Title

Flexible Transportation: A Solution for Reducing Greenhouse Gas Emissions in San Diego

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1. Background

Climate Change is one of the biggest threats facing civilization. The global land-ocean temperature anomaly in 2019 has reached 1.1°C above pre-industrial levels (1850-1900 average) [1]. The impacts of global warming continue to produce extreme weather and abrupt changes across the globe at both individual and societal levels. Communities across the world continue to face the effects of sea-level rise, flood, drought, extreme heat, wildfire, and biodiversity loss. Business and global economies are also affected by changes in supply chain and production systems

The main cause of climate change comes from the increase in greenhouse gas (GHG), involving carbon dioxide (CO_2), methane, nitrous oxide, ozone, etc. Gases produced from human activities such as carbon dioxide and methane lead to abnormal change in GHG levels. Fossil fuel burning and land use change contribute to a significant amount of GHG released to the atmosphere. In the United States, the sources of GHG emissions in 2018 were Transportation (28%), Electricity (27%), Industry (22%), Commercial and Residential (12%), and Agriculture (10%) [2]. Fossil fuel burning in transportation is the top contributor to total GHG emissions.

In San Diego County, the share of GHG emissions from the transportation sector is double than the national average: 45% in San Diego County in 2014 [3] compared to 28% nationally as of 2018. According to San Diego County 2014 Greenhouse Gas Emissions Inventory, the top three vehicle categories contributing to on-road transportation GHG emission were passenger cars (39%), light-duty trucks (29%), and medium-duty trucks (17%) [3]. To reduce the amount of GHG emissions in the transportation sector, Vehicle Miles Traveled (VMT) must be reduced while Average Vehicle Occupancy (AVO) has to be increased. Many policies have been proposed to achieve GHG reduction goals such as transit-oriented development, parking pricing policy, road pricing management, and commute trip reduction [4].

One policy oftens proposed is promoting the use of public transit. As public transit can move more people with fewer vehicles, public transit produces significantly lower GHG emissions per passenger mile compared to Single Occupancy Vehicle (SOV) [5]. However, The network of public transit in San Diego County only provides services to a limited number of San Diegans who live in a transit zone. Bus and rail routes are only designed to serve a specific population group along the fixed route. To travel over a long distance, commuters typically need to make several transit stops between modes of transit to get to the destination. For example, to get from Sorrento Valley to San Diego International Airport, it would take 1 hour and 46 minutes with 3 buses changing. Whereas, it would take only 30 minutes by a private vehicle. The inconvenience of traveling time and mode switching discourages people from using public transportation.

To solve this problem, flexible transportation has been proposed as an alternative/supplement to traditional public transit. Flexible transportation is a term describing non-fixed-route or demand-responsive transportation models. Unlike fixed-route transit, flexible transportation can provide services to people living outside transit zones and can operate on a flexible origin to destination route [6]. The service can be customized based on demand and adjusting for vehicle type, capacity, and route. Transportation providers can be more cost-effective by adopting flexible transportation strategies. Whereas, commuters can receive more convenient transit services that respond to their needs as demonstrated by the popularity in ride-hailing services [7].

2. Motivation

Considering the trips in San Diego by destination purpose, work trips provide the highest number of trips per day (10.0% of 12.32 million trips) beside home (28.8%) [8]. Furthermore, 51.2% of the total trips occurred from SOV. One strategy that can reduce work commute trips and increase AVO is a vanpool program. A vanpool is a travel mode that groups people who live nearby to commute to work together. The cost of a vehicle lease, gas, and insurance are shared between vanpool members and the driver is volunteered by members of the group. There are existing vanpool programs in many cities such as Los Angeles, King County in Washington, and San Diego. The cities or transportation departments provide incentives to the participants by supporting a partial amount of the vehicle lease cost. The participants benefit from the program by saving the parking cost and gas as well as being able to utilize the High-occupancy vehicle (HOV) network.

This work focuses on increasing the number of vanpools in the San Diego region by identifying potential vanpool routes and studying the existing San Diego Association of Governments (SANDAG) vanpool program. The potential vanpool routes are created by analyzing the data from SANDAG Activity-Based Model (ABM) which simulates San Diego residents' travel patterns. The potential routes were then used to calculate the benefits of VMT and GHG reduction. This study can be used as an example for developing flexible transportation for other trip purposes in San Diego in the future.

3. Methods

3.1 Analyzing travel patterns in San Diego

This study used simulated trip data from SANDAG ABM2 2016 scenario with the 2020 synthetic population [9]. The model incorporates data such as household travel survey and census records into the forecast. The data from the model represents all the trips made by individuals on an average weekday. SANDAG ABM works by first creating a synthetic population that represents the people in San Diego. Information such as household data and individual characteristics are included in this synthetic population. Then, the model assigns the places that each individual is likely to go to such as a workplace, school, and university. After that, the model predicts how many cars each household is likely to have, based on household size, income, and distance from the places they usually go to. Next, the model predicts individual daily activities such as going to work, shopping, and going home as well as the mode choice of each trip based on origin, destination, time, and cost. Finally, the model combines all the trips generated from ABM with trips generated from other models such as a cross-border model, visitor model, and external trips model and assigns them to the transportation network as shown in Figure 1.

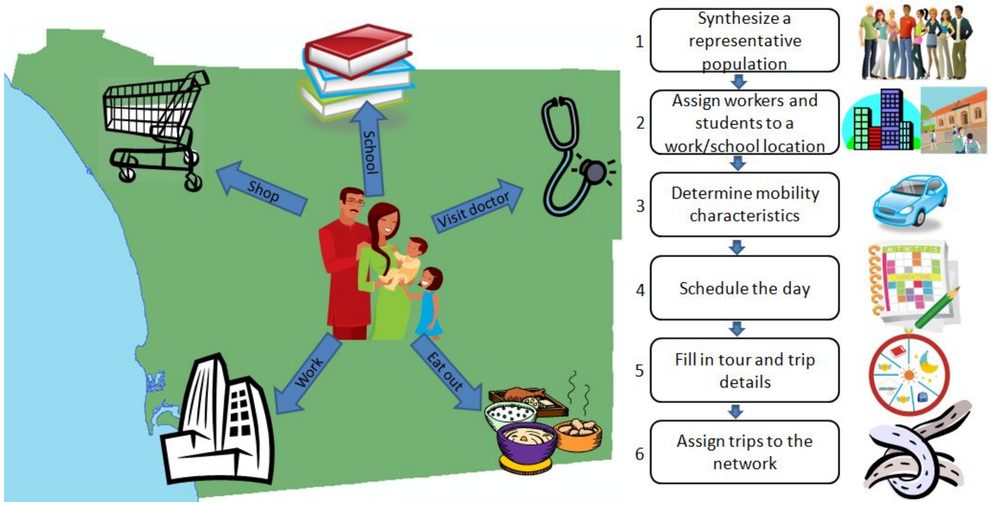

Figure 1 The sequence of ABM components [9]

The trip data from SANDAG ABM provides 4 CSV files; synthetic household, synthetic persons, individual trips output, and joint trip output. As this study focused on reducing SOV, the individual trip file is mainly used to conduct the analysis. Four main groups of ABM data parameters are used in this study: ID of trips and tours, the purpose of trips and tours, trip origin and destination, trip characteristics (mode, duration, time, distance).

3.2 Categorizing trips by trip purpose

To understand the impact of VMT from different types of trips, trips are grouped by different parameters and plotted into the graphs. The parameters used for grouping are tour mode, tour purpose, and time of day. The explanation of each tour purpose is explained below:

1. Work: Working at a regular workplace
2. Work-Based: Work-related activities outside the home
3. University: College
4. School: High school and grade school
5. Escort: Picking up/drop-off passengers
6. Shop: Shopping away from home
7. Maintenance: Personal business/services and medical appointments

8. Eating Out: Eating outside of home
9. Discretionary: Other activities such as volunteer work, religious activities, etc.
10. Visiting: Visiting friends or family

The graphs are plotted to give a better understanding of which type of trips have the largest percentage among all the trips generated in San Diego. To estimate potential trips that could be converted to flexible transit, single trips with one destination are chosen as targets over multi-trips. Because commuters having only one destination can achieve the same goal of the trip and switch from driving alone to a shared ride. As one tour can contain many trips and one person can have many tours, person ID and tour ID are used to get unique tours from all the trips. The destinations in each unique tour were then counted. The unique tours that contain only one destination are considered as a single trip. The same process of grouping and plotting was applied to single trips to find the trip purpose target and transit mode with the highest number of single trips.

3.3 Grouping work trip by origin-destination

The single work trips are grouped into potential routes by origin and destination area. The zoning used to specify area size in this study are zip code, census tract, and MGRA. Each type of zoning has been tested to see a different result of potential commuters and routes. Potential routes were ranked by the score calculated from the number of single work trips on the route and the distance from the origin to destination as follows:

Route distance = average origin to destination distance from all trips on the route

$\text{Total VMT}_{\text{route}}$ = No. of single work trips $\times$ Route distance* (miles)

Route score = $\frac{X - X\,min}{Xmax - Xmin} \times 10$, When X = total $\text{VMT}_{\text{route}}$

* When the distance is less than a defined minimum distance (10 miles for census tract), set Total $\text{VMT}_{\text{route}}$ equal to 0

The routes having high scores represented a large number of people driving to work on the same route. Therefore, those routes have a higher potential in setting a vanpool route to reduce greater SOV and VMT than others. A specific minimum distance of 10 miles was used to prevent the score from weighting many short trips that occur between adjacent areas.

3.4 Visualizing potential vanpool route

This study used Kepler.gl for visualizing and analyzing travel patterns and potential vanpool routes. Kepler.gl is an open-source geospatial data analysis tool created by Uber [10]. The tool can handle large geospatial data, render, and visualize them on a web-based application. Dataset can be simply uploaded to Kepler.gl website by drag and drop and the customization of visualization can be done without coding. This study also used other tools including GeoPandas and ipyleaflet python library to create interactive maps, such as choropleth maps of trip origins and destinations, and location maps of tours from individual persons.

3.5 Calculating VMT and GHG reduction based on scenarios

Two types of adoption scenarios are created for estimating the benefits of potential vanpool routes; group forming size and signup rate. Group forming size represents the ability of commuters on the same route to get together and form a vanpool of 5, 10, and 15 seats. The ideal scenario is commuters on the same route can get together in groups of 15 people and form a vanpool. Whereas the minimum benefit scenario is that commuters on the same route are grouped with a maximum of 5 people per vanpool. To evaluate the current status of the SANDAG Vanpool program and potential program expansion, The signup rate was simulated at different percentages of 10, 25, 50, 75, and 100 percent of commuters who are willing to sign up for the vanpool program on each route. Group forming size and signup rate scenarios are assigned for all potential routes and used to calculate the number of vehicles switching from driving alone to vanpool and the total VMT reduction.

GHG emissions reduction of each scenario was calculated based on VMT and number of vehicle switching by using the average fuel economy of major vehicle category [11] and average GHG emissions from a typical passenger vehicle [12] as following:

Passenger vehicle:	24.2 miles per gallon and 8,887 grams CO_2 per gallon
Van:	17.5 miles per gallon and 10,180 grams CO_2 per gallon

3.6 Identifying transit hubs and High-Occupancy Vehicle (HOV) network

To analyze the characteristics of SOV work trips, the distance from the trip origin to the nearest transit hub was calculated for all the trips. The trips having origins far from transit hubs might be easier to adopt flexible transportation services. While the trips originating close to transit hubs might be more convinced to use existing transit infrastructure. Transit hub locations are identified by selecting the bus transit center, rail station, and trolley station from SANDAG TRANSIT STOPS GTFS data [13].

The HOV network was also used to calculate the incentive of vanpooling on the potential routes. Firstly, HOV inventory data was acquired from Caltrans [14]. Secondly, driving directions were calculated for all potential vanpool route zip codes by using Google Maps Directions API [15]. Lastly, the route summary was used to estimate the HOV lane accessibility of each potential route.

3.7 Analyzing the current vanpool program

The current status of the vanpool program data in San Diego was acquired from the SANDAG iCommute team [15]. The data were used to approximate total VMT reduction from existing programs and compare to possible VMT reduction from potential vanpool routes. The historical ridership of vanpool programs in San Diego and other cities were also analyzed from the data acquired from the National Transit Database (NTD) [16].

To further understand the characteristics of current vanpool participants, the 2013-2017 American Community Survey (ACS) 5-year Estimates data was used to find the correlation between selected economic characteristics and the number of vanpools in each zip code area. The data include information such as employment status, occupation, income, and health insurance coverage, etc.

3.8 Analyzing COVID-19 impact on current public transportation

This study also looked at the impact of COVID-19 on the ridership of public transportation and travel patterns in San Diego. The commuting behavior of people might change after entering the reopening phase from the lockdown and public transit providers would need to change their operating strategy to respond to decreasing demand. The impact on public transportation ridership was analyzed from NTD Unlinked Passenger Trips (UPT) data [16]. The changes in total VMT were acquired from StreetLight Data [17] and the changes in travel pattern data were acquired from Google Community Mobility Reports [18].

4. Results and Discussion

4.1 Population and Daily VMT (DVMT)

The data from the U.S. Census Bureau and California Public Road Data shows an increasing trend in total population and daily VMT in San Diego County [19][20] (**Figure 2**). While the increase in total population tends to slow down after 2015, DVMT has continued to increase significantly since 2011. Apart from the population, many factors include households, mean household income, employment, and lane miles also contribute to VMT growth [21]. The increasing trend in daily VMT points out the need to reduce VMT growth as transportation is the largest sector contributing to GHG emissions in San Diego.

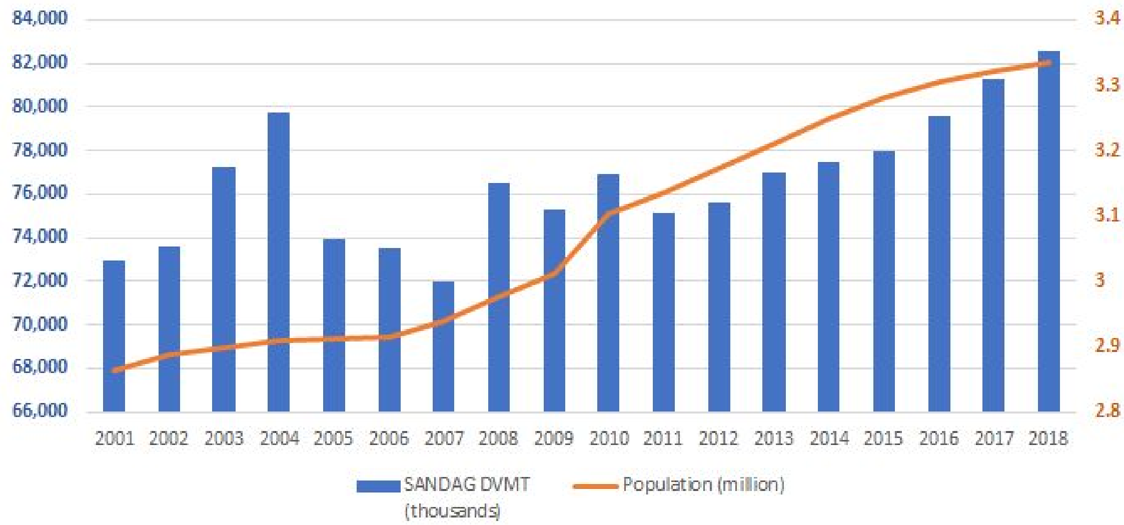

Figure 2 San Diego County population and DVMT

4.2 Travel pattern from SANDAG ABM

Travel patterns in San Diego have been analyzed for flexible transit solutions. The total number of trips in one day is 6,451,231 trips which are categorized into individual trips and joint trips. Individual trips are composed of 6,192,015 trips (1,899,701 tours) from 1,401,422 people and joint trips are composed of 259,216 trips (84,104 tours) from 70,294 households as shown in **Figure 3**.

The main mode of transit of joint trips is shared ride with two people whereas the main mode for individual trips is driving alone. As shown in **Figure 4**, the tour purposes with the highest number of trips for joint trips are maintenance, shop, and discretionary respectively, while the top three tour purposes for individual trips are work, escort, and school. As this study focuses on reducing SOV and VMT, the study chose to target drive alone trips which by far the most common mode of all individual trips.

To create a potential flexible transit service, single trips are targeted. 898,358 single trips are identified from all individual unique tours which contain only one destination. Note that this is equivalent to two unique destinations (origin and destination) in **Figure 5**. The top commute modes among single trips are drive alone (306,297 trips), shared ride with 2 people, and shared ride with 3 people as in **Figure 6**. Single trips with drive alone mode are then chosen as a target for the next step.

Work trip has the highest number of 133,507 trips and total VMT of 1,424,789 miles among other trip purposes in the single drive-alone trips (**Figure 7**). Compared to other trip purposes, work trips also have the greater distance in each trip up to 30 miles (**Figure 8**). Escort trips also have a large number of trips but most of the trips only have an average distance shorter than 8 miles. Work trips were therefore selected as a target for further study.

Most single drive-alone work trips occur in the morning (5 am to 9:30 am), whereas other trip purposes have different time characteristics. For example, escort trips occur in the morning and afternoon, and eating out trips occur around noon and evening. As shown in **Figure 7** and **Figure 9**, most drive-alone trips are coming from work trips especially in the morning. If the number of drive-alone work trips can be reduced or spread out later in the day, the overall number of vehicles on the road and the congestion would be greatly reduced. The time duration of each trip purpose is shown in **Figure 10**. Work trips and university trips have similar duration characteristics with time duration from 1 to 50 minutes and most of the trips being approximately 20 minutes.

In addition, most single drive-alone work trip origins are not far from the transit hub (less than 4 miles) as shown in **Figure 11**. However, the distance that is considered to be walkable is about 0.5 miles or 10-minute walk. It means that only 12,665 trips (9.48%) out of 133,507 work trips have the origin located in a walkable range to the nearest transit hub. The above result supports the fact that it is inconvenient for commuters to use existing public transit to get to work and flexible transit can be a solution to people who live far from the transit hub.

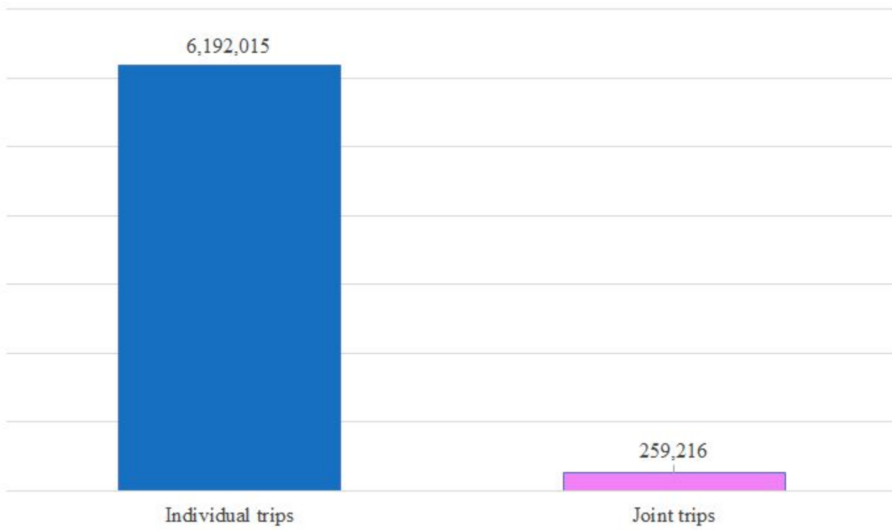

Figure 3 Total number of individual trips and joint trips (household trips)

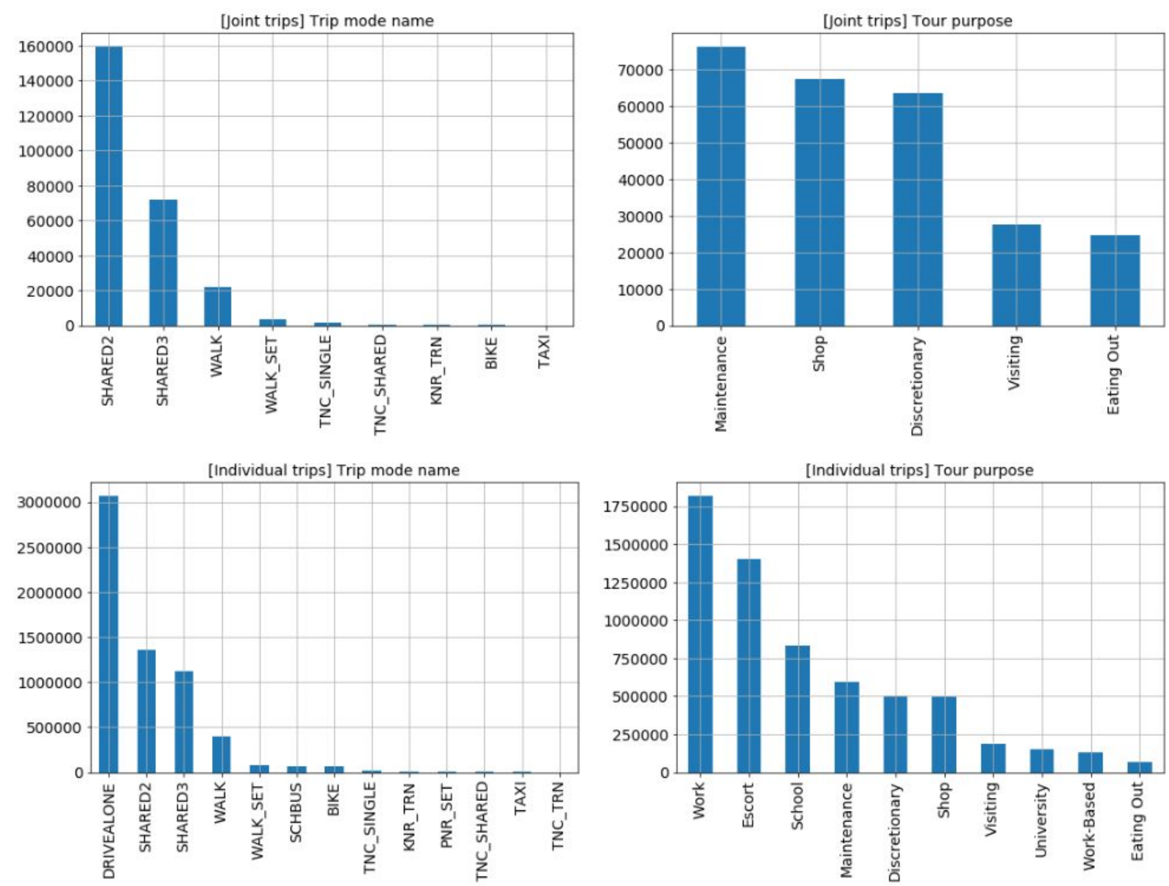

Figure 4 Trip mode and tour purpose of joint trips (above) and individual trips (below)

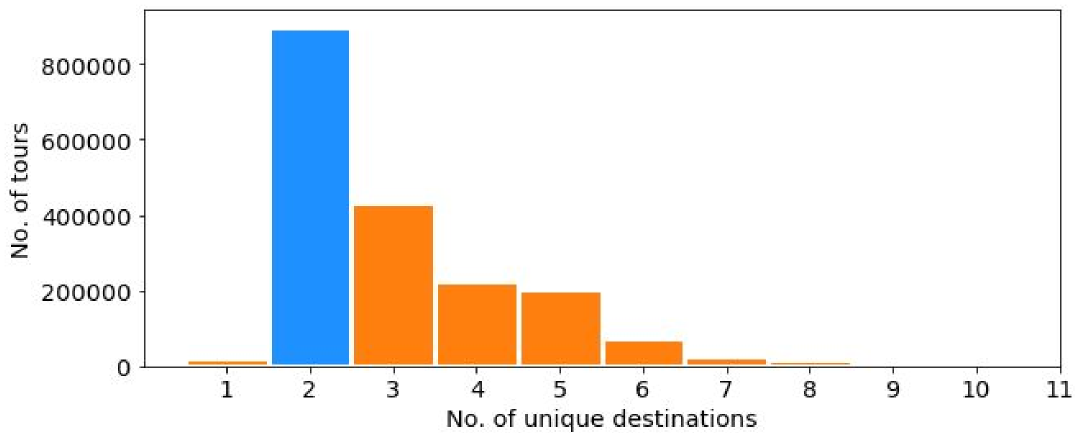

Figure 5 Histogram of unique destinations per tour

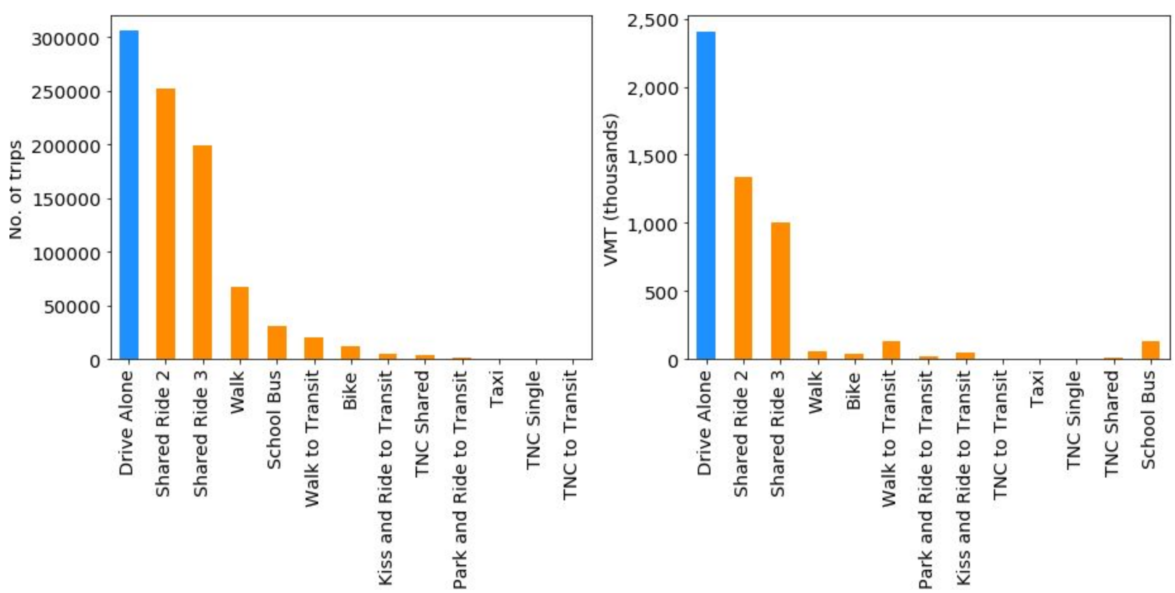

Figure 6 No. of single trips (left) and total VMT (right) of by trip mode

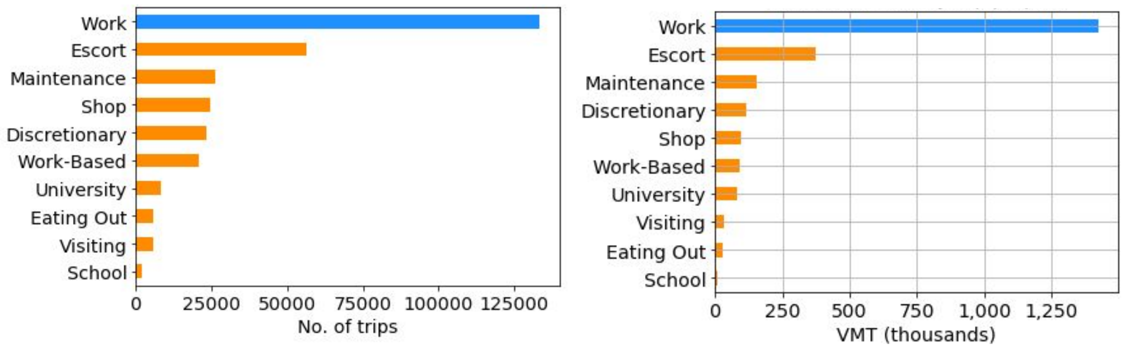

Figure 7 No. of single drive-alone trips (left) and total VMT (right) by trip purpose

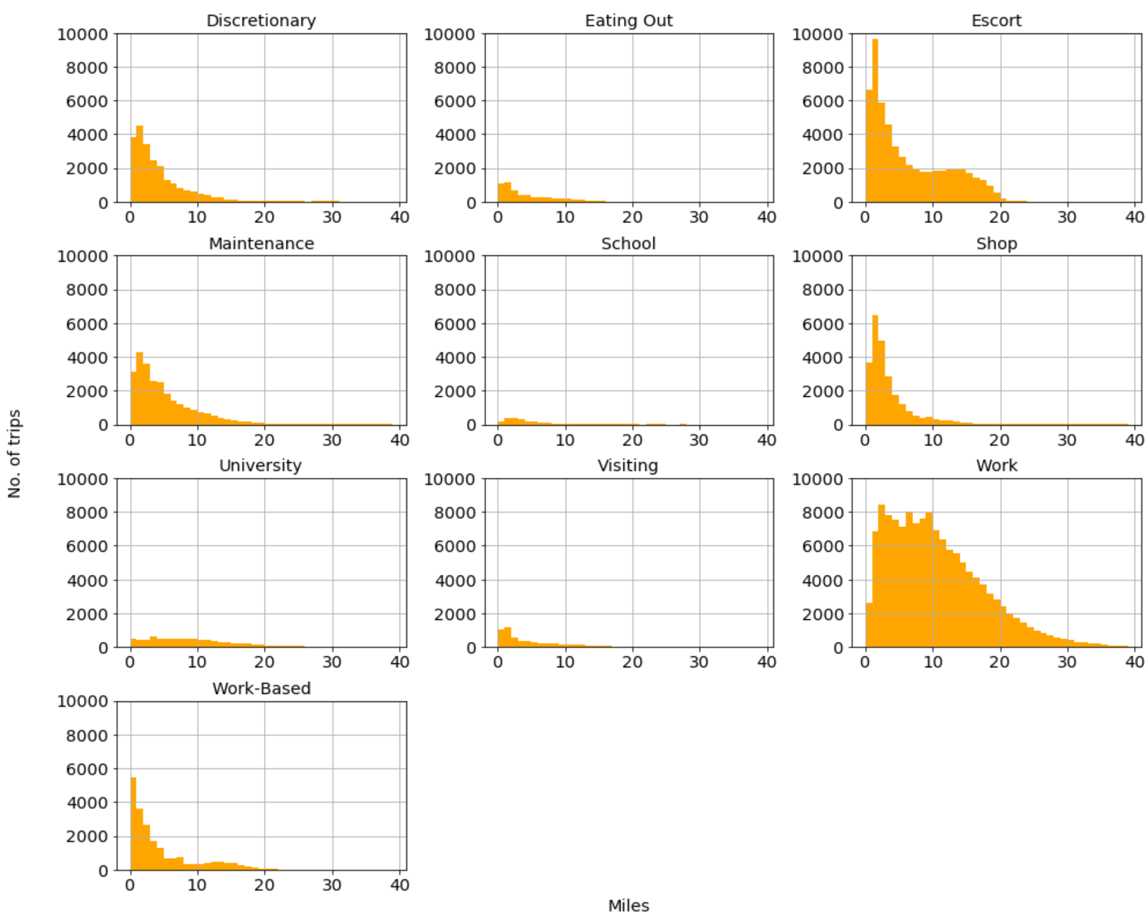

Figure 8 Histogram of VMT of each single drive-alone trip purpose

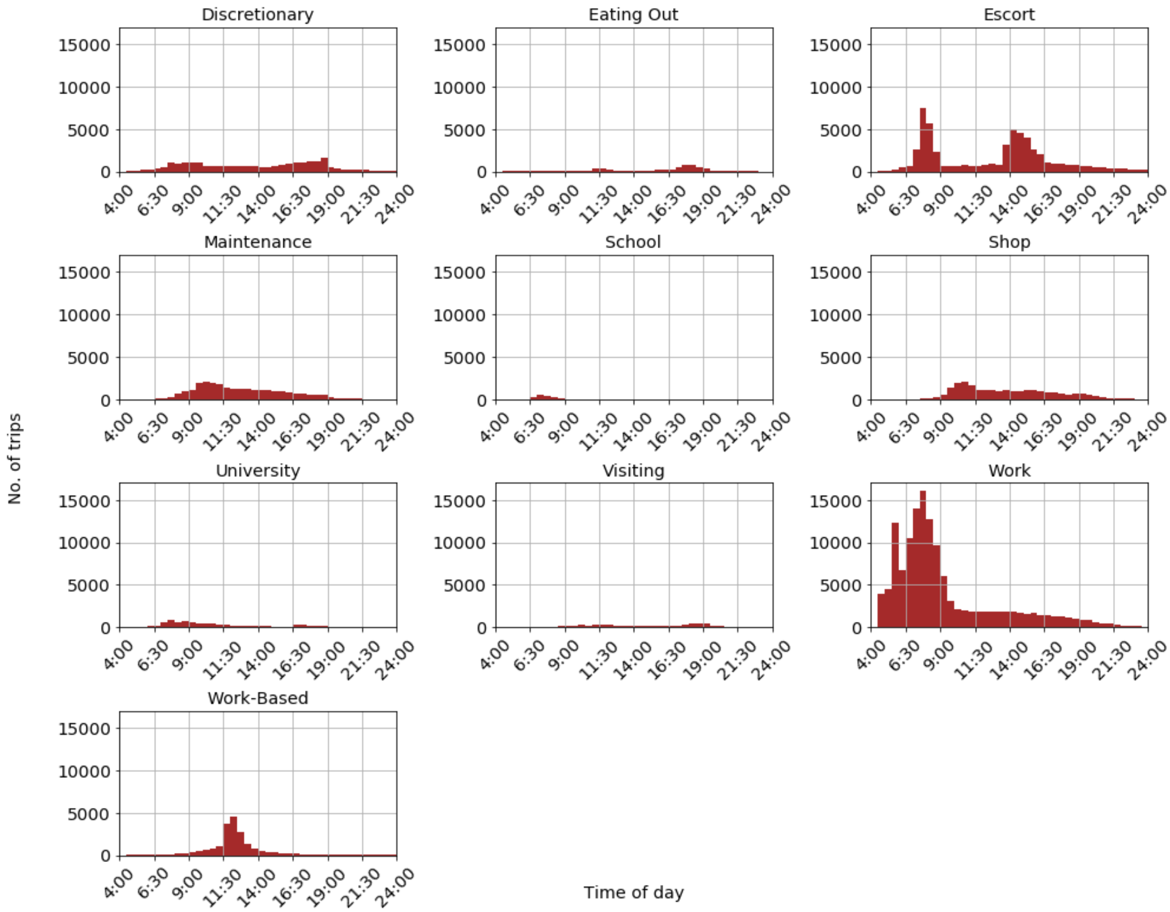

Figure 9 Histogram of time period by single drive-alone trip purpose

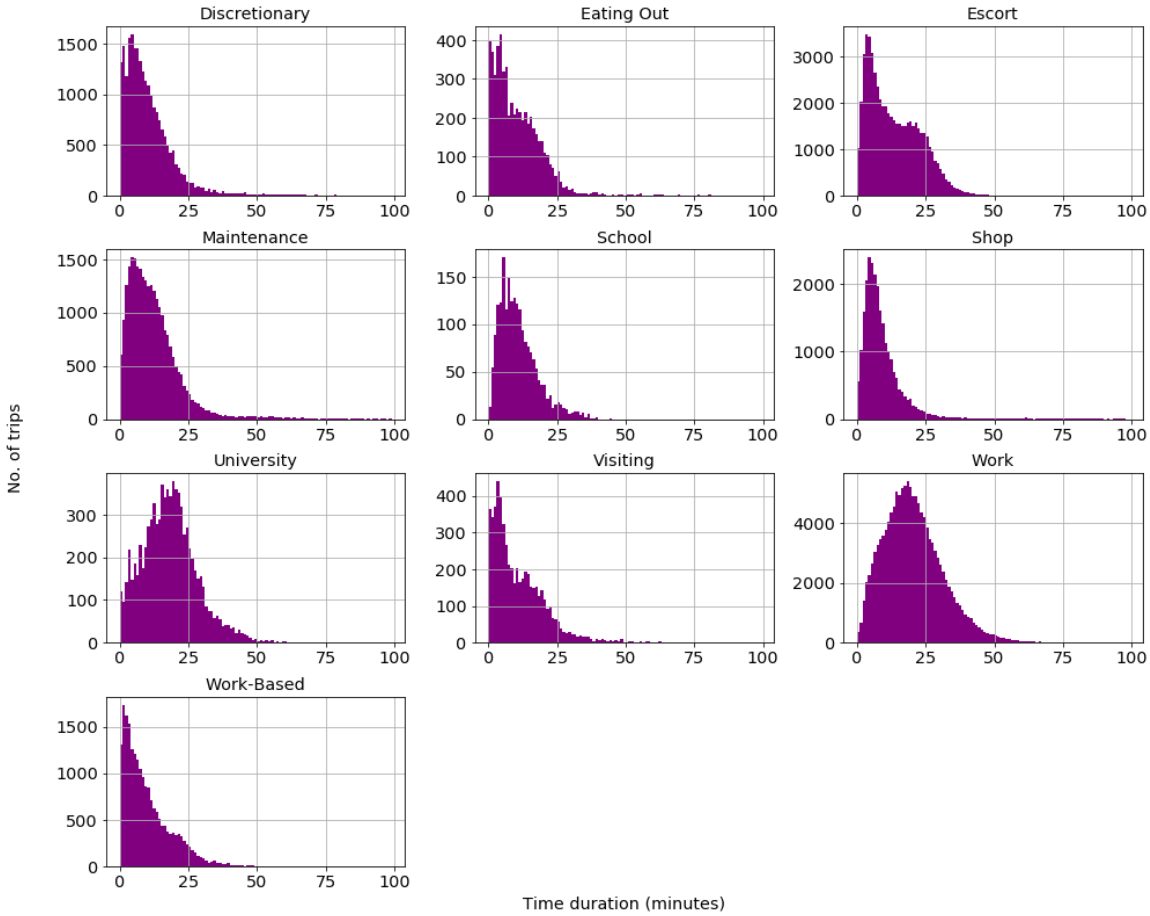

Figure 10 Histogram of time duration by single drive-alone trip purpose

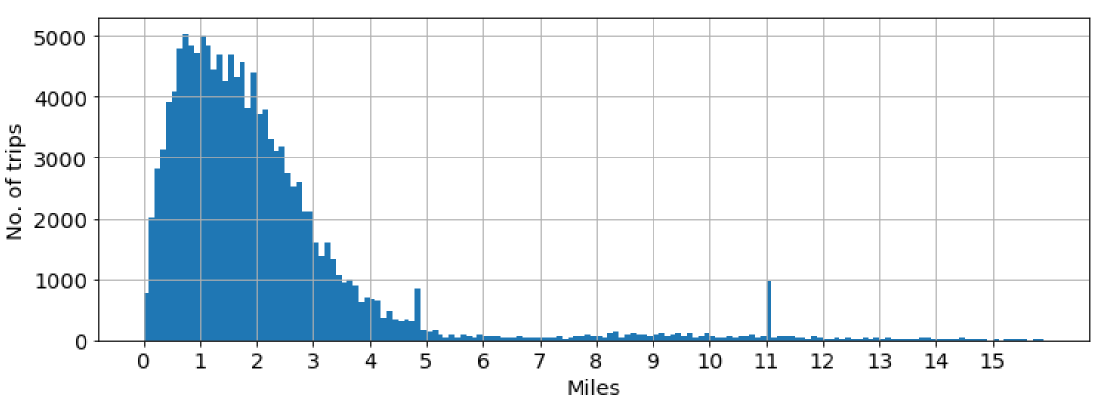

Figure 11 Distance from transit hub for each single drive-alone trip origin

4.3 Work trip origins and destinations

Figure 12 shows the origins of work trips spreading out across San Diego County with the highest concentration around Marine Corps Base Camp Pendleton, Chula Vista, Rancho Penasquitos, and Carmel Valley, respectively. In contrast, the destinations of work trips are concentrated only in a few places ranking from Kearny Mesa, Sorrento Valley, UC San Diego, Mission Valley East, and Downtown San Diego, respectively. These popular origins and destinations indicated high potential in creating the vanpool routes.

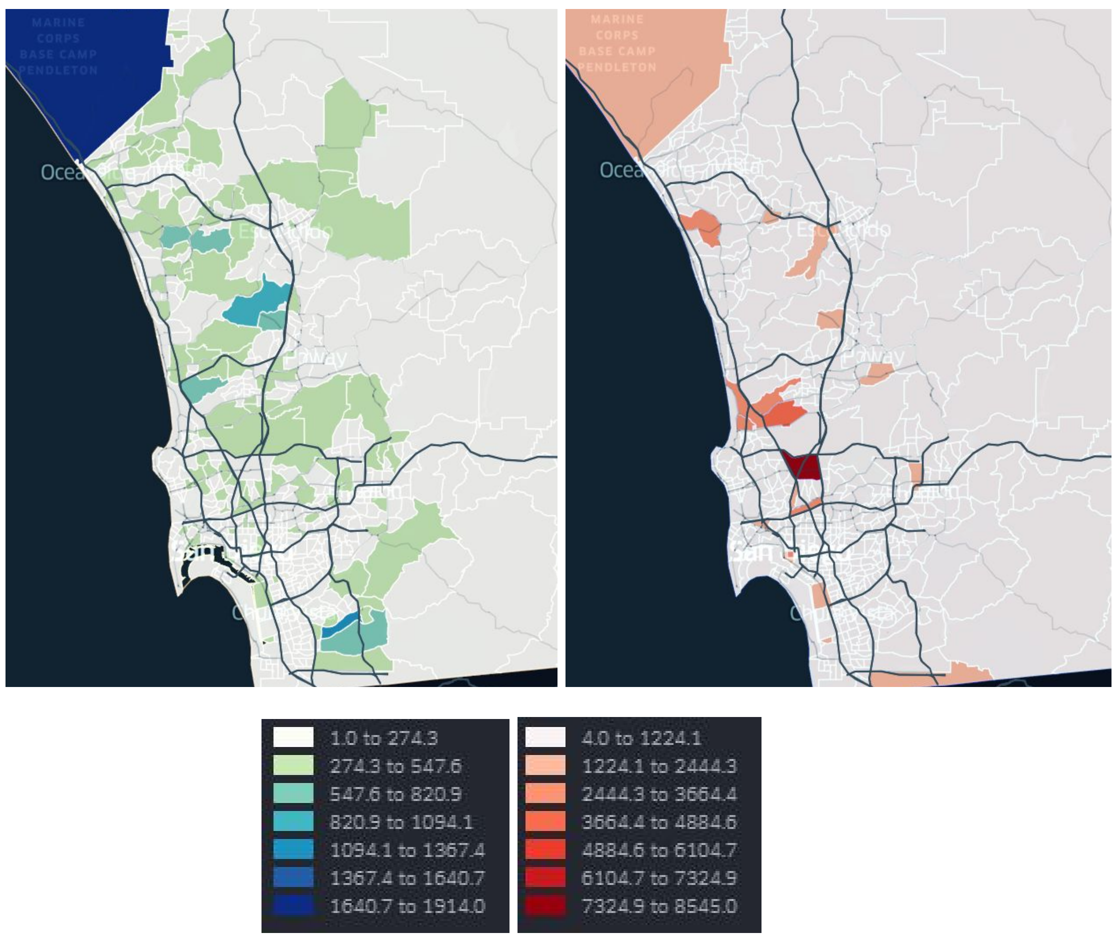

Figure 12 Origins (left) and destinations (right) of home-work trips by census tract

4.4 Grouping work trip route by MGRA, census and zip code

Three types of zonings including MGRA, census tract, and zip code are tested for grouping work trips into origin-destination (OD) routes. As the results in **Figure 13** and **Figure 14**, MGRA is the smallest zoning designated by SANDAG whereas zip code is the biggest zoning. The OD MGRA routes have only a few work trips on each route making it unsuitable for vanpool routes. On the other hand, zip code zoning is much bigger and yields a higher number of work trips on each route. Census tract has slightly more number of work trips on the same route than MGRA and less than zip code. Taking both the number of work trips from each OD route and area size by different zoning, census tract zoning has the most potential for setting up vanpool routes as the area size is not too big and the number of work trips on each route is not too low.

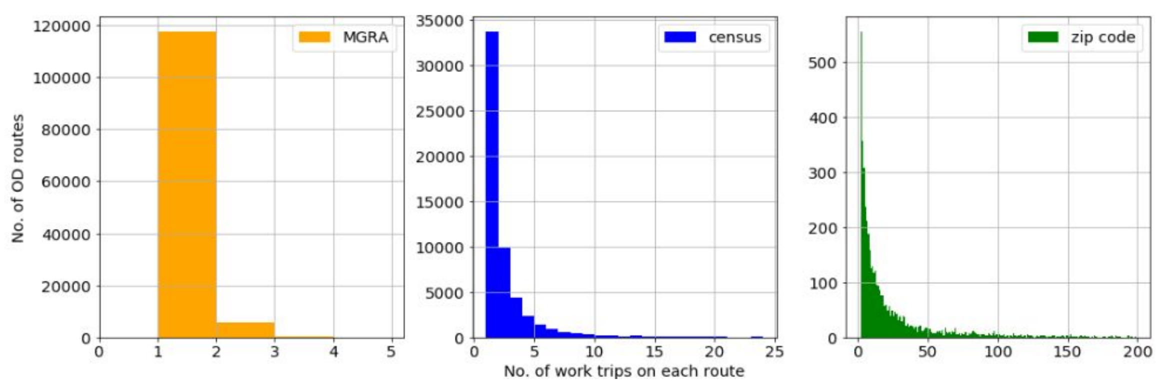

Figure 13 Histogram of number of work trips on each route by different zoning

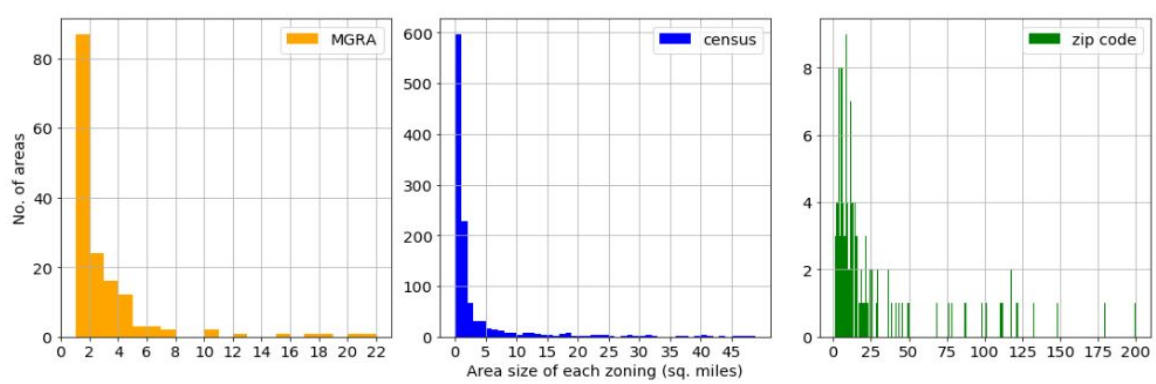

Figure 14 Histogram of area size by different zoning

4.5 Potential vanpool route for work trips

The potential vanpool routes have been created from grouping OD work trips by census tracts. The potential vanpool routes were visualized on kepler.gl at https://bit.ly/vanpool_routes. The resulting routes are shown in **Figure 15**. Each line represents an OD vanpool route. The thicker lines indicate the higher number of work trips on the same route. The score of each route was calculated based on the number of work trips on the route and the OD distance. The visualization of potential routes can be filtered and ranked based on the score for simplification in data analysis. The top 20 potential vanpool routes ranked by route score are listed in **Table 1**.

Figure 15 Potential vanpool routes visualization

Table 1 Top 20 potential vanpool routes

Route no.	Origin census tract	Destination census tract	Number of work trips on the route	Average trip distance (miles)	Average trip duration (mins)	Route score
1	18700	22100	66	19.10322	41.46106	10
2	13310	8511	63	19.96807	35.85576	9.977599
3	21000	20904	46	26.44878	36.40443	9.64968
4	17030	8511	67	17.28566	31.7225	9.185658
5	8333	8511	61	10.92873	22.2123	5.287481
6	17030	8350	44	15.04048	32.17286	5.248845
7	13310	5300	41	15.73008	28.35345	5.115218
8	13314	8511	24	25.50884	40.95171	4.855694
9	16701	8511	44	13.85348	25.08981	4.834606
10	16100	8511	45	13.17471	23.67826	4.702221
11	17032	8511	36	15.45733	28.72729	4.413533
12	10014	8511	26	21.06882	33.20338	4.344733
13	16804	8511	33	16.21679	27.91621	4.244517
14	16702	8511	35	15.28911	27.64019	4.244238
15	17030	8339	30	17.10553	30.48864	4.070121
16	8335	8511	36	14.19573	28.96518	4.053309
17	17030	8305	29	16.78794	30.78997	3.861401
18	21100	21202	20	24.28482	27.60873	3.852249
19	18507	22100	42	11.33467	25.38858	3.775788
20	18513	18700	30	15.41138	34.74395	3.667011

4.6 HOV network utilization

As it is computationally expensive to calculate direction for all OD census tract routes, OD zip code routes were used to calculate route directions. 59.06% of all work trips from all zip code routes are eligible for HOV lane usage at least once in the trip route. Among all highways containing HOV lanes, I-805, I-15, and I-5 have the top use percentage for eligible work trips, respectively, as in **Figure 16**.

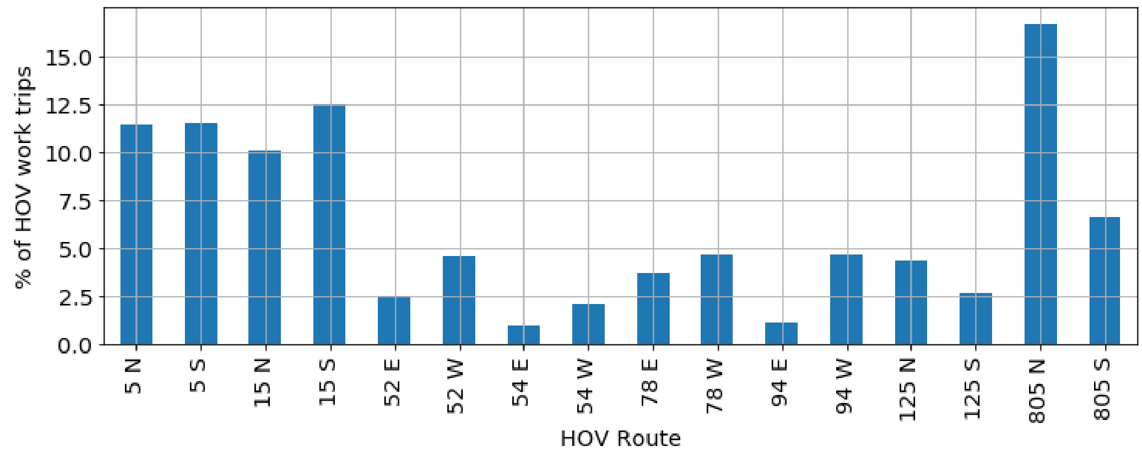

Figure 16 Percent usage of HOV route in eligible work trips

4.7 GHG and VMT reduction benefits

The benefits of the vanpool program were estimated by signup rate and group forming size scenarios as shown in **Figure 17**. The minimum benefit scenario simulated with a 10% signup rate and group forming size of 5 passengers yielded 126 vanpools resulting in the total reduction of 504 vehicles from the original of 133,507 vehicles in San Diego (0.4% reduction). When considering the maximum benefit scenario of 100% signup rate and group forming size of 15 passengers, 6,302 vanpools can be arranged and 50,392 vehicles can be reduced (37.7% vehicle reduction). These vehicle decreases resulted in VMT and CO_2 reduction of 3,121 to 421,761 miles (0.2% to 29.6%) and 0.98 to 143.06 tons of CO_2 (0.2% to 27.3%), respectively.

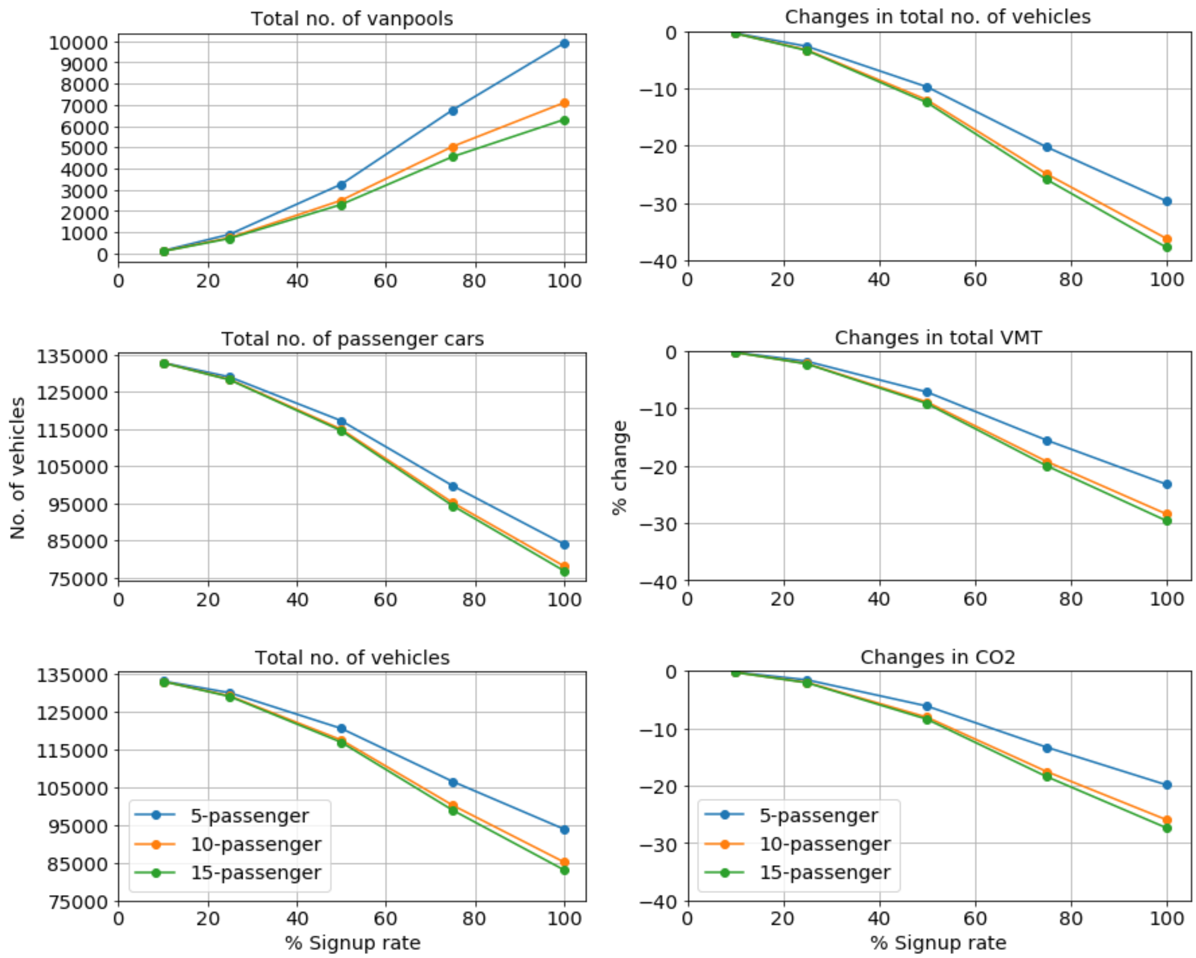

Figure 17 Number of vehicles and benefits per each vanpool scenario

Future studies can incorporate more detailed factors into benefit estimation. Instead of using a fixed fuel efficiency value for vanpool and passenger cars, the fuel efficiency value can be based on different parameters such as the age of the vehicle, vehicle size, etc. Time of day and average speed on different roads can be used to develop a more accurate model of GHG emissions. Other benefits of the vanpool program on an individual level such as saving on parking, time, fuel, and vehicle cost are also important to estimate the benefits scenario of the vanpool program.

4.8 Current SANDAG Vanpool program

As of March 2020, The SANDAG Vanpool Program has a total number of 614 vanpools participating (**Figure 18**). The average trip distance of the vanpools is 51.35 miles and the mode vehicle capacity is 7 seats (**Figure 19**). Daily one-way VMT reduction is approximated to be 178,469 to 242,467 miles. SANDAG required a minimum of 80% occupancy and 5 passengers per vanpool. Compared to potential vanpool scenarios, the current SANDAG Vanpool program achievement is similar to the 25% signup rate and 15 passenger group forming size scenario (626 vanpools). However according to the SANDAG website [22], the total number of vanpools participating in the program has been slightly decreasing since 2017. A similar trend has been found in the number of unlinked passenger trips (UPT) from NTD (**Figure 20**). UPT is counted when passengers board vehicles. All of the top five vanpool programs in the United States have seen a decrease in ridership since 2014. Only California Vanpool Authority that has the number of ridership increasing. While SANDAG had its lowest number of ridership in its vanpool program since 2017, the number has risen after mid-2019. To further understand existing vanpool participants, SANDAG vanpools anonymous data and ACS 5-year data have been used to find the relationship between vanpool participants and population demographics. The top 10 demographic factors are listed below:

	Population demographics	**Correlation**
1.	Employed in Transportation, warehousing, utilities	0.6499
2.	Children of the household 6-17 years old	0.6082
3.	Employed in Retail trade	0.6039
4.	Production, transportation, and material moving occupations	0.6012
5.	Population 16+ years old in civilian lf - unemployed	0.5896
6.	Sales and office occupations	0.5867
7.	Employed in Public administration	0.5783
8.	Households with SSI	0.5709
9.	Civilian noninstitutionalized population for insurance	0.5706
10.	Females 16+ years old	0.5703

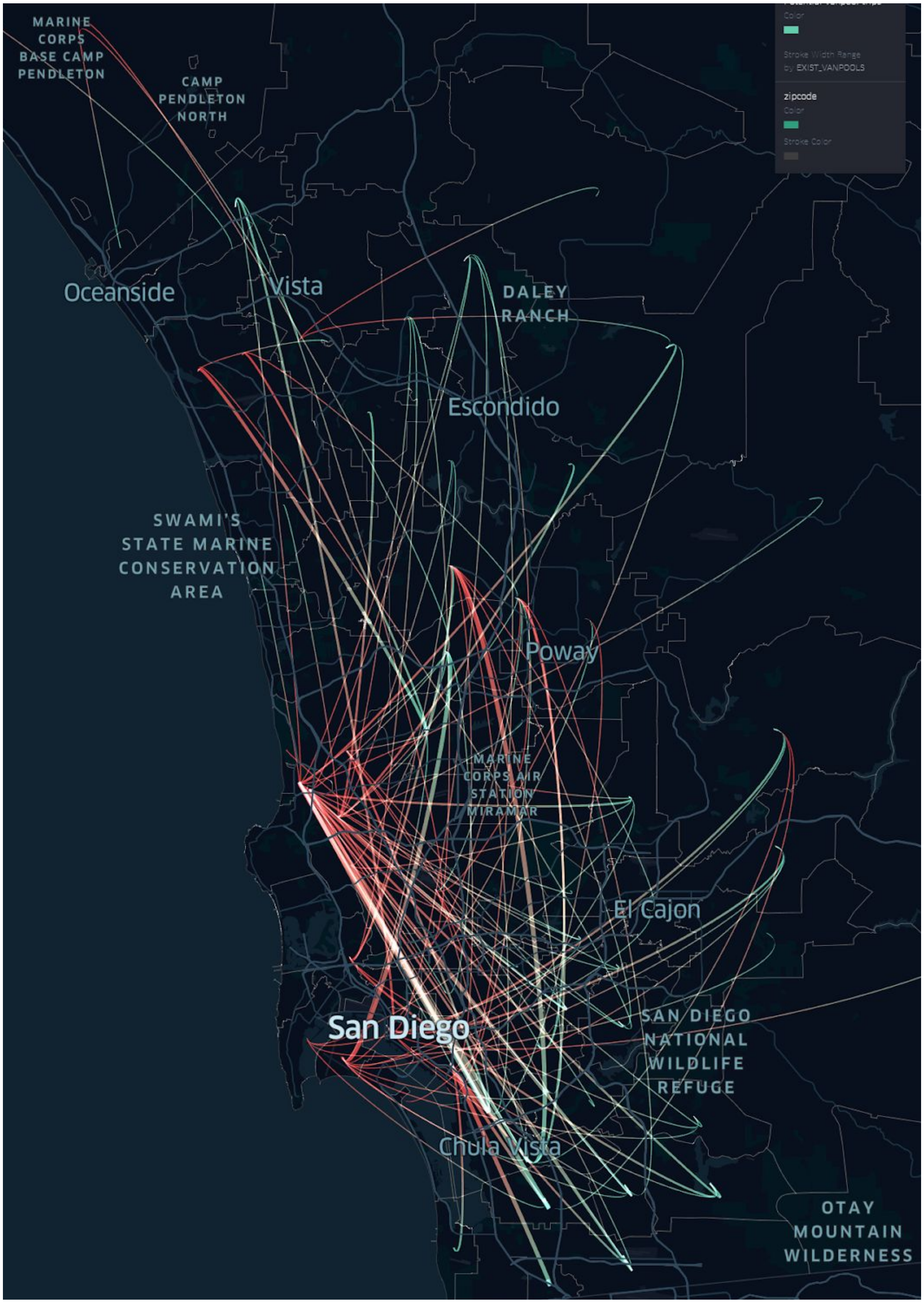

Figure 18 SANDAG Vanpool routes by zip code as of March, 2020

The correlation of population demographics and number of current vanpool participants showed that areas with a high number of people with jobs in transportation, warehousing, and utilities are more likely to have a higher number of vanpool participants. To increase the number of participants in the vanpool program, the potential vanpool routes created in this study can be used as a tool to target commuters who drive-alone to work in a specific origin and destination area. Specific occupation types can also be used to target potential participants. However, the program should offer support to all people with any occupation type to ensure that everyone can equally participate in the vanpool program. The current achievement of the SANDAG vanpool program compared to estimated scenarios showed the potential of expanding the program and increasing the number of participants.

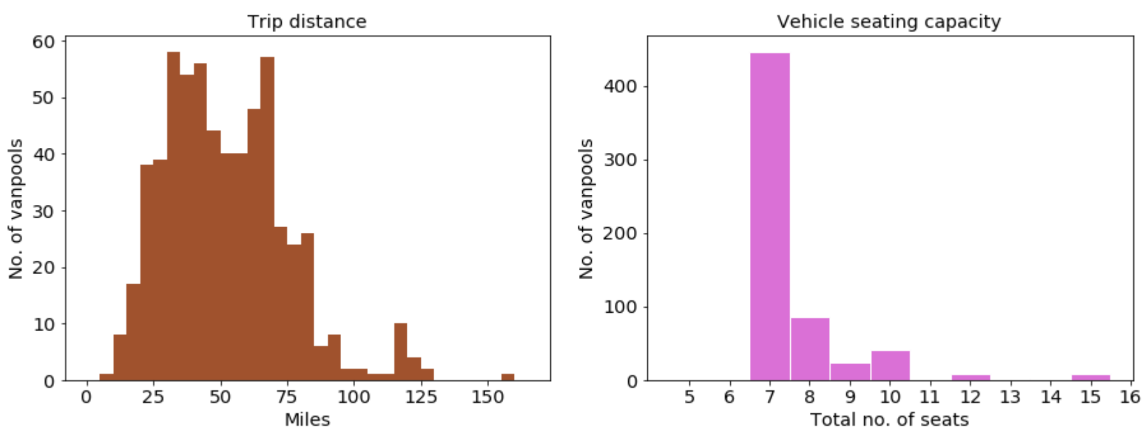

Figure 19 SANDAG Vanpool trip distance and seating capacity

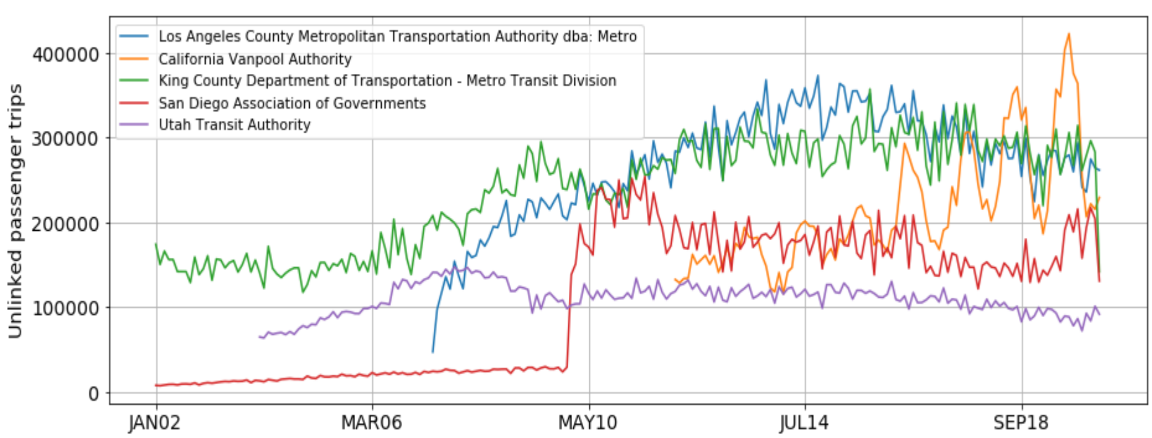

Figure 20 Ridership of Top 5 vanpool programs in the United States

4.9 Service metrics comparison

Considering the cost per VMT reduction, vanpool is the most cost-effective option compared to the trolley and bus in San Diego. According to 2018 data, The cost per passenger mile of vanpool is only $0.09 compared to $0.42 for the trolley, $0.75 for MTS contracted bus, and $1.06 for MTS directly-operated bus (**Table 2**). Because vanpool has lower operating costs and high vehicle occupancy, vanpool is much more cost-efficient than bus and trolley. The operating cost of vanpool also doesn't take driver cost into account as the driver is volunteered/arranged by a member of the group. Vanpool requires a minimum of 5 people to form a group while bus and trolley still have to operate even if there are no passengers (deadheading).

Although the fare per passenger of vanpool is still higher than bus and trolley, the fare from vanpool passengers covers a full total operating expense (106% Recovery Ratio). The average bus recovery ratio is only 31% and the recovery ratio for the trolley is 44%. In other words, more than half of the bus and trolley operating expenses are covered by subsidies. Passenger Miles Traveled (PMT) in 2018 also represents a large number of VMT reductions from the current vanpool program (85.6M miles) compared to buses (185.3M miles) and trolleys (214M miles). VMT reduction from vanpool is equivalent to 46% of VMT reduction from buses and 40% of VMT reduction from trolleys. As the average passenger trip length of vanpool (49 miles) is much longer than the bus (3.92 miles) and trolley (5.79 miles), the VMT from vanpool is significant to total VMT reduction from public transit. In terms of public spending, the vanpool program is a better cost-effective investment to reduce VMT than bus and trolley.

Table 2 2018 San Diego Public Transit Service Metrics [25]

	San Diego Trolley	**MTS Directly-Operated Bus**	**MTS Contracted Bus**	**SANDAG Vanpool**
Vehicles operated in maximum service (VOMS)	97	232	274	714
Fare Revenues per Unlinked Passenger Trip	$1.06	$1.01	$0.97	$4.89
Fare Revenues per Total Operating Expense (Recovery Ratio)	0.44	0.21	0.40	1.06
Cost per hour	$188.87	$135.20	$61.40	$18.40
Cost per Passenger	$2.44	$4.85	$2.45	$4.61
Cost per Passenger Mile	$0.42	$1.06	$0.75	$0.09
Total Operating Expenses	$90,313,010	$110,955,049	$60,588,478	$8,017,914
Fare Revenues Earned	$39,353,823	$23,034,059	$23,963,800	$8,514,025
Unlinked Passenger Trips	36,995,201	22,866,573	24,687,604	1,740,540
Average Passenger Trip Length (miles)	5.79	4.57	3.27	49.18
Passenger Miles Traveled	214,376,455	104,544,729	80,770,023	85,605,989
Deadhead Miles	102,020	1,526,852	1,580,230	0

4.10 COVID-19 impact on public transportation

According to StreetLight Data, DVMT in San Diego County has dropped significantly from the impact of the COVID-19 lockdown. After the end of March, DVMT has dropped by 77.5% compared to the average DVMT in January (**Figure 21**). These changes match with Google mobility data that show the changes in movement trends (**Figure 22**). The movement in the transit station category has decreased by almost 75% by the middle of April. Even though both DVMT and mobility changes have been slightly bouncing back at the beginning of May, the number is still relatively low compared to the normal time before the lockdown.

As shown in **Figure 23**, the ridership of public transportation in San Diego also decreased significantly by the end of March. Data from NTD show a 26% decrease in light rail UOT and 29-37% for buses compared to the previous month. Hybrid rail UPT dropped by 18% and commuter rail UPT dropped by 53%. Vanpool UPT decreased by 40%.

The decreasing trend in public transit ridership has been shown in the past. Between 2009 and 2018, bus ridership in San Diego declined by 12.2% compared to the national average drop of 14.4% [23]. Trolley ridership has also decreased by 10% in 2018 after reaching its highest point in 2015. Even though the ridership of public transit in San Diego has slightly increased in 2019, the numbers are still far below their peak level in the past. One cause of the decrease in public transit ridership comes from the growth of transportation network companies (TNCs) like Uber [24].

In a short term trend, public transit ridership in San Diego might rebound back in the recovery phase of COVID-19. However, ridership in the long term trend is still hard to imagine. The opening of UC San Diego Blue Line trolley in 2021 may bring more riders to public transit but the competition of ridesharing companies is also expected to gain more market share.

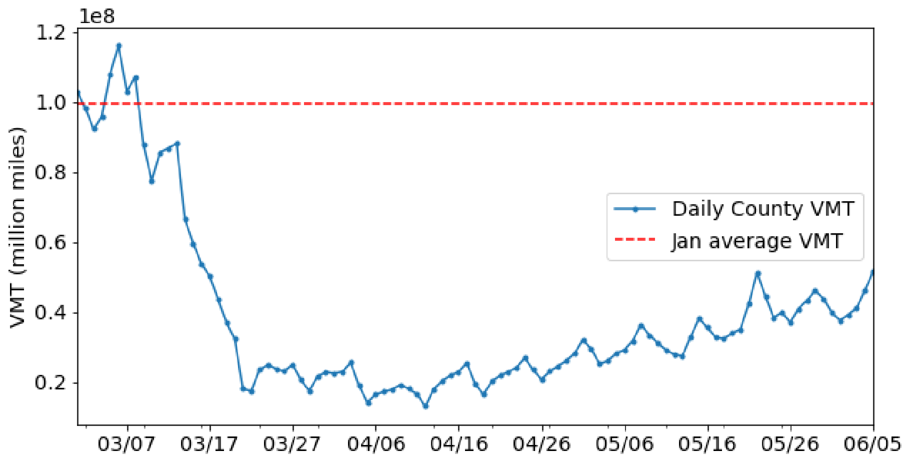

Figure 21 San Diego County Daily VMT (3/1/2020 - 6/5/2020)

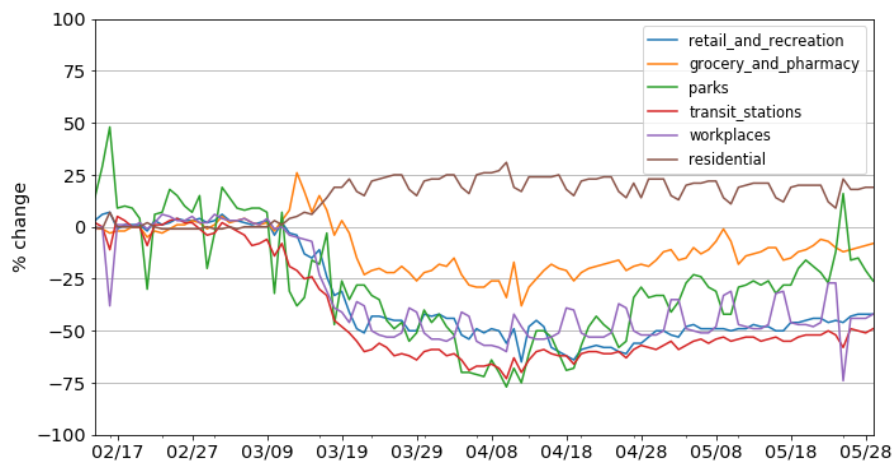

Figure 22 San Diego County Mobility Change (02/15/2020 to 05/29/2020)

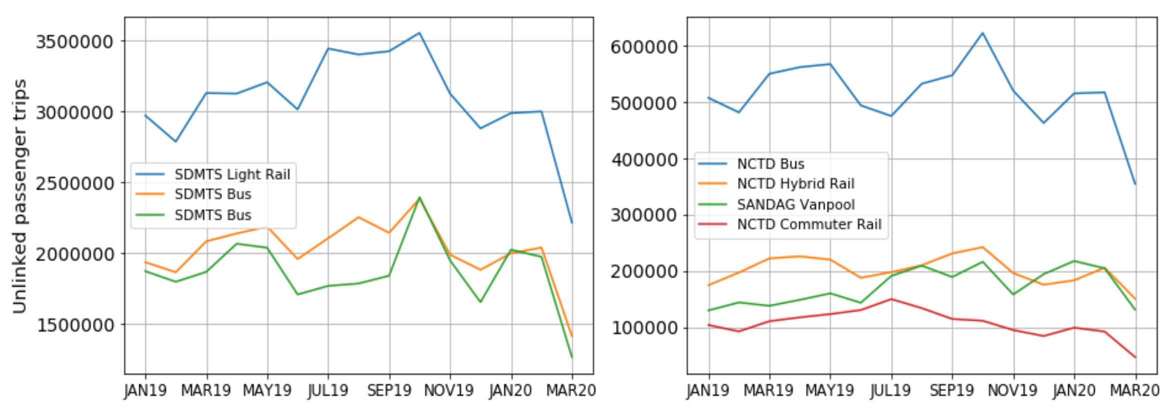

Figure 23 Ridership of San Diego public transit (01/2019 - 03/2020)

5. Conclusions

This study analyzed travel patterns in San Diego and created potential vanpool routes for replacing driving alone work trips. The potential routes and route score can be used to prioritize and target groups of individuals who are suitable for the vanpool program by the geographic area of home and workplace. Based on the result, the current SANDAG Vanpool program has an opportunity to expand the program and increase the number of participants. Potential benefits of vanpools are estimated to have a total daily reduction of up to 50,392 vehicles, 421,761 VMT, and 143.06 tons of CO_2. Compared to scenarios for a radical expansion of legacy forms of fixed-route transit, the flexible transit deployment would require significantly less operational subsidy, due in large part to unpaid drivers, and radically less expense to the public for hard infrastructure investments. Expanding flexible transit thus makes economic sense.

To improve this study, the potential vanpool route can incorporate more detailed factors such as route direction and work trips in between OD of the routes. The route can also be flexible and does not need to be a direct route from origin to destination. A more accurate assessment of the replacement value of vanpool can be studied by considering a more detailed cost associated with vanpools (e.g. age of car and size) and saving benefits from switching from SOV. The benefit of VMT and GHG reduction can be further assessed by considering different vehicle fuel efficiency, time of day, and average speed from different road types. Apart from work trips, other types of shared vanpool routes can also be created for single/mixed trip purposes.

Work trip vanpool program can be used as an example in tackling VMT and GHG emission in San Diego. By adopting flexible transit concepts, vanpools can offer an opportunity to decrease total VMT and increase AVO while accommodating an increase in passenger travel and securing an absolute decrease in GHG emission reductions. Flexible transit can be a supplementary solution to existing public transit and serve specific trip purposes and communities more efficiently. Flexible transit can also attract new transit users given a preferred travel experience with a straight point to point transport and absent mode changes or transfers for riders that have origins and destinations outside of transit adjacent development. This study has shown that flexible transit has the potential to be a solution to both transportation and GHG emissions problems in San Diego.

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