RESEARCH BRIEF

Objective Driving Data in the LongROAD Study:

An Overview of Changes to Data Collection Procedures from a Datalogger to a Travel App

September 2021

Of the almost 222 million licensed drivers in the United States, one in five are 65 years or older (FHWA, 2017). Older drivers remain one of the highest risk groups for vehicle crash-related deaths due to health declines and frailty (Lombardi et al., 2017). To address this, it is important to understand their driving behavior as well as health, functional, and behavioral changes that occur as older drivers age (Blanchard et al., 2010). This requires, in part, reliable and accurate measures of driving exposure (how much older people drive), driving patterns (when and where they drive), and driving habits (how they drive).

Driving patterns and behaviors have generally been obtained through self-reported measures, such as questionnaires and surveys. However, these methods have limitations, including recall bias, making it difficult to collect objective and consistent driving data. To ensure accurate driver-behavior data, in-vehicle recording devices using Global Positioning Systems (GPS) can be effective. These devices are useful for objectively measuring naturalistic driving trips and behavior. Smartphone travel applications (apps) have emerged in recent years as another method for collecting driving data. One benefit of these travel apps is that they do not require installation in a study participant's vehicle and can track a subject in any vehicle in which they travel.

Collecting objective driving data can allow for the exploration of changes that happen over time among older adults with regard to safe driving and mobility. Such data are considered integral to the Longitudinal Research on Aging Drivers (LongROAD) study, a multisite prospective cohort study designed to collect data on the medical, behavioral, environmental, and vehicle technological factors influencing older adults' driving and safety. When the study initially began, travel apps were not as predominant and dataloggers were chosen as the method for collecting objective driving data. However, significant improvements in travel apps have since emerged. Thus, the role of travel apps was reconsidered as the LongROAD study progressed to a new phase in 2018. The objective of this research brief is to provide details on the transition from the Danlaw datalogger to the new LongROAD travel app.

The research brief includes the following:

1. Background on the differences between the original Danlaw datalogger and the new LongROAD travel app
2. Findings of the pilot study conducted prior to the full integration of the LongROAD travel app
3. Description of the transition from the Danlaw datalogger to the LongROAD travel app
4. Preliminary results of the driver identification tests, which were needed to ensure the LongROAD travel app appropriately recognized the participant as the driver.

LongROAD Study Overview

The Longitudinal Research on Aging Drivers (LongROAD) study collects data from active older drivers recruited at ages 65 to 79 years who were identified by screening electronic medical records of health systems or primary care clinics affiliated with five study sites (Cooperstown, New York; Baltimore, Maryland; Denver, Colorado; San Diego, California; and Ann Arbor, Michigan). A total of 2,990 participants were enrolled in the study. More details of the study can be found in past research documents (Kelley-Baker et al., 2017; Li et al., 2017), and other work is available on the AAA Foundation for Traffic Safety website (https://aaafoundation.org/).

A significant strength of the LongROAD study is the collection of objective driving data, which include but are not limited to miles driven, trips taken, time and day of travel, turns, and speed. This objective driving data can be used to analyze driving behaviors of older adults in conjunction with other data collected by the LongROAD study. These include the participant's self-reported driving habits, demographic information, health conditions, and physical, cognitive, and social health functioning, among others.

Differences between the Danlaw Datalogger and the LongROAD Travel App

The Danlaw datalogger is a device plugged into a vehicle's on-board diagnostics (OBD) port that collects and transmits vehicle and sensor data via cellular connection. As noted, this device was part of the initial LongROAD data collection procedures and captured driving data from late 2015 to early 2019 with the majority of the dataloggers removed by February 2019. Ultimately, the LongROAD travel app was gradually introduced as a replacement for the Danlaw datalogger starting in mid-2019. Due to the staggered and ongoing roll-out of the LongROAD travel app, the objective driving data collected for participants have gaps of varying lengths. Further details are provided in later sections of the brief.

The LongROAD travel app is a smartphone application produced by Tourmaline Labs (TL). This travel app utilizes a smartphone's accelerometer and GPS to identify and process driving-related data including velocity, angular motion, GPS coordinates, rapid deceleration, and other motion data. All data are collected, encrypted, and sent for secured data storage. Derived variables generated from these raw data include days driven, miles driven, number of left turns, number of right turns, ratio of left and right turns, speeding events, trips at night, and other variables for each participant by month. Table 1 shows a complete list of the variables generated from the LongROAD travel app.

Data collected or derived from the app is similar to that which was collected via the Danlaw datalogger; however, there are notable differences. The Danlaw datalogger was a vehicle-based data collection method that was installed in the primary vehicle of each participant and collected data only from that vehicle. The LongROAD travel app is a portable smartphone data collection method that moves with the participant (thus allowing for the collection of data from participants driving any vehicle).

When the LongROAD travel app was introduced in 2019, trip and mileage data were gathered and compared using both the Danlaw datalogger and LongROAD travel app; however, despite many similarities there were important nuances in how each device operated that precluded a more meaningful validation or benchmarking exercise. For example, as noted, the Danlaw datalogger only tracked data from the vehicle in which it was installed, whereas the app collects data on all trips made by the driver. Therefore, the app tracks more miles traveled than did the Danlaw datalogger. Furthermore, the Danlaw datalogger tracked trips by measuring when the engine started and stopped, whereas the app determines the start and end of trips based on the amount of time the vehicle is stopped. If the vehicle stops and resumes motion in fewer than 5 minutes, the app would considered it a single trip, rather than a separate trip. For example, a quick stop at a gas station would have been considered two trips on the Danlaw datalogger but not necessarily so on the LongROAD travel app.

Another difference between the systems relates to the resolution of data, particularly for examining rapid deceleration events (RDEs). The smartphone app, having a higher sampling rate than the Danlaw datalogger (100 Hz vs. 4 Hz), captures more granular vehicle movements, including RDEs. If an RDE were to fall between the Danlaw datalogger's measurement cycles, the RDE would not be captured accurately or in some cases at all. With its higher sample rate, the LongROAD travel app is able to capture events that would have been missed by the Danlaw datalogger.

In terms of accessibility, participants downloaded the LongROAD travel app from either the Apple App Store for iOS devices or the Google Play Store for Android devices. During the transition from the Danlaw datalogger to the LongROAD travel app, participants were notified about the protocol change through mail or email. Download of the LongROAD travel app occurred either during a participant's in-person follow-up assessment, with the assistance of LongROAD personnel; during a follow-up telephone interview; or during an onboarding call for app installation. Once a participant consented to the

Table 1: Variables Derived from the LongROAD Travel App

Variable	Definition
Days driving	Total number of days in month with at least one trip
Trips	Total number of trips in month
Miles	Total number of miles driven in month
Miles per trip	Total miles driven in month divided by total number of trips in month
Total trip minutes	Total minutes of driving in month
Minutes per trip	Total driving minutes in month divided by total number of trips in month
Trip chains	Number of trip chains in month (Note: chain is a series of trips starting and ending at home)
Minutes per chain	Total driving minutes for chains in month divided by number of trip chains in month
Miles per chain	Total miles of chains in month divided by number of trip chains in month
No. of trips at night	Number of trips during which ≥80% of trip was during nighttime in month (Nighttime was defined as civil twilight or a solar angle >96°)
% trips at night	Percent of all trips in month during nighttime
No. trips during day	Number of trips in month not classified as nighttime
% trips during day	Percent of trips in month not classified as nighttime
No. trips in AM peak	Number of trips in month during 7:00-9:00 AM on weekdays
% trips in AM peak	Percent of trips in month during 7:00-9:00 AM on weekdays
No. trips in PM peak	Number of trips in month during 4:00-6:00 PM on weekdays
% trips in PM peak	Percent of trips in month during 4:00-6:00 PM on weekdays
No. trips on high-speed roads	Number of trips in month where ≥20% of distance travelled was at a speed of ≥60 miles/hour
% trips on high-speed roads	Percent of trips in month where 20% of distance travelled was at a speed of ≥60 miles/hour
No. trips within 25 miles of home	Number of trips traveled within 25 miles of home in month
% trips within 25 miles of home	Percent of trips traveled in month within 25 miles of home
No. left turns	Number of left turns made in month
No. right turns	Number of right turns made in month
Right-to-left turn ratio	Ratio of all right and left turns in month
No. rapid deceleration events	Number of events with deceleration ≥0.4 g (hard braking, near crash, crash) in month
No. speeding events	Number of trip segments with speed ≥80 miles/hour sustained for ≥8 seconds in month

app installation, instructions were sent via email and, if necessary, assistance was provided over the phone. This ensured that the participants did not install the app prior to consenting. Upon installation of the LongROAD travel app on the participant's smartphone, a unique participant identification number was generated to link the driving data collected via the LongROAD travel app with the remaining participant data collected in the LongROAD study (Kelley-Baker et al., 2017; Li et al., 2017).

LongROAD Travel App Pilot Study

Prior to the introduction of the travel app into the LongROAD study, a pilot test was conducted at the University of California–San Diego in January 2019. Although, as noted above, the app data could not be directly benchmarked against the data from the Danlaw datalogger due to the differences in collection procedures, the pilot study was critical in determining participants' willingness to transition to the app, assessing the quality of the data collected for future research, and providing participants the opportunity to offer feedback on the app before its implementation in the full LongROAD sample. The pilot study was carried out simultaneously with the development of the LongROAD study app procedures.

There were 32 participants in the pilot study. The pilot was conducted before the driver detection algorithm was trained (which is detailed below). Thus, the investigators were not able to distinguish whether the miles logged on the LongROAD travel app were due to the participants' driving or traveling as passengers. As such, participants were asked to track the percentage of time they were driving rather than riding as a passenger in a vehicle. In addition, they were asked the percentage of time they carried their phones while driving. This was an important aspect to the pilot study because the app identifies drivers only if the driver carries her/his phone while driving. If a participant does not carry her/his phone while driving, data will not be collected on all of their driving trips. To be successful, the study sites needed assurance that the study participants carried their phones a minimum of 90% of the time they were driving a vehicle. Study participants were obligated to turn on GPS location services; if such services were turned off, the respective study site was notified that data were not being collected and the participant was prompted to turn GPS back on. The pilot was also important for developing a system for identifying the participant as a driver (which is detailed below). Lastly, the pilot study results verified that participants carried their phone in cars more than 90% of the time through self-reported measures.

Implementation of the LongROAD Travel App

In conjunction with the pilot, a procedural document was created to provide a roadmap for each study site to start onboarding and installing the LongROAD travel app on participants' phones. The development of the document was guided by the pilot study as well as each entity's Institutional Review Board (IRB) to ensure data quality and privacy standards were upheld. The procedural document included background information on the app's development by Tourmaline Labs, the functionality of the app, the installation process, the driver detection algorithm, and the data handling procedures. The manual also provided procedures for tracking changes in participant driving activity and troubleshooting difficulties with installation of the app.

Appendix A illustrates the key app and data handling procedures, including a detailed explanation of the onboarding process and the roles of different entities (i.e., TL and study sites). The detailed procedures were developed to ensure the following:

1. LongROAD travel app data was linked to the proper LongROAD participant.
2. Data from non-participants was purged (since the app is publicly available through the IOS app store and the Google play store).
3. Troubleshooting procedures were developed to ensure continuous data collection and data quality.
4. Alerts were provided to prompt study sites to follow up on participants who may have ceased driving.

Upon completion of the pilot and development of procedures, each site sought approval from their IRB committee. Concerns typically revolved around data security during collection, transmission, and storage. As data communication was encrypted, each site received approval from its respective IRB committee.

Once each IRB approved the changes to the data collection method, the process to install the LongROAD travel app on participants' phones began. Each site transitioned to the app between April and August 2019, with the University of California–San Diego having started the onboarding process first due to their involvement in the pilot test. As of June 2021, a total of 1,273 of the original 2,990 participants had been successfully transitioned to the LongROAD travel app, and efforts were continuing to onboard additional participants. Other LongROAD participants are not using the travel app due to one or more of the following reasons: not having a smartphone or adequate phone plan; not meeting the inclusion criteria of carrying a smartphone at least 90% of the time; having privacy concerns; and/or generally declining to use the LongROAD travel app. A majority of data collection via the Danlaw dataloggers ceased by February 2019.

Development and Implementation of Driver Detection Algorithm

A significant difference between the Danlaw datalogger and the LongROAD travel app is how it identifies each participant as a driver. For the Danlaw datalogger, the participant and other users of the primary vehicle were each asked to carry a unique Bluetooth card so the Danlaw datalogger could appropriately identify the participant as the driver when applicable. The LongROAD travel app is unable to use such a tracking method, so a deep-learning algorithm was developed to identify participants' driving using a "driving signature." In addition, the previously collected Danlaw datalogger data was used to validate that the participant was the one who drove.

The driving detection algorithm uses methods grounded from speech recognition research to identify the participant based on his or her distinguishing characteristics. For instance, an individual's driving pattern while making left or right turns is unique. Thus, turning characteristics, such as deceleration, changes in angular momentum, and acceleration through turns, as well as other driving characteristics were used to develop identifiable driving signatures. These signatures help the algorithm identify whether, for a given trip, a participant was driving or riding as a passenger. The driver detection algorithm first classifies each of a participant's trips into one of two classes. The first class is *dominant driver*, or the most frequent driver profile predicted by the algorithm. The second class is *other driver* for the remainder of the driver predictions. In order to determine whether the *dominant driver* was the actual LongROAD participant or another individual (e.g., a caregiver), TL used the available data from the Danlaw datalogger to determine which driver profile (*dominant* or *other*) was the LongROAD participant. In cases where the predictive model was not able to successfully identify the LongROAD participant, study sites reached out to the participants for further verification of their driving history. The study site would ask the participant to identify at least 50 consecutive miles when the participant was driving, providing additional data to help the algorithm recognize when the participant was driving. Appendix B contains more information on how the accuracy of the detection of participants' driving was assessed.

Lessons Learned and Framework for Future Research

The transition from an OBD-based datalogger to a travel app modernized the LongROAD study's approach for examining travel behavior and driving patterns. In the process of transitioning from the Danlaw datalogger to the LongROAD travel app, there were a number of lessons learned that could be useful for future work in this area.

Challenges in Comparing Data Collected Using Different Procedures.

As a result of the differences in how the driving data were collected, data from the LongROAD travel app and Danlaw datalogger are not directly comparable. The Danlaw datalogger was an in-vehicle recording device, whereas, the LongROAD travel app collects data through the study participants' smartphones. Even though these two methods collect the same set of variables, technical differences between the two devices result in disparate levels of granularity, accuracy, and precision in tracking. For example, the LongROAD travel app may capture more rapid deceleration events because of the higher sampling rate (100 Hz) relative to the Danlaw datalogger (4 Hz). Additionally, factors such as the definition of a trip differ between the two data collection procedures. The Danlaw datalogger records engine stop and start times to measure trips, whereas the LongROAD travel app uses the length of time that the vehicle is stopped to estimate the start and stop of a trip. These nuances make it difficult to directly compare the data. Further, the Danlaw dataloggers were discontinued, thus the driving data collected through the second phase of the study only reflects the participants using the LongROAD travel app.

Decline of Objective Driving Data when Transitioning Between the Two Driving Data Collection Procedures.

Some participants were not eligible or did not consent to use the LongROAD travel app due to lack of an appropriate smartphone device, lack of an adequate phone plan, and/or privacy concerns, among other issues. However, even though these participants declined or were ineligible to provide objective driving in the second phase of the study, they still continued to contribute through a self-reported driving questionnaire, a health and functioning questionnaire, medical record review, driving and crash record review, and other LongROAD data collection procedures and tools.

These onboarding issues are not unique to the LongROAD Study and reflect the growing concerns of those whose travel patterns are captured through travel apps. In a report by the Federal Highway Administration examining the current practices and future development of smartphone apps for the transportation sector, some of the primary concerns cited by travel app users were privacy and smartphone accessibility (Shaheen et al., 2016). To mitigate such concerns, practitioners and app developers need to establish data standards and data user agreements to protect privacy as well as provide similar experiences for all users irrespective of the type of phone operating system or plan.

No data was collected when a participant did not have their phone during a given trip. While only participants who reported regularly carrying their phone while driving (at least 90% of the time) were eligible to use the LongROAD travel app, it is possible that there were additional missed trips for participants who in fact carried their phones less frequently. Lastly, the rollout of the travel app was gradual due to each study site needing to obtain IRB approval and the staff time required to onboard participants to the travel app. Thus, the objective driving data collected during the transition has gaps.

While there were data collection challenges, the increasing availability of smartphone travel apps provides a more modern approach to collecting objective driving data.

Maintaining Clear and Constant Communication with All Stakeholders.

Due to the size and scope of the data collection transition during the second phase of the LongROAD study, technical challenges were inevitable. For instance, whether it was a participant having issues installing the LongROAD travel app, the app data not being transmitted to the Tourmaline Labs servers, or challenges with participant detection using the driver identification algorithm, the study sites, data coordinating center, and the app developers need to be in constant communication to effectively address every issue that emerges.

Furthermore, a well thought out pilot study and a detailed procedural manual is important to identify potential issues and develop troubleshooting procedures to mitigate issues throughout the study. Appendix A illustrates steps on how to handle common and uncommon issues. These include but are not limited to the steps to take when a driver ceases driving or when app data is not being received, as well as general troubleshooting procedures. Regular coordination meetings and updates from study sites, app developers, and the data coordinating center helped ensure that issues were addressed immediately.

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ABOUT THE AAA FOUNDATION FOR TRAFFIC SAFETY

The AAA Foundation for Traffic Safety is a 501(c)(3) nonprofit, publicly supported charitable research and education organization. It was founded in 1947 by the American Automobile Association to conduct research to address growing highway safety issues. The organization's mission is to identify traffic safety problems, foster research that seeks solutions, and disseminate information and educational materials. AAA Foundation funding comes from voluntary, tax-deductible contributions from motor clubs associated with the American Automobile Association and the Canadian Automobile Association, individual AAA club members, insurance companies and other individuals or groups.

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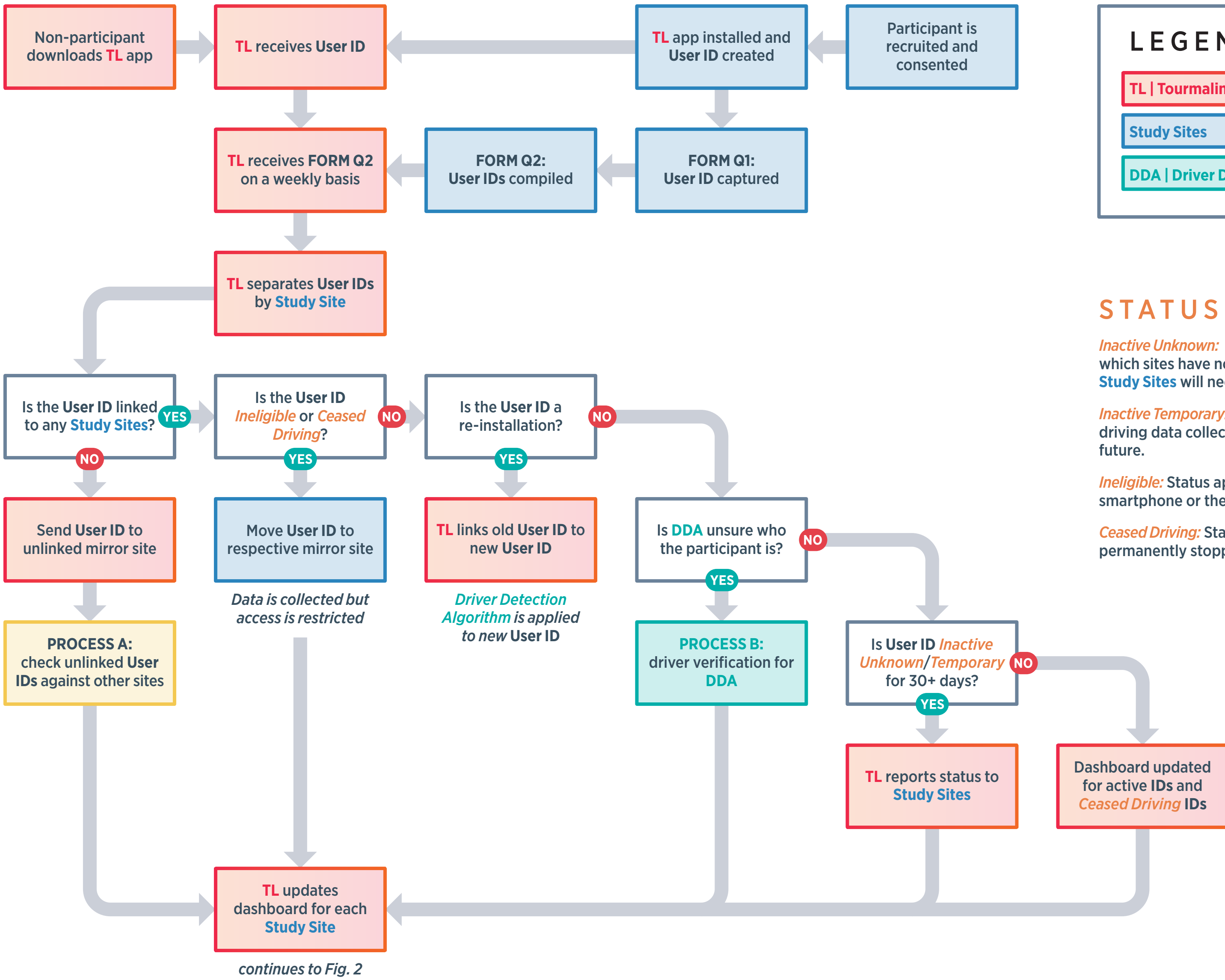
Appendix A



LEGEND

- TL | Tourmaline Labs™
- Study Sites
- DDA | Driver Detection Algorithm

STATUS DEFINITIONS

Inactive Unknown: App **User IDs** that have at least 30 days of inactivity, and for which sites have not provided further information. These are participants that **Study Sites** will need to follow-up on directly.

Inactive Temporary: App **User IDs** where the reason for inactivity is known and driving data collection is reasonably expected to resume at some point in the future.

Ineligible: Status applied to the **User ID** when the participant no longer has a smartphone or the participant removes consent for driving data collection.

Ceased Driving: Status applied to the **User ID** when the participant has permanently stopped driving.

Figure 1. Key App and Data Handling Procedures, Participant Capture

Appendix A

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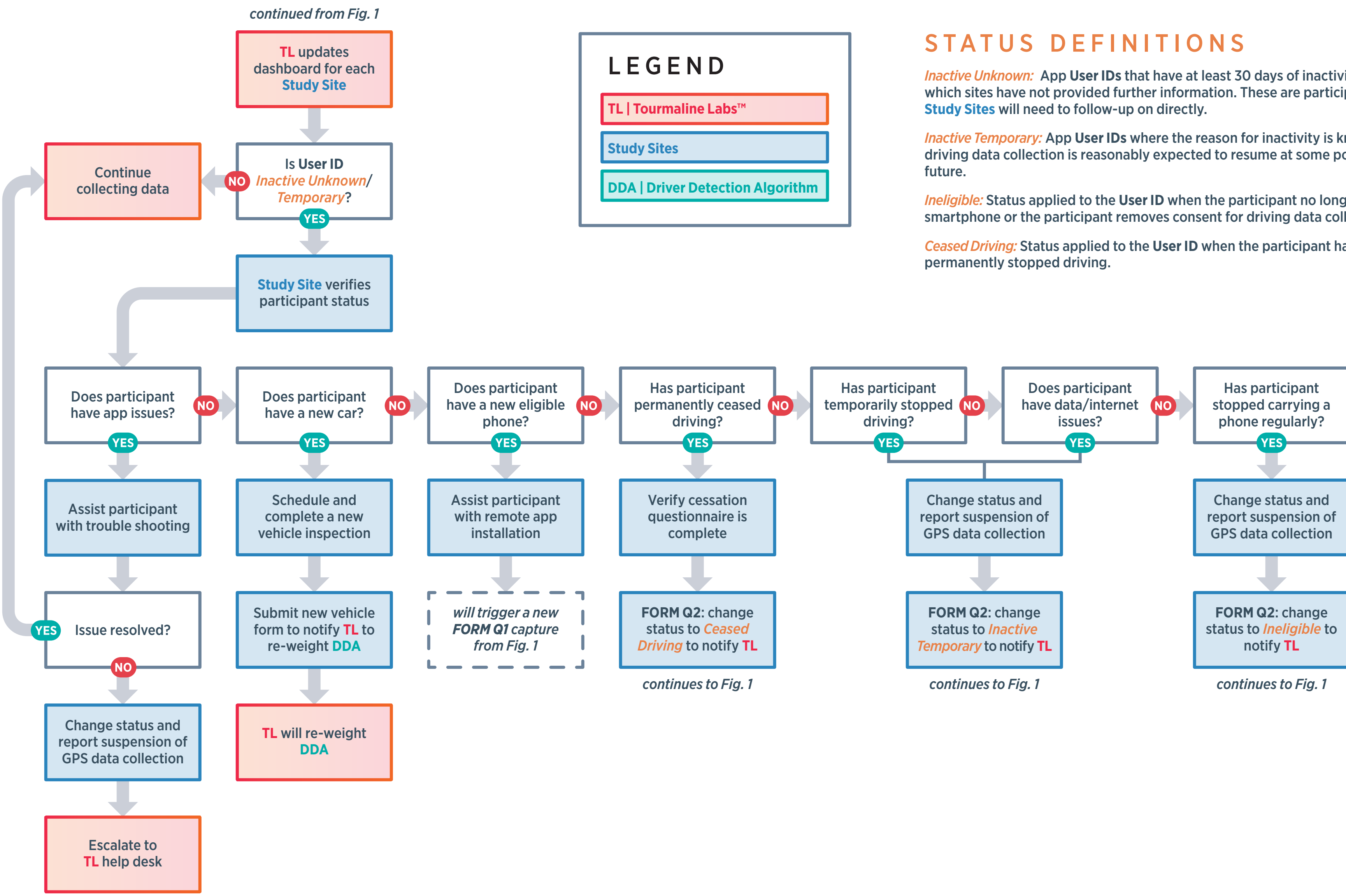

Figure 2. Key App and Data Handling Procedures, Participant Status Verification

Appendix B

F-scores were used to assess the accuracy of predictive models from the LongROAD travel app data in determining whether a participant was a driver or a passenger on a given trip. F-scores measure a test's accuracy in classifying driver profiles into two groups, the dominant driver (each LongROAD participant) or other drivers (e.g., caregiver, spouse, etc.). The score considers whether each classification was a "True Positive" (correctly identified the dominant driver), a "False Positive" (incorrectly identified an "other" driver as the LongROAD participant driver), or a "False Negative" (incorrectly identified the LongROAD participant driver as an "other" driver).

An F-score is calculated from the precision and recall of the test:

$$\textit{Precision} = \frac{\substack{\textbf{\# of true positive results} \\ \text{(i.e., correctly identified dominant drivers)}}}{\substack{\textbf{\# of all positive results, including those not identified correctly} \\ \text{(dominant drivers + other drivers)}}}$$

$$\textit{Recall} = \frac{\substack{\textbf{\# of true positive results} \\ \text{(i.e., correctly identified dominant drivers)}}}{\substack{\textbf{\# of all samples that should be identified as positive} \\ \text{(i.e., drivers that should be dominant drivers)}}}$$

$$\textit{F-score} = 2\left[\frac{(\textit{Precision} \times \textit{Recall})}{(\textit{Precision} + \textit{Recall})}\right]$$