffic flow and passenger throughput

- **Laurence Leeds, Senior Adviser, South Florida Commuter Services**
- **Jeremy Dilmore and Tushar Patel, District Five TSM&O**
- **Peter Vega, District Two TSM&O**

"FDOT discourages using phone apps while driving."

Vanpooling has untapped potential to grow in South Florida due to longer distance commutes

I95 Express Lanes operate at slower speeds than general purpose lanes

Insufficient traffic congestion in South Florida to garner political support to put enough carrots and sticks in place to support wider use of carpooling

FDOT has been "burned" by vendors many times in the past

RideFlag app needs to be able to integrate with FDOT back-office system

Equity: FDOT will not use RideFlag if customers cannot access it

FDOT is looking for app multi-functionality; RideFlag app must be able to integrate

Validation accuracy rate must be very high

FDOT very skeptical of new technologies, must prove that user cannot trick the app

FDOT's big challenge is insufficient staffing and expertise in the TSM&O field

Vendor claims of privacy and security safeguards are generally not believed by the public

Toll pricing in Jacksonville and elsewhere is so low that people will just pay the toll rather than choosing to carpool to avoid paying

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Business Model Canvas—Customer Segments

	Jobs	Pains	Gains
Customer Profile—Managed Lane Authority	• Toll collection • Vetting vendors • Evaluating technologies and products • Planning/construction • Deployment/operations	• Dishonest vendors • Products and services that break • Inability to maintain equipment • Insufficient staff expertise • HOV unenforceability	• Equity, sustainability • Multimodal mobility • Safety • Efficiency • Safeguard privacy, security of public • FDOT 511 alerts and other communications all in one app download
	Products and Services	**Pain Reliever**	**Gain Creator**
RideFlag	• Vehicle occupancy validation • Instant digital rewards delivery • RideFlag can integrate with FDOT back-office system	• High carpool occupancy validation accuracy	• RideFlag can integrate with other apps, e.g., link to ridematching gamification to supplement carpooler rewards, i.e., RideAmigos in SFCS • Supports carpool/vanpool travel modes • Eliminates need for external cameras

Business Model Canvas—Customer Segments

	Jobs	Pains	Gains
Customer Profile—Managed Lane Authority	• Toll collection • Vetting vendors • Evaluating technologies and products • Planning/construction • Deployment/operations	• Dishonest vendors • Products and services that break • Inability to maintain equipment • Insufficient staff expertise • HOV unenforceability	• Equity, sustainability • Multimodal mobility • Safety • Efficiency • Safeguard privacy, security of public • FDOT 511 alerts and other communications all in one app download
	Products and Services	**Pain Reliever**	**Gain Creator**
RideFlag	• Vehicle occupancy validation • Instant digital rewards delivery • RideFlag can integrate with FDOT back office system	• High carpool occupancy validation accuracy	• RideFlag is multifunctional and can integrate with other apps • Supports carpool/vanpool travel modes • Eliminates need for external cameras

Next Iteration

Customer Segment	Revised Hypotheses
Motorists	• If an app is required to be used by carpoolers and vanpoolers to use the I95 Express Lanes for free, it would discourage motorists from carpooling. • The RideFlag app would pair well with other capabilities like FL511 alerts.
Managed Lane Authorities	• The procedure to snap a photo after all passengers enter the car, and before the driver shifts into Drive, abides by FDOT policy to not use a smartphone while driving. • An accurate carpool occupant validation of 99 percent is sufficient to satisfy FDOT's requirement for accuracy. • There are protocols that can be applied to verify to FDOT's satisfaction that user data security and privacy are safeguarded.

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Future Interview Questions for Managed Lane Authorities

1. What standards for product technical support would be required for FDOT to be confident in the vendor's responsiveness and reliability?
2. How is product performance tested by FDOT? How good is good enough?
3. What standards must be used to meet FDOT requirements for cybersecurity and customer data privacy?
4. What is expected of vendors regarding provision of support to FDOT for engagement with the media and with customers?
5. What would FDOT think of a "hackathon" to see if vehicle occupany detection can be tricked?
6. What should I have asked?
7. Who else should we talk with?

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Future Interview Questions for Motorists

1. What incentives would attract you?
2. Do you think this application is something you would use regularly, on daily basis?
3. Do you like to carpool? Is it an option you would like to choose on regular basis?
4. What is something you like and dislike about the carpooling?
5. Which is more of an obstacle to carpool: having to take a photo daily of the carpool participants or pre-registering the participants in the vehicle? Why?
6. What else should I have asked?
7. Who else should we talk with?

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Target Interview List

- Fred Heery, FDOT Central Office, State TSM&O Program Engineer
- Alex Adames, FDOT District One TSM&O Manager
- Megan Arasteh, FDOT District Seven TSM&O Manager
- Brian Stanger, District Five, Modal Planning
- Eric Hill, Director of Transportation Systems Management & Operations, MetroPlan Orlando
- Courtney Reynolds, Transit Planning Manager, VHB, Inc. reThink commuter assistance program for FDOT District Five
- Kenneth Boden, Manager of Commuter Services, Tampa Bay Area Regional Transit Authority
- Dion Beucknam, Corporate Rental Manager, Commute with Enterprise, South Florida office
- Margaret Kubilins, City of Tampa Traffic Engineer and former FDOT District Seven TSM&O project manager
- Dheeraj Sai Chava, Data Engineer, CVS , Former USF BAIS student.
- Nikhila Raviprolu, Graduate Student Assistant at MUMA college of Business, USF Engineering management Graduate Student.
- Daniel Prashanth Naguri, Cloud Engineer, Adobe, Former USF BAIS student.

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Results of 2nd Set of Customer Interviews

Customer Segment	Revised hypotheses after first set of interviews	Value Proposition to be tested
Motorists	• If an app is required to be used by carpoolers and vanpoolers to use the I95 Express Lanes for free, it would discourage motorists from carpooling. • The RideFlag app would pair well with other capabilities like FL511 alerts.	✓ Receive incentives and rewards for carpooling. ✓ Enjoy faster speeds on the Express Lanes due to less vehicles using them.

- **Dheeraj Sai Chava**

Dheeraj presently works at CVS as a data engineer. He carpools during holiday trips and during grocery shopping. If he had a chance he would always choose carpooling and he does not really like driving alone.

Dheeraj has traveled on I95 a few times. He thinks that HOV lanes are helpful to travel faster. He is excited about RideFlag and would use the app. He said that it would be great if carpoolers who travel to the same area could enter different drop-off locations.

Incentives that would interest Dheeraj: free toll pass, free parking spots in the destination area, certain % discount in fuel or any other commercial businesses.

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Results of 2nd Set of Customer Interviews

Customer Segment	Revised hypotheses after first set of interviews	Value Proposition to be tested
Motorists	• If an app is required to be used by carpoolers and vanpoolers to use the I95 Express Lanes for free, it would discourage motorists from carpooling. • The RideFlag app would pair well with other capabilities like FL511 alerts.	✓ Receive incentives and rewards for carpooling. ✓ Enjoy faster speeds on the Express Lanes due to less vehicles using them.

- **Daniel Prashanth Naguri**

Daniel presently works at Adobe as a cloud engineer. Daniel would choose to carpool when ever possible. He is an enthusiast for saving fuel and reducing pollution.

Daniel has used the I95 several times and has always used the HOV lanes, once or twice he has seen cars with only one person using the HOV lanes and since there were no police officials on that day, the single occupant cars have exploited the HOV services. He also had a doubt if even travelling with dogs was considered carpool.

Daniel was thrilled about the RideFlag application. He also was concerned on how it would stop the single occupant vehicles to use the HOV lanes. He suggested that Single occupant vehicles should be fined a huge amount for using the HOV lanes.

He said that it would be helpful if there were any incentives provided because he must take the time to actually register himself in the program, download the application and remember to use it. It would be helpful if he got any incentives for taking the time to do the steps.

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Results of 2nd Set of Customer Interviews

Customer Segment	Revised hypotheses after first set of interviews	Value Proposition to be tested
Motorists	• If an app is required to be used by carpoolers and vanpoolers to use the I95 Express Lanes for free, it would discourage motorists from carpooling. • The RideFlag app would pair well with other capabilities like FL511 alerts.	✓ Receive incentives and rewards for carpooling. ✓ Enjoy faster speeds on the Express Lanes due to less vehicles using them.

- **Manthena Surya Narayana Rohith Varma**

Rohith presently works at Nielson as a software engineer. He has carpooled several times. He said that he would carpool only if necessary and would sometimes choose not to carpool depending on the circumstances.

He has used the I95 HOV lanes while he stayed in Miami for 2 months. He said that during the peak business hours sometimes there was no difference between the HOV and normal lanes. So, if he would carpool during his work hours it sometimes really would not matter if he used or did not use the HOV lane.

Rohith said that he would use the RideFlag application only if it gave him incentives, otherwise RideFlag might be an extra effort to his routine. He would not use it if there were no benefits.

A list of few incentives he would like are, free toll, free parking spots in prime location and prime time, % discount on fuel, reward points to use in groceries or flight tickets.

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Results of 2nd Set of Customer Interviews

Customer Segment	Revised hypotheses after first set of interviews	Value Proposition to be tested
Managed lanes authorities	• The procedure to snap a photo after all passengers enter the car, and before the driver shifts into Drive, abides by FDOT policy to not use a smartphone while driving. • An accurate carpool occupant validation of 99 percent is sufficient to satisfy FDOT's requirement for accuracy. • There are protocols that can be applied to verify to FDOT's satisfaction that user data security and privacy are safeguarded.	✓ Improve HOV lane enforceability ✓ Improve traffic flow and passenger throughput

Margaret Kubilins, P.E., City of Tampa, formerly worked in TSM&O at FDOT District Seven and is now the City's Smart Mobility Chief Engineer. We discussed the different kinds of apps that the City uses and what the City's needs are.

The City wants apps that provide real-time data management as applied to right-of-way permitting for utility contractors. The City wants this process to automatically push out traffic advisories via Twitter ad Google and feed information on lane closures to WAZE. Field inspectors need highly accurate lat./long. coordinates attached to maintenance work orders. Moovit's Mobility-as-a Service (MaaS) pilot will own the data—the City wants to keep potential privacy and security breaches at arm's length.

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Results of 2nd Set of Customer Interviews

Customer Segment	Revised hypotheses after first set of interviews	Value Proposition to be tested
Managed lanes authorities	• The procedure to snap a photo after all passengers enter the car, and before the driver shifts into Drive, abides by FDOT policy to not use a smartphone while driving. • An accurate carpool occupant validation of 99 percent is sufficient to satisfy FDOT's requirement for accuracy. • There are protocols that can be applied to verify to FDOT's satisfaction that user data security and privacy are safeguarded.	✓ Improve HOV lane enforceability ✓ Improve traffic flow and passenger throughput

Alex Adames, FDOT District One Interim TSM&O Manager, said they are involved in the FRAME project (Florida's Regional Advanced Mobility Elements), involving Districts One, Five, and Seven, which uses Connected Vehicle (CV) technology and Intelligent Transportation Systems (ITS) to communicate traffic incidents, harmonize speed, reduce wrong-way driving, and improve freight travel times. The technology uses roadside units, on-board units, and detection devices.

Mr. Adames said that the CCTV units at their transportation management centers are used only for observation, and does not record anything, due to user privacy concerns, and due to data storage limitations.

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Results of 2nd Set of Customer Interviews

Customer Segment	Revised hypotheses after first set of interviews	Value Proposition to be tested
Managed lanes authorities	• The procedure to snap a photo after all passengers enter the car, and before the driver shifts into Drive, abides by FDOT policy to not use a smartphone while driving. • An accurate carpool occupant validation of 99 percent is sufficient to satisfy FDOT's requirement for accuracy. • There are protocols that can be applied to verify to FDOT's satisfaction that user data security and privacy are safeguarded.	✓ Improve HOV lane enforceability ✓ Improve traffic flow and passenger throughput

Chrissie Collins, FMS/AMS Specialist IV, FDOT District One, is the head of IT for District One and previously worked in cybersecurity at FDOT Central Office. My description of vehicle occupancy detection technology made Ms. Collins think of China's use of facial differentiation for behavior modification purposes.

Even if RideFlag is proven to FDOT to be cybersecure and completely protects user privacy, the optics are bad and Ms. Collins does not think carpoolers will use it.

Ms. Collins proposed a technology alternative from the FRAME project, using the MAC addresses of users' Bluetooth devices, and lat./long. coordinates upon entry/exit of the I95 Express Lanes.

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Business Model Canvas—Customer Segments and Value Proposition for Motorists

	Personal Business	Pains	Gains
Customer Profile—Motorists	• Travel to and from work during weekdays	• Cumbersome required carpool registration process. • By FL Rule, fellow carpoolers must both live and work within certain specified radius of each other. • Perception of lack of HOV enforcement. • Perception that there is no time advantage in Express Lanes.	Registered carpools access the Express Lanes for free during rush hour
	Products and Services	**Pain Reliever**	**Gain Creator**
RideFlag	• Vehicle occupancy validation • Instant digital rewards delivery capability	Restore Express Lanes time advantage by giving Authority the means to enforce HOV	Validates carpool for free access to Express Lanes

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Business Model Canvas—Customer Segments and Value Proposition for Managed Lanes Authority

	Jobs	Pains	Gains
Customer Profile—Managed Lanes Authority	• Toll collection • Vetting vendors • Evaluating technologies and products • Planning/construction • Deployment/operations	• Dishonest vendors • Products and services that break • Inability to maintain equipment • Insufficient staff expertise • HOV unenforceability • Public perception	• Equity, sustainability • Multimodal mobility • Safety • Efficiency • Safeguard privacy, security of public • FDOT 511 alerts and other communications all in one app download
	Products and Services	**Pain Reliever**	**Gain Creator**
RideFlag	• Vehicle occupancy validation • Instant digital rewards delivery • RideFlag can integrate with FDOT back office system	• High carpool occupancy validation accuracy	• RideFlag is multifunctional and can integrate with other apps • Supports carpool/vanpool travel modes • Eliminates need for external cameras

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Summary

- **Potential Customers**: motorists along I-95 corridor who are highly motivated to save money, managed lanes authorities, FDOT Central Office Policy Planning Division for vehicle occupancy data
- **Why they would *not* use RideFlag vehicle occupancy detection**: Most FDOT Districts do not operate high occupancy vehicle (HOV) lanes; while security and privacy protections of RideFlag app are strong, public perception may be otherwise and FDOT is sensitive to public perception
- **Lessons Learned about Customer Discovery**: great variation of opinions and preferences within customer groups, thread of conversations can go in unexpected directions, questions beget more questions

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ICorps Findings

From interviews:

- Motorist perception of no enforcement and no time advantage on the 95EL
- FDOT is more concerned about data privacy and security breaches, dishonest vendors, products and services that break, inability to maintain equipment, insufficient staff expertise
- Carpooling, HOV and TDM is noticeably absent from FTP or in its strategic planning documents.
- FDOT is doing project on I75 and I4 in D 1,5,7 for CV and ITS to harmonize speed, reduce freight travel times: more interested in TSM&O
- FDOT rules on I95EL makes it difficult to form and keep an HOV
- FDOT would like RideFlag to be integrated into an all-in-one app with FL511
- The optics are bad regarding facial differentiation

Incentives:

- free toll
- free parking spots in the destination area
- free parking spots in prime location and prime time
- % discount on fuel
- reward points to use in groceries or flight tickets.
- free or discount in sunpass
- free coffee in gas stations or any discount in food and beverages places.

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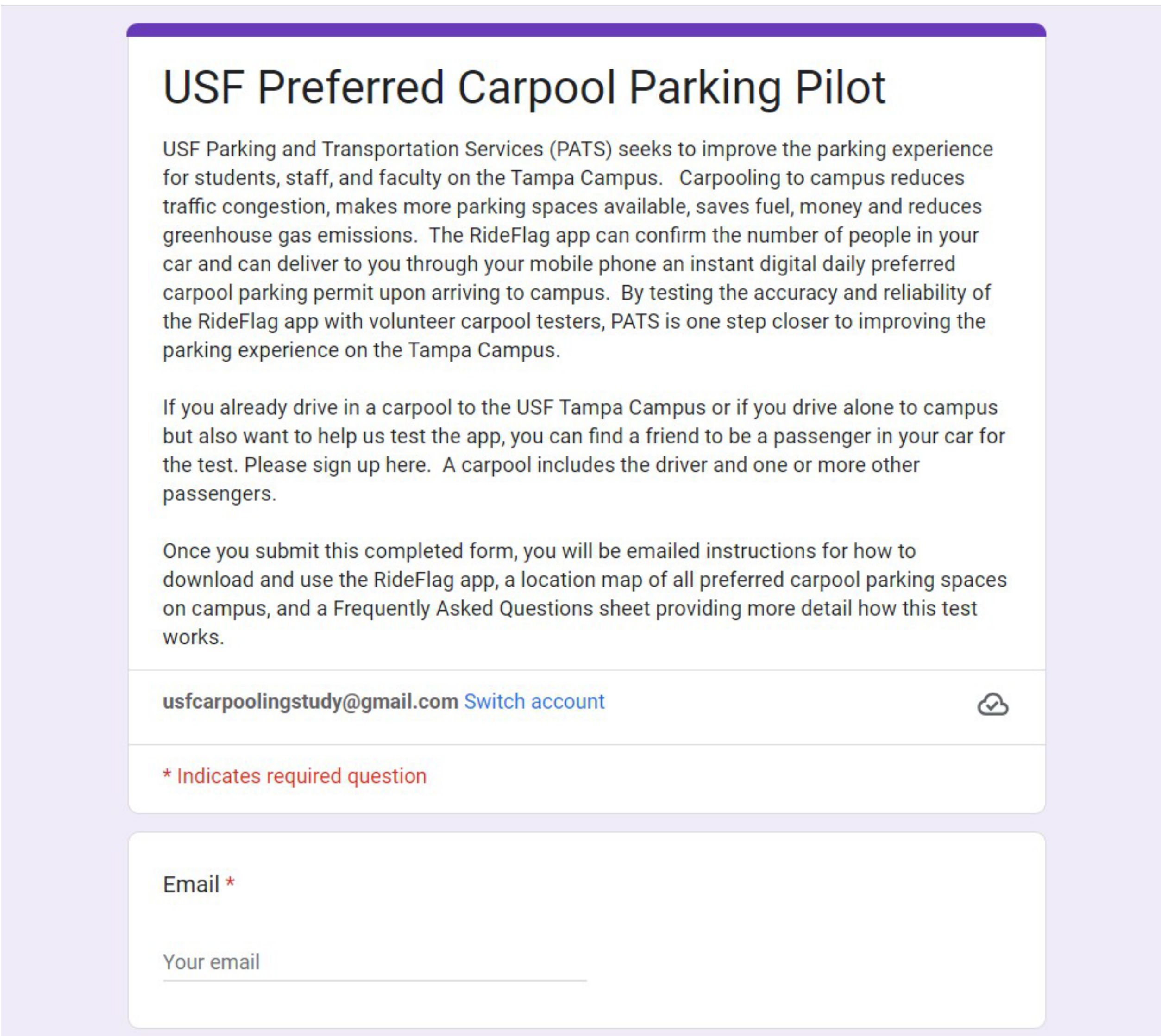
Appendix B

Agreement to Participate Form



USF Preferred Carpool Parking Pilot

USF Parking and Transportation Services (PATS) seeks to improve the parking experience for students, staff, and faculty on the Tampa Campus. Carpooling to campus reduces traffic congestion, makes more parking spaces available, saves fuel, money and reduces greenhouse gas emissions. The RideFlag app can confirm the number of people in your car and can deliver to you through your mobile phone an instant digital daily preferred carpool parking permit upon arriving to campus. By testing the accuracy and reliability of the RideFlag app with volunteer carpool testers, PATS is one step closer to improving the parking experience on the Tampa Campus.

If you already drive in a carpool to the USF Tampa Campus or if you drive alone to campus but also want to help us test the app, you can find a friend to be a passenger in your car for the test. Please sign up here. A carpool includes the driver and one or more other passengers.

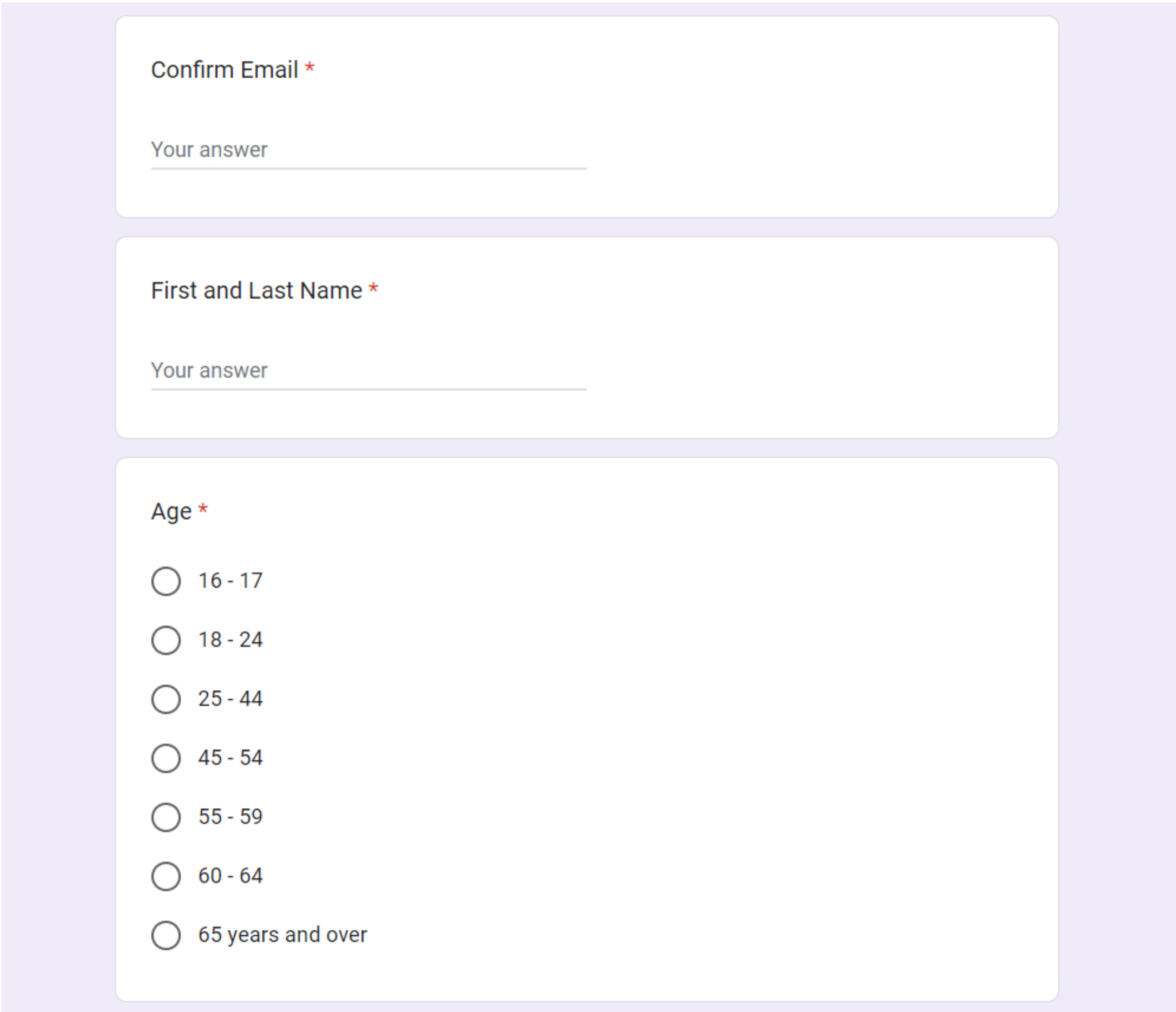
Once you submit this completed form, you will be emailed instructions for how to download and use the RideFlag app, a location map of all preferred carpool parking spaces on campus, and a Frequently Asked Questions sheet providing more detail how this test works.

usfcarpoolingstudy@gmail.com Switch account

* Indicates required question

Email *

Your email



Confirm Email *

Your answer

First and Last Name *

Your answer

Age *

- 16 - 17
- 18 - 24
- 25 - 44
- 45 - 54
- 55 - 59
- 60 - 64
- 65 years and over

Mobile Number *

Your answer

Phone OS (Operating System) *

- ◯ Android (e.g., Samsung, Oneplus, Google Pixel, etc..)
- ◯ IOS (e.g., iPhone)
- ◯ Other: ____

Are you U.S citizen or permanent resident? *

- ◯ U.S Citizen
- ◯ Permanent Resident
- ◯ Other: ____

Are you a USF Employee ? *

- ◯ Yes
- ◯ No

Do you agree to participate in the study? *

- ◯ Yes
- ◯ No

A copy of your responses will be emailed to the address you provided.

Submit

Clear form

Never submit passwords through Google Forms.

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Google Forms

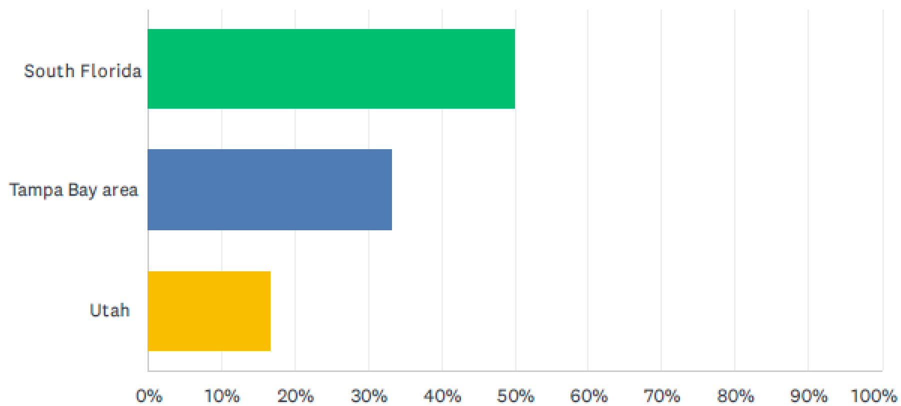
Appendix C

NICR RideFlag Exit Survey

NICR RideFlag Exit Survey

Q1 Please select your location.

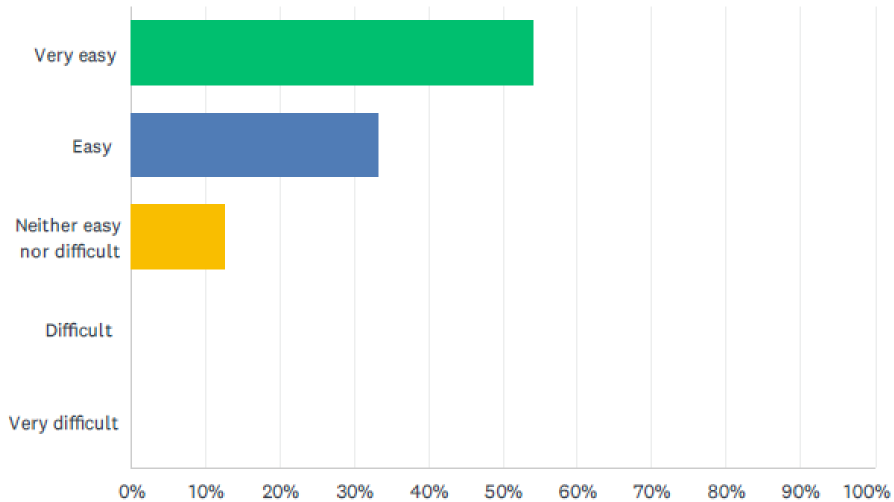
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
South Florida	50.00%	12
Tampa Bay area	33.33%	8
Utah	16.67%	4
TOTAL		24

Q2 How did you find your experience downloading the USF Carpool Study app?

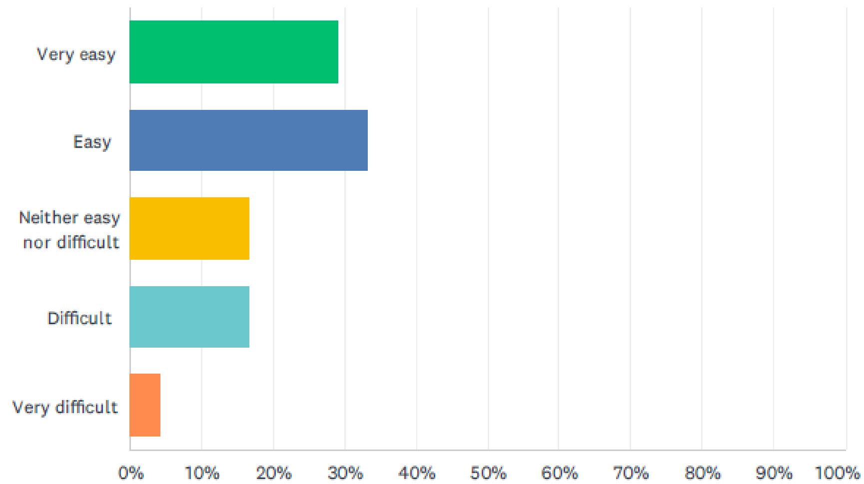
Answered: 24   Skipped: 0



ANSWER CHOICES	RESPONSES	
Very easy	54.17%	13
Easy	33.33%	8
Neither easy nor difficult	12.50%	3
Difficult	0.00%	0
Very difficult	0.00%	0
TOTAL		24

Q3 How did you find your experience logging your first carpool trip using the app?

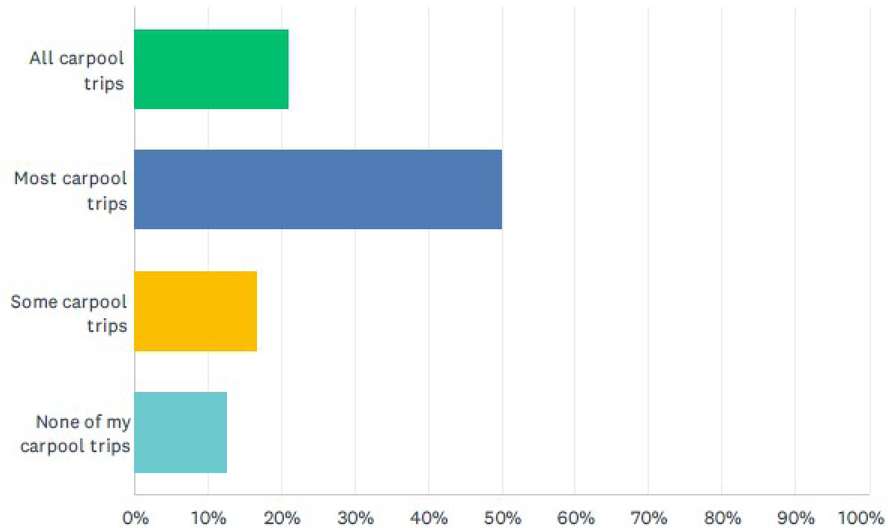
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Very easy	29.17%	7
Easy	33.33%	8
Neither easy nor difficult	16.67%	4
Difficult	16.67%	4
Very difficult	4.17%	1
TOTAL		24

Q4 When you clicked "Verify HOV" or "Verify Carpool", for how many of your carpool trips did the app register all the faces in your phone screen within about ten seconds?

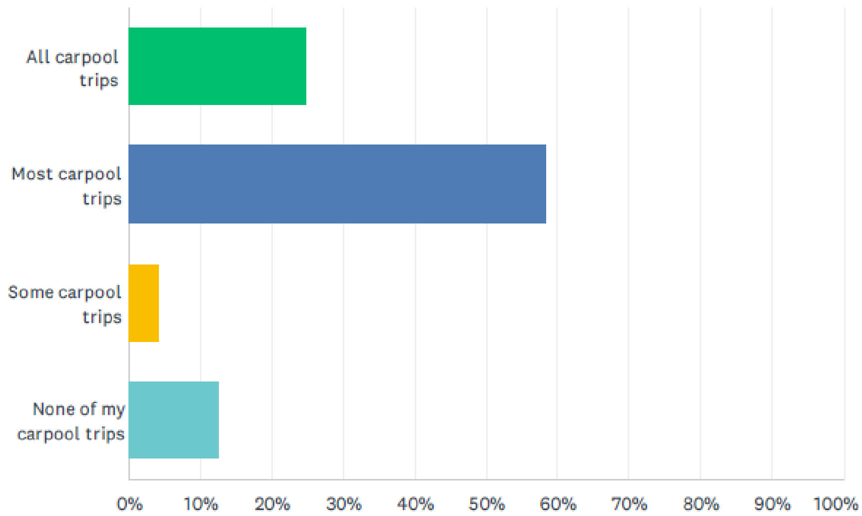
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
All carpool trips	20.83%	5
Most carpool trips	50.00%	12
Some carpool trips	16.67%	4
None of my carpool trips	12.50%	3
TOTAL		24

Q5 For how many of your carpool trips did the app verify your carpool?

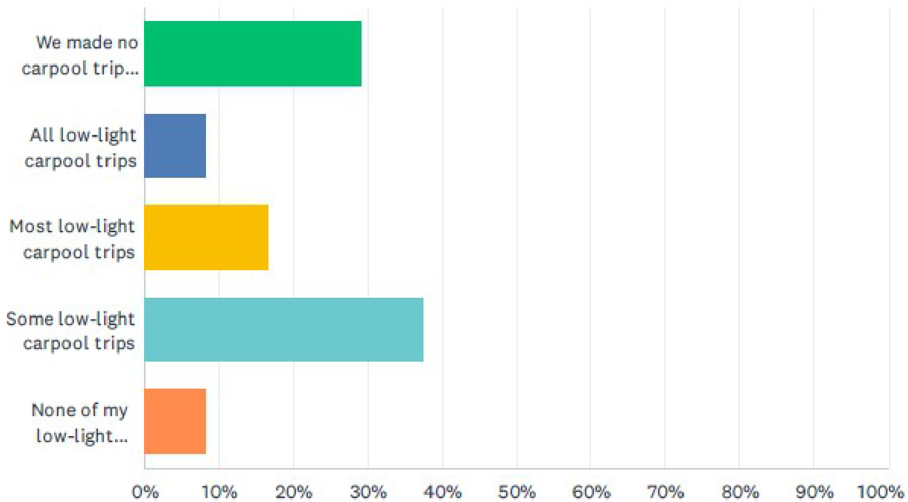
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
All carpool trips	25.00%	6
Most carpool trips	58.33%	14
Some carpool trips	4.17%	1
None of my carpool trips	12.50%	3
TOTAL		24

Q6 For how many of your carpool trips did the app verify your carpool in low light (e.g., dawn, dusk, or night) conditions?

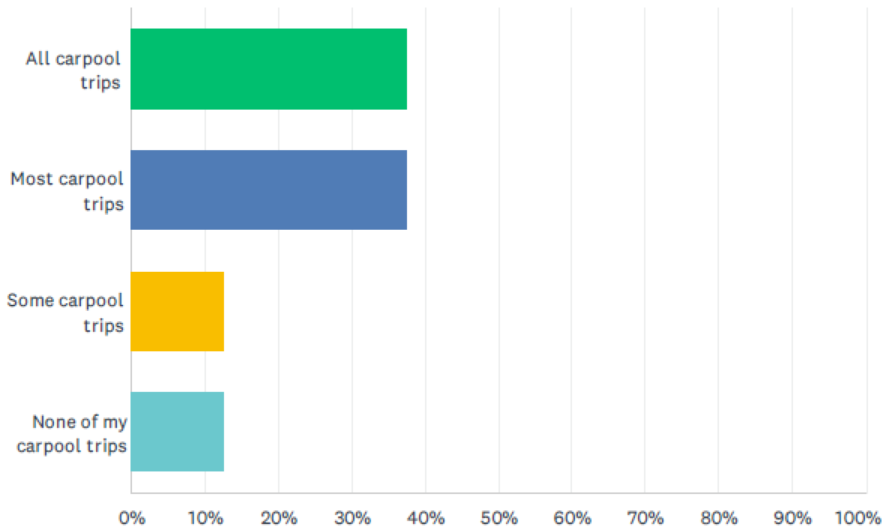
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
We made no carpool trips under low light conditions.	29.17%	7
All low-light carpool trips	8.33%	2
Most low-light carpool trips	16.67%	4
Some low-light carpool trips	37.50%	9
None of my low-light carpool trips	8.33%	2
TOTAL		24

Q7 After each of your carpool trips ended, how often did the app accurately credit your carpool trip in your Trip History?

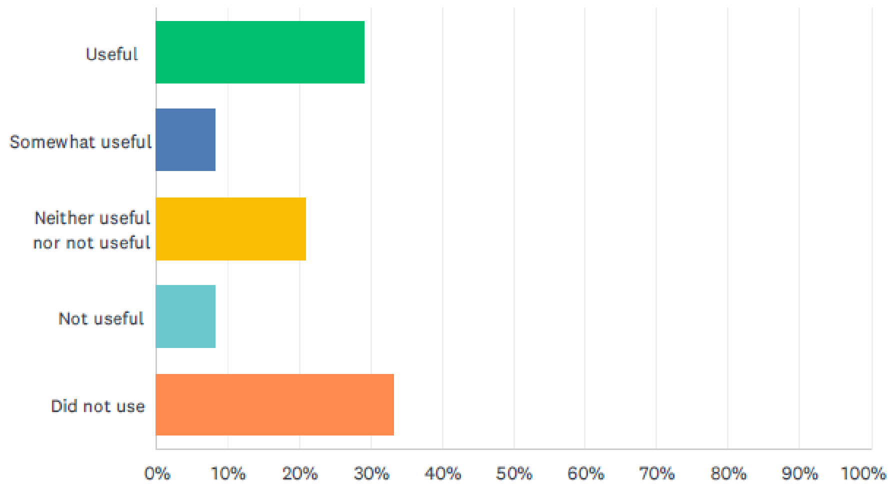
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
All carpool trips	37.50%	9
Most carpool trips	37.50%	9
Some carpool trips	12.50%	3
None of my carpool trips	12.50%	3
TOTAL		24

Q8 How do you rate the Tips in the Help screen?

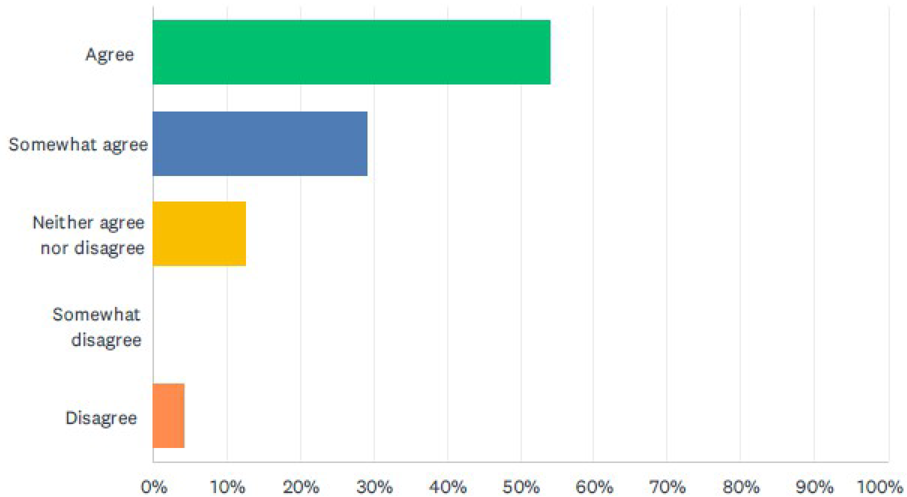
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Useful	29.17%	7
Somewhat useful	8.33%	2
Neither useful nor not useful	20.83%	5
Not useful	8.33%	2
Did not use	33.33%	8
TOTAL		24

Q9 Please rate the extent to which you agree or disagree with the following sentence: "While using the USF Carpool Study app for logging my carpool trips, I feel that my personal privacy is satisfactorily protected."

Answered: 24 Skipped: 0

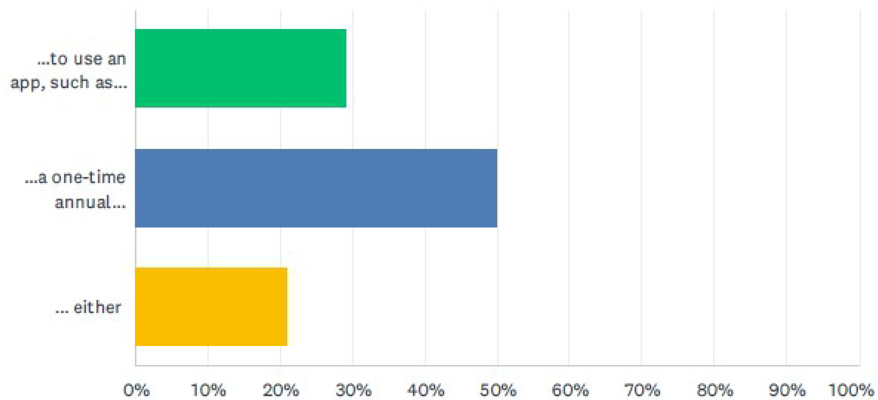


ANSWER CHOICES	RESPONSES	
Agree	54.17%	13
Somewhat agree	29.17%	7
Neither agree nor disagree	12.50%	3
Somewhat disagree	0.00%	0
Disagree	4.17%	1
TOTAL		24

NICR RideFlag Exit Survey

Q10 If I wish to immediately gain free access to a high-occupancy toll lane, I would prefer…

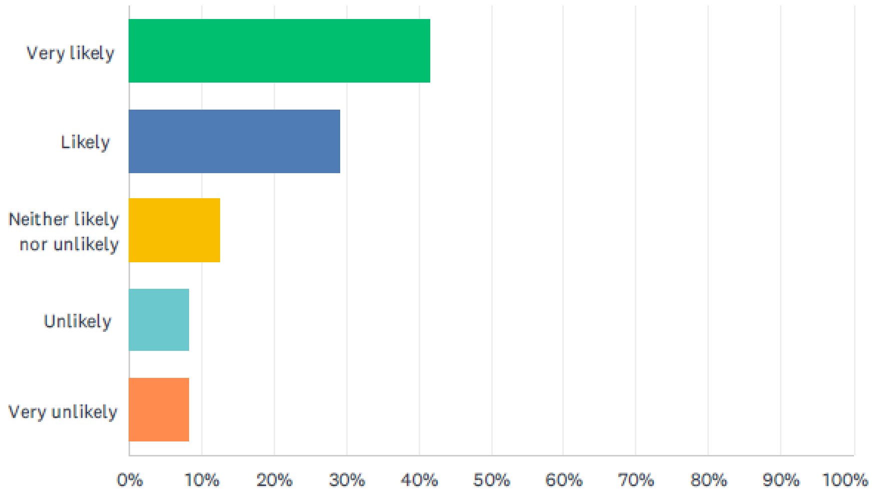
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
…to use an app, such as the USF Carpool Study app, to verify anyone in my carpool each time.	29.17%	7
…a one-time annual pre-registration of each regular member of my carpool with a commuter assistance program.	50.00%	12
… either	20.83%	5
TOTAL		24

Q11 How likely are you to recommend the USF Carpool Study app to a friend, family member, or co-worker who wants to use high-occupancy toll lanes?

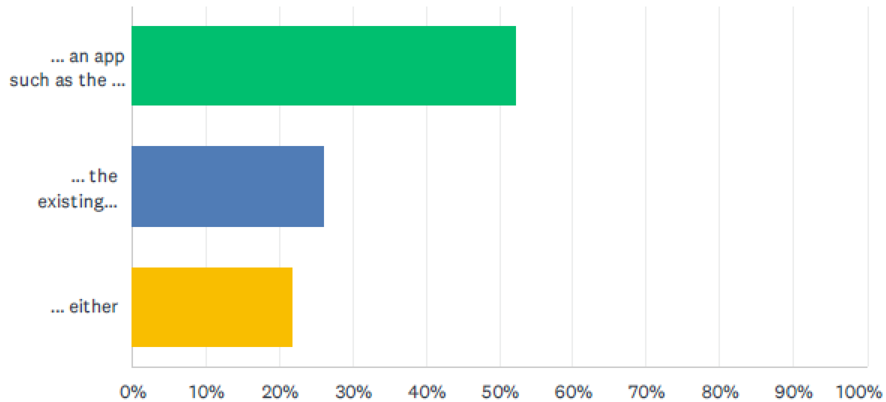
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Very likely	41.67%	10
Likely	29.17%	7
Neither likely nor unlikely	12.50%	3
Unlikely	8.33%	2
Very unlikely	8.33%	2
TOTAL		24

Q12 Compared to the beginning of the study, I would prefer using…

Answered: 23 Skipped: 1



ANSWER CHOICES	RESPONSES	
… an app such as the USF Carpool Study app	52.17%	12
… the existing carpool verification process in my region	26.09%	6
… either	21.74%	5
TOTAL		23

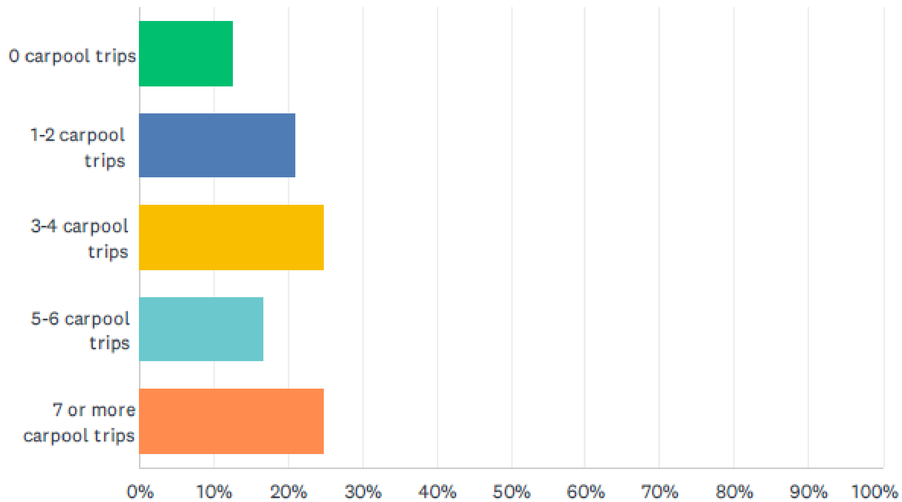
Q13 Please explain you answer to the previous question

Answered: 15 Skipped: 9

#	RESPONSES	DATE
1	The app was very glitchy. I stopped logging my trips all together as it did not recognize our faces consistently. I had to reach out to help frequently	3/9/2023 3:30 PM
2	We currently don't have a carpool verification process in place in Utah, and numerous drivers enter the carpool lanes illegally.	3/9/2023 1:40 PM
3	The USF Carpool Study app was very easy to easy and worked great.	3/9/2023 11:56 AM
4	Although sometimes it didn't register or recognize the faces in my carpool I would say that most of the times it did. Bye when it didn't was very frustrating	3/8/2023 10:40 AM
5	less action required every trip	3/8/2023 9:42 AM
6	It is easy in the end, and accurate	3/8/2023 8:00 AM
7	In the beginning the app would work fine and capture all trips but as the program continued it became harder and harder to record trips. Though I capture more trip than required I would have kept recording so you had more data but it became harder and harder to capture each trip.	3/6/2023 3:14 PM
8	It's quick and easy	3/6/2023 2:45 PM
9	I don't know of any other carpool app. This one still has a few bugs to work out.	3/6/2023 11:24 AM
10	This app does not remind me of those trips	3/6/2023 10:34 AM
11	It's too easy to forget to use the app.	3/6/2023 10:15 AM
12	Right now, my car pool verification process in utah is noninvasive. I just flip the switch on my little device on my windshield.	3/6/2023 9:36 AM
13	There aren't really any carpool lanes where I drive on I-275, so I think something like this app would be a good start.	3/6/2023 9:32 AM
14	I think either option is easy and convent	3/6/2023 9:16 AM
15	App is more convenient and easily accessible from the comfort of my car seat.	3/6/2023 9:07 AM

Q14 Before August 2022, how many one-way carpool trips did you take, per week, on average?

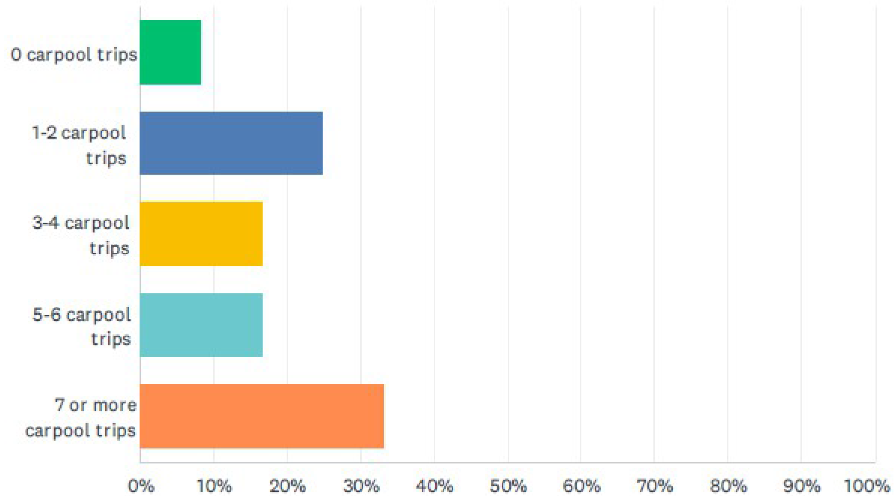
Answered: 24   Skipped: 0



ANSWER CHOICES	RESPONSES	
0 carpool trips	12.50%	3
1-2 carpool trips	20.83%	5
3-4 carpool trips	25.00%	6
5-6 carpool trips	16.67%	4
7 or more carpool trips	25.00%	6
TOTAL		24

Q15 Since August 2022, how many one-way carpool trips do you currently take, per week, on average?

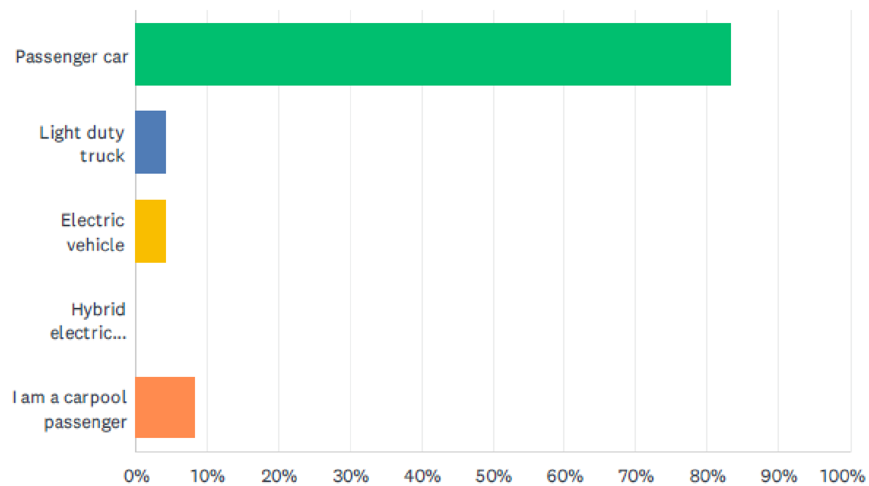
Answered: 24   Skipped: 0



ANSWER CHOICES	RESPONSES	
0 carpool trips	8.33%	2
1-2 carpool trips	25.00%	6
3-4 carpool trips	16.67%	4
5-6 carpool trips	16.67%	4
7 or more carpool trips	33.33%	8
TOTAL		24

Q16 If you are the carpool driver, what type of vehicle do you drive?

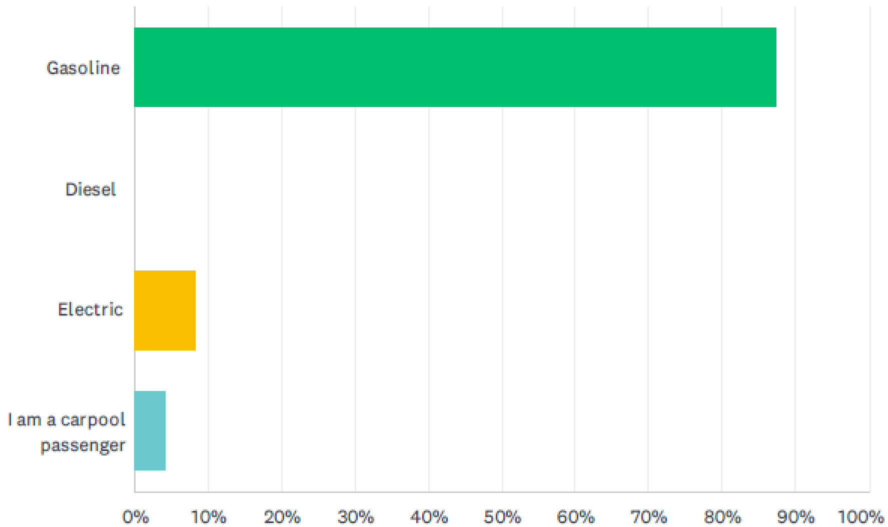
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Passenger car	83.33%	20
Light duty truck	4.17%	1
Electric vehicle	4.17%	1
Hybrid electric vehicle	0.00%	0
I am a carpool passenger	8.33%	2
TOTAL		24

Q17 If you are the carpool driver, what type of fuel does your vehicle use?

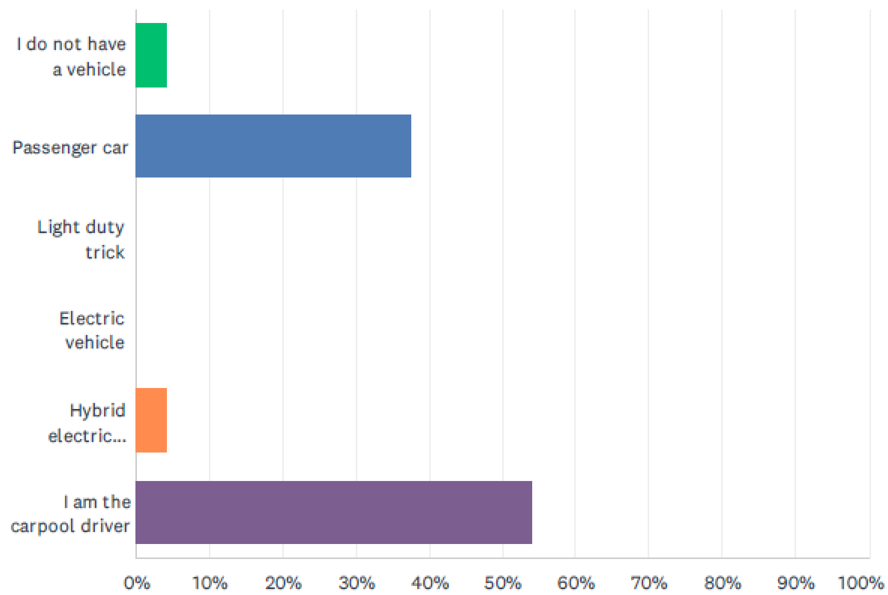
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Gasoline	87.50%	21
Diesel	0.00%	0
Electric	8.33%	2
I am a carpool passenger	4.17%	1
TOTAL		24

Q18 If you are a carpool passenger, what vehicle did you formerly use to drive?

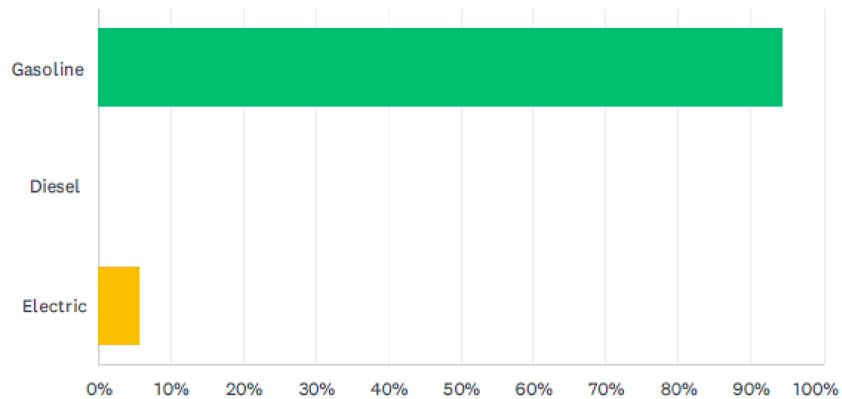
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
I do not have a vehicle	4.17%	1
Passenger car	37.50%	9
Light duty trick	0.00%	0
Electric vehicle	0.00%	0
Hybrid electric vehicle	4.17%	1
I am the carpool driver	54.17%	13
TOTAL		24

Q19 If you are a carpool passenger, what type of fuel would the vehicle you would leave at home use

Answered: 18 Skipped: 6



ANSWER CHOICES	RESPONSES	
Gasoline	94.44%	17
Diesel	0.00%	0
Electric	5.56%	1
TOTAL		18

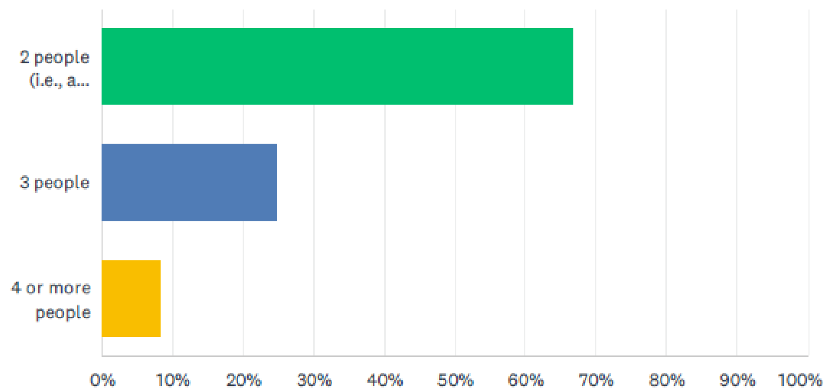
Q20 On average, how many miles do you travel one-way per carpool trip?

Answered: 23 Skipped: 1

#	RESPONSES	DATE
1	20	3/9/2023 11:41 PM
2	30	3/9/2023 3:31 PM
3	35	3/9/2023 1:42 PM
4	20	3/9/2023 11:58 AM
5	20	3/9/2023 11:57 AM
6	11	3/8/2023 10:41 AM
7	25	3/8/2023 9:44 AM
8	12	3/8/2023 9:20 AM
9	20	3/8/2023 8:01 AM
10	10	3/6/2023 3:38 PM
11	18	3/6/2023 2:46 PM
12	30	3/6/2023 11:54 AM
13	12	3/6/2023 11:25 AM
14	10	3/6/2023 10:35 AM
15	17	3/6/2023 10:23 AM
16	19	3/6/2023 10:16 AM
17	30	3/6/2023 10:05 AM
18	20	3/6/2023 9:54 AM
19	30	3/6/2023 9:37 AM
20	7	3/6/2023 9:34 AM
21	15	3/6/2023 9:17 AM
22	15	3/6/2023 9:17 AM
23	10	3/6/2023 9:08 AM

Q21 How many people are in your carpool, on average, including yourself?

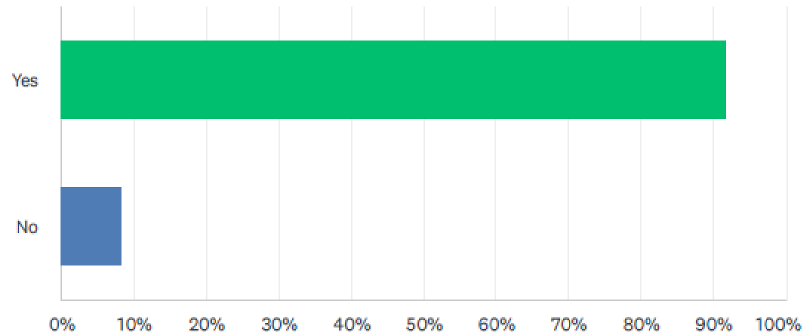
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
2 people (i.e., a 2-person carpool)	66.67%	16
3 people	25.00%	6
4 or more people	8.33%	2
TOTAL		24

Q22 When you carpool, do your usually carpool with the same person?

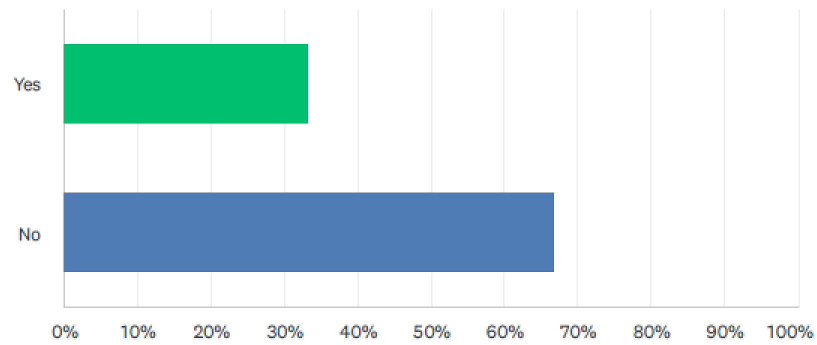
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	91.67%	22
No	8.33%	2
TOTAL		24

Q23 Are you presently registered as a member of a HOV3 carpool with South Florida Commuter Services (SFCS)?

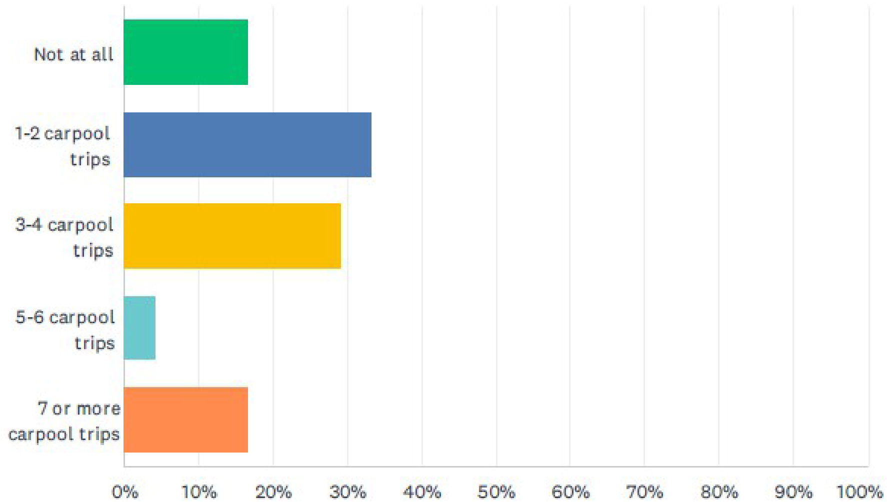
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	33.33%	8
No	66.67%	16
TOTAL		24

Q24 If this USF Carpool Study app were to provide toll-free access for carpooling with at least 3 people after the Study ended, how often would you carpool per week?

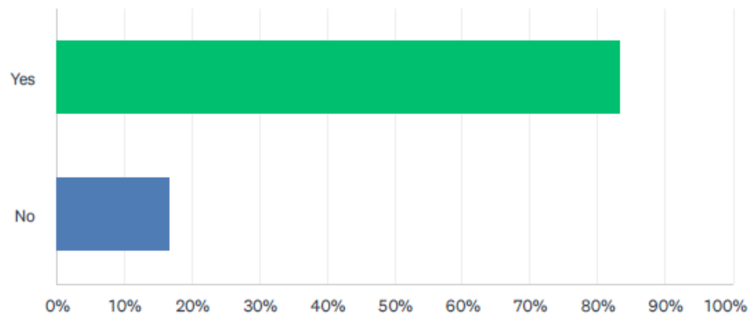
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Not at all	16.67%	4
1-2 carpool trips	33.33%	8
3-4 carpool trips	29.17%	7
5-6 carpool trips	4.17%	1
7 or more carpool trips	16.67%	4
TOTAL		24

Q25 If this USF Carpool Study app were to provide toll-free access for carpooling with 3 or more people after the study ended, would you recommend it to others?

Answered: 24 Skipped: 0

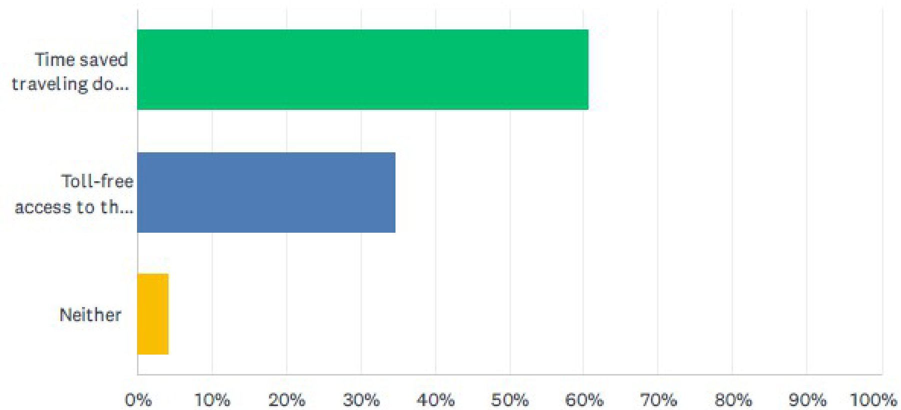


ANSWER CHOICES	RESPONSES	
Yes	83.33%	20
No	16.67%	4
TOTAL		24

#	PLEASE EXPLAIN WHY YOU WOULD OR WOULD NOT RECOMMEND THE APP.	DATE
1	The app was difficult to use	3/9/2023 3:31 PM
2	Most of the folks I know who carpool are in groups of 2, but I would still recommend the app.	3/9/2023 1:45 PM
3	I would recommend it because the app for this carpool study was very easy to use.	3/9/2023 11:58 AM
4	I would recommend it if it would seem that it works out for them	3/8/2023 10:44 AM
5	everyone likes free	3/8/2023 9:45 AM
6	This would be a huge benefit to folks commuting on the Veterans or on the Selman expressway in Tampa Bay. I don't use these roads personally to get to the office, but I know people who do use them daily and would recommend the app to reduce the cost of their commute.	3/8/2023 9:24 AM
7	It is easy and accurate	3/8/2023 8:01 AM
8	Strictly for the opportunity of saving money on tolls	3/6/2023 3:39 PM
9	Carpools are usually 2 people and not a lot of people have a carpool of 2 or more	3/6/2023 2:47 PM
10	it might help in some situations	3/6/2023 10:36 AM
11	App had issues with verifying only two people	3/6/2023 10:24 AM
12	Toll free. Yes.	3/6/2023 9:37 AM
13	The app seems helpful and would incentivize carpooling.	3/6/2023 9:36 AM
14	I think its an easy way to show you are carpooling	3/6/2023 9:18 AM
15	Since I like to car pool, I would certainly recommend this to all of it was made toll free	3/6/2023 9:09 AM

Q26 If you were to carpool and travel down a high-occupancy toll lane, which incentive would interest you more?

Answered: 23 Skipped: 1



ANSWER CHOICES	RESPONSES	
Time saved traveling down the high-occupancy toll lane	60.87%	14
Toll-free access to the high-occupancy toll lane	34.78%	8
Neither	4.35%	1
TOTAL		23

Q27 What level of total daily financial incentive to carpool would be so low that carpooling wouldn't be worth considering?

Answered: 24 Skipped: 0

#	RESPONSES	DATE
1	5.0	3/9/2023 11:42 PM
2	0.5	3/9/2023 4:32 PM
3	5.0	3/9/2023 3:32 PM
4	2.0	3/9/2023 1:49 PM
5	4.0	3/9/2023 11:59 AM
6	5.0	3/8/2023 3:39 PM
7	6.0	3/8/2023 10:45 AM
8	2.0	3/8/2023 9:46 AM
9	2.0	3/8/2023 9:26 AM
10	7.0	3/8/2023 8:02 AM
11	2.5	3/6/2023 3:43 PM
12	2.0	3/6/2023 2:48 PM
13	3.0	3/6/2023 11:56 AM
14	2.0	3/6/2023 11:27 AM
15	10.0	3/6/2023 10:37 AM
16	5.0	3/6/2023 10:24 AM
17	1.0	3/6/2023 10:18 AM
18	5.0	3/6/2023 10:06 AM
19	5.5	3/6/2023 9:55 AM
20	5.0	3/6/2023 9:38 AM
21	2.0	3/6/2023 9:38 AM
22	4.0	3/6/2023 9:19 AM
23	5.0	3/6/2023 9:18 AM
24	5.0	3/6/2023 9:12 AM

Q28 What level of total daily financial incentive to carpool would tempt you to consider carpooling?

Answered: 24 Skipped: 0

#	RESPONSES	DATE
1	10.0	3/9/2023 11:42 PM
2	5.0	3/9/2023 4:32 PM
3	10.0	3/9/2023 3:32 PM
4	3.5	3/9/2023 1:49 PM
5	5.0	3/9/2023 11:59 AM
6	5.0	3/8/2023 3:39 PM
7	8.0	3/8/2023 10:45 AM
8	5.0	3/8/2023 9:46 AM
9	5.0	3/8/2023 9:26 AM
10	10.0	3/8/2023 8:02 AM
11	5.0	3/6/2023 3:43 PM
12	5.0	3/6/2023 2:48 PM
13	5.0	3/6/2023 11:56 AM
14	5.0	3/6/2023 11:27 AM
15	10.0	3/6/2023 10:37 AM
16	10.0	3/6/2023 10:24 AM
17	5.0	3/6/2023 10:18 AM
18	5.0	3/6/2023 10:06 AM
19	5.5	3/6/2023 9:55 AM
20	10.0	3/6/2023 9:38 AM
21	4.0	3/6/2023 9:38 AM
22	5.0	3/6/2023 9:19 AM
23	20.0	3/6/2023 9:18 AM
24	0.0	3/6/2023 9:12 AM

Q29 What level of total daily financial incentive to carpool would start to make carpooling enticing, so that you would begin taking steps to forming a carpool?

Answered: 24 Skipped: 0

#	RESPONSES	DATE
1	15.0	3/9/2023 11:42 PM
2	5.0	3/9/2023 4:32 PM
3	15.0	3/9/2023 3:32 PM
4	5.0	3/9/2023 1:49 PM
5	7.0	3/9/2023 11:59 AM
6	5.0	3/8/2023 3:39 PM
7	10.0	3/8/2023 10:45 AM
8	10.0	3/8/2023 9:46 AM
9	5.0	3/8/2023 9:26 AM
10	20.0	3/8/2023 8:02 AM
11	6.0	3/6/2023 3:43 PM
12	7.0	3/6/2023 2:48 PM
13	5.0	3/6/2023 11:56 AM
14	10.0	3/6/2023 11:27 AM
15	10.0	3/6/2023 10:37 AM
16	10.0	3/6/2023 10:24 AM
17	20.0	3/6/2023 10:18 AM
18	50.0	3/6/2023 10:06 AM
19	5.5	3/6/2023 9:55 AM
20	20.0	3/6/2023 9:38 AM
21	5.0	3/6/2023 9:38 AM
22	8.0	3/6/2023 9:19 AM
23	10.0	3/6/2023 9:18 AM
24	0.0	3/6/2023 9:12 AM

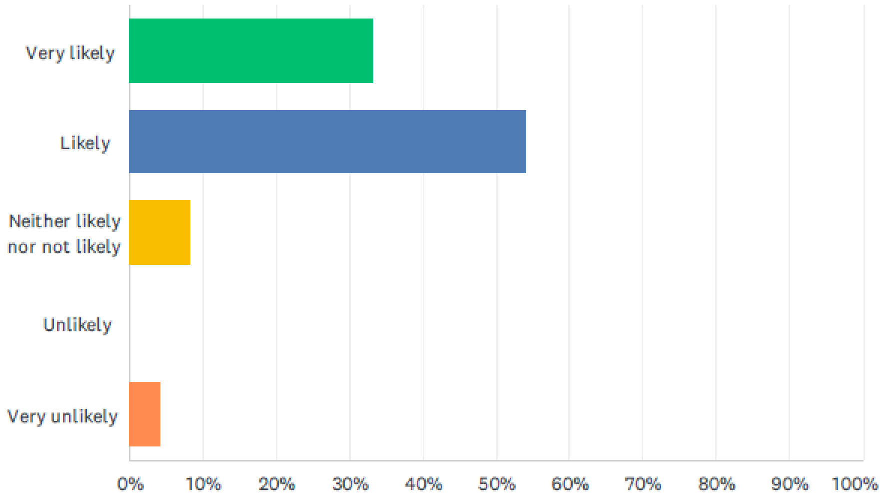
Q30 What level of total daily financial incentive to carpool would be so appealing that you would start carpooling as soon as possible??

Answered: 24 Skipped: 0

#	RESPONSES	DATE
1	20.0	3/9/2023 11:42 PM
2	5.0	3/9/2023 4:32 PM
3	20.0	3/9/2023 3:32 PM
4	6.0	3/9/2023 1:49 PM
5	9.0	3/9/2023 11:59 AM
6	5.0	3/8/2023 3:39 PM
7	10.0	3/8/2023 10:45 AM
8	20.0	3/8/2023 9:46 AM
9	10.0	3/8/2023 9:26 AM
10	25.0	3/8/2023 8:02 AM
11	10.0	3/6/2023 3:43 PM
12	15.0	3/6/2023 2:48 PM
13	5.0	3/6/2023 11:56 AM
14	10.0	3/6/2023 11:27 AM
15	10.0	3/6/2023 10:37 AM
16	15.0	3/6/2023 10:24 AM
17	20.0	3/6/2023 10:18 AM
18	50.0	3/6/2023 10:06 AM
19	5.5	3/6/2023 9:55 AM
20	50.0	3/6/2023 9:38 AM
21	8.0	3/6/2023 9:38 AM
22	10.0	3/6/2023 9:19 AM
23	15.0	3/6/2023 9:18 AM
24	0.0	3/6/2023 9:12 AM

Q31 On a scale of 1 to 5, how likely are you to carpool at the incentive level of ${{ Q28 }} per day

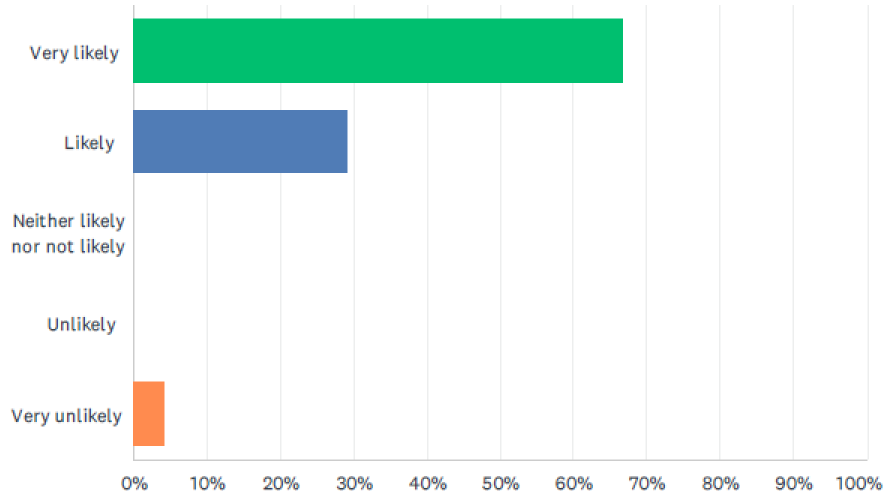
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Very likely	33.33%	8
Likely	54.17%	13
Neither likely nor not likely	8.33%	2
Unlikely	0.00%	0
Very unlikely	4.17%	1
TOTAL		24

Q32 On a scale of 1 to 5, how likely are you to carpool at the incentive level of ${{ Q29 }} per day

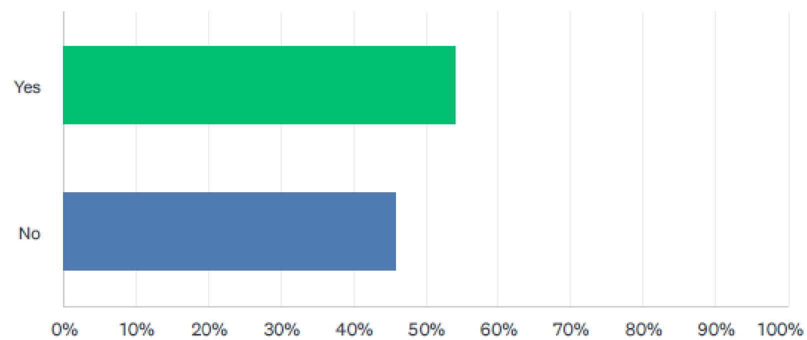
Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Very likely	66.67%	16
Likely	29.17%	7
Neither likely nor not likely	0.00%	0
Unlikely	0.00%	0
Very unlikely	4.17%	1
TOTAL		24

Q33 May we contact you to hold a brief interview by phone call or Microsoft Teams Meeting, to further discuss the functionality of the USF Carpool Study app?

Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	54.17%	13
No	45.83%	11
TOTAL		24

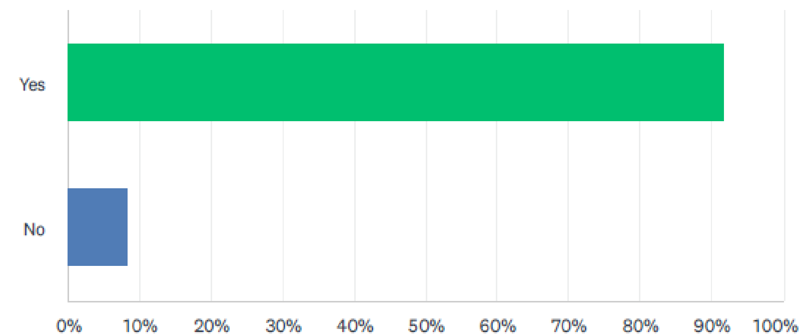
Q34 Please share any comments about your use or attempted use of the USF Carpool Study app.

Answered: 8 Skipped: 16

#	RESPONSES	DATE
1	It was great in the beginning after that it was hard to register the carpool occupants	3/8/2023 10:46 AM
2	My carpool partner and I started out using the app without accessing I-275. We simply failed to read the details of the program before starting out and were initially puzzled by why none of our trips were counting. After reading and understanding the purpose of the study, the app was simple to operate and extremely accurate. We even tried to fool the app by driving on streets close to and parallel to I-275. The app had no trouble detecting the difference. I think this app would be a great asset to a regional authority that was trying to incentivize carpool formation by allowing access to toll roads at low or no cost.	3/8/2023 9:35 AM
3	I thought the app was overall easy, I would forget sometimes to start the trip or verify the trip	3/8/2023 8:03 AM
4	It is easy and simple, the app would sometimes take a little too long recognising the faces	3/6/2023 2:49 PM
5	It would crash and not count the ride that was started properly. So we would loose the trip. It would take over 2-3 mins to get it to start properly and recognize 2 people. Too long!	3/6/2023 11:29 AM
6	I thought it was user friendly and usually didn't have issues with it picking up faces.	3/6/2023 9:40 AM
7	N.a	3/6/2023 9:39 AM
8	The app needs to be refined. I clearly remember that at least 20% of my trip went unregistered in the app and it was very frustrating. Also the app needs to be active in the background if the screen goes to sleep, it doesn't not and that is not very helpful.. The app needs to work better. At least the support team was good so it kind of alleviated the pain of using the app	3/6/2023 9:14 AM

Q35 Are you are interested in participating in another round of testing with RideFlag, please reply directly to sophia@rideflag.com indicating your interest or check "Yes" below. Check "No" if you do not wish to continue testing.

Answered: 24 Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	91.67%	22
No	8.33%	2
TOTAL		24

Appendix D

Visual Guides for App Downloads on iOS and Android Phones

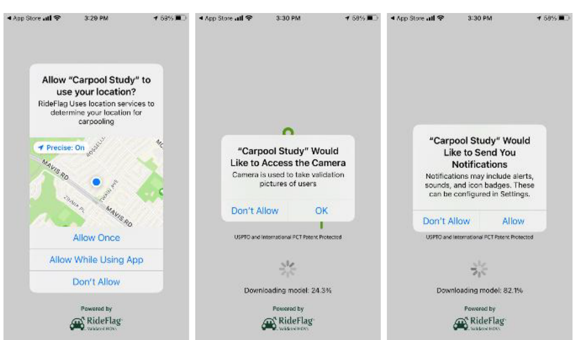
iOS App download

To download the app please click this [link](https://apps.apple.com/us/app/carpool-validation-pilot/id1620562053) (https://apps.apple.com/us/app/carpool-validation-pilot/id1620562053) At the app on the store, click the download button

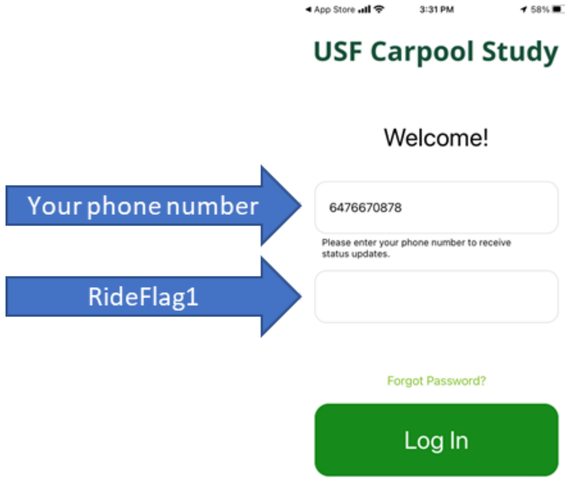
Once downloaded, click the “Open” button

The app will ask you for permissions, please select:

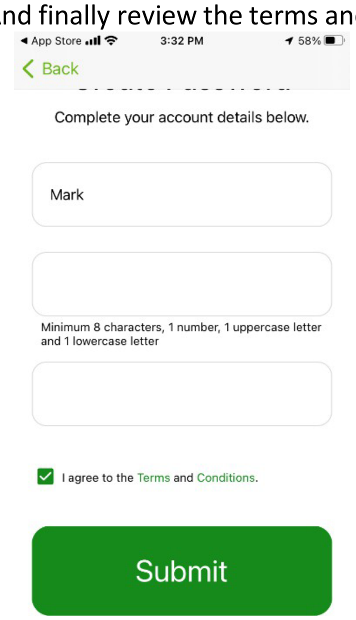
- “Allow while using the app” for using your location (required to get the trip credit for travelling on the highway),
- “OK” for access to the camera (required to count the occupants for the trip)
- “Allow” for sending notifications (required for any notifications about the trip you are in)

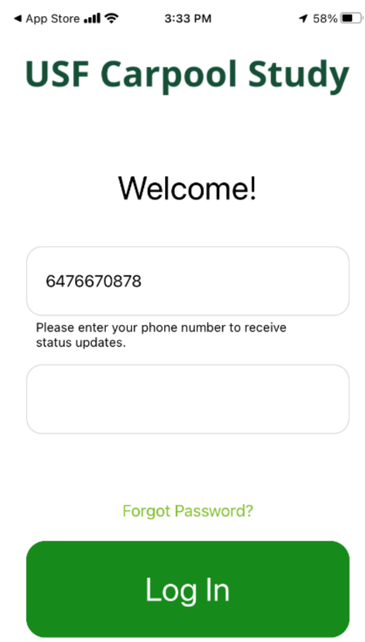


The app will then ask you to enter the phone number you have pre-registered with and the initial password: RideFlag1 (capital R and F are important)



The app will now ask you to set your password to something unique to you. Put in a name to refer to your account, and the password you would like to use with the account (you will have to put the same password in both boxes to ensure it is the password you want to use). And finally review the terms and conditions and click the Agree checkbox.

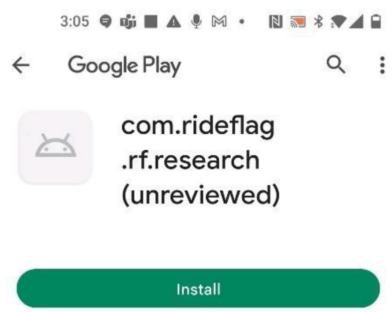




Once you hit submit, simply log in using the password you just created

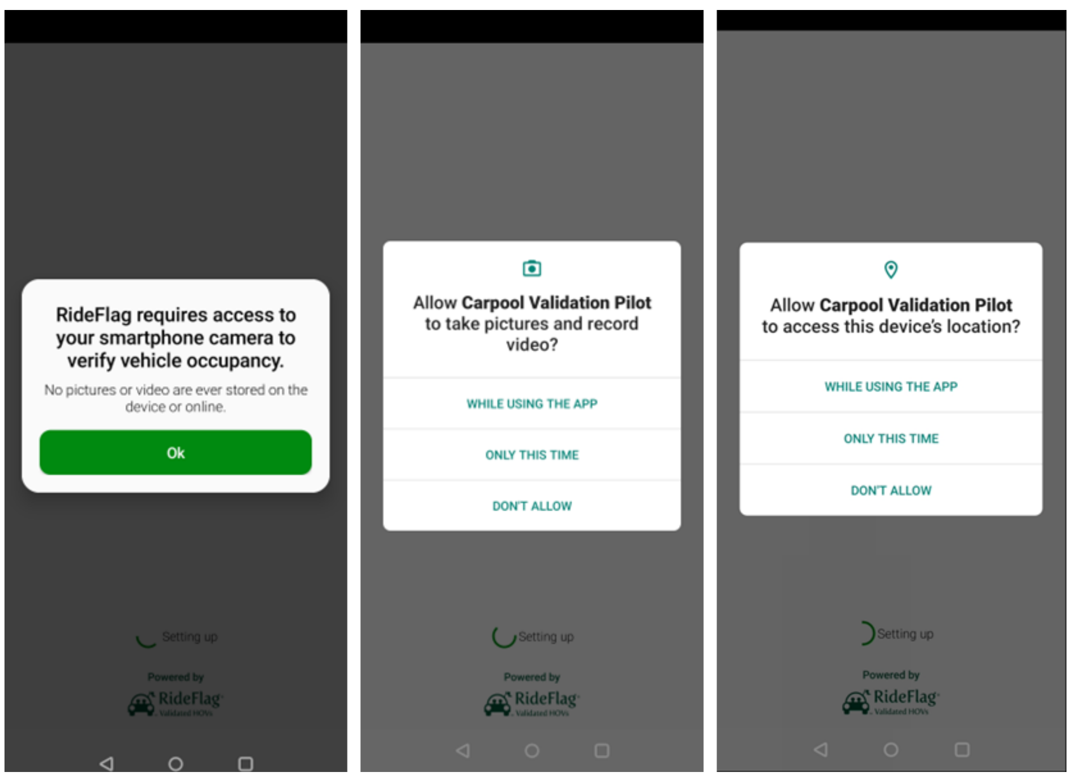
Android App Download

To download please click this [link](https://play.google.com/store/apps/details?id=com.rideflag.rf.research)
([https://play.google.com/store/apps/details?id=com.rideflag.rf.resea
rch](https://play.google.com/store/apps/details?id=com.rideflag.rf.research)) At the google play store, tap the Install button:

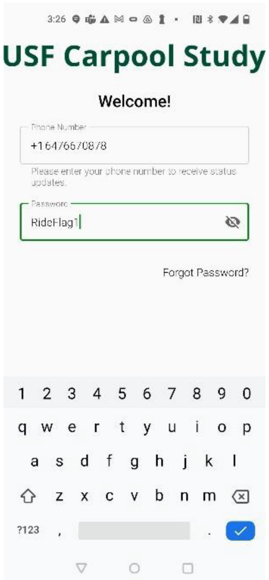


The app will ask you for permissions, please select:

- “OK” for access to the camera (required to count the occupants for the trip)
- “while using the app” for using your camera only while using the app
- “while using the app” for using your location (required to get the trip credit for travelling on the highway)

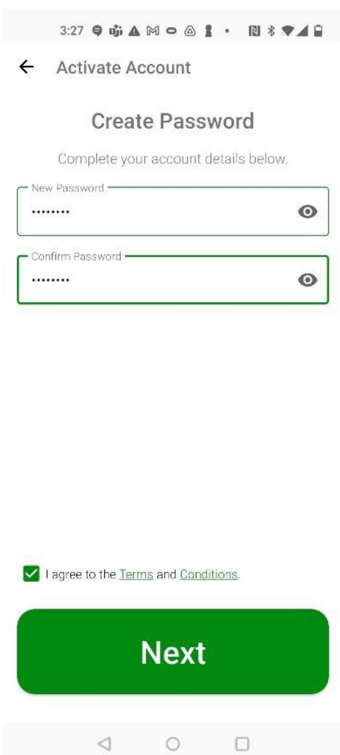


The app will then ask you to enter the phone number you have pre-registered with and the initial password: RideFlag1 (capital R and F are important)



The app will now ask you to set your password to something unique to you. Put in the password you would like to use with the account (you will have to put the same password in both boxes to ensure it is the password you want to use).

And finally review the terms and conditions and click the Agree checkbox. This will take you into the app.



Appendix E

RideFlag Technologies, Inc. Definitions for Data Generated by App

Definitions for data generated by the RideFlag vehicle occupancy detection app. Definitions provided by RideFlag Technologies, Inc.

Table Users		
	Column Name	Description
Unique Key	user_id	unique user identifier. We are using the full 10 digit phone number
	Name	user's provided name
	Email	user's provided email
	modified on	text version of the date last modified
	created_on	text version of the date created
	total_owned trips	last known count of trips (regardless of whether they were completed trips)

Table Trips		
	Column Name	Description
Unique Key	trip_id	unique user identifier.
	trip_start_time	text version of date/time stamp of when the user Verified HOV
	valid	if the trip was an awarded trip and was completed sucessfully
	occupancy	count of occupants
	owner_id	user_id of the user whose phone was used
	end_time	text version of date/time stamp of when the user ended the trip with either end trip or reverify HOV
	start_type	Current rules in your region dictate that the car must be stopped to validate HOV
	vehicle_id	the vehicle used
	passenger_carpool_distance	total occupant distance
	event_status	trip status
	total_driven distance	total vehicle distance from the trip start to the trip end
	reward_granted	

Table Occupants		
	Metric	Description
Unique Key	trip_id	trip_id for the occupants
Unique Key	rider_id	distinct name assigned to the occupant found in the camera
	average_real_score	the average realness from the sample images gathered
	average_Exit_score	The average realness from the sample images gathered on the Reverify occupant camera session
	similarity_score	This is the relative similarty of the matched faces between the signature gathered on the first camera session compared to the reverify occupants camera session

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