Appendix B

Base Year Inventory Report

Proposed Clean Miles Standard Regulation

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SB 1014

Clean Miles Standard

2018 Base-year Emissions Inventory Report

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Contents

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Executive Summary

Senate Bill 1014 (SB 1014[1]), enacted in 2018, directs the California Air Resources Board (CARB) and the California Public Utilities Commission (CPUC) to develop and implement measures to reduce GHG emissions from transportation network companies (TNC). As a first step, SB 1014 requires CARB to determine the 2018 base year TNC specific CO2 emissions, in units of grams of CO2 per passenger-mile traveled (gCO2/PMT), inventory for the combined TNC industry by January 1, 2020.[2]

CARB staff estimates that the 2018 TNC vehicle fleet emitted 301 gCO2/PMT, approximately 50 percent higher than the statewide passenger vehicle fleet average of 203 gCO2/PMT. The analysis also indicates that the industry-wide TNC fleet has a 7 percent lower passenger occupancy than the California statewide passenger vehicle fleet and TNC vehicles operate approximately 61 percent of its vehicle miles traveled with a passenger in the car. Lastly, the TNC fleet is relatively more fuel efficient than the California fleet due to having higher fraction of newer model year vehicles and higher percentage of passenger cars versus light trucks. In addition, the TNC fleet has a larger fraction of high-mileage hybrid vehicles as compared to the average California passenger vehicle fleet.

TNCs provide on-demand ride services where rides are arranged online to connect a passenger with drivers using their personal vehicles. In California, vehicles employed by TNCs make up 2.5 percent of the vehicle population, and are growing at a rapid pace. Because TNCs operate differently than traditional transportation modes such as buses, trains, or taxis, the impact on future trends of GHG emissions and VMT on a per passenger mile basis is uncertain. At the present time, GHG emissions from the TNC sector is small compared to the total light duty vehicle sector. Nevertheless, we anticipate growth in VMT attributable to TNCs, which necessitates formulation of immediate policies.

[1] SB 1014 (Skinner, 2018). California Clean Miles Standard and Incentive Program.
[2] Pub. Utils. Code § 5450(b)(1).

Following the enactment of the SB 1014, CARB requested TNCs to provide the California records for trips conducted in calendar year 2018 to develop the base year emissions inventory. CARB staff performed the following data checks and analysis to ensure the emissions were defensible and clearly underscore the emission drivers to meet program needs:

- **Overlapping trips:** Overlapping trips occur due to a common practice of TNC drivers running multiple applications simultaneously between services – called multi-apping – to increase the chance of finding a ride. Most of the time, overlapping trips occur when driver is awaiting a ride request through the TNCs.[3] According to CARB's analysis, almost 11 percent of Vehicle Miles Traveled (VMT) during this time overlaps between at least two companies.
- **Deadheading:** Deadhead miles are miles that are associated with travel periods without a passenger in the car. The TNC trip data shows that approximately 38.5 percent of TNC's total VMT are deadhead miles. A study by Fehr and Peers on VMT distribution, based on data from two major TNC companies and for six metropolitan regions in the US, also supports our conclusions.[4]
- **Occupancy:** Occupancy refers to the number of passengers per fare, excluding the driver. Higher occupancy can significantly reduce the gCO_2/PMT. CARB estimates that the 2018 average fleet occupancy for the TNC industry is 1.55 (an average of the occupancy in "pooled" and "non-pooled" rides) passengers.
- **Fuel Efficiency:** In 2018, vehicles utilized for TNCs are generally newer as compared to the California passenger vehicle fleet with higher fraction of the vehicles being hybrid electric vehicles. TNCs vehicles also have a higher percentage of passenger cars as opposed to light trucks (e.g., SUVs). Additionally, the use of electric vehicles (zero emissions or plug-in hybrid electric) can significantly improve the fleet average fuel efficiency. Data provided by

[3] When TNC drivers are waiting for potential riders while logged into one or more TNC applications, this is referred to as Period 1. Period 1 (and the other Periods 2 and 3) are defined in the Methodology section of this document.

[4] Estimated TNC share of VMT in six US metropolitan regions – Fehr & Peers (2019)

TNCs indicates that the total 2018 TNC fleet electric VMT (eVMT) is about 33.7 million miles, or roughly 0.8 percent of the total VMT generated by the TNC fleet.

- **Operating Speed:** Generally, lower traveling speeds (below 55 mph) increase the emissions of CO_2 per mile. According to the data provided by TNCs, the TNC vehicles on average travel 10 miles per hour slower than the California passenger vehicle fleet. This may negatively affect TNC's average in-use fuel efficiency relative to that of the California fleet. However, note that at lower traveling speeds, hybrid electric vehicles demonstrate higher fuel efficiency as compared to conventional vehicles as a result of energy recovery using the regenerative braking systems.

The following document provides a detailed description of the results and methods used to calculate the emissions from the TNC fleet.

1. Background

According to the 2017 U.S. Environmental Protection Agency's (U.S. EPA) Greenhouse Gas (GHG) emissions inventory, transportation sector generates the largest share of GHG emissions in the U.S.[5] CARB's official GHG emissions inventory[6] shows that the transportation sector accounts for almost 50 percent of greenhouse gas (GHG) emissions in California when one includes emissions from fuel production (also known as "upstream" emissions), with light-duty vehicles making up 70 percent of the transportation sector's direct emissions. Additionally, according to the American Lung Association's 19th Annual Air Quality Report, seven of the 10 most polluted cities in the nation are in California. In 2017, transportation was responsible for more than 75 percent of statewide nitrogen oxide (NOx) emissions. Over the next decade, California is planning to undergo a significant transformation in its transportation system to reduce both criteria and greenhouse gas emissions with the goal of reducing population exposure to transportation-related air pollution while at the same time promoting economic growth. Senate Bill (SB 32) the California Global Warming Solutions Act—as amended in 2016—set forth a statewide GHG reduction goal of 40 percent below the 1990 level by 2030. As outlined in CARB's 2017 Scoping Plan, additional emission reduction programs are needed to ensure California meets that goal. To achieve these goals, CARB has established several policies, including vehicle emission standards such as the Advanced Clean Cars, fuel carbon intensity requirements such as the Low Carbon Fuel Standard, and SB 375 (Sustainable Community Strategies). New legislative programs such as SB 1014 (California Clean Miles Standards), and AB 617 (Community Air Protection Program) are also developed with the goal to further reduce transportation related emissions while promoting economic, environmental, and social equity in all regions of California.

Current reports estimate that as of 2019, more than 600,000 zero emission and plug-in hybrid vehicles operate on California roadways. While a few years ago, a mere five

[5] https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions
[6] https://ww2.arb.ca.gov/our-work/programs/ghg-inventory-program

makes and models of electric vehicles were available, more than forty-six makes and models of electric vehicles are commercially available today[7]. At least six of the models available now have more than 200 miles of zero emission range. Over 21,000 public and workplace electric charging stations support this growing number of ZEVs. Forty-one hydrogen fueling stations are also available for use by consumers in California. CARB is also seeking to reduce Vehicle Miles Traveled (VMT), with the goal of investing in a transportation system that makes it easy and affordable for all Californians to pursue a healthy and sustainable life.

Despite all the successes to date, we still need to address the forthcoming challenges. For example, as noted in the 2018 Progress Report of California's Sustainable Communities and Climate Protection Act (responding to SB 150), California is not on track to meet the greenhouse gas reductions expected under SB 375 for 2020, with emissions from statewide passenger vehicle travel per capita increasing[8]. While overall, California has achieved its combined sector 2020 climate target ahead of schedule due to strong performance in the energy sector, meeting future targets will require a greater contribution from transportation. With emissions from the transportation sector continuing to rise despite increases in fuel efficiency and decreases in the carbon content of fuel, California will not achieve the necessary greenhouse gas emissions reductions to meet mandates for 2030 and beyond without significant changes to how communities and transportation systems are planned, funded, and built.

The emergence of on-demand transportation services offered through digital platforms have transformed the urban mobility landscape as well as the ways people travel. This transformation has raised complex questions about the implications for the future of transportation in California. In 2013, the CPUC enacted regulations applicable to companies offering these services – referred to as TNCs – in order to ensure public

[7] https://www.veloz.org/sales-dashboard/

[8] 2018 Progress Report of California's Sustainable Communities and Climate Protection Act (SB 375).

safety and customer protection. According to the CPUC[9], a TNC is a company or organization operating in California that provides transportation services using an online-enabled platform to connect passengers with drivers using their personal vehicles. The growth of the TNC sector in the past couple of years raises uncertainties around its environmental impacts.

With the enactment of SB 1014, CARB requested TNCs to provide detailed level trip data for all vehicles that utilized their services in 2018. According this dataset, more than 640,000 vehicles (2.5 percent of the total light duty vehicle population in California) operated in the ride-sharing business. Figure 1 shows the distribution of TNC vehicles by census block groups in California based on their registration.

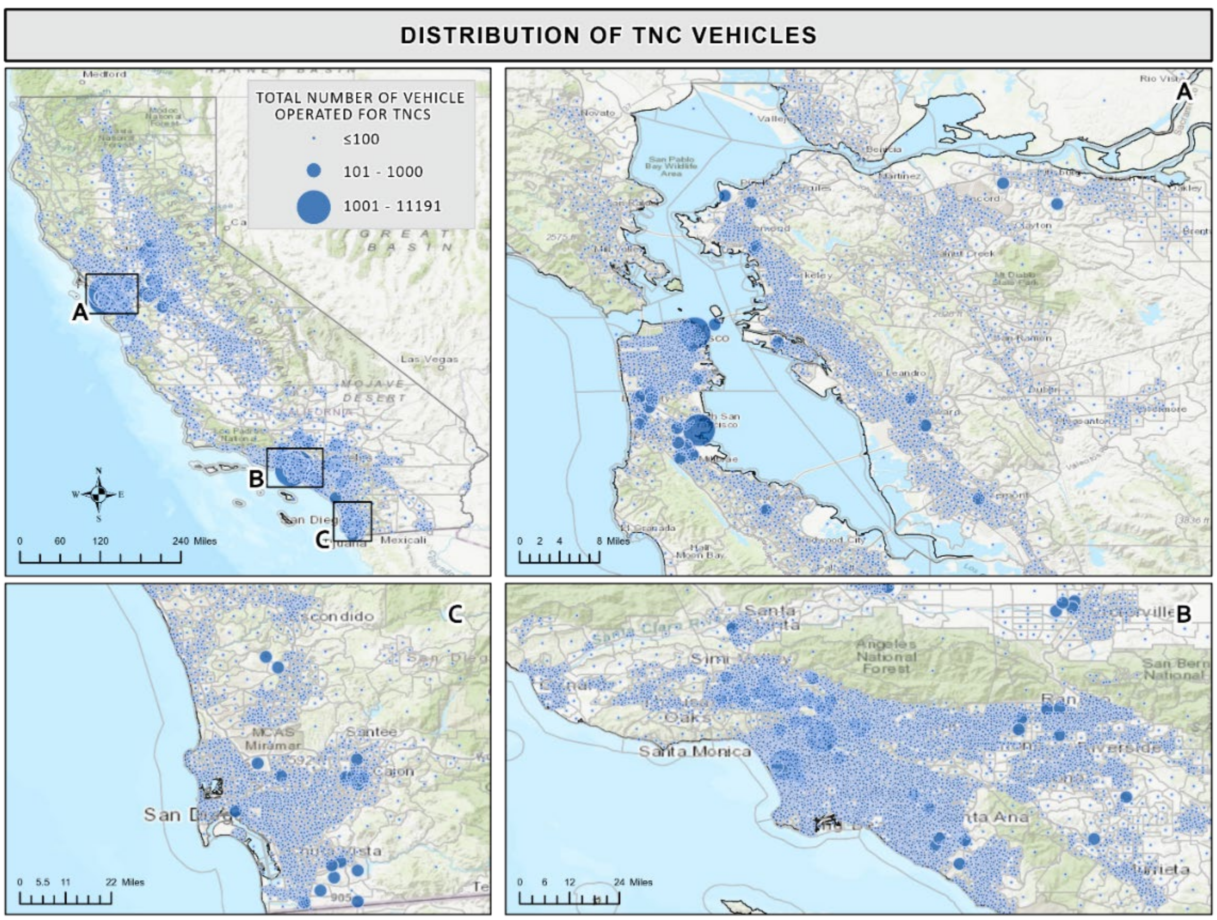

Figure 1. Distribution of the TNC fleet by census block group. Upper-left panel shows California data. Panels (A), (B) and (C) zoom in San Francisco, Los Angeles, and San Diego, respectively.

[9] California Public Utilities Commission (2018). Electrifying the Ride-sourcing Sector in California.

Data indicate that TNC vehicles are mostly concentrated in urban areas of northern and southern California and operation of TNCs is highly localized to large cities, such as Los Angeles, San Francisco, and San Diego.

The TNC category is growing faster relative to other categories of commercial passenger vehicle fleets regulated by the CPUC[7]. There are several studies on the growth and share of TNCs VMT at the global, state, and local level. The Bloomberg New Energy Finance (BNEF) projects the share of global vehicle miles traveled (VMT) by TNCs to grow from less than 5 percent today to 19 percent by 2040.[10] In California, the VMT contribution is slightly lower statewide. For example, according to recent data provided by TNCs for California, the total VMT share of TNC companies was estimated to be 1.2 percent of the total California light duty VMT. However, the VMT trends are much more substantial in urban areas. For example, according to San Francisco County Transportation Authority, TNCs contribute to 15 percent of all intra-San Francisco vehicle trips, which is 12 times the number of taxi trips in 2016.[11] Additionally, a study by Fehr & Peers conducted in six US metropolitan regions indicates that VMT share of TNCs in 2019 may have reached as high as 3 percent region-wide and approximately 2 - 13 percent when looking solely at the core county of each region, with King County in Seattle representing the least and San Francisco County representing the most[12]. Interestingly, existing research has indicated conflicting results on the impact of TNCs on VMT. Some research suggests that TNCs may cause a net increase in VMT and a reduced use of other travel modes such as mass transit and active transport (i.e., walk, bike, and scooter), while other research suggests TNCs may complement mass transit.[13] Recently, the CPUC estimated that between November 2016 and October

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[10] BNEF. Electric Vehicle Outlook (2019). (Global projection of total kilometers traveled by passenger vehicles operating in TNCs.)

[11] San Francisco County Transportation Authority, TNCs Today: A Profile of San Francisco Transportation Network Company Activity (San Francisco County Transportation Authority, 2017).

[12] Fehr & Peers, Memorandum, Estimated TNC Share of VMT in Six US Metropolitan Regions, Revision 1, Aug 2, 2019

[13] Clewlow, Regina R., and Gouri Shankar Mishra (2017)."Disruptive transportation: The adoption, utilization, and impacts of ride-hailing in the United States." University of California, Davis, Institute of Transportation Studies, Davis, CA, Research Report UCD-ITS-RR-17-07

2017, TNCs were responsible for approximately 0.54 percent of California's transportation sector GHG emissions equivalent to 0.8 percent of California's light-duty vehicle GHG emissions.[2] While GHG emissions from TNCs is still a small fraction of California light duty vehicle GHG emissions, considering the growth in their VMT in the past few years, it is important to establish policies that will ensure California will remain on its path to meet its air quality and climate goals, while mitigating congestion and VMT.

Enacted in 2018, SB 1014 – the Clean Miles Standard and Incentive Program (CMS) – directs CARB and the CPUC to develop and implement a new regulation for TNCs to reduce GHG emissions. SB 1014 requires CARB to establish by January 1, 2020, a GHG emission baseline for TNCs on a per-passenger-mile basis. This bill also requires CARB to adopt and set annual GHG reduction targets for TNC companies by January 1, 2021. The TNCs shall develop and submit a GHG emission reduction plan beginning January 1, 2022 and every two years thereafter, to meet the GHG reduction requirements, with implementation beginning in 2023. It is worth mentioning here that the CPUC will oversee the implementation of the CMS program and track compliance. The CMS regulation will be aligned with some forthcoming and existing regulations and programs in California such as next generation of the Advanced Clean Cars regulations and SB 375.

Currently, the CPUC, through the Passenger Charter Party Carriers' Act, has authority to regulate TNCs.[14] The CPUC regulates insurance requirements, increasing access to TNC services for persons with disabilities and underserved communities, and driver background checks. SB 1014 is the first legislation in the nation requiring TNCs to reduce GHG emissions. As directed in SB 1014, emission reductions will be measured on a grams-CO2-per-passenger-mile-traveled (gCO2/PMT) basis.[15] With the expected fast-paced growth of TNCs, we must ensure that the VMT contributed by TNCs are as clean as possible by requiring an increasing percentage of VMT from TNCs to be

[14] AB-45 (2012) Charter-party carriers of passengers: alcoholic beverages: open containers.
[15] Pub. Utils. Code § 5450(b)(1).

achieved by zero-emission means – in other words, promoting an increase in electric vehicle miles traveled (eVMT). SB 1014 separately directs CARB and the CPUC to consider passenger-miles traveled using zero-emission vehicles.[16]

TNCs are also in a position to influence the availability and uptake of active transport with bike-share and scooter-share services on their platforms. SB 1014 requires CARB and the CPUC to consider the facilitation by TNCs of walking, biking, and other modes of active or zero-emission transportation.[17] Again, TNC services not only can complement, but also encourage mass transit use by providing first- and last-mile trips connected to transit trips. A multi-modal mobility landscape in California can meet a variety of mobility needs while slowing VMT growth and achieving GHG reductions.

As the first step in the adoption and implementation of requirements under SB 1014, CARB staff utilized trip level data provided by 14 TNC companies to establish a 2018 base year GHG emissions inventory for TNCs. This emissions inventory will allow CARB staff to better understand the efficiency of ridesharing transportation in California and assess its impacts on regional and statewide GHG emissions. This will also provide a reference point to establish future emission targets, track progress toward goals for emission reduction from TNCs, and facilitate decision-making on future policies. This white paper presents CARB's methodology, assumptions, and preliminary results for developing a 2018 base year emissions inventory and next steps.

2. Methodology

Under SB 1014, CARB is tasked with setting a 2018 base year GHG emissions inventory for TNCs operating in California. The 2018 base year emission inventory is a reference point with which current and future emissions can be compared. The CO2 emissions trend can serve as a baseline that represents a business as usual (BAU) trajectory for estimation of future year CO2 emissions. Both base year and baseline emissions can be used to evaluate the effectiveness of future compliance scenarios for

[16] Pub. Utils. Code § 5450(b)(2).
[17] Pub. Utils. Code § 5450(b)(1).

reducing grams of CO2 per PMT. This section describes the methodology for determining GHG emissions from the TNCs.

As a prerequisite, it is essential for the reader to know how TNC companies characterize different segments of their trips. The typical TNC's ride hailing business model involves three distinct trip periods:

- *Period 1* (*P1)* is the period of time after a driver logs into a TNC application but is not yet matched with a passenger. During this time period, the driver awaits a ride request through the TNCs;
- *Period 2* (*P2)* starts when a match is made and accepted by the driver, but before the passenger has entered the vehicle. During this period of time, the driver is *en route* to pick up the passenger;
- *Period 3* (*P3)* begins when a passenger has been picked up and is an occupant of the TNC driver's vehicle. This period of time lasts until the driver completes the transaction (on the online-enabled application or platform), or until the ride is completed, whichever is later.

To compute grams CO2 per PMT for the base year inventory, the following equation was used:[18]

$$\frac{\text{Grams } CO_2}{\text{PMT}} = \frac{\text{VMT (miles) x In-Use Fuel Consumption (gal/mi) x Conversion Factor (g}CO_2\text{/gal)}}{\text{Ride VMT (miles) x Occupancy + Active/Transit PMT}} \quad \text{Eq. (1)}$$

Where

- **VMT** represents the total number of miles traveled by TNCs in calendar year 2018.
- **In-Use Fuel Consumption** represents the in-use fuel efficiency of the vehicles operating in TNCs based on the U.S. EPA Fuel Economy data, combined with in-use efficiency data collected through a comprehensive testing program to adjust the fuel efficiency for real world driving conditions (traffic/congestion) as opposed

[18] This equation is described at Public Utilities Code section 5450(b)(1).

to laboratory test conditions that is used by the U.S. EPA to derive Fuel Economies.

- **Conversion Factor** is used to convert gallons of fuel to grams of CO2 emissions. Currently staff use a common conversion factor of 8,887 grams of CO2 emissions per gallon of gasoline consumed.[19]
- **Occupancy** represents an average occupancy for pooled and non-pooled rides (excluding driver).
- **Ride VMT** represents the portion of total VMT that is associated with the P3.
- **Active/Transit PMT** is the total number of passenger-miles from other travel modes such as walking, bike, scooter and public transportation. Active/Transit PMT tends to lower the trip gCO2/PMT.

Due to a common practice of drivers being available for jobs on multiple platforms at the same time, staff deployed an algorithm to identify and remove trip data that were duplicated among multiple companies. More detail is provided in Section 2.2.

For each vehicle in the TNC-provided data, staff derived the fuel economy rating (miles per gallon or mpg) from the U.S. EPA's FuelEconomy.gov website. Staff converted the fuel economy rating from mpg to grams of CO2 per mile using a conversion factor specific to each fuel type. Then, for each TNC driving period, staff adjusted the CO2 emission rates using Speed Correction Factors (SCF) to adjust the fuel efficiency for different driving conditions. SCFs basically are adjustment factors used by California's Emissions FACtor (EMFAC) model[20] to adjust both criteria and GHG emissions for different driving conditions and speed. We then multiplied the adjusted CO2 emission rates (i.e., in-use CO2 emission rates) by VMT to calculate the per-trip CO2 emissions. Summing the per-trip CO2 emissions for all vehicles, trips, and trip periods results in the gCO2 emissions for the entire TNC fleet in 2018.

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[19] https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle

[20] EMFAC is the California's official on-road emissions inventory model that is developed and used by CARB to assess emissions from on-road vehicles including cars, trucks, and buses in California, and to support CARB's regulatory and air quality planning efforts. More information can be found at: https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory

The denominator of Eq. (1) represents the passenger miles travelled or PMT. To calculate the trip PMT, staff multiplied the trip VMT by occupancy. Due to lack of data on occupancy, CARB staff relied on estimated average occupancy derived from a CARB In-House TNC Data Logger Study. Details of this study is presented in Section 2.3. Once the PMT was calculated, the active and transit PMT can be added to account for use of other modes of transportation such as biking, walking, scooter use or commuting by other transit modes. Due to lack of information on active transportation and transit passenger miles traveled facilitated by TNCs, for the 2018 base year inventory, staff assumed the active/transit PMT to be negligible. Please note that although the active and transit PMT is assumed to be negligible in the current analysis, it may be a contributing factor in future years.

2.1. Activity Data Description

As the first step in developing the emissions inventory, CARB staff reviewed the data provided by the TNCs and identified certain data quality issues, including:

- Overlapping trip records associated with the same Vehicle Identification Number (VIN) and TNC company. A number of vehicles appeared to take multiple trips simultaneously (their trip records overlapped), suggesting that VINs were copied incorrectly into the data.
- Incorrect VINs. Staff identified a number of VINs that do not exist in California DMV vehicle registration database.
- Zero mile trips. A number of trips logged zero VMT.
- Missing or multiple trip IDs. Some trips did not contain trips identification numbers.

CARB had numerous collaborative discussions with the TNC companies and requested resubmittal of data to rectify the issues mentioned above. Following a second official data request, TNCs prepared revised versions of data and shared those with CARB. In the revised version of the data, most issues were either resolved or addressed. Both the original and revised copies are currently housed at CARB's secured data servers and each set contains over approximately 1.4 billion trip records. Please note that confidential data and information provided by the TNCs were submitted to CPUC pursuant to General Order 66-D.

The trip data requested by CARB included the following fields: 1) Unique trip ID; 2) Unique driver ID; 3) Vehicle ID number; 4) Make and Model; 5) Trip periods; 6) VMT; 7) Date and time for start and end of each trip; 8) Latitude and longitude; 9) Pooled or shared rides; and 10) Surge period. The revised version included two additional pieces of information: 1) License Plate Numbers for VINs with data issues; and, 2) begin and end zip codes. Using this dataset, staff calculated the following summary statistics, comparing the TNC-specific statistics against statewide passenger vehicle statistics from the EMFAC2017 model.[21]

Table 1. Summary Statistics of TNC Trips vs California Trips

	TNC California	***California Passenger Vehicles (EMFAC2017)***
Total number of vehicles	642,000[22]	25.6 million
Total VMT	4.3 billion miles	342.3 billion miles
Number of trips (only P3)[23]	365 million*	41.4 billion
Average Trip Length	12 miles per trip[24]	8.3 miles per trip
Cars vs. Trucks (percent)	79 vs. 21	63 vs. 37
VMT-weighted Avg. MY	2010.5	2009
Average Age	7.5	9

As shown in Table 1, the total VMT made by TNC vehicles in California in calendar year 2018 totals 4.3 billion miles, equivalent to approximately 1.2 percent of California's VMT for passenger vehicles. Out of the 25.6 million passenger vehicles registered in California, 2.5 percent or roughly 642,000 vehicles have been operating for TNCs at some point in calendar year 2018. These vehicles provided a total of 365 million trips within California, with an average VMT of roughly 12 miles per trip (including deadhead miles). According to EMFAC2017, the average trip length for passenger vehicles in

[21] CARB EMFAC2017 web platform, accessible through https://www.arb.ca.gov/emfac/2017/

[22] This is a conservative estimate on the number of vehicles that utilized TNC's passenger transportation services in 2018. Considering that some vehicles have changed their license plates over the course of 2018, the actual number might be slightly lower than this.

[23] Number of P3 trip records is calculated based on the raw count of reported P3 trip records. Please note that counting the number of unique trip IDs may result in a different number of trips.

[24] Please note that the trip length for TNCs include deadhead miles

California is 8.3 miles per trip. Please note that EMFAC model refers to a trip as an engine ON/OFF event, and the trip definition is not necessarily consistent with how TNCs define a trip. For example, a vehicle being moved within a garage is counted as one trip in EMFAC, while this would not be considered a passenger trip in TNC data. Considering these caveats, overall, TNC vehicles accounted for only 0.9 percent of the California trips. Note that the total number of trips for TNCs is based exclusively on the total count of P3 trips, because only the revenue generating trips were taken into account for this metric. In terms of car and truck split, 79 percent of the TNC fleet is considered to be passenger cars and the rest are 21 percent, is considered to be trucks. In contrast, the California fleet car and truck split is 63 percent passenger cars and 37 percent of light trucks. According to the data, on average, the 2018 TNC vehicle fleet is approximately 1.5 years younger than California fleet average vehicles.

2.2. Trip Overlap Removal

Industry-wide TNC fleet metrics, such as total CO2 emissions per passenger mile and percent eVMT, depend on a correct estimation of VMT. Hence, to estimate total California emissions across the entire industry as a whole, it is crucial to remove the overlapping trip VMT that occur due to a common practice of TNC drivers running multiple apps simultaneously and toggle back and forth between services – called multi-apping – to increase the chance of finding a ride. For example, some drivers may install multiple TNCs apps on their smart phones to not only increase chances of receiving a ride requests from any of the companies but also look for the one that offers higher monetary compensation. An example is illustrated below in Figure 2.

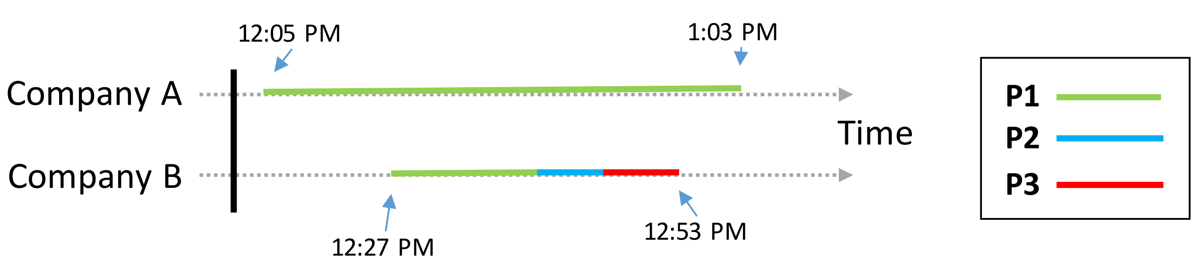

Figure 2. An example of multiple overlapping trip records

As shown in Figure 2, the driver starts Company A app at 12:05 PM which initiates a P1 trip period. At 12:27 PM, the driver decides to run Company B app as well. Both P1 trip periods are shown using green bars. Within the next few minutes, the driver receives a ride request from Company B (beginning of blue bar). The driver then driver accepts the ride, drivers to the passenger (blue bar), picks up the passenger (beginning of red bar), travels to the requested passenger destination (red bar), and drops him/her at a destination at 12:53 PM (end of red bar). The blue and red bars represent the P2 and P3 periods respectively. Finally, the driver turns off the Company B app at 12:53 PM after the P3 ride and the Company A app at 1:03 PM. As shown, the submitted trip records starting at 12:27 PM and ending at 12:53 PM reflect mileage that is recorded by both companies and therefore is double counted. The double counting of mileage results in overestimation of CO2 emissions when emissions are estimated across the entire industry as a whole.

According the TNC data, out of 640,000 TNC vehicles operating in California, roughly 22 percent of them worked at least for two companies simultaneously within calendar year 2018. To remove the overlapping trip mileage, for any given vehicle, one could simply iterate through the trip records ordered by trip start time, and then fix all the trip records that overlap with a given trip by simply querying for the overlapping beginning and end time periods. This presents, however, a couple of challenges:

- **Overlap test.** Searching for overlapping time periods is computationally intensive, especially when it comes to resolving overlapping trip periods for 1.4 billion trips. A trip period can be as long, longer, or shorter than another trip period. It can be also be partially covering other trips on the left or right ends, or can be containing or contained in other trip period(s).
- **Recursion.** Due to some bad quality data, multiple trip records may overlap. For cases such as this, every time the above algorithm is run between two given trip periods, new trip records could be generated that may still be overlapping with other trip records. Hence, the algorithm must be re-run with the newly generated trip records as well as the rest of the records.

CARB staff attempted to fix the overlapping trip records using the above mentioned algorithm. However, our initial attempts indicated that fixing the entire trip records using CARB's available computational resources could take a long time. In order to significantly expedite the VMT overlap removal process, CARB staff developed a new algorithm named *Stick Painting Algorithm*. This algorithm is extremely efficient and resolves the issue of overlapping trips for billions of trip records within a reasonable amount of time. The "Stick Painting Algorithm" is described in detail below.

Stick Painting Algorithm

Unlike all common solutions to the aforementioned problem, the *Stick Painting algorithm* is a *table lookup-less algorithm*. Because there is no need to find overlapping trips, the algorithm is much faster over other *conventional table-lookup* algorithms. The algorithm also leaves no room for recursion and instead fixes all the overlapping trips in one iteration. The steps involved and assumptions used in fixing the overlapping trip periods are described below and illustrated in Figure 3.

Assumptions

- Assume that time is a long wooden stick, and the length of the stick regardless of the measurement unit is represented by number of seconds in a year;
- The beginning and the end of the stick can be marked with location indices 0 and 31,536,000 (total number of seconds in a year) respectively, and any location on the stick can be referenced using a unique location index;
- The stick can be painted on using multiple different colors;

Steps

1. Assign a color to each time period. In Figure 3, colors green, blue, and red are assigned to P1, P2, and P3, respectively;
2. Separate the trip records, by VIN, and extract the records associated with each VIN in a separate file called a *VINfile*;
3. For each VINfile, sort the trip records by start time in a descending order and group records by time period.
    - 3.1. Iterate through the P1 trip records and for each trip record paint a segment on the stick that corresponds to the beginning and end of the trip period using color green;
    - 3.2. Repeat the previous Step 3.1 with P2 records followed by P3 trip records.

4. Find the location index 0 or the beginning of the stick and move gradually towards location index 31,536,000 or the end of the stick. While moving, find the painted segments and reconstruct the trip records using the color of each painted segment on the stick and the location indices of the segments; and finally,
5. Re-adjust the VMTs, for all the surviving trip records, using the durations of the new or surviving trip periods, and the average speeds obtained from the original trip records.

Note that it is acceptable to paint over a part of the stick that is already painted. This is how the algorithm *find* and *removes* duplicative VMT. In simple words, the algorithm prioritizes the P3 over P2, and P2 over P1 trips, and remove overlaps caused as a result of multi-apping or data quality issues. The prioritization is a consequence of iterating first with P1 trips, before moving on to P2 and P3 trips, respectively.

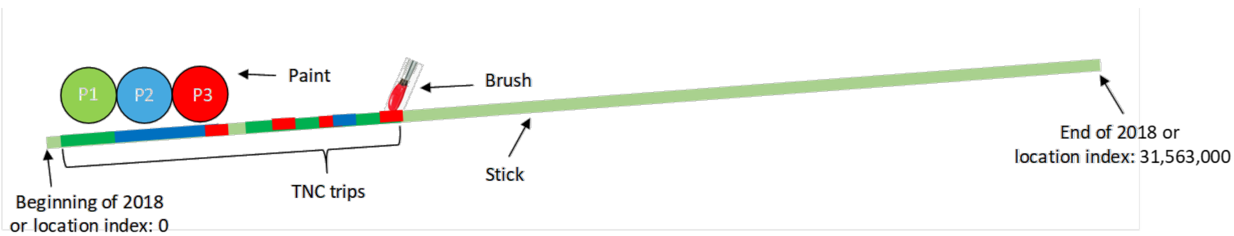

Figure 3. Graphical Illustration of the Stick Painting Algorithm

2.3. Occupancy

As described earlier, SB 1014 requires CARB to establish a base year GHG emissions for TNCs on a per-passenger-mile basis. SB 1014 direct staff to estimate total passenger-miles completed using an average passengers-per-trip estimate to account for trips where exact passenger head count data was not captured. Herein after in this document, staff use the term *occupancy* as the number of passengers per fare not including the driver. As mentioned in the preceding Section 2.1, although CARB received rideshare data for calendar year 2018 from California TNC companies (data from over 640,000 vehicles), information on the number of passengers per ride (occupancy) was not included in this dataset.

Some occupancy data are available through literature. For example, staff identified three recent studies that provide estimations of occupancy associated with ride-sharing businesses in California as well as in other states. The first study by Circella *et al.*[25] used an online survey that sampled over 1200 trips in California showing an average occupancy of about 1.9 passengers per trip in year 2018. The occupancy levels were calculated from trips across different days of the week and time of day. For weekdays, the average occupancy was 1.69, for weekends it was 1.93, for weekend days it was 1.95 and for weekend nights it was 2.16 passengers per trip. In the second study by Henao *et al.*[26], data from 416 ride-hailing trips in the Denver metropolitan region during the fall of 2016 was analyzed to determine an occupancy of 1.34 (average occupancy was 1.36 passengers per ride, and distance weighted occupancy was 1.31). In the third study by Gehrke *et al.*[27], data from 942 ride-hailing trips in the Greater Boston area during fall 2017 was analyzed resulting in an overall average occupancy of 1.52 (and an average of 1.4 for pooled rides and 1.54 for non-pooled rides).

The first study provided preliminary results from an online survey that were based on the analysis of unweighted data, where the reliability of responses have not yet been thoroughly examined. The latter two studies surveyed Denver and Boston area drivers and does not specifically represent California ridership. Therefore, CARB initiated a Data Logger Study in the spring of 2019 to collect vehicle activity, including occupancy and driving patterns, as well as engine data from up to 40 vehicles operating in California.

CARB Data Logger Study

In order to better understand in-use emissions, activity profiles, as well as average occupancy of pooled and non-pooled rides within the TNC network, a test program was

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[25] Giovanni Circella, Grant Matson, Farzad Alemi, and Susan Handy. *Panel Study of Emerging Transportation Technologies and Trends in California: Phase 2 Data Collection*. (2019) National Center for Sustainable Transportation, University of California Davis, Institute of Transportation Studies.

[26] Alejandro Henao, Wesley E. Marshall. *The impact of ride-hailing on vehicle miles traveled*. (2018) Springer Science+Business Media, LLC, part of Springer Nature 2018.

[27] Steven R. Gehrke, Alison Felix, and Timothy G. Reardon. *Substitution of Ride-Hailing Services for More Sustainable Travel Options in the Greater Boston Region*. (2019) Transportation Research Record I-9, National Academy of Sciences: Transportation Research Board 2019, DOI: 10.1177/0361198118821903 journals.sagepub.com/home/trr.

initiated in January 2019 to collect vehicle activity and engine data from up to 40 randomly selected vehicles operating in southern and northern California. The list of solicited participants are shown in Table 2 with their vehicle description (model year, make and model), and each driver's home city.

Table 2. CARB Logger Study Participant List

Vehicle ID	Model Year	Make	Model	City	Vehicle ID	Model Year	Make	Model	City
1	2017	Hyundai	Ioniq hyb	Riverside	**22**	2014	Nissan	Versa	Palm Springs
2	2012	Honda	Civic	Riverside	**23**	2017	Dodge	Gr Caravan	Huntington Bch
3	2018	Hyundai	Tucson	Riverside	**24**	2018	Hyundai	Elantra	Carlsbad
4	2011	Hyundai	Equus	San Diego	**25**	2013	Toyota	Prius	Sacramento
5	2015	Honda	Civic	San Jose	**26**	2012	Toyota	Prius C	San Jose
6	2015	Hyundai	Elantra	Lake Elsinore	**27**	2017	Hyundai	Sonata	Yorba Linda
7	2019	Kia	Optima	San Diego	**28**	2015	Toyota	Prius	San Diego
8	2016	Mazda	3 Sport	San Diego	**29**	2016	Nissan	Versa Note	N Highlands
9	2017	Toyota	Camry	San Diego	**30**	2015	Toyota	Prius	San Pablo
10	2012	Toyota	Prius PHEV	Novato	**31**	2018	Toyota	Camry	Concord
11	2013	Hyundai	Sonata	San Diego	**32**	2016	Lincoln	MKZ	Richmond
12	2012	Subaru	Impreza	San Diego	**33**	2018	Mazda	3	Fullerton
13	2013	Ford	Explorer	San Diego	**34**	2010	Lexus	GS350	Hayward
14	2017	Ford	Fusion PHEV	Richmond	**35**	2014	Kia	Soul	Santa Monica
15	2018	Honda	Accord hyb	Sacramento	**36**	2016	Hyundai	Sonata hyb	El Cerrito
16	2013	Toyota	Prius C	Los Angeles	**37**	2013	Nissan	Sentra	Brea
17	2017	Kia	Optima	Bellflower	**38**	2017	Honda	Civic	Hesperia
18	2015	Toyota	RAV4	Glendale	**39**	2007	Honda	Odyssey	Tulare
19	2019	Honda	Insight hyb	Hayward	**40**	2014	Toyota	Prius Plug-in	San Jose
20	2015	Toyota	Prius	San Mateo	**41**	2019	Subaru	Outback	Berkeley
21	2017	Hyundai	Elantra	Whittier	**42**	2007	Toyota	Prius	Berkeley

Through this test plan, and with the assistance of a State Contractor, data was collected over a two-week period using small portable data logging units (i.e., HEM Mini Loggers) that were plugged into the procured vehicle's diagnostic link connector. The on-board logger units collected engine data in a second-by-second format. The data were analyzed by CARB staff to determine each vehicle's driving details which included idling durations, number of engine starts, speed distributions, trip miles traveled, and in-use fuel consumption. Results from the analysis of the logger data are presented in the subsequent section of this report. Each driver was also requested to collect supplemental information in a trip diary such as the time of each event, the TNC type hailed, and occupancy.

Table 3 shows an example of the driver's trip diary where each event was recorded by time, with TNC companies (listed as companies A, B and C in this example), and the option to identify the fare as a pooled or non-pooled type.

Table 3. CARB Data Logger Study – Driver's Trip Diary Example

Daily Trip Diary			
Date:	______________		
Vehicle:	______________		Driver: ______________
Odometer:	______________		
	Event Code S: Start the App O: App turned Off W: Waiting R: Receive Call P: Pick Up D: Drop Off *Circle one for each line:*	TNC Type AP: Pooled AN: Non Pooled BP: Pooled BN: Non Pooled CP: Pooled CN: Non Pooled *Circle one:*	Number of Passengers (not including driver) *Circle one:*
Time (am/pm)	Event	TNC Type	No of Passengers
	S O W R P D F	AP AN BP BN CP CN	1 2 3 4 5 6
	S O W R P D F	AP AN BP BN CP CN	1 2 3 4 5 6
	S O W R P D F	AP AN BP BN CP CN	1 2 3 4 5 6
	S O W R P D F	AP AN BP BN CP CN	1 2 3 4 5 6
	S O W R P D F	AP AN BP BN CP CN	1 2 3 4 5 6

Note: In the example shown in Table 3, the format for TNC Type is AP: Company A - Pooled, AN: Company A - Non Pooled, BP: Company B - Pooled, BN: Company B - Non Pooled, etc.

Information collected through the trip diaries were used to determine the TNC type, the number of passengers per ride, and the distribution of occupancy between pooled and non-pooled fares.

From the list of 42 solicited participants, a total of 31 trip diaries were available for occupancy analysis (3 loggers failed to connect to the vehicle, 6 drivers elected to drop out of the study, and 2 loggers were lost through the mail during retrieval). The information from each trip diary was interpreted by staff and entered into a database containing the fields for Vehicle ID, Date, Time, Event, Period, TNC Type and Number of Passengers. The Period was identified by the Event code (W=Period 1, R=Period 2, P=Period 3). For occupancy analysis, staff sorted the data by Period 3 which indicated the number of passengers in each vehicle during that fare. Analysis of this filtered dataset for 31 drivers is shown in Table 4. This dataset was used to calculate average occupancy by pooled or non-pooled TNC type, as well as the number of fares used to derive the averages. It should be noted that the vehicles driven by participants 23 and 39 were minivans showing higher average occupancies.

Table 4. Rideshare Occupancy by Pooled or Non-Pooled Type (31 Trip Diaries)

Location	Vehicle	Trip Type	No. Fares	Avg. Passengers
Riverside	1	Pooled	9	1.11
		Non-Pooled	66	1.58
Riverside	2	Pooled	0	0.00
		Non-Pooled	77	1.39
Riverside	3	Pooled	9	1.25
		Non-Pooled	147	1.31
San Jose	5	Pooled	17	1.45
		Non-Pooled	48	1.49
Lake Elsinore	6	Pooled	2	2.00
		Non-Pooled	117	1.01
San Diego	8	Pooled	4	1.00
		Non-Pooled	87	1.55
San Diego	9	Pooled	55	1.43
		Non-Pooled	95	1.54
Novato	10	Pooled	1	1.00
		Non-Pooled	42	1.40
San Diego	11	Pooled	50	1.44
		Non-Pooled	147	1.46
San Diego	12	Pooled	26	1.04
		Non-Pooled	61	1.34
San Diego	13	Pooled	6	1.33
		Non-Pooled	25	2.96
Richmond	14	Pooled	1	2.00
		Non-Pooled	103	1.76
Sacramento	15	Pooled	0	0.00
		Non-Pooled	37	1.22
Los Angeles	16	Pooled	4	1.25

Location	Vehicle	Trip Type	No. Fares	Avg. Passengers
		Non-Pooled	112	1.34
Bellflower	17	Pooled	9	1.22
		Non-Pooled	78	1.21
San Mateo	20	Pooled	4	1.00
		Non-Pooled	2	1.50
Whittier	21	Pooled	31	1.32
		Non-Pooled	147	1.06
Palm Springs	22	Pooled	0	0.00
		Non-Pooled	43	2.21
Hunt. Beach	23	Pooled	0	0.00
		Non-Pooled	79	3.38
Sacramento	25	Pooled	29	2.86
		Non-Pooled	131	1.64
San Jose	26	Pooled	0	0.00
		Non-Pooled	84	1.24
Yorba Linda	27	Pooled	0	0.00
		Non-Pooled	41	1.24
San Diego	28	Pooled	16	1.13
		Non-Pooled	87	1.43
N. Highlands	29	Pooled	0	0.00
		Non-Pooled	67	1.24
Fullerton	33	Pooled	0	0.00
		Non-Pooled	7	1.29
Hayward	34	Pooled	25	1.56
		Non-Pooled	75	1.45
Brea	47	Pooled	3	1.00
		Non-Pooled	59	1.42
Tulare	39	Pooled	18	3.22
		Non-Pooled	36	4.08
San Jose	40	Pooled	0	0.00
		Non-Pooled	41	1.90
Berkeley	41	Pooled	12	1.17
		Non-Pooled	107	1.65
Berkeley	42	Pooled	5	2.00
		Non-Pooled	170	1.56

For each Period 3 event, the driver recorded the number of passengers using the trip diary. However, there were occasions when a passenger is picked up, and one (or more) other passengers are picked up before the first passenger is dropped off. The driver recorded the pick up and drop off times of each passenger. Staff adjusted these events by weighting the occupancy rate by time each passenger spent in the vehicle. An example of the adjustment is shown in Table 5. In this example, the average occupancy for this fare is 1.33 passengers. In this data set, a total of 27 fares were adjusted for multiple passengers within each fare.

Table 5. An Example of Time Weighted Adjustment for Passengers (fictitious data)

Time	Event	TNC Type	No. Passengers	Minutes	Occupancy	Adjusted Occupancy
5:15 PM	Pick Up	Pooled	1			**1.33**
5:15 PM	Pick Up	Pooled	1	0:10	1	
5:22 PM	Drop Off			0:07	2	
5:26 PM	Drop Off			0:04	1	

Total Fare Time: 21 minutes
Adjusted Occupancy: $(\frac{10}{21} \times 1) + (\frac{7}{21} \times 2) + (\frac{4}{21} \times 1)$

The average number of passengers, or occupancy, by TNC type for 336 pooled fares and 2,418 non-pooled fares were determined and are shown in Table 6. For pooled rides, the average number of passengers per fare was determined to be 1.57 ± 0.92 (standard deviation), and for the non-pooled, the average occupancy was determined to be 1.54 ± 0.94 passengers per fare.

Table 6. Pooled and non-pooled occupancies

Occupancy	Average Occupancy	No. of fares
Pooled Rides	1.57±0.92	336
Non-pooled Rides	1.54±0.94	2418

A t-Test (Two-Sample Unequal Variance) was also performed to check if the means of the pooled and non-pooled datasets are equal although the number of fares were distinctly different (336 fares for pooled rides and 2418 fares for non-pooled rides). Generally, a t-test can be used to determine if the means of two sets of data are significantly different from each other. The results of the t-Test concluded that the average occupancy between pool and non-pooled rides does not differ significantly.

2.4. Fuel Economy

To calculate the total CO2 emissions for each trip, first CARB staff assigned each TNC vehicle a fuel economy rating obtained from U.S. EPA's Federal Fuel Economy Data.[28] Staff converted the fuel economy rating to a base CO2 emission rate in units of grams CO2 per mile, and subsequently adjusted it using a speed correction factor as described earlier in section 2. Staff used the resulting CO2 emission rates to calculate CO2 emissions for each trip.

Figure 4 illustrates how staff determined the fuel economy. First, CARB staff constructed a list of all unique VINs. Staff then used vehicle registrations data from the California Department of Motor Vehicles (DMV) to derive basic vehicle characteristics such as make, model, series, and model year. Staff also queried a proprietary VIN decoder tool developed by IHS Markit named VINtelligence for more detailed vehicle characteristics such as transmission type, fuel type, and drivetrain type.[29] Staff combined the basic and detailed vehicle characteristics from DMV and VINtelligence along with the VINs into a database to facilitate further matching of vehicle characteristics against those listed in U.S. EPA FuelEconomy.gov database. This table is referred to as "*TNC fuel economies.*"

CARB staff downloaded the U.S. EPA rated fuel economy data for all available model years from www.fueleconomy.gov and loaded it into another database referred to as "*EPA fuel economies.*" As shown in Figure 4, staff used these tables as input to an advanced matching algorithm where the algorithm iterated through the *TNC fuel economies* database and, for each VIN record, it searched the *EPA fuel economies* database to finds a vehicle with the most similar vehicle characteristics.

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[28] U.S. EPA FuelEconomy.Gov database accessible through https://www.fueleconomy.gov/feg/download.shtml

[29] IHS MARKIT, VIN Services, VINtelligence, https://ihsmarkit.com/products/automotive-vin-interpretation-decoding.html

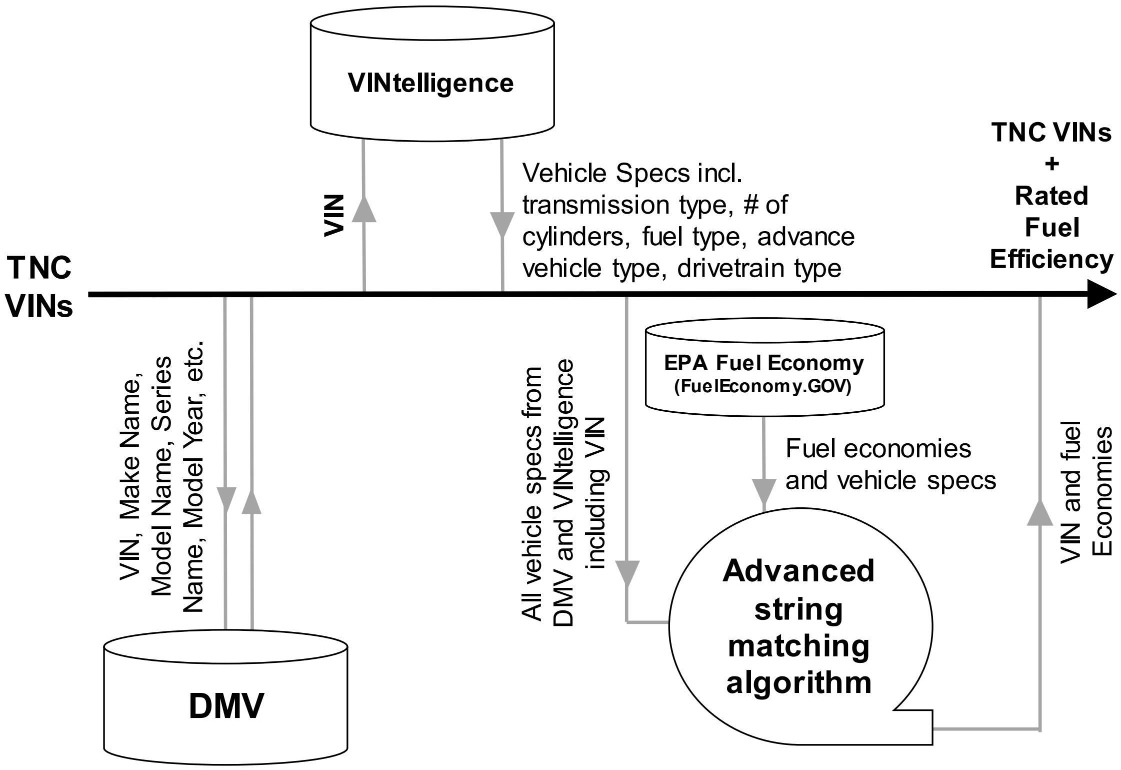

Figure 4. Flow chart to determine fuel economy rating of TNC fleet

To identify the most similar vehicle in the *EPA fuel economies* database to a given TNC vehicle, staff relied on cosine similarity as a measure of analogy between the two vehicles. Mathematically, cosine similarity measures the cosine of the angle between two vectors projected in a multi-dimensional space. Given that two vehicle makes and models along with their vehicle characteristics can be encoded in terms of two numerical vectors $\vec{a}$ and $\vec{b}$ in a vocabulary space that is N dimensional, the similarity between the characteristics of two vehicles can be expressed simply using the following equation:

$$\cos\theta = \frac{\sum_{i=1}^{N} a_i b_i}{\sqrt{\prod_{i=1}^{N} a_i^2}\sqrt{\prod_{i=1}^{N} b_i^2}} \quad \text{Eq. (2)}$$

As an example, the cosine similarity is calculated for the following two vehicles as described below. The goal is to determine how similar these two vehicles are.

1) 2018 Toyota Prius Prime 2WD Automatic PHEV
2) 2018 Toyota Prius Eco 2WD Automatic

The first step is to create a list of the words from both vehicles:

List of words used in the description of both vehicles (1) and (2):

[‘2018’, ‘Toyota’, ’Prius’, ‘Prime’, ‘2WD’,’Automatic’, ‘PHEV’, ‘Eco’]

This list forms a vocabulary space. Using this list, it is possible to generate a numerical representation for each vehicle description, also called a *word vector*. This is done by counting how many times each word appears in the description of each vehicle at each specific location in the above list. Word vectors $\vec{a}$ and $\vec{b}$ are created for vehicles (1) and (2), respectively, as shown below.

Table 7. Cosine Similarity – an example

Vocabulary	$\vec{a}$	$\vec{b}$	$a_i b_i$
2018	1	1	1
Toyota	1	1	1
Prius	1	1	1
Prime	1	0	0
2WD	1	1	1
Automatic	1	1	1
PHEV	1	0	0
ECO	0	1	0
$\sqrt{\prod_{i=1}^{N} a_i^2}$	$\sqrt{7}$	-	-
$\sqrt{\prod_{i=1}^{N} b_i^2}$	-	$\sqrt{6}$	-
$\sum_{i=1}^{N} a_i b_i$	-	-	5

Using the information provided in the Table 7, it is now possible to calculate the cosine similarity for the two vehicles as:

$$\cos\theta = \frac{\sum_{i=1}^{N} a_i b_i}{\sqrt{\prod_{i=1}^{N} a_i^2}\sqrt{\prod_{i=1}^{N} b_i^2}} = \frac{5}{\sqrt{7}\times\sqrt{6}} \approx 77 \text{ percent}$$

For this analysis, staff calculated the cosine similarity between all possible pairs of vehicle records listed in the databases *TNC fuel economies* and *EPA fuel economies*; staff then selected only pairs with the highest cosine similarity scores. Subsequently, the 2-cycle (i.e., unadjusted) city MPGs of the most similar matches/vehicles from EPA fueleconomy.gov were assigned to the input VINs for all TNC vehicles. This analysis was also quality checked to ensure that correct fuel economy values are assigned to each vehicle.

Following the above methodology, staff obtained 2-cycle[30] city MPGs for all TNC vehicles that operated in California in 2018. A cumulative probability distribution for 2-cycle city MPGs derived for these vehicles is shown in Figure 5. As shown, the TNC vehicle fleet has higher fuel efficiency ratings than the average California passenger fleet. Please note that for California fleet (dashed line), staff are only showing the 2-cycle city MPG for passenger vehicles of model years 2009 and later registered in California DMV vehicle registration database. Staff estimated the 2018 VMT weighted average fuel economy rating for the TNC vehicle fleet at approximately 39.7 miles per gallon, while for California fleet (all model years), staff estimated the 2018 fuel economy of the passenger vehicle fleet at approximately 26.7 miles per gallon[31]. The average 2-cycle city MPG for California passenger vehicles of model years 2009 and later (represented by dashed-line in Figure 5) is 27.5 mpg.

To be consistent with how EMFAC calculates emissions, CARB staff had to convert the unadjusted 2-cycle city fuel economy ratings (miles/gallon) to a CO2 emission rate (g CO2/mile) using a fuel specific conversion factor of 8,887 grams CO2 per gallon of gasoline, and 10,180 grams CO2 per gallon of diesel.[32]

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[30] CAFE fuel economy and GHG emission testing is performed over two U.S. EPA laboratory test cycles: FTP-75 and HWFET. This sometime is referred to as the U.S. EPA 2-cycle test.

[31] Based on EMFAC2017 model using an average speed of 27.5 mph (i.e., average speed of UC Bag 2). Please note that this includes passenger vehicles for all model years.

[32] U.S. EPA website, URL: https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

It is noteworthy to mention that the 2-cycle (i.e., unadjusted) U.S. EPA city fuel economy, is based on CO2 emissions measured under three phases of Federal Test Procedure (FTP) dynamometer cycle.[33] These emission are then weighted across all three phases of FTP cycle to derive an FTP composite also known as “2-cycle city” CO2 emission rates as well as fuel economy. In the early 1990’s, chase car and instrumented vehicle data collection efforts revealed that the FTP does not sufficiently represent contemporary driving, therefore, starting with EMFAC 2000, the model used emission factors that are derived under Unified Cycle (UC) to estimate emissions from cars and trucks.[34] The UC cycle is consistent of three phases, of which phases 1 and 3 are mainly used to determine start emissions (i.e., excess emissions during engine start), whereas phase 2 is mainly used to estimate running emissions. Thus, CARB staff converted the FTP-based CO2 emission rates, derived from the U.S. EPA 2-cycle fuel economies to UC Phase 2 based emission rates.

For the above conversion, staff queried CARB’s Vehicle Emissions Database System (VEDS), for more than a thousand vehicles that were tested under both test cycles, and were able to derive a correlation for CO2 emission rates (g/mile) under a composite FTP cycle and phase 2 of UC cycle. As shown Figure 6, the best linear fit has a slope of 0.99 and a coefficient of determination of 92 percent indicating a very high correlation between the composite FTP and Phase 2 of UC cycle (i.e., UC Bag 2) CO2 emissions. Hence, the FTP Composite emission rates were used as a surrogate for UC Bag 2 emission rates. Please note that the UC Bag 2 emissions rates were further corrected to account for real world driving conditions as explained in the next section.

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[33] U.S. EPA, Dynamometer Drive Schedules, https://www.epa.gov/vehicle-and-fuel-emissions-testing/dynamometer-drive-schedules

[34] Ibid.

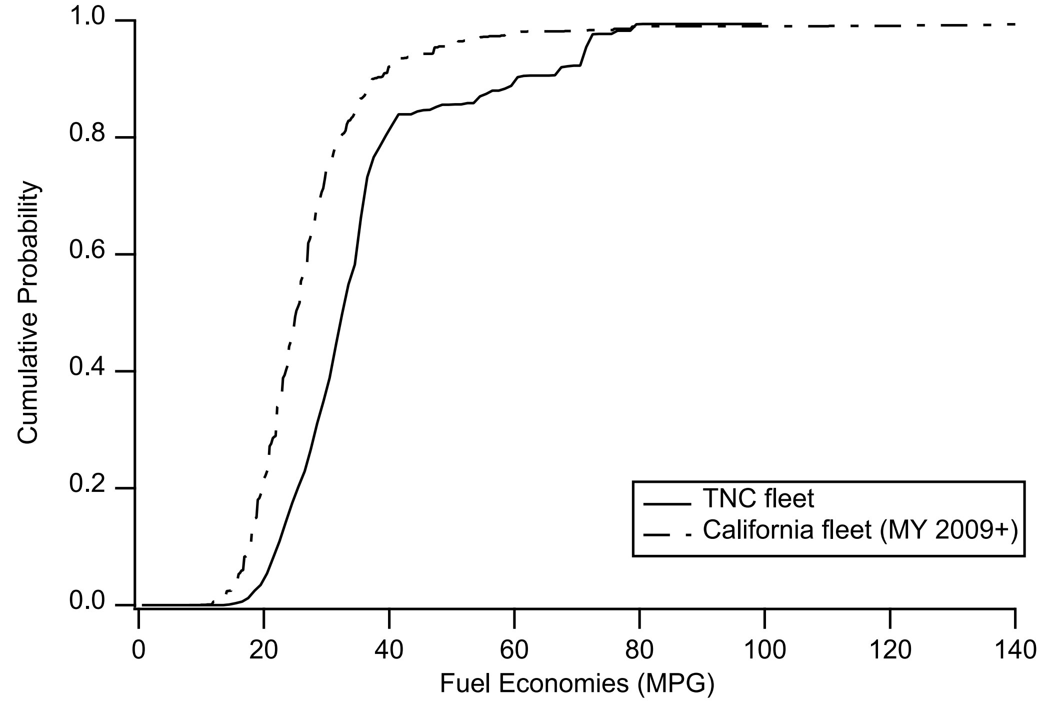

Figure 5. Cumulative distribution of fuel economy ratings between CA and TNC vehicle fleets

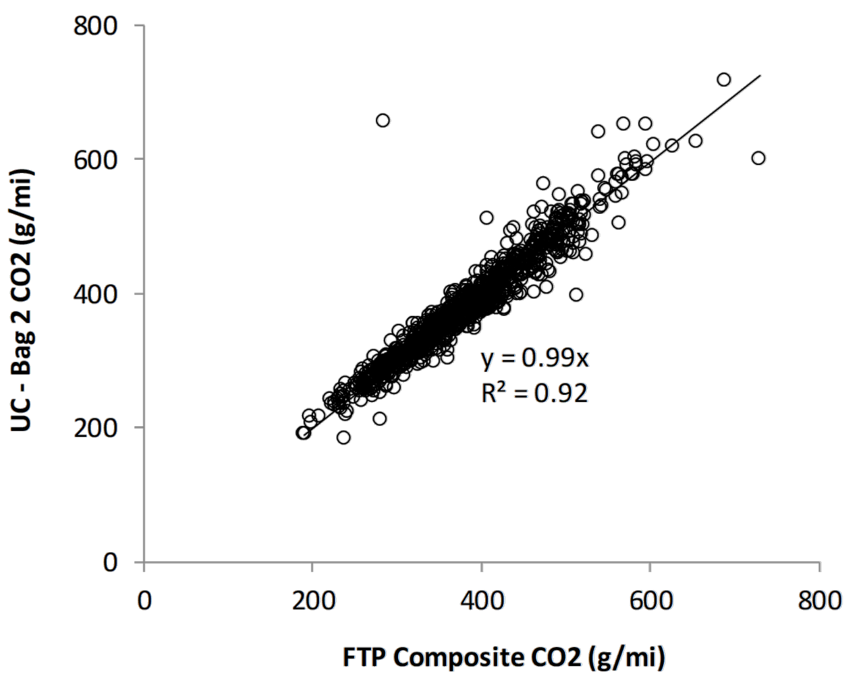

Figure 6. Comparison between CO2 emission rates of FTP and UC-Bag 2 cycles

2.5. Drive Cycle Correction (Speed Correction Factors)

As mentioned in Section 2.3 of this white paper, CARB staff obtained 1-Hz activity data from TNC vehicles that participated in the CARB Data Logger Study. CARB staff was only able to retrieve data from 28 vehicles. Every vehicle data set contained second-by-second speed (km/hr) and fuel consumption (ml/sec), amongst other vehicle operational parameters. The instantaneous speed and fuel consumption information allowed us to determine CO2 emissions as well as distance traveled.

$$\text{CO2 emission rate}\left(\frac{\text{g}}{\text{sec}}\right) = \text{fuel consumption}\left(\frac{\text{ml}}{\text{sec}}\right) \times \frac{\text{1gallon}}{\text{3785.41 ml}} \times \frac{\text{8,887 gram CO2}}{\text{1 gallon of gasoline}} \quad \text{Eq. (3)}$$

By pairing up the timestamp of the logger's data and the trip diary of the corresponding vehicle, staff was able to extract number of trips for 28 vehicles where data logger data were retrieved. Each trip has a distanced travelled and corresponding CO2 emissions. The trip counts for each vehicle is summarized below in Table 8.

Table 8. TNC Vehicle Trip Counts

Vehicle Number	Number of Trips	Vehicle Number	Number of Trips
1	243	21	427
2	231	22	138
3	455	23	84
5	188	25	380
8	100	26	263
9	431	27	127
10	101	28	217
11	457	29	155
12	258	33	13
14	138	34	94
15	60	37	163
16	17	41	291
17	265	42	342
20	12	**Total Trips**	**5,650**

Staff then calculated average trip CO2 emission rate (gram/mile) by dividing total CO2 emissions over total distance travelled of that trip. For 191 out of the total 5,650 trips; the average speed was less than 1 mph. These trips resulted in mathematically high average CO2 (g/mi) trip emission values because of the very small denominator values (distance). Combined with uncertainties surrounding GPS and ECU speed measurements at low vehicle speeds, staff considered these less than 1 mph data points to be unreliable, and therefore excluded these 191 trips from the average CO2 trip emission calculation.

Figure 7 illustrates the trip average CO2 emission distribution as a function of vehicle speed. The trend shows CO2 emissions decrease as vehicle speeds increase.

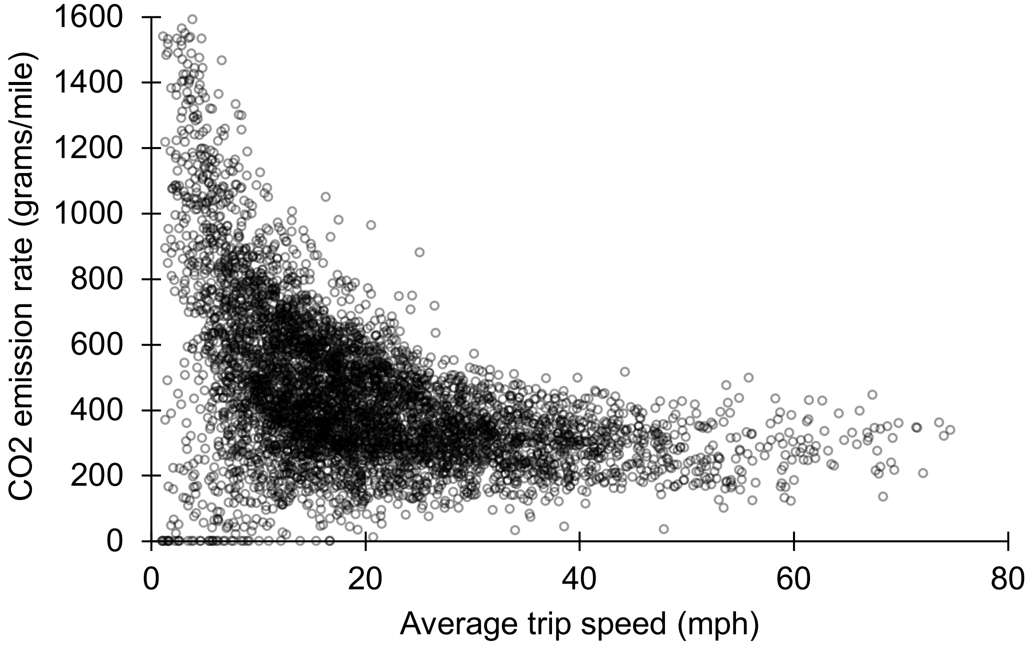

Figure 7. CO2 emission rate as a function of trip speed

Based on its average speed, staff binned each trip in 5 mph increments. Table 9 is the statistical representation of the 5,459 TNC trips recorded during CARB's TNC logger study. The summary shows that the majority (68 percent) of the trips have an average speed between 10 to 25 mph (almost 75 percent of trips having an average trip speed less than 25 mph) with CO2 emissions ranging from 400 to 600 gCO2/mi. Figure 8 shows the average CO2 emissions by speed bin indicating that emissions (gCO2/mi) decrease with increasing vehicle speed.

Table 9. Statistical Summary of CO2 emissions (g/mi) by Speed Bin

Speed Bin (mph)	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**
Mean CO2 emission rates (grams/mile)	1,256	615	490	416	383	330	317	294	297	283	261	273	300	297	320
95 percent Confidence Interval	108	20	11	9	10	9	10	11	13	15	22	32	27	34	45
Number of trips	319	785	1,147	1,056	719	492	333	239	139	92	59	32	22	19	6

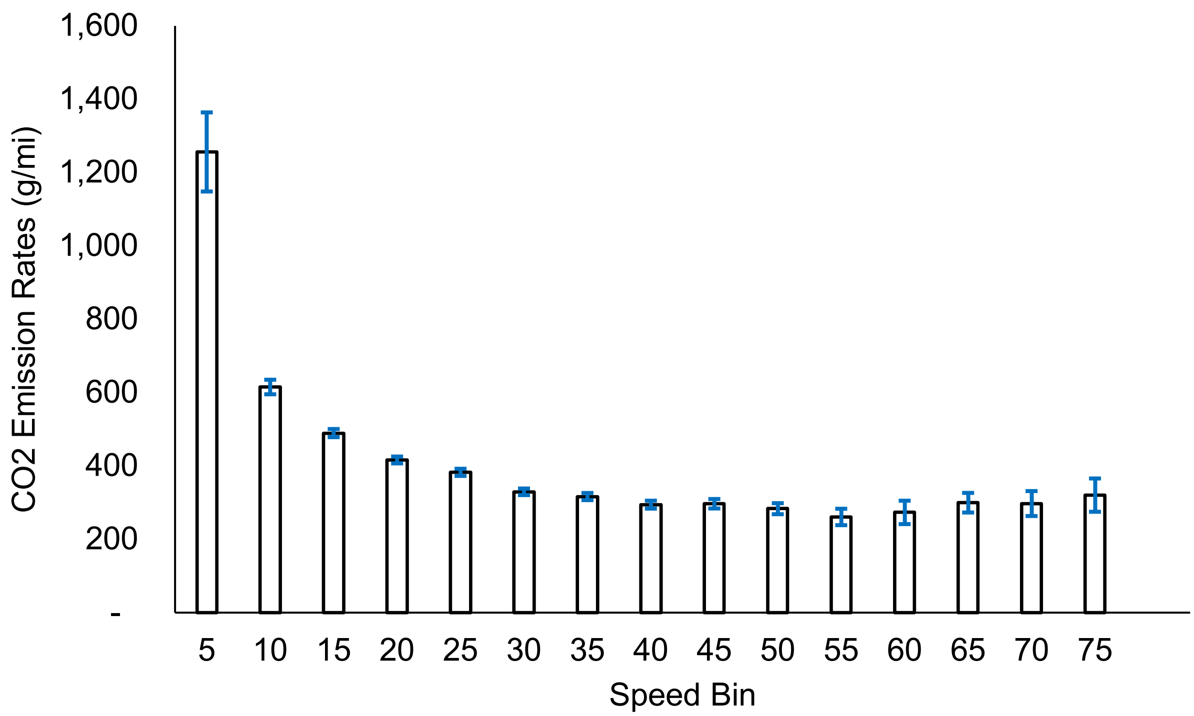

Figure 8. Summary of average CO2 emissions by speed bin and standard deviations (95 percent CI)

CO2 Emissions: TNC Trip Average vs. EMFAC2017

As discussed earlier, staff used CARB's data logger study mainly to determine speed correction factors to adjust the U.S. EPA rated fuel economy derived for TNC vehicles for different driving conditions. To do so, staff normalized trip average CO2 emission rates at 30 mph speed bin (i.e., all CO2 emission rates by speed bin were divided by the CO2 emission rate at 30 mph speed bin) to calculate the speed correction factor. The average speed of phase 2 of the UC cycle is about 27.5 mph which falls in speed bin 30. A comparison of speed correction factors for EMFAC2017 and the one derived from CARB's data logger study is shown in Figure 9. Interestingly, Figure 9 shows that when compared at 30 mph, TNC emissions are less affected at both lower and higher speeds than modeled by EMFAC. The TNC specific speed correction factors at lower speeds might be affected by higher efficiency of hybrid electric vehicles that utilize regenerative braking systems as compared to conventional vehicles. Please note that the speed correction factor developed as part of the CARB data logger study is used in estimation of GHG emissions for the TNC fleet.

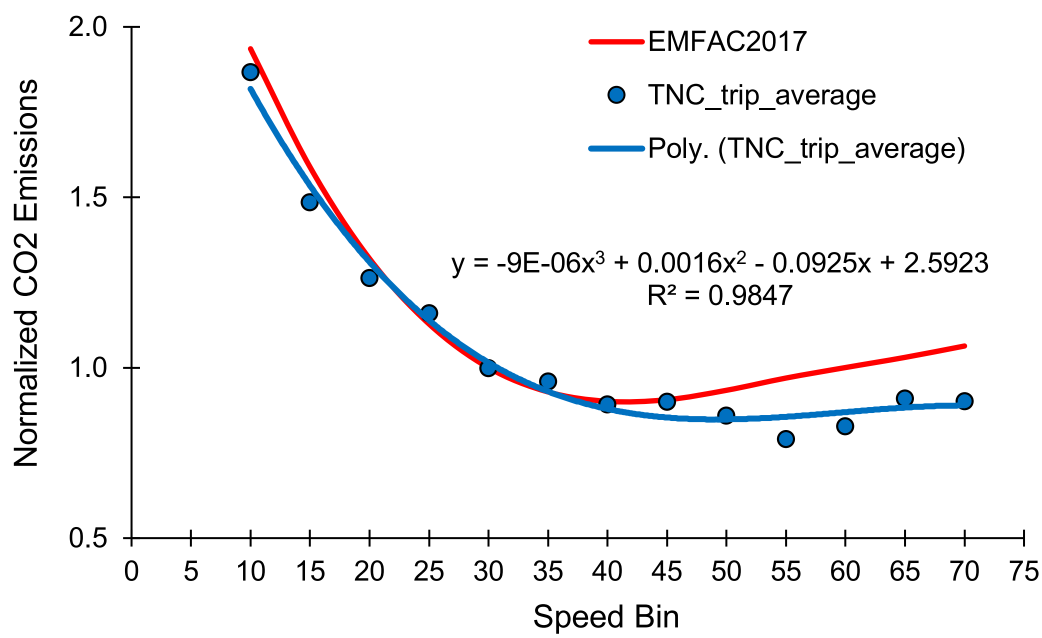

Figure 9. A comparison of speed correction factors (CO2 speed correction factors normalized at 30 mph) derived from CARB's TNC data logger study with EMFAC2017

2.6. Electric VMT (eVMT)

By operating Zero Emission Vehicles (ZEV) in the fleet, TNCs can accumulate zero emission mileage that will potentially reduce their operational grams CO2 emissions per passenger miles traveled (PMT). This section summarizes the process used to derive the percent electric VMT, or eVMT for the TNC vehicles in the 2018 dataset. The percent eVMT for a given vehicle is proxy for the fraction of electric miles traveled out of the total VMT associated with that vehicle.

ZEVs consist of a few distinct technology types: Plug-in Hybrid Electric Vehicles (PHEVs), Battery Electric Vehicles (BEVs), and Fuel Cell Electric Vehicles (FCEVs). BEVs have electric motors and do not rely on any fuels besides electricity. Similarly, FCEVs are electric vehicles that use a fuel cell, instead of a battery and are powered by hydrogen. By definition, we can assume 100 percent eVMT for BEVs and FCEVs. However, PHEVs use a combination of an electric motor powered by battery and an internal combustion engine powered by gasoline. Thus, for PHEVs the percent eVMT is not necessarily 100 percent and should be estimated.

Due to lack of publicly available information regarding the charging behavior among the TNC drivers, for this analysis, staff assumed that each PHEV owner only fully charged his or her vehicle once a day and would traveled on a full-charged battery until the battery is depleted. This way, the percent eVMT can be formulated as shown in Eq. (4). Here $VMT_{e\text{-}range}$ refers to U.S. EPA's all-electric range (AER) which is the driving range of a vehicle using only power from its electric battery. For this analysis, CARB staff used the combined AER data from U.S. EPA to determine the $VMT_{e\text{-}range}$ for roughly 6,000 PHEV vehicles in the 2018 TNC dataset.

To account for the impact of high mileage vehicles on the *fleet average percent eVMT*, staff estimated a *VMT weighted average percent eVMT* and then used that estimate to calculate eVMT associated with PHEVs operating in TNC fleets, and also to adjust the estimated CO2 emissions for those vehicles.

Following the described approach, the average percent eVMT for the entire PHEV TNC fleet is estimated to be approximately 22.7 percent. This number is based on U.S. EPA rated all electric range and average daily VMT for roughly 6,000 PHEV in the 2018 TNC dataset. The distribution of the percent eVMT for these vehicles is shown in Figure 10.

$$\text{Percent } eVMT = \begin{cases} \dfrac{VMT_{e-range}}{VMT_{daily}} \times 100 & if \quad VMT_{e-range} < VMT \\ 100 & if \quad VMT_{e-range} \geq VMT \end{cases} \qquad \text{Eq. (4)}$$

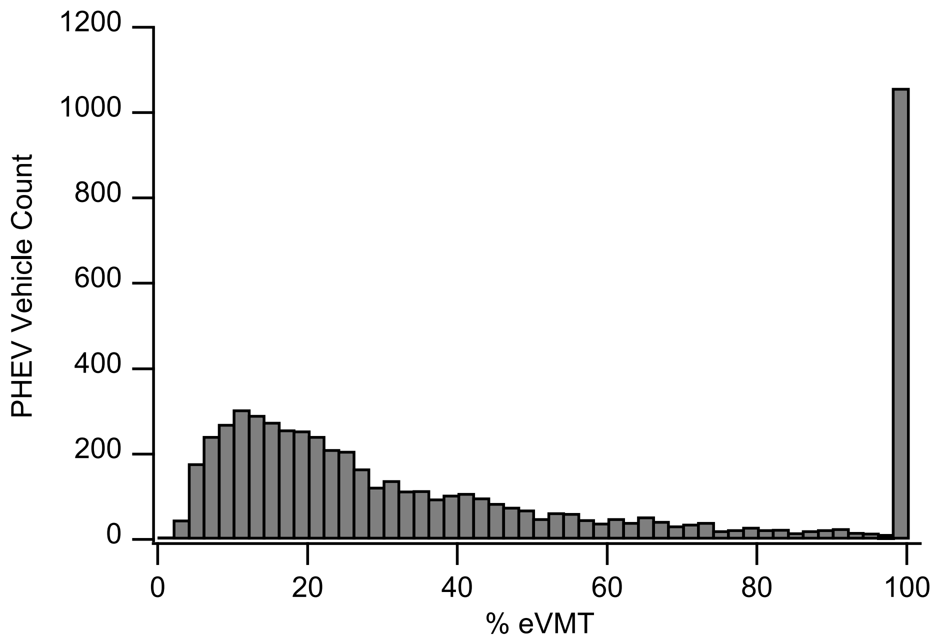

Figure 10. A histogram representing PHEV vehicle count as a function of percent eVMT

Overall, out of 4.2 billion VMT produced by TNC vehicles, 43.6 million miles was attributed to PHEVs. Hence, using the 22.7 percent eVMT assumption, it is estimated that PHEVs operating in TNCs generated roughly 10 million electric miles in 2018. Considering that BEVs and FCEVs additionally generated another 23.6 and 0.17 million miles of eVMT, respectively, the total TNC fleet eVMT is estimated to be at around 34.4 million miles, or roughly 0.8 percent of the total VMT generated by TNC fleet in calendar year 2018. Table 10 provides more detail.

Table 10. Summary statistics of population, VMT, and eVMT for PHEV, BEV, and FCEV vehicles

	PHEV	BEV	FCEV
Population (percent of TNC)	5,978 (0.9%)	3,581 (0.6%)	52 (0.01%)
VMT (million miles)	44.2	24.2	0.16
eVMT (million miles)	10.0	24.2	0.16

3. Results

CARB held its second public workshop for the Clean Miles Standard on September 25, 2019. The workshop covered CARB proposed methodology for calculating the 2018 base year emissions, and preliminary results based on the original trip records TNCs provided to CARB in March 2019. In this section, similar findings and results are presented, except that the current analysis has been updated and is based on the revised TNC data provided in August 2019 and incorporates the feedback that CARB received during and after the workshop on the proposed methodology and results.

After removing the overlapping trip VMT, CARB staff estimated the total mileage associated with each period (i.e. P1, P2 and P3) was estimated and shown in Figure 11. As shown, approximately 28 percent, 11 percent, and 61 percent of the total VMT are attributed to P1, P2, and P3 periods, respectively. Other than the total VMT, the next major factor that can strongly impact CO2 emission per PMT is the deadhead miles. Deadhead miles refers to the sum of period 1 and period 2 VMT. Using this definition it is estimated that in 2018, almost 38.5 percent of total TNC VMT in California was deadhead miles.

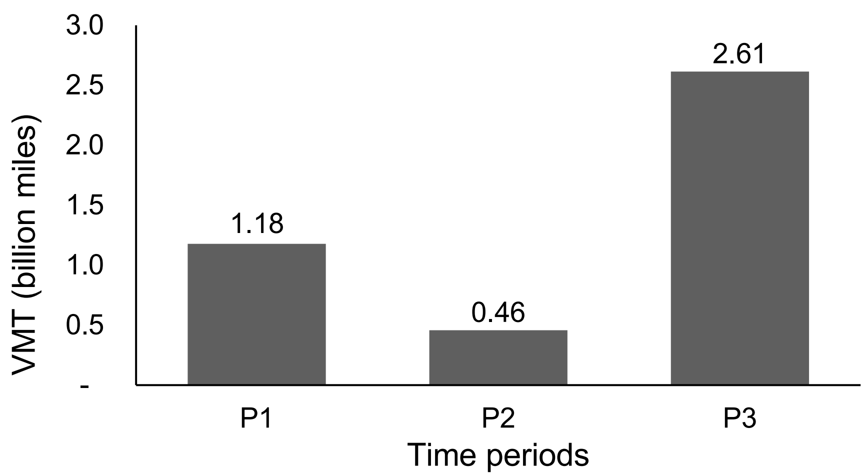

Figure 11. VMT by time period

Comparing the total VMT before and after removal of the overlapping trip records, the algorithm described in section 4 eliminates nearly 3.4 percent of the total VMT (Table 11). The percentage of the removed VMT goes up significantly to 10.7 percent when only P1 are examined. P2 VMT was reduced by only a slight 0.7 percent. Interestingly, 0.2 percent of the P3 trip periods overlapped with other trip records and was removed.

One possible explanation is that drivers often do not update their vehicle VIN on TNC apps, hence, trip records for different vehicles end up with one vehicle. Although minor, some of these issues still exists in the 2018 TNC dataset that CARB received in August 2019.

Table 11. Change in VMT before and after fixing overlapping trips and removal of duplicative VMT

	Overlap Removal (Billion miles)		
Trip periods	**VMT_{Before}**	**VMT_{After}**	**Percent change**
P1	1.321	1.179	-10.7
P2	0.463	0.460	-0.7
P3	2.618	2.613	-0.2
Total	*4.402*	*4.252*	*-3.4*

As discussed in Section 2.5, average trip speed is an important factor impacting CO2 emission rates of TNC vehicles. Figure 12 demonstrates VMT distribution by speed for both TNC and California vehicle fleet. Data for California vehicle fleet were obtained from CARB EMFAC2017 model for light duty vehicles operating in calendar year 2018. As shown, TNC vehicles experience significantly lower travel speeds as compared to California passenger vehicle fleet. The lower fleet wide average speeds of TNCs, as discussed previously, can decrease the fleet average fuel efficiencies and hence increase CO2 emissions per mile.

The TNCs did not include vehicle speed in their data submission. Thus, CARB staff calculated speed by dividing trip distance by vehicle travel time. For that reason, occasionally due to an incorrectly reported VMT or time duration, or due to low resolution of VMT versus time, the calculated speeds exceeded 80 mph, which is relatively uncommon on California roadways. To avoid anomalous effects to estimated emissions, CARB's speed estimate was capped at 80 mph, totaling around 3 percent of the total VMT.

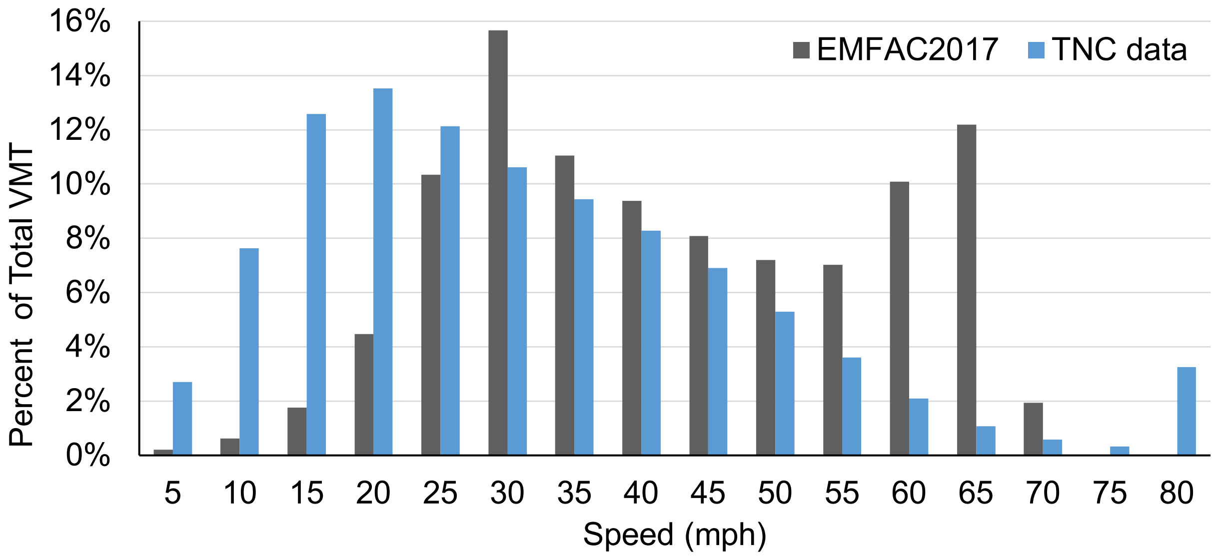

Figure 12. VMT distribution by speed for TNC and California vehicle fleet based on CARB EMFAC2017

Because of California's Pavley and LEV 3 GHG emission standards for light duty vehicles, staff expects newer vehicles to have lower GHG emissions as compared to older ones. A comparison of vehicle population by model year for TNCs and California vehicle fleet is shown in Figure 13. In this figure, staff obtained vehicle model years for TNC vehicles by decoding their VINs using the IHS VINtelligence service. For the California vehicle fleet, vehicle population by model year was estimated using EMFAC2017 model for calendar year 2018. According to these estimates, vehicles operating for TNCs are relatively newer (by 1.5 years) than California average passenger vehicles. Additionally, there is a relatively higher fraction of hybrid electric vehicles operating for TNCs which contribute to higher fuel efficiency of the TNC fleet.

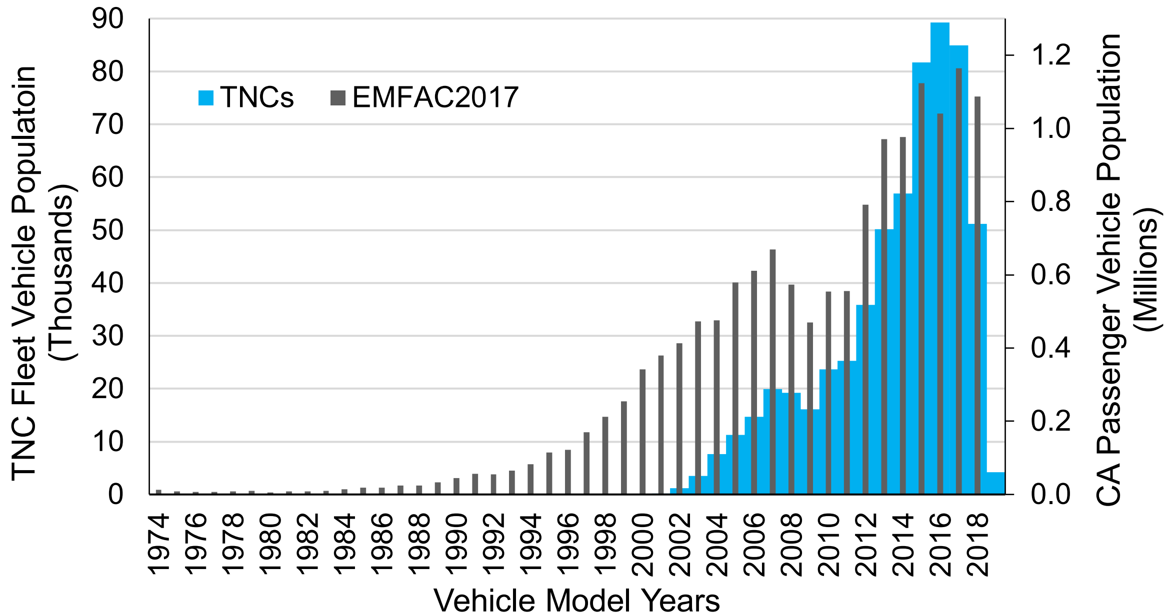

Figure 13. Vehicle model year distributions for TNC vs. California vehicle fleets

The in-use fuel efficiency depends on parameters such as vehicle model year distribution, vehicle technology, speed distribution, and U.S. EPA rated fuel economy. Hence, CO2 emission performance of TNC and California vehicle fleet can be compared directly using in-use fuel efficiency. With the aid of EMFAC2017, it is possible to estimate an in-use fuel efficiency for California vehicle fleet by dividing the total VMT in miles from passenger vehicles over their total fuel consumptions in gallons. Similarly, the fuel efficiency of TNC vehicle fleet can be calculated using the total fuel consumption and VMT associated with all time periods P1 through P3. Following this approach, CARB staff estimated that the TNC and California vehicle fleets have average fuel efficiencies of 31.1 and 26.0 miles per gallon, respectively.

The 2018 dataset also provided information on whether a ride was initiated as a “pool” ride or not. A “pool ride” refers to a ride where passengers pay a reduced trip fare for sharing their ride, or segments of it, with other passengers traveling in the same general direction. Using the 2018 dataset, staff quantified TNC-wide pooled vs non-pooled splits. The data indicates that out of 2.61 billion miles of P3 VMT, 22 percent is associated with pooled rides and the rest with non-pooled rides. Pooled rides do not necessarily imply the presence of a second rider in the vehicle. Pooled rides may include riders that were not matched too; under such conditions, a passenger requests a pooled ride and travels without any other passenger in the vehicle. As mentioned earlier, occupancies of 1.54 and 1.57 were used for non-pooled and pooled rides, respectively.

Finally, as shown in Figure 14 and using the input parameters described above, staff estimated the base year grams CO2 per PMT for the TNC vehicle fleet to be approximately 301 gCO2/PMT. This number is calculated by summing up the CO2 emissions for all time periods and records divided by the sum of estimated passenger miles traveled across all TNC companies (Eq. 1). Figure 14 shows a comparison of average gCO2 per PMT for the TNC and CA fleet. For California fleet average, staff used an average occupancy of 1.68 derived from 2010 – 2012 California Household Travel Survey[35] which resulted in an average gCO2 per PMT of 203 gCO2/PMT. This implies that TNCs emit approximately 50 percent more GHG emissions per PMT than California passenger vehicles.

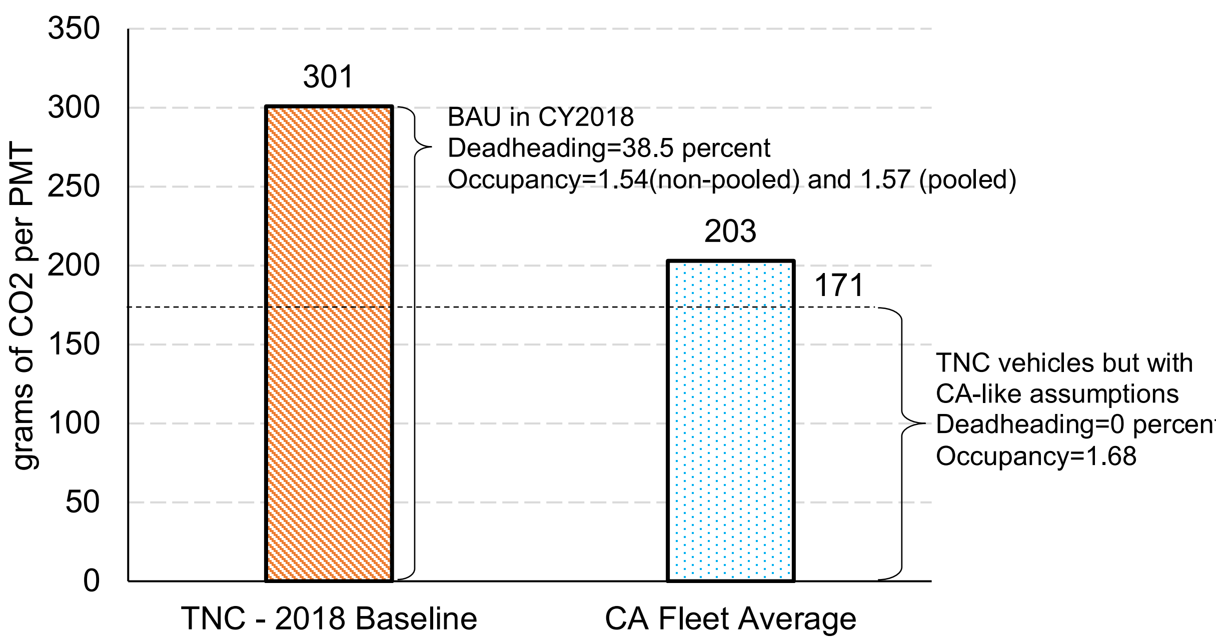

Figure 14. Base year grams CO2 per PMT

[35] https://dot.ca.gov/programs/transportation-planning/economics-data-management/transportation-economics/ca-household-travel-survey

The difference between California and TNC base year gCO2 emissions per PMT is likely due to the following differences.

- **Occupancy:** According to the California Household Travel Survey, the average CA vehicle trips have an average occupancy of 1.68 which is 7.6 percent higher than an average TNC trip.
- **Deadheading:** 2018 TNC dataset shows that approximately 38.5 percent of TNC total VMT are deadhead miles. Obviously, this brings down the PMT/VMT ratio to about 0.95 as compared to a California PMT/VMT of 1.68. Deadheading does not contribute to the total PMT, since the occupancy associated with travel time periods P1 and P2 is zero. For this analysis, we do not assume any deadhead miles for non-TNC California passenger vehicles.
- **Vehicle Model Year and Technology:** As shown in Figures 5 and 13, the TNC drivers use newer and more fuel efficient (e.g., hybrid) vehicles as compared to average California vehicle fleet. The average TNC vehicles as a whole has higher fuel economy ratings.
- **Operating Speed:** CO2 emissions are directly affected by speed correction factors illustrated in Figure 9. Figure 12 demonstrates that the TNC vehicles on average travel roughly 10 miles per hour slower than their California vehicle fleet counterparts. This can impact the TNC fleet average in-use fuel economy relative to that of the California passenger fleet.

Please note that the occupancy, deadhead miles and operating speed contributes to increasing emissions from the TNC fleet as compared to the CA fleet, however, the relatively higher fuel efficiency of TNC vehicles negates the aforementioned impacts to some extent.

To better understand the impact of occupancy and deadheading on grams CO2 emissions per PMT, staff developed a simple sensitivity analysis tool. The tool uses the following equation to model the TNC fleet average grams CO2 emissions per PMT as a function of occupancy and fraction of deadheading.

$$grams\ CO2\ per\ PMT = \frac{C}{\mu \times (1-\delta) \times \omega} \qquad \text{Eq. (5)}$$

Where μ is the fleet average in-use mpg, δ is the fraction of deadheading, ω represents occupancy, and C is a conversion factor used to convert gallon to grams of CO2. Because staff estimated the fleet average in-use fuel efficiency assuming gasoline as the vehicle fuel, staff used a conversion factor C of 8,887 gCO2 per gallon in Eq. (5).

The results of the sensitivity analysis are shown in Figure 15. Each plotted curve on the chart represents a different occupancy (ω) assumption ranging from 1.5 to 2.0. The x- and y-axes represent fraction of deadheading and grams CO2 per PMT, respectively.

The blue solid circle on the right shows the current TNC-wide grams CO2 per PMT and the red one shows that of California vehicle fleet. CARB staff calculated the estimated TNC fleet average using a deadhead mileage percent of roughly 39 percent, an average occupancy of approximately 1.55, and an in-use fuel efficiency of 31 mpg; staff calculated the California average using an average occupancy of 1.68 and zero deadhead miles.

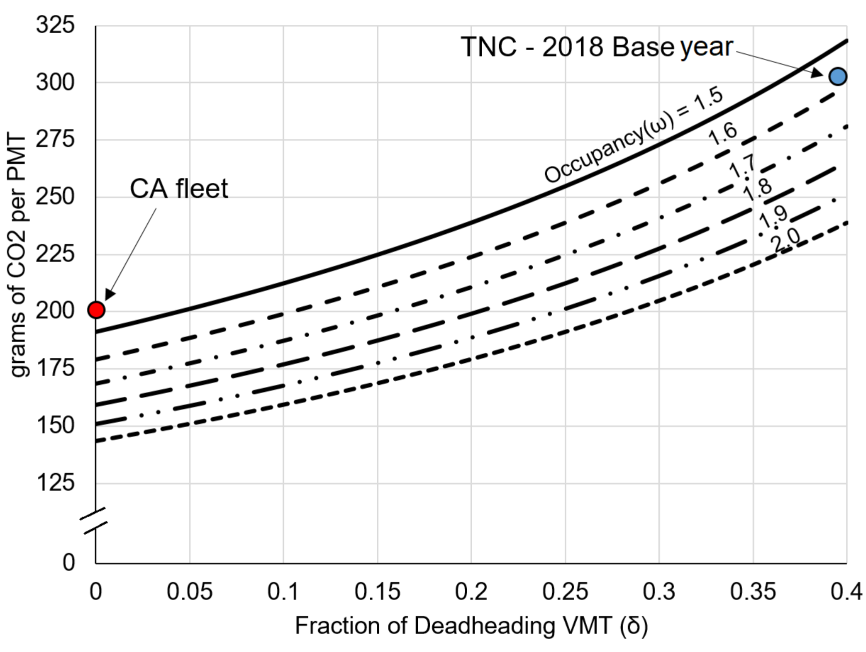

Figure 15. Grams CO2 per PMT as a function of occupancy ($\boldsymbol{\omega}$) and deadheading ($\boldsymbol{\delta}$)

This charts shows that if TNCs raise their occupancy to 2.0 passenger per trip, their grams CO2 per PMT would go down to nearly 233 gCO2 per PMT, or if their deadhead mileage fraction goes down to 0.28 and their occupancy goes to 1.7, their grams CO2 per PMT would go down to about 241 gCO2 per PMT. Note that this chart does not reflect the impact of increase in eVMT, and improvement in fuel efficiency, as well as changes to model year distributions, and speed distribution (e.g., lower congestion).

4. Next Steps

Built upon the 2018 base year emissions inventory, staff is developing a business as usual (BAU) inventory projecting GHG emissions per passenger mile from the overall California TNC fleet for future years. Staff will present draft input assumptions that go into the BAU inventory, as well as regulatory scenarios, will be presented at a public workshop for comments in early 2020. Staff will consider the public comments and finalize the BAU inventory in the spring of 2020. The same inventory modeling tool will be used to estimate GHG reductions per passenger mile for regulatory target scenarios for the Clean Miles Standard Regulation expected to go to the board in December 2020.