

Evaluating Policies and Incentives to Reduce Vehicle-Miles-Traveled and Air Pollutant Emissions through the Promotion of Telework and Remote Services

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Jiaqi Ma, University of California, Los Angeles

Yifang Zhu, University of California, Los Angeles

Yueshuai He, University of California, Los Angeles

Qinhua Jiang, University of California, Los Angeles

Qiao Yu, University of California, Los Angeles



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About the Pacific Southwest Region University Transportation Center

The Pacific Southwest Region University Transportation Center (UTC) is the Region 9 University Transportation Center funded under the US Department of Transportation’s University Transportation Centers Program. Established in 2016, the Pacific Southwest Region UTC (PSR) is led by the University of Southern California and includes seven partners: Long Beach State University; University of California, Davis; University of California, Irvine; University of California, Los Angeles; University of Hawaii; Northern Arizona University; Pima Community College.

The Pacific Southwest Region UTC conducts an integrated, multidisciplinary program of research, education and technology transfer aimed at *improving the mobility of people and goods throughout the region*. Our program is organized around four themes: 1) technology to address transportation problems and improve mobility; 2) improving mobility for vulnerable populations; 3) Improving resilience and protecting the environment; and 4) managing mobility in high growth areas.

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Disclosure

Principal Investigator, Co-Principal Investigators, others, conducted this research titled, “Evaluating Policies and Incentives to Reduce Vehicle-Miles-Traveled and Air Pollutant Emissions through the Promotion of Telework and Remote Services” at Department of Civil and Environmental Engineering, University of California Los Angeles. The research took place from 01/01/2022 to 12/31/2022 and was funded by a grant from the Caltrans in the amount of \$79,999.77. The research was conducted as part of the Pacific Southwest Region University Transportation Center research program.

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Abstract

The development of Information and Communications Technologies (ICT) and the popularity of broadband internet services make telework and teleservices available to the public, and the COVID-19 pandemic has changed people's attitudes towards telework and teleservices. In the post-pandemic era, people are more inclined to perform daily activities remotely. While the effectiveness of telework and teleservices as a potential solution to alleviate congestion and emissions remain unclear, it is necessary to understand how people's travel patterns change due to telework and teleservices in the post-pandemic era and explore to what extent telework and teleservices can reduce VMT as well as GHG and air pollutants emissions. In this project, we proposed an integrated research framework to address the research needs in Los Angeles (LA) County, which consists of field data, demand modeling, dynamic supply modeling, and environmental analysis. We designed and distributed an online survey to collect peoples' telework and teleservice statuses and activity choice preferences towards different types of teleservices, then implemented the survey data to update an activity-based model to obtain the travel demand changes. At last, the travel demand results were input to an agent-based mesoscopic transportation simulation model (LA-Sim) to evaluate the impacts on the transportation system and emissions in LA county. The survey data and model results indicate that, overall telework adoption rate rises from 6% to 24% compared to pre-pandemic era. Although the total number of trips has increased by 4%, the total vehicle miles traveled (VMT) during the post-pandemic era barely change (-1.5%). Similar results are found for emissions. This result suggests that the adoption of telework and teleservice results in a slightly net reduction in total VMT and emissions and it might be more efficient to alleviate negative impacts on local areas near freeways.

Evaluating Policies and Incentives to Reduce Vehicle-Miles-Traveled and Air Pollutant Emissions through the Promotion of Telework and Remote Services

Executive Summary

The COVID-19 pandemic has resulted in some of the most significant shifts in every part of our lives and society. Transportation is among the most impacted sectors, as people's travel behaviors are experiencing massive and unprecedented changes due to the global pandemic. As a result of COVID restrictions such as social distancing and lockdown, the public tend to want less in-person interactions to travel and prefer to perform activities remotely. People are more inclined not only to perform their working tasks from home, commonly known as work from home (WFH) or telework, but also to perform their daily routine activities through remote approach, or teleservice, such as online-shopping, e-banking, online health care, and so on. All these changes in people's activity preference have led to shift in travel patterns, which might result in changes with unpredictable duration and extent in travel demand and the transportation system. Studying the shift in people's travel pattern and its impact on the transportation system is substantial for transportation policymakers to develop solutions in the post-pandemic era.

This research aims to investigate how people's travel patterns are affected by the pandemic, and to what extent the changes in travel pattern would impact the transportation system. This research is carried out in multiple stages. First, we designed and distributed an online survey in Spring 2022 to collect people's activity and travel choices to overview the travel pattern changes. The survey collected both the revealed preference and the stated preference and was distributed to the residents across the Los Angeles County. Second, we developed a series of logit choice models based on the survey data to capture people's telework status and activity frequency choices for both teleservice and non-teleservice activities. These model results were further used to update an existing activity-based travel demand model (ABM) to obtain the travel demand changes induced by the COVID-19. Third, the travel demand results were input to an agent-based mesoscopic transportation simulation model (LA-Sim) to evaluate the impacts of the changing travel demand on the transportation system. At last, we designed multiple test scenarios and carried out sensitivity experiments in both the network level and the corridor level to evaluate how the transportation system performs under a couple of telework and teleservice promoting assumptions.

Selected findings from this study that can inform policymakers about the features of the post-pandemic travel and help them find solutions to enhance the transportation performance include:

- The post-pandemic activity frequency increases compared to the pre-pandemic era. While work trips in post-pandemic era decrease by 11%, non-work trips increase by 3%, resulting in a 1% growth in total trips.
- The adoption of telework and teleservice results in a decrease in VMT. The vehicle miles traveled (VMT) during the post-pandemic era drops by 1.5%. While the non-work trips induced VMT barely changed (0.2%), the VMT drop in total trips is mainly contributed by work trips (-7.7%).
- The ground transportation generated emission decreases by around 0.4% for the whole network. While the majority of the LA county shows decreased emission compared to pre-pandemic era, some specific regions such as the north area to downtown LA produces more emission than before the pandemic.
- Existing telework and teleservice adoption status would reduce the peak hour traffic by a small margin and maintain a close daily pattern in traffic volume, VMT, and speed. However, the impacts of further promoting teleservice in communities near the major freeway on corridor traffic varies across communities. The promoting of teleservice in communities near the central parts of I-405 would induce more traffic on the corridor, while enhancing the teleservice level in the communities near the edge segments could reduce the volume and VMT on the freeway.

Introduction

The development of Information and Communications Technologies (ICT) and the popularity of broadband internet services make telework and teleservice available to the public. According to the Telework Enhancement Act of 2010 (US Congress, 2010), "The term 'telework'¹ or 'teleworking' refers to a work flexibility arrangement under which an employee performs the duties and responsibilities of such employee's position, and other authorized activities, from an approved worksite other than the location from which the employee would otherwise work." Although the Act defined the legal responsibilities of the parties involved in telework, and executive agencies were required to create policies enforcing the Act, the proportion of telework workers only increased by about 2 to 3 percent from 2005 to 2015 in the US (Mas and Pallas, 2020). On the other hand, "teleservice" is becoming more prevalent in people's life. In this project, teleservice refers to "the delivery of services from a distance using telephony and /or digital technologies (Joint Technology Committee, 2019)," such as online shopping, online education, telemedicine, online banking, etc. Taking online shopping as an example, about three quarters of Americans have shopped online in 2022 and this number is predicted to increase in the future (Tighe, 2022).

The breakout of the COVID-19 pandemic completely changed the trend. During the pandemic, states and localities across the US have issued stay-at-home orders, and many people have started to switch to telework (Mendelson, 2020). Big tech companies, such as Facebook, Google, Twitter, and Amazon, implemented work-from-home policies to prevent the spread of the coronavirus (Duffy, 2020). A survey conducted in the US by Pew Research indicated that only 20% of workers were doing telework before the pandemic, while the number increased significantly to 71% during the pandemic (Parker et al., 2020). Moreover, people's attitudes also changed due to the pandemic. Approximately 83% of employers and 71% of employees in the US said telework during the pandemic had been a success (PWC, 2020). Although telework may bring multiple benefits to employers (Laumer and Maier, 2021; Global Workplace Analytics, n.d.), some employers started to require their employees back to offices after the pandemic (Vynck, 2022). Shamshiripour et al. (2020) showed that there was a significant increase in teleworking and teleshopping during the pandemic in Chicago, where out of 71% of workers who had zero experience working from home-even before the pandemic, only about half of them continued to work at their workplaces. They also showed that 45% and 67% of them become new tele-shoppers for fresh food and grocery shopping, respectively. Beck and Hensher (2020) also reported the impact of COVID-19 on activity-travel behavior change in Australia. They showed that 47% of respondents shifted to telework. The pandemic also disrupted the respondents' out-of-home activities such as social activity, dine-in, and shopping by 80%, 76%, and 76%, respectively. Shakibaei et al. (2021) found that personal activity patterns during COVID strongly correlate with their demographic attributes. For shopping activities, males and people living in a household with less than four family members were more active than their counterparts.

¹ There might be other terms that have the same definition as telework, such as "telecommuting" and "remote work." We will use "telework" in this report for simplicity.

The potential of telework and teleservices to mitigate traffic congestion and improve air quality has captured the attention of policymakers and researchers for decades (Mokhtarian and Varma, 1998; Mitomo and Oniki, 1999; Lari, 2012; Giovanis, 2018), while some researchers argue that the mitigation might be unclear (Mokhtarian, 1998). As a result of large-scale telework during the pandemic, both traffic congestion and emissions have a record drop during the pandemic (Newburger, 2020). Our team's study also found significantly reduced vehicle activity and improved air quality in March-April 2020 (Liu et al., 2021). Nonetheless, with the economy starting to reopen in summer 2020, emissions went back to a similar level of 2019 in the second half of 2020 (Tollefson, 2021). Furthermore, since people's travel behaviors changed substantially during the pandemic (e.g., avoid taking transit), the congestion after the pandemic might be more severe than in the pre-pandemic era (Wang et al., 2021), which may lead to increased VMT and GHG emissions. The commuting trips of teleworkers would be omitted, which alleviates the pressure on the road network during peak hours. However, flexible work arrangements from telework may induce more non-mandatory trips for teleworkers, which occur around their home instead of workplaces. Such induced trips may lead to unexpected congestion and air pollutants in some areas. Moreover, the prevalence of teleservice may offset some of the induced trips, which makes the impacts even harder to be understood and evaluated.

It is necessary to comprehensively understand how people are making decisions about telework and teleservices in the post-pandemic era and evaluate the consequent impacts on transportation systems. The results of this project would inform the public agencies in promoting telework and leveraging the potential benefits to society in the post-pandemic era.

Methodology and Model Specification

We adopted an integrated activity-based and agent-based simulation approach to evaluate the impacts of telework and teleservice in LA County. The methodology framework is presented in **Fig 1**. First, we designed and distributed a mixed method survey (stated and revealed preference) in LA County to collect data of people's telework and teleservice choices and associated travel behavior changes. Next, based on the synthetic population and activity-based model (ABM) developed by the Southern California Association of Governments (SCAG), we re-calibrated necessary behavioral models according to data collected to incorporate the new travel behaviors and predicted the associated disaggregated travel demand. At last, an agent-based mesoscopic transportation simulation model (LA-Sim) developed by the Mobility Lab at UCLA and the EMFAC model from the California Air Resources Board (CARB) were employed to evaluate the impacts of changing travel demand on the transportation system and traffic-related emissions. A couple of scenarios were designed and implemented in the integrated model to evaluate the effectiveness of promoting telework and teleservice in LA County and provide policy recommendations to Caltrans. The rest of this section will describe the details of methodology and model specification.

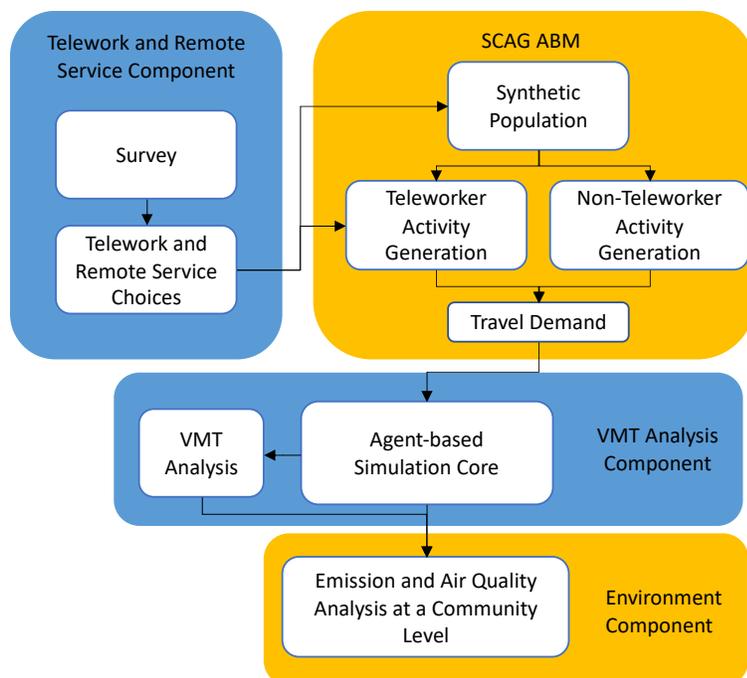


Fig 1. Model framework.

Survey

General Design

The data used in this study comes from a survey conducted for May 2022 to June 2022 in LA County. The survey was distributed online collaborating with a professional survey online sampling and data collection company—Dynata (Dynata, 2022). The survey was designed to collect data about people's choice of telework and teleservices, as well as the associated travel behavior changes. Considering the total budget cap and project schedule, we determined the sample size to be around 1,000. Because of the limitation of the web survey, the quotas initially proposed might not be fully realized with the existing respondent pool. Therefore, we optimized the list of quotas and only kept the most significant ones: age, ethnicity, education attainment, employment status, household size, and annual household income. The survey consists of three layers. The first layer asks questions about the socio-economic characteristics of people. In the second layer, questions are about pre-/post-pandemic telework statuses, commuting cost and time with typical transportation modes. For those who work remotely, we also asked about their weekly telework frequencies. In the third layer, we asked about people's weekly activity frequencies in terms of both teleservice activities and in-person activities during post-pandemic era.

Survey Data Post-Processing

In total, we collected 1089 valid survey responses across the LA County. To guarantee the sample we collected can realistically represent the population of LA County, a raking adjustment was adopted to adjust the sample weight of each respondent and align the

weighted sample with the aggregated socio-economic distributions of the population from the 2016 activity-based model from the Southern California Association of Governments (SCAG, 2020). Variables and variable categories used for raking are as follows:

- Age (less than 18, 18-25, 25-40, 40-65, above 65)
- Ethnicity (Hispanic, White, African American, American Indian, Asian, Other)
- Education (below high school, high school, associate/2-year college, bachelor, master and above)
- Employment status (Employed or not)
- Household income (less than 25K, 25K-50K, 50K-75K, 75K-100K,100K-125K,125K-150K, 150K-200K, above 200K)

The raking procedure was based on an iterative proportional fitting procedure and involves simultaneous ratio adjustments to two or more marginal distributions of population counts. (Kalton and Flores-Cervantes, 2003). The raking procedure was performed in a sequence of adjustments. Base weights (sampling weights) were first adjusted to one marginal distribution and then to the second marginal distribution, and so on. One sequence of adjustments to the marginal distributions was known as a cycle or iteration. The procedure was repeated until convergence was achieved. The comparison of weighted sample and quotas from the SCAG population is presented in **Table 1**.

Table 1. Raw and weighted survey data compared with quotas.

Demographic Attribute		Quotas	Raw Survey Data	Weighted Survey Data
1. Age	age <18	3%	1%	4%
	18<=age<25	13%	23%	13%
	25<=age<40	27%	34%	28%
	40<=age<65	40%	28%	40%
	age >=65	16%	14%	16%
2. Ethnicity	Hispanic	44%	46%	43%
	Non-Hispanic white	29%	35%	30%
	Non-Hispanic black	8%	6%	8%
	Non-Hispanic American Indian	0%	1%	0%
	Non-Hispanic Asian	16%	7%	16%
	Non-Hispanic Other	2%	4%	3%
3. Education Attainment	Less than high school	25%	5%	22%
	High school diploma	20%	33%	21%
	Associate/2-year College degree	29%	18%	30%
	Bachelor degree	17%	25%	18%

	Master's degree +	9%	19%	9%
4. Employment Status	Employed	56%	61%	56%
	Unemployed	44%	39%	44%
5. Household Annual Income	< \$25k	26%	19%	26%
	\$25k to \$50k	22%	21%	22%
	\$50k to \$75k	16%	18%	16%
	\$75k to \$100k	11%	14%	11%
	\$100k to \$125k	8%	9%	8%
	\$125k to \$150k	5%	7%	5%
	\$150k to \$200k	6%	6%	6%
	> \$200k	7%	6%	6%

Model Specification

Activity-Based Travel Demand Modeling (ABM)

The ABM used in this study is developed based on the existing ABM platform developed by SCAG, which is one of the largest Metropolitan Planning Organizations in the US. It encompasses six counties in California with more than 19 million population. The 2016 ABM developed by SCAG is one of the largest ABM in practice, and it provided a foundation for SCAG's decision-making of transportation planning. The SCAG ABM has the following characteristics:

- 24-hour travel demand patterns with necessary level of temporal resolution (15 min time interval)
- Detailed synthetic population with demographic and socio-economic information
- Individual travel choices considering intra-household interactions

Fig. 2 is the system design of the SCAG ABM. The model simulates people's activity-related choices from long-term to short-term, considering people's socio-economic attributes and spatial-temporal constraints.

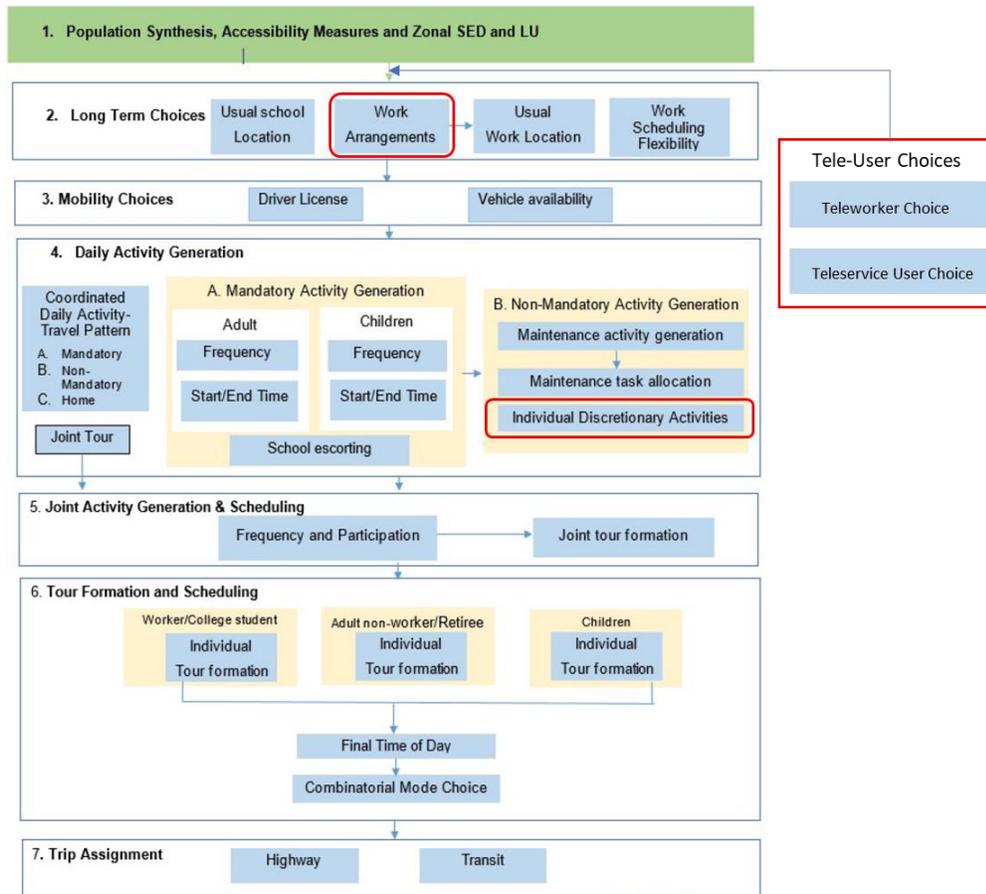


Fig 2. Model updates on SCAG ABM.

To incorporate people's travel behavior changes due to the emergence of telework and teleservice, several components of the SCAG ABM were updated, as the red boxes in **Fig. 2** show. In the long-term choice layer, we added a telework user choice module to select teleworkers from the workers. Besides, we inserted a teleservice user choice module in the long-term choice layer to select teleservice users from the general population. The selected teleworkers' workplace types were updated to home correspondingly in work arrangement module. For those who are marked as teleservice users, updates were made in their daily activity generation layer. Specifically, their non-mandatory activity frequencies were updated according to the activity frequency choice model developed by the survey data. Similar updates were made to maintenance and individual discretionary activity generation models.

Telework Model

This model is used to determine whether a worker in the synthetic population choose to telework or not on a typical workday. In the survey, we designed two revealed preference questions that are related to worker's current telework status: (1) "Are you currently teleworking at least occasionally?" and (2) "How many days per week on average are you currently teleworking?" According to the responses of the first revealed preference question, 43% of workers at least telework occasionally. Based on the results from question 2, however,

we discovered that only 17% of teleworkers telework 5 days a week, meaning that the majority of teleworkers only partially telework across the week. Therefore, instead of directly using the response from the first question, it's better to first develop the weekly telework frequency model using data from the second revealed preference question and then convert the weekly frequency to daily telework frequency.

The utility functions are defined in Eq. (1). The weekly telework frequency model has 6 choice alternatives, ranging from 0 to 5, each indicating the number of days the workers choose to telework during a week, or weekly telework frequency. The choice of zero weekly telework frequency is regarded as the reference.

$$U_{i,n} = h_i(X_n; \beta) + \varepsilon_i \quad (1)$$

where $U_{i,n}$ represents the utility of individual n who choose to telework n days a week (n ranges from 0 to 5), X_n is the vector of explanatory variables for individual n , β is the vector of parameters that needs to be estimated from data, ε_i is the random disturbance terms, $h(X_n; \beta)$ is the function to calculate the systematic utility of choosing to telework n days a week. The most common specification of $h_i(X_n; \beta)$ is a linear format:

$$h(X_n; \beta) = \beta_{i,0} + \sum_{k=1}^K \beta_k * x_{nk} \quad (2)$$

where $\beta_{i,0}$ is the alternative specific constant term, β_k is the parameter to be estimated for k th explanatory variable, and x_{nk} is the value of k th explanatory variable of people n .

Assume the random disturbance terms ε_i are independent and identically distributed (i.i.d.) extreme value distributed (Gumbel distribution), the probability of individual n choosing the weekly telework frequency of i is:

$$P_n(i) = P_n \left(U_{i,n} \geq \max_{j=1, \dots, J, j \neq i} U_{j,n} \right) \quad (3)$$

According to the properties of Gumbel Distribution, Eq. (3) can be further expressed as:

$$P_n(i) = \frac{e^{\mu h_i(X_n; \beta)}}{e^{\mu h_i(X_n; \beta)} + e^{\ln \sum_{j=1}^{J, j \neq i} e^{\mu h_j(X_n; \beta)}}} \quad (4)$$

Table 2. Estimation results of telework weekly frequency model.

Variable Number	Variable Name	Weekly Telework Frequency Model	
		Coefficient (std)	
Constant			
1	One	-2.79	(0.44) ***
2	Two	-2.07	(0.42) ***
3	Three	-2.13	(0.42) ***
4	Four	-3.14	(0.45) ***
5	Five	-2.63	(-0.43) ***
Household Income			
6	25k to 50k	-0.386	(0.389)
7	50k to 75k	0.834	(0.371) *
8	75k to 100k	1.1	(0.398) **
9	100k to 125k	0.603	(0.428)
10	125k to 150k	1.84	(0.486) ***
11	150k to 200k	0.558	(0.479)
12	200k +	0.521	(0.495)
Industry Sector			
13	Manufacturing, Wholesale	-1.22	(0.347) ***
14	Retail	-0.542	(0.332)
15	Education & Health/Social Service	-0.396	(0.304)
16	Finance, Investment, Real Estate	0.237	(0.435)
17	Arts, Entertainment, and Hospitality, Food Service	-0.581	(0.368)
18	Public Administration	-1.13	(0.555) *
Education Attainment			
19	Associate/2-year College	0.4	(0.243).
20	Bachelor	0.993	(0.296) ***
21	Master +	1.79	(0.427) ***
Household Size			
22	Size = 3	0.527	(0.24) *
; *, **, and *** indicate statistical significance at the 0.1, 0.05, 0.01, 0.001 levels, respectively			
Summary statistics of weekly telework frequency model			
Number of estimated parameters: 22			
Sample size: 600			
Initial log likelihood: -1075.056			
Final log likelihood: -757.0437			
Rho-square: 0.296			

The log-likelihood across the sample is calculated as Eqs. (5) – (6). The parameter vector β can be estimated by any optimization algorithm by maximizing the log-likelihood.

$$LL = \log \prod_{n=1}^N \prod_{i=1}^5 P_n(i)^{y_{n,i}} \quad (5)$$

$$y_{n,i} = \begin{cases} 1, & \text{if individual } n \text{ select alternative } i \\ 0, & \text{otherwise} \end{cases}, i \in \{0,1,2,3,4,5\} \quad (6)$$

The weekly telework frequency model helps to determine the number of days that a worker choose to telework during a week. For the workers who choose to telework at least once a week, the next step is to select the teleworkers on a typical workday. We consider the typical workday as a randomly selected day from Monday to Friday, then the probability that a teleworker n choose to telework on the typical day is proportional to the number of telework days during the week. This probability can be expressed as:

$$P_n = \frac{F_n}{F_{max}} \quad (7)$$

where P_n is the probability that a teleworker n choose to telework on the typical day, F_n refers to the weekly telework frequency of individual n , F_{max} is the maximum number of telework days, or five (5) in this case.

In our model, we first apply the telework weekly frequency model to the workers in the synthetic population, and then select a fraction of workers to be considered as teleworkers on the typical workday by the probability defined in Eq. (7).

Teleservice Model

The teleservice model is intended to explore how many people in the population would choose teleservices in their daily lives and at what frequency would they use different types of teleservices. The teleservice model is divided into two segments. The first segment is the teleservice user choice model, which is used to separate the population who at least occasionally adopt teleservice from those who don't choose teleservice at all. The second segment of the model is the teleservice frequency model, which is used to estimate the frequency of people to use teleservices under different activity types.

(1) Teleservice user choice model

The teleservice user choice model is a binary choice model based on the revealed preference question in the survey: "Do you currently use any type of teleservices (e.g., online shopping, online education, telehealth) at least occasionally?" This model is used to select active teleservice users from the whole population. Considering people's employment status might impact their choices on the adoption of teleservice, we divided the population into the worker group and non-worker group. For workers, we further divided them into the teleworker group

and the non-teleworker group. The teleservice user choice model is then segmented into three sub-models, each will estimate the proportion of teleservice users in their population groups.

The binary logit model format is similar to the multinomial model introduced in the telework model section. The only difference is that the number of model alternatives is reduced to two: Yes or No.

Table 3. Estimation results of Teleservice user choice model for teleworkers.

Variable Number	Variable Name	Teleservice User Choice Model for Teleworkers	
		Coefficient (std)	
Constant			
1	Teleservice User (Yes)	-2.62(0.52) ***	
Housing Tenure			
2	Owned	-1.43 (0.573) *	
3	Rented	-2.1 (0.568) ***	
Industry Sector			
4	Retail	1.14 (0.606) .	
5	Education & Health/Social Service	-0.602 (0.481)	
Education Attainment			
6	Associate/2-year College	0.971 (0.497) .	
Household Size			
7	Size = 3	-1.22 (0.64) .	
; *, **, and *** indicate statistical significance at the 0.1, 0.05, 0.01, 0.001 levels, respectively			
Summary statistics of Teleservice user choice model for teleworkers			
Number of estimated parameters: 7			
Sample size: 316			
Initial log likelihood: -168.0637			
Final log likelihood: -95.4312			
Rho-square: 0.432			

Table 4. Estimation results of Teleservice user choice model for non-teleworkers.

Variable Number	Variable Name	Teleservice User Choice Model for non-Teleworkers	
		Coefficient (std)	
Constant			
1	Is teleservice user	-1.88 (0.416) ***	
Age			
2	25~39	-1.43 (0.573) *	
3	>65	-2.1 (0.568) ***	
Gender			
4	Female	-1.22 (0.64) .	
Household Income			
5	25k to 50k	0.458 (0.0.296)	
6	50k to 75k	0.767 (0.328) *	

7	125k to 150k	1.63 (0.684) *
8	150k to 200k	3.71 (2.07) .
Industry Sector		
9	Manufacturing, Wholesale	1.11 (0.42) ***
10	Education & Health/Social Service	0.776 (0.364) *
Ethnicity		
11	Non-Hispanic white	0.912 (0.323) ***
12	Non-Hispanic black	0.857 (0.452) .
Household Size		
13	Size = 4	0.674 (0.271) *
; *, **, and *** indicate statistical significance at the 0.1, 0.05, 0.01, 0.001 levels, respectively		
Summary statistics of Teleservice user choice model for non-teleworkers		
Number of estimated parameters: 13		
Sample size: 342		
Initial log likelihood: -251.4623		
Final log likelihood: -204.2192		
Rho-square: 0.188		

Table 5. Estimation results of Teleservice user choice model for non-workers.

Variable Number	Variable Name	Teleservice User Choice Model non-Workers
		Coefficient (std)
Constant		
1	Teleservice User (Yes)	-2.17 (0.28)***
Age		
2	>65	-0.754 (0.284) ***
Gender		
3	Female	-1.22 (0.64) .
Household Income		
4	25k to 50k	0.494 (0.27) .
5	50k to 75k	0.652 (0.354) .
6	150k to 200k	0.757 (883)
Education		
7	High school	1.15 (0.314) ***
8	Associate/2-year College	1.57 (0.33) ***
9	Bachelor	1.81 (0.41) ***
10	Master +	1.56 (0.6) ***
Ethnicity		
11	Non-Hispanic white	1.43 (0.317) ***
12	Non-Hispanic black	0.616 (0.85)
13	Non-Hispanic Asian	0.841 (0.341) *
Household Size		
14	Size = 2	0.567 (0.227) *
; *, **, and *** indicate statistical significance at the 0.1, 0.05, 0.01, 0.001 levels, respectively		
Summary statistics of Teleservice user choice model for non-workers		
Number of estimated parameters: 14		
Sample size: 430		

Initial log likelihood:	-334.9749
Final log likelihood:	-259.9569
Rho-square:	0.224

To validate that the segmented models provide a better estimation for people’s adoption on teleservice, we also developed a combined model which uses the responses from the whole population as the input data, regardless of their employment status. We then compared the two model estimation results using a likelihood ratio test. The model segmentation is verified if the following criteria is met:

$$2 \left(LL(\beta_t) + LL(\beta_{nt}) + LL(\beta_{nw}) - LL(\beta_p) \right) \geq \chi_n^2 \quad (8)$$

where $LL(\beta_t)$, $LL(\beta_{nt})$, $LL(\beta_p)$, and $LL(\beta_{nw})$ are the log-likelihood for the teleworker model, the non-teleworker model, the non-worker model, and the pooled model, respectively. n denotes the degree of freedom and is calculated as such:

$$n = K_t + K_{nt} + K_{nw} - K_p \quad (9)$$

where K_t , K_{nt} , and K_p are the number of coefficients in the teleworker model, the non-teleworker model, the non-worker model, and the pooled model, respectively.

From **Table 3** to **Table 5**, we can get the chi-square statistic test ($p \leq 0.001$) using Eq. (3) is:

$$2 \left(LL(\beta_t) + LL(\beta_{nt}) + LL(\beta_{nw}) - LL(\beta_p) \right) = 111.99 > \chi_n^2 = 32.91 \quad (10)$$

which indicates that the three segmented models have significant differences in estimating the teleservice choice. Therefore, our initial conclusion is that the teleservice choice model should be segmented into three models to estimate the teleservice choice for teleworkers, non-teleworkers, and non-workers.

(2) Teleservice activity frequency model

After we obtain the estimation on people’s adoption on teleservice, the next step is to estimate the frequency of people using the teleservice on a typical weekday. On the one hand, from the survey data collection perspective, it’s hard to directly ask the respondents how many teleservices they would use on a typical day, since people’s daily activity frequency may vary from day to day within a week. People’s weekly activity pattern, however, is usually more consistent from week to week. Therefore, by asking about respondents’ weekly activity frequency, we are more likely to obtain an accurate estimation of their number of activities under different activity purposes. On the other hand, from travel demand modeling perspective, we are more interested in investigating what people’s activity pattern would be on a typical weekday. Therefore, in this

section, we will follow a similar modeling approach as described in the telework modeling section. In the modeling of teleservice activity frequencies, we first estimate people’s weekly teleservice frequencies by teleservice types, and then convert the weekly teleservice frequency into daily teleservice frequencies.

The activities that can be conducted in the form of teleservice in SCAG ABM are eating out (food delivery), personal maintenance (online shopping, tele-health care, online banking, etc.), and personal discretionary (online movies, online religious activities, etc.). **Table 6** provides an example of the estimated parameters for one of the teleservice activity frequency models, the weekly food delivery frequency model for breakfast.

Table 6. Estimation results of Teleservice users’ breakfast eating out choice.

Variable Number	Variable Name	Weekly Food Delivery Frequency for Breakfast Coefficient (std)
Constant		
1	One	-1.04 (0.652)
2	Two	-2.17 (0.67) **
3	Three	-3.93 (0.785) ***
4	Four	-4.26 (0.832) ***
5	Five	-4.99(-0.996)***
Household Income		
6	25k to 50k	-0.781 (0.353) *
7	50k to 75k	-0.729 (0.351) *
8	75k to 100k	-0.798 (0.405) *
Age		
9	Age>65	-2.61 (0.766) ***
Auto Ownership		
10	Auto = 1	-1.02 (0.534) *
11	Auto = 2	-1.42 (0.571) **
12	Auto = 3	-2.88 (0.693) ***
13	Auto >= 4	-3.14 (0.808) ***
Gender		
14	Female	-0.368 (0.242)
Housing Tenure		
15	Rented	-0.653 (0.283) *
Ethnicity		
16	Non-Hispanic Asian	-2.77 (0.611) ***
Employment Status		
17	Unemployed	-1.3 (0.396) ***
Education Attainment		
18	Associate/2-year College	0.4 (0.243).
19	Bachelor	0.993 (0.296) ***

20	Master +	1.79 (0.427) ***
Household Size		
21	Size = 3	0.558 (0.335) .
22	Size = 4	0.717 (0.295) *
. , * , ** , and *** indicate statistical significance at the 0.1, 0.05, 0.01, 0.001 levels, respectively		
Summary statistics of weekly food delivery frequency for breakfast model		
Number of estimated parameters: 22		
Sample size: 711		
Initial log likelihood: -1120.663		
Final log likelihood: -341.4473		
Rho-square: 0.695		

Because the alternatives defined in SCAG’s choice models of the abovementioned activity types reflect the activity frequencies on a typical weekday, we need to map the weekly choice results generated from the survey data to the daily frequency results as used in SCAG ABM. The detailed data process can be found in the **Appendix B**.

Agent-Base Transportation Simulation

The ABM provides a realistic prediction of people’s travel demand on a typical weekday, while the movement of travelers and vehicles in the transportation network is not explicitly captured. We adopted the agent-based simulation toolkit-Multi-Agent Transport Simulation (MATSim) to simulate the movement of travelers and vehicles in a multimodal network of LA County. The traffic volume distribution across LA County can be obtained from the simulation results with a link-level spatial resolution and temporal resolution at each second. The multimodal network consists of a road network and a transit network, as **Fig 3** shows. About 354,735 links are incorporated into the multimodal network. The road network is generated from the Open Street Map data, while the transit network is developed from General Transit Feed Specification (GTFS) data.

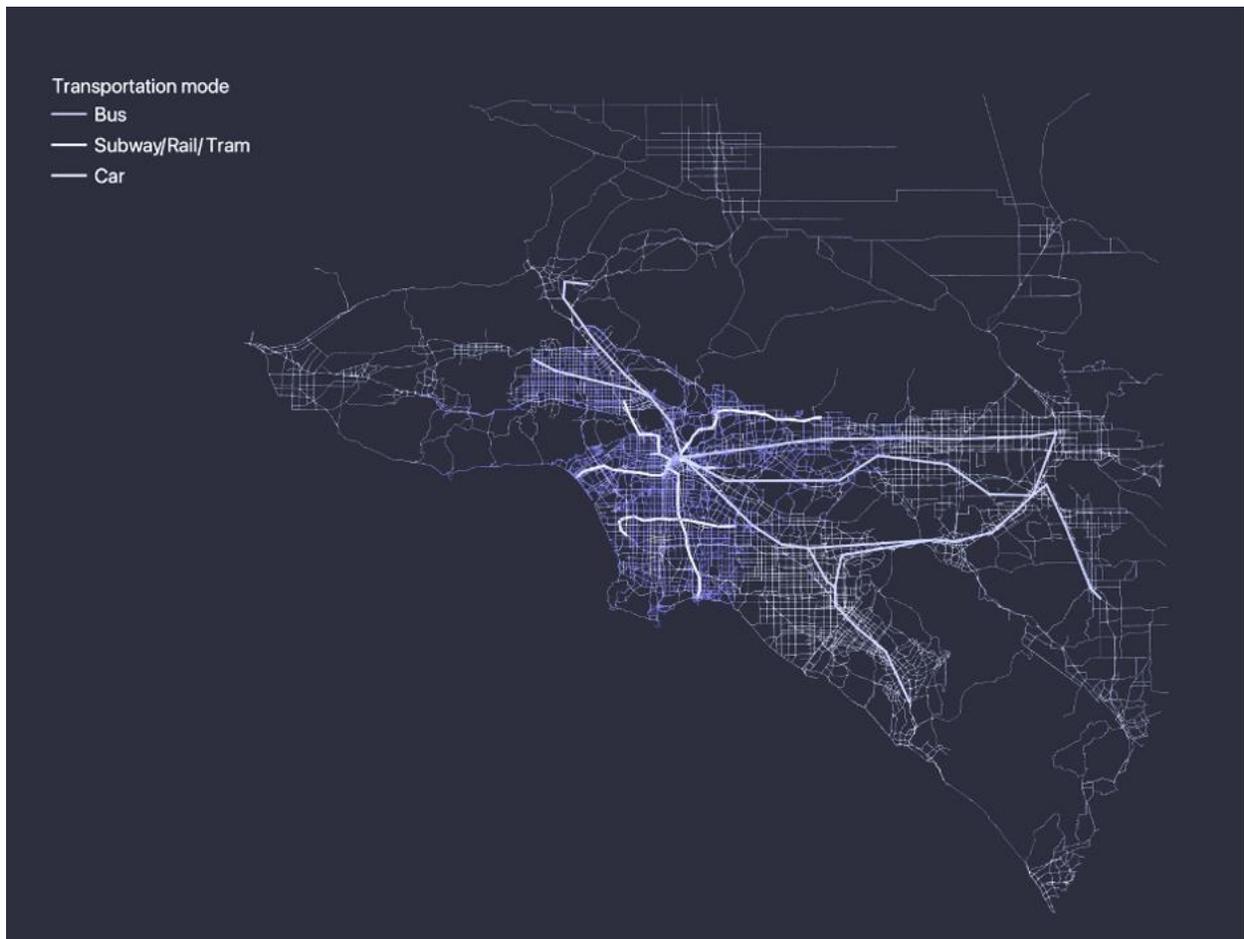
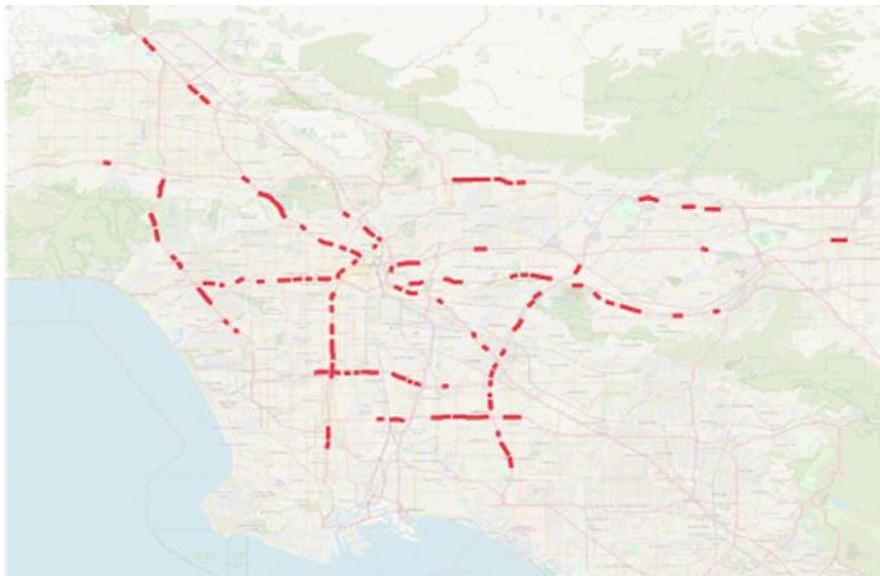
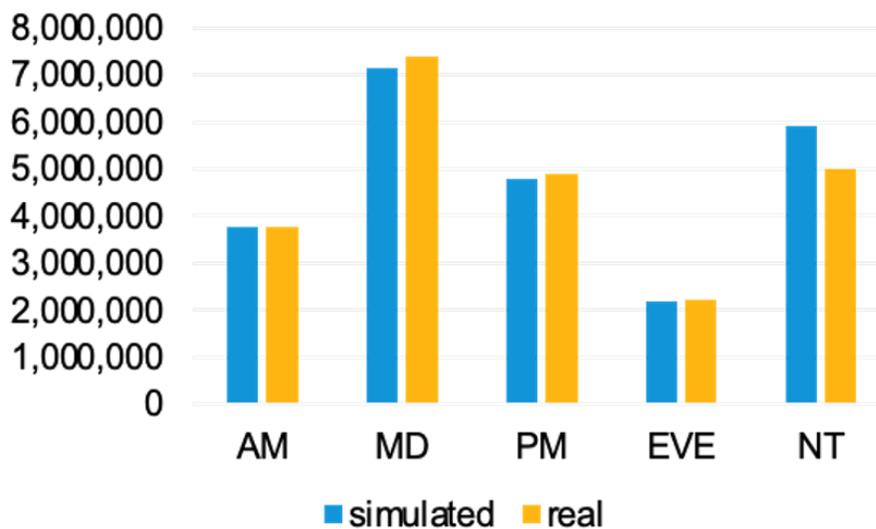


Fig 3. Multimodal network of LA County.

Considering the computational efficiency of large-scale simulation, 10% of the population was simulated in this research. An iterative calibration approach was adopted to accommodate the road capacity to the 10% population sample (He et al., 2021). By selecting traffic count data from major freeways across LA County (PeMS, 2020) as the validation set (presented in **Fig 4 (a)**), the simulated traffic volumes were compared to the validation set, and the results are presented in **Fig 4 (b)**.



(a)



(b)

Fig 4. (a) Traffic count locations selected across LA County; (b) Comparison of simulated and real traffic volumes in LA County.

EMission FACTor (EMFAC) model

On road emission rates of air pollutant and greenhouse gases for Los Angeles County are retrieved from EMFAC2021 v1.0.2 [<https://arb.ca.gov/emfac/>], an official emission inventory database developed by California Air Resource Board. We calculated a vehicle-population-weighted emission rate for each pollutant and for each emission process. Emission rates are then matched with link-level hourly vehicle volumes and vehicle activities (starting or ending a vehicle) to calculate emissions from different emission processes including running exhaust

emissions (RUNEX), start exhaust tailpipe emissions (STREX), tire wear particulate matter emissions (PMTW) and brake wear particulate matter emissions (PMBW). The emissions of all emission processes are then aggregated together to reflect the total emission of a specific link.

Scenario Specification

Based on the updated travel demand model developed in this study, we designed a series of scenarios to illustrate how the adoption of telework and teleservice impact people’s travel choices and how the changes in peoples’ travel patterns affect the transportation system. The scenarios are carried out from two levels, the network level and the corridor level. The network level experiments focus on investigating the impact of telework and teleservice on the transportation system for LA county, while the corridor-level experiments concentrate a major corridor in LA county, Interstate 405 (I-405) and analyze how the changes of travel patterns in communities along I-405 influence the traffic on this corridor.

Network Level Scenario

The base scenario incorporates both the telework model updates and teleservice model updates into the SCAG ABM, this model reflects the current telework and teleservice status of the population in LA county. To investigate the impact of telework and teleservice on transportation system respectively, we designed two independent scenarios for telework and teleservice. One is the telework only scenario, where only the telework model update is added to the SCAG ABM. The other one is the teleservice only scenario, where only the teleservice model update is corporate into the SCAG ABM. At last, two extended scenarios are designed to illustrate how the enhanced telework rate in five selected industry sectors. The five selected industry sectors are: Finance, Management, Professional Services, Information, and Education. These sectors are defined by McKinsey (McKinsey Global Institute, 2020) as the industries with the highest potential for remote work in the United States. The specification of each scenario is presented in **Table 8**.

Table 8. Network level scenario specification summary.

Scenario Index	Scenario Name	Model Update Specification
A	SCAG base	SCAG 2016 baseline model
B	Telework only	Implement the telework user choice model in the SCAG base model
C	Teleservice only	Implement the teleservice user choice model and updated non-mandatory activity frequency model in the SCAG base model
D	Tele-Base	The combination of scenario B and C
E	Extended telework scenario 1	Tele-Base + Increasing the telework rate in 5 industries by 50%

F	Extended telework scenario 2	Tele-Base + Increasing the telework rate in 5 industries by 100%
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Corridor Level Experiment

In the corridor level analysis, our focus is to illustrate how further improved level of teleservice in certain communities would impact the traffic on major corridors based on the telework and teleservice status in the Tele-Base scenario. We selected I-405 as the target freeway to study how the enhanced teleservice rate would change the traffic performance on the corridor. The reason of selecting I-405 as the experiment corridor is that I-405 annually ranks as one of the most congested freeways in California and the US. For LA county, I-405 is more than just a congested freeway—it also serves as a transportation corridor of local, regional, and national significance, linking critical gateways and trade hubs. The I-405 freeway is equally important for commuters, residents, and visitors within the region. More than a quarter of LA County’s population (nearly 2.8 million residents) live within 3 miles of the I-405 freeway—known as the I-405 Corridor—and about 28 percent of jobs in LA County (1.4 million) are located within those boundaries.

As shown in **Fig 5 (a)**, the I-405 passes through four Councils of Government (COG) within the LA county: The San Fernando Valley, Westside Cities, South Bay Cities, and Gateway cities. LA Metro has defined some spotlight communities within the I-405 corridor that have major impacts on the traffic on I-405 in the I-405 Comprehensive Multimodal Corridor Plan (Metro, 2022). In this study, we select 4 representative spotlight communities for further analysis: the San Fernando Valley (SFV) community, the Westwood area in Westside Cities, the Inglewood community in South Bay Cities, and the Long Beach region in Gateway Cities. The selected spotlight communities are shown in **Fig 5 (b)**.

These communities are considered as hubs of major activities along the I-405 corridor. Out of the four communities, the Westwood/UCLA campus community generates over 110,000 daily trips and the majority of them are activities related to the UCLA campus. The SFV, Inglewood, and Long Beach are all densely populated communities and are major activity centers that draw people from across the region. For SFV, Inglewood, and Long Beach, we assume an extreme case scenario where all the non-work and non-school related activities are conducted by teleservice. As for the Westwood scenario, since the main activity type is school/university related, we take one step further and assume that all the non-work activities, including school/university activities are performed in the form of teleservice. The scenario specification is summarized in **Table 9**. Please refer to the I-405 Comprehensive Multimodal Corridor Plan (Metro, 2022) for more detailed introduction on the I-405 corridor.

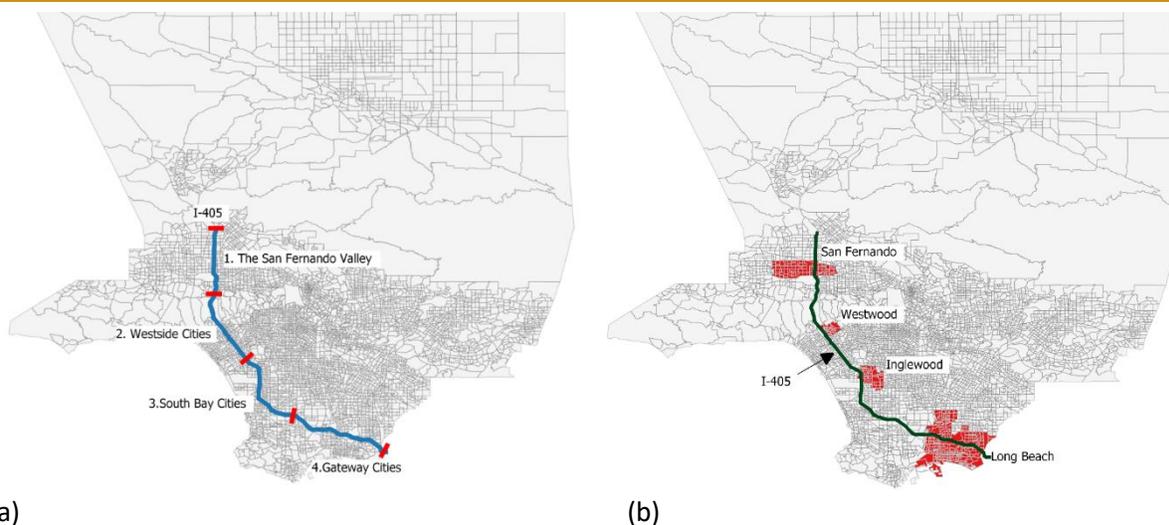


Fig 5. Corridor map for (a) I-405 corridor and related communities; and (b) Selected spotlight communities along I-405 corridor.

Table 9. Corridor level scenario specification summary.

Scenario Index	Scenario Name	Model Update Specification
G	San Fernando Valley	Tele-Base + Converting all non-work and non-school activities into teleservice activities in San Fernando Valley community
H	Westwood	Tele-Base + Converting all non-work activities into teleservice activities in Westwood community
I	Inglewood	Tele-Base + Converting all non-work and non-school activities into teleservice activities in Inglewood community
J	Long Beach	Tele-Base + Converting all non-work and non-school activities into teleservice activities in Long Beach community

Results and Discussions

Network Experiment Results

Activity Analysis

Table 10 provides a summary of activity counts by activity type under different test scenarios. The number of work activities drops in all scenarios compared to the SCAG base scenario (except for the teleservice-only scenarios that has no constraint on work arrangement). The telework extended scenarios (E and F) show a massive decrease in work activities (-15% and -18%), which indicates the telework promotion policy has an effective influence on reducing work activities. On the other hand, the number of non-work activities increases for all test cases due to flexible activity schedules and consequent preference to more non-work activities,

excepting the telework only scenario where the model only considers the change in telework adoption without consideration of the preference change in adopting teleservice. This indicates that the reduction of non-work activities within the work tours (e.g., grocery shopping on the way home) is greater than the newly generated non-work activities due to the flexible work schedule brought by teleworking. When the telework model update is combined with the teleservice model update change in preference, the non-work activities are significantly increased by 7%. This demonstrates that the causes of growth in total activities can be explained from two aspects: 1) the increased telework rate allows more flexible daily activity schedule for the generation of non-work activities, and 2) people’s preference on conducting non-work activities has increased since the base year of 2016 because of telework. Considering the teleservice in the non-work activities which may not result in actual trips, we divided the results into two categories, namely including and excluding teleservice activities. In the first category, all non-work activities are counted no matter whether they are accomplished through teleservice, while for the second category, only activities that result in actual trips are counted. The changes in work and non-work activities result in a drop in the total number of activities compared to the SCAG base case. The decrease in work activities is offset by the increase in non-work trips. Even when eliminating the teleservice activities, the number of traveled activities still increases significantly. Note that when comparing the tele-base and two extended scenarios, although the work activities decreased largely (-11%, -15%, and -20%), the increase of non-work activities barely changed (4%, 3%, and 2%). This indicates that workers from these industry sectors (Finance, Management, Professional Services, Information, and Education) tend to maintain their daily activity patterns even when their work patterns have switched to telework.

Table 10. Number of activities by activity type.

Index	Scenario	Work	Including Teleservice Activities		Excluding Teleservice Activities	
			Non-Work	Work + non-Work	Non-Work	Work + non-Work
A	SCAG base	4.11×10 ⁶	2.23×10 ⁷	2.64×10 ⁷	2.05×10 ⁷	2.47×10 ⁷
B	Telework only	3.71×10 ⁶ (-10%)	2.21×10 ⁷ (-1%)	2.58×10 ⁷ (-2%)	2.21×10 ⁷ (-1%)	2.58×10 ⁷ (-2%)
C	Teleservice only	4.02×10 ⁶ (-2%)	2.40×10 ⁷ (8%)	2.80×10 ⁷ (6%)	2.31×10 ⁷ (4%)	2.71×10 ⁷ (3%)
D	Tele-Base	3.64×10 ⁶ (-11%)	2.37×10 ⁷ (7%)	2.74×10 ⁷ (4%)	2.29×10 ⁷ (3%)	2.65×10 ⁷ (1%)
E	Extended telework scenario 1	3.51×10 ⁶ (-15%)	2.37×10 ⁷ (6%)	2.72×10 ⁷ (3%)	2.28×10 ⁷ (3%)	2.64×10 ⁷ (0%)

F	Extended telework scenario 2	3.38×10 ⁶ (-18%)	2.36×10 ⁷ (6%)	2.70×10 ⁷ (2%)	2.28×10 ⁷ (2%)	2.62×10 ⁷ (-1%)
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Table 11 shows the changes in average trip length of each scenario. We found that the average commuting distance (work trip length) decreases significantly after people shifted to telework in Scenarios B, D, E, and F. This illustrates that workers with longer commuting distance are more likely to switch to telework than workers with shorter commuting distance. Meanwhile, the average length of non-work trips decreased in all scenarios, which leads to a net decrease in average trip length of all types of activity. Specifically in the telework only scenario, people are conducting non-work trips near home instead of workplaces, which leads to a decreased average length of non-work trips. For all other scenarios incorporating preference changes in non-work activities (C-F), people are seeking for non-work activities in near place when they are planning for induced trips, which accounts for the reduced trip length.

Table 11. Average trip length by activity type (mile)

Index	Scenario	Work	Non-Work	All types of activity
A	SCAG base	29.65	14.81	16.30
B	Telework only	28.67 (-3.3%)	14.60 (-1.4%)	15.90 (-2.4%)
C	Teleservice only	29.23 (-1.4%)	13.82 (-4.4%)	15.26 (-4.3%)
D	Tele-Base	28.37 (-4.3%)	13.71 (-5.3%)	14.98 (-6.2%)
E	Extended telework scenario 1	27.90 (-5.9%)	13.64 (-5.8%)	14.83 (-7.1%)
F	Extended telework scenario 2	27.58 (-7.0%)	13.62 (-5.9%)	14.76 (-7.6%)

VMT Analysis

Table 12 summarizes the VMT by activity type for different test scenarios. All scenarios have shown a decrease in the VMT of both work and non-work trips. The current telework status (Scenario D) results in 7.7% decrease in work trip VMT compared to the SCAG base scenario. When the telework rate of five selected industry sectors is increased to 75% and 100%, as in extended scenarios 1 and 2, the VMT drops become even more significant (-11.1% and -13.7%). From the **Table 12**, we may note that the VMT generated by non-work trips also decreases. Although the trip numbers increase for most scenarios in **Table 11**, the VMT of non-work trips decreases by 1% to 2% across test scenarios. This can be explained by two facts: 1) the increased non-work trips are mostly short trips, and 2) a large portion of the long-distance non-work trips are replaced by teleservice activities.

Table 12. VMT by activity type (mile)

Index	Scenario	Work	Non-Work	Total
A	SCAG base	6.64×10^7	2.55×10^8	3.21×10^8
B	Telework only	6.09×10^7 (-8.2%)	2.57×10^8 (1.0%)	3.18×10^8 (-0.9%)
C	Teleservice only	6.62×10^7 (-0.3%)	2.51×10^8 (-1.4%)	3.17×10^8 (-1.2%)
D	Tele-Base	6.13×10^7 (-7.7%)	2.55×10^8 (0.2%)	3.16×10^8 (-1.5%)
E	Extended telework scenario 1	5.90×10^7 (-11.1%)	2.55×10^8 (0.3%)	3.14×10^8 (-2.1%)
F	Extended telework scenario 2	5.73×10^7 (-13.7%)	2.57×10^8 (0.9%)	3.14×10^8 (-2.1%)

Fig 6 provides a map to show the percentage change of VMT in tele-base scenario compared to the SCAG base scenario. The dark blue indicates the VMT increases, while the light green means there's a VMT drop on the link. We can find most of the freeway and arterial links maintain very close VMT compared to the SCAG base. However, some regions such as the freeway near north to the downtown LA, the upper part of the I-405, and a couple of east boundary links near San Bernadino show increased VMT. These increased VMT links indicate that the non-work trip induced VMT growth exceeds the work trip induced VMT drop. Meanwhile, we can also find some area with significant VMT decrease such as links near southeast boundary of LA county. This indicates that a large portion of commute trips through these links have been replaced by telework.

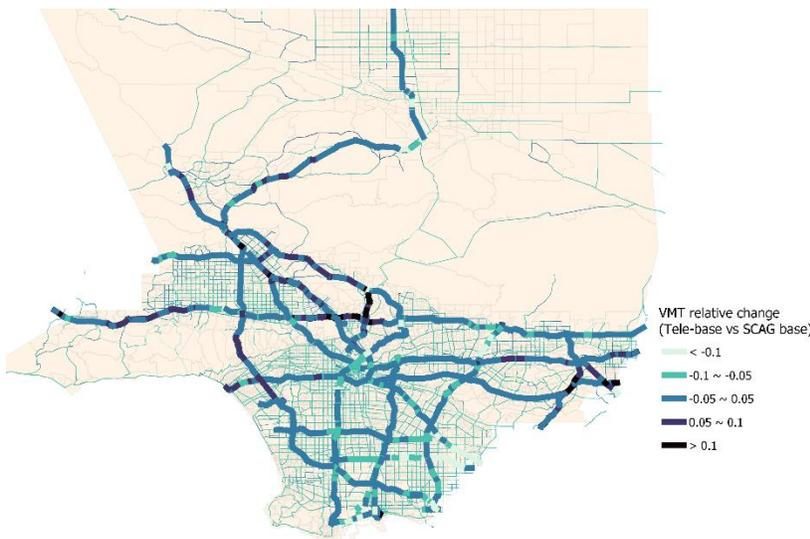


Fig 6. Percentage change of VMT in tele-base scenario compared to the SCAG base scenario

Emission Analysis

Total on-road mobile source emissions associated with each scenario were estimated using the latest emissions model EMFAC22 developed by the California Air Resources Board. Although

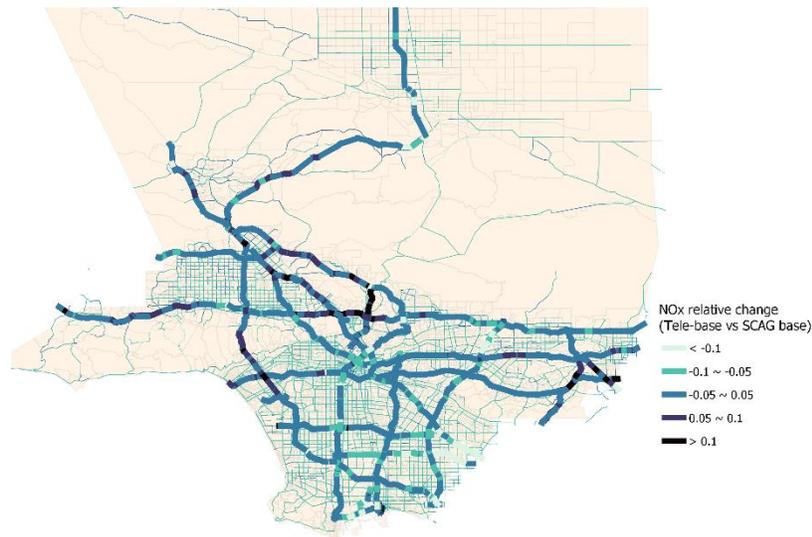
the base year of the transportation models (SCAG ABM and LA-Sim) is 2016, the emission inventory changed significantly from 2016 to 2022. Considering the travel patterns in LA County don't change too much as the daily VMT decreased by around 4.4% from 2016 to 2022, we used the EMFAC22 to estimate the emission from traffic. The deltas between the test scenarios (Scenarios B-F) relative to the baseline (Scenario A) yield the relative benefit of these scenarios. The emission reduction results are provided in **Table 13**. We divided the emission sources into two categories: the air pollutants (NOx and PM2.5) and the GHG (CO2 equivalent). The first category focuses on emissions that are hazardous to health, while the second category focuses on the emission that contributes to the climate change. Compared to the SCAG baseline scenario (Scenario A), all test scenarios except Scenario C reveal benefits in emission reduction on both air pollutants and GHG. Note that the relative reduction proportion in VMT doesn't correspond with the reduction in emission. Scenarios with greater VMT reduction in Table 12 don't necessarily cause a greater reduction in emission. Scenario C and D have more VMT reduction than scenario B, while they both show less emission reduction than scenario B. This can be explained by the fact that the increase in trip frequency could offset the benefits caused by reduced VMT in emission reduction. As in scenarios C and D, the trip frequencies are increased due to the growing number of non-work trips compared with scenario B, and the engine start at each trip will cause additional emissions, so that there is a slight increase in emissions even when the VMTs in scenarios C and D are slightly less than that in scenario B.

Table 13. Emissions by pollutant type (gram).

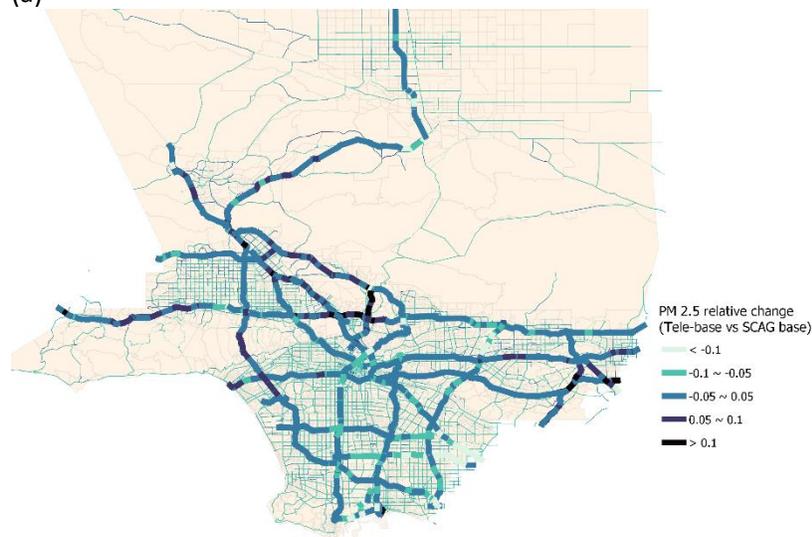
Index	Scenario	Air Pollutants		GHG
		NOx	PM2.5	CO2 equivalent
A	SCAG base	5.88×10^7	2.81×10^6	1.18×10^{11}
B	Telework only	5.80×10^7 (-1.3%)	2.77×10^6 (-1.5%)	1.16×10^{11} (-1.5%)
C	Teleservice only	5.97×10^7 (-1.6%)	2.84×10^6 (0.9%)	1.19×10^{11} (0.9%)
D	Tele-Base	5.90×10^7 (0.4%)	2.80×10^6 (-0.4%)	1.17×10^{11} (-0.4%)
E	Extended scenario 1 (Telework + Teleservice + Increased telework rate 1)	5.87×10^7 (-0.2%)	2.78×10^6 (-1.1%)	1.16×10^{11} (-1.1%)
F	Extended scenario 2 (Telework + Teleservice + Increased telework rate 2)	5.85×10^7 (-0.5%)	2.77×10^6 (-1.5%)	1.16×10^{11} (-1.5%)

Fig 7 provides the percentage emission reduction along freeways within the LA county boundary of the tele-base scenario (Scenario D) relative to the SCAG base scenario (Scenario A). The lighter color represents more reduction, while the darker color denotes an increased emission. As seen in **Fig 7**, the majority of the freeway links have induced less emission than the

baseline scenario, this is due to the VMT reduction caused by the reduced work trip frequency and the reduced non-work trip length. In some areas, however, such as the freeways north to downtown region and the area near the east border with Orange County, we can see the emissions are even more than in the baseline scenario. This is because, for these regions, the VMT increment caused by the growth of non-work trips exceeds the VMT reduction induced by the decrease in work trips.



(a)



(b)

Fig 7. Percentage change of emission under the tele-base scenario compared to the SCAG base scenario: (a) NOx; (b) PM2.5

Corridor Experiment Results

As introduced in the experiment specification, we selected four communities: SFV, Westwood, Inglewood, and Long Beach near the I-405 and converted part of the activities to teleservice to illustrate how activity pattern changes would impact the traffic and emissions on the I-405. In the Westwood scenario, all the university/school and non-mandatory activities (eat-out, personal/household maintenance, discretionary, etc.) are converted to teleservice. In the other three scenarios, all activities excluding work or university/school are converted to teleservice. For the abovementioned trips, it is important to analyze where they originate and how the elimination of these trips affects the I-405 corridor. Fig 8 shows the origins of the trips with the specific activity types that end in the four selected communities. Note that some boundary TAZs show relatively large trip origin counts, such as the east boundary near San Bernadino County. This is because trips originating from out of LA county are aggregated and counted to the boundary TAZs adjacent to those external counties. The trips end in Westwood and Inglewood have origins around the I-405 with a concentration on nearby areas, while the origins of trips to SFV and Long Beach are widely distributed across LA County.

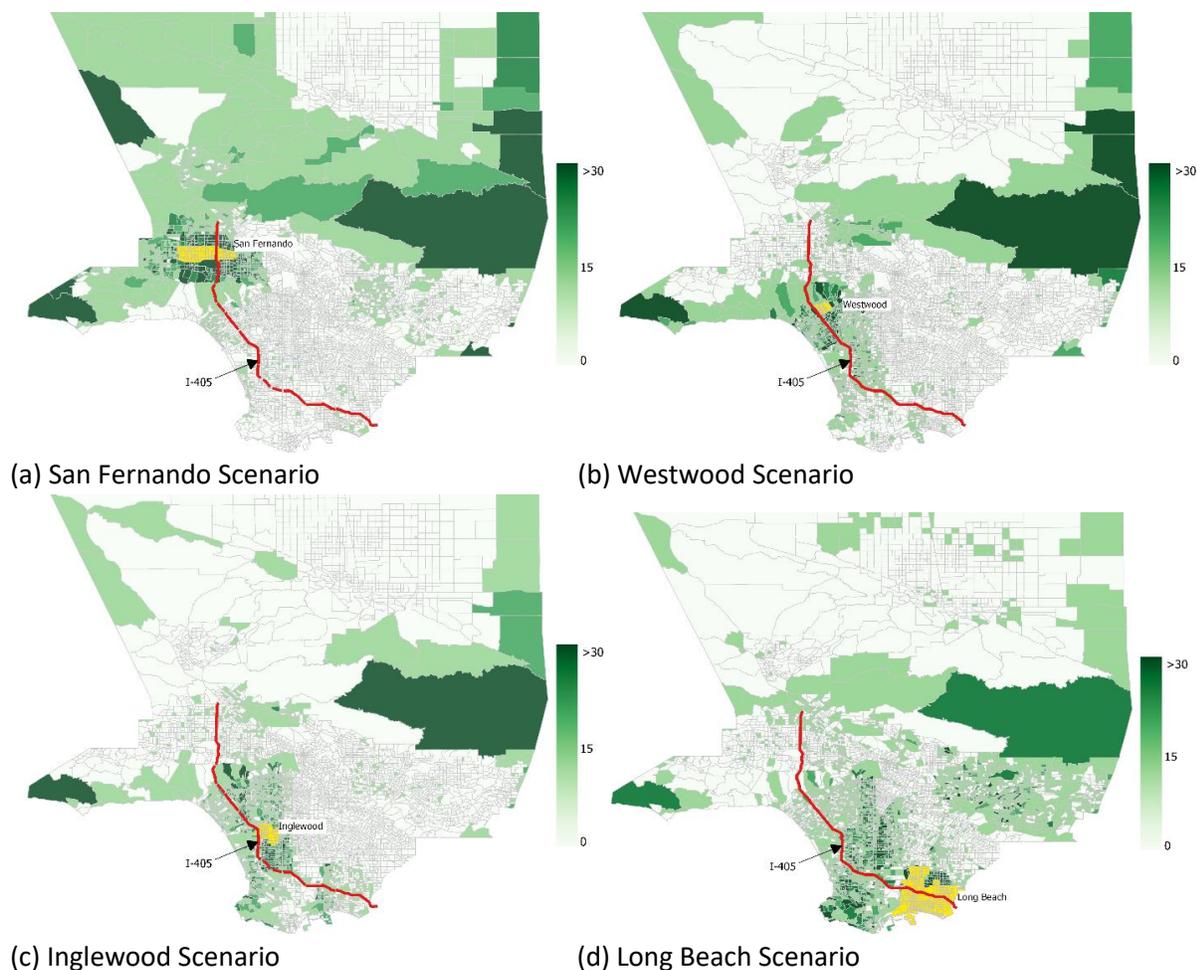


Fig 8. Spatial distribution of trip origins for non-work trips ends in selected communities

Traffic Volume Analysis

Fig 9 provides the temporal distribution of the traffic volume on I-405 across different scenarios. There are three major findings in Fig 9. First, the peak traffic volume during morning peak hours is reduced in test scenarios compared to the SCAG baseline scenario. Specifically, the volume from 6 to 7 AM decreases from 4.5 million to 4.1 million (-9%). This is due to the reduced work trips caused by the increased adoption of telework in test scenarios. Second, the reduced school and non-mandatory trips in the Westwood area result in a significant growth in traffic volume on I-405 (9AM to 10PM). This can be explained by the fact that the reduced trips to Westwood reduced the congestion on I-405, which therefore attracts more vehicles to use the I-405. On the other hand, the reduced trips in the other three communities do not cause a significant change in volume, which indicates that the size of decreased non-mandatory trips to SFV, Inglewood, and Long Beach is not large enough to alter the demand on I-405, so that the volume on I-405 is not influenced significantly even if these trips are canceled. Third, the volume in the tele-base, SFV, Inglewood, and Long Beach scenarios are significantly less than the SCAG baseline scenario after 8 PM. This is because the total traffic volume decreases during the evening/nighttime period, and even though the congestion on the I-405 is well relieved, the reduction of volume won't induce additional traffic on the I-405.

Note that the reduction of non-work trips results in different volume changes on I-405 for different scenarios respectively. One explanation for this phenomenon can be found in Fig 8. As seen in **Fig 8**, the origins of the trips traveling to Westwood are very concentrated along the I-405 corridor, which makes these trips highly reliant on this corridor. On the other hand, the origin TAZs of trips traveling to Long Beach are distributed widely across the LA county, indicating that these trips have more route alternatives instead of solely using the I-405.

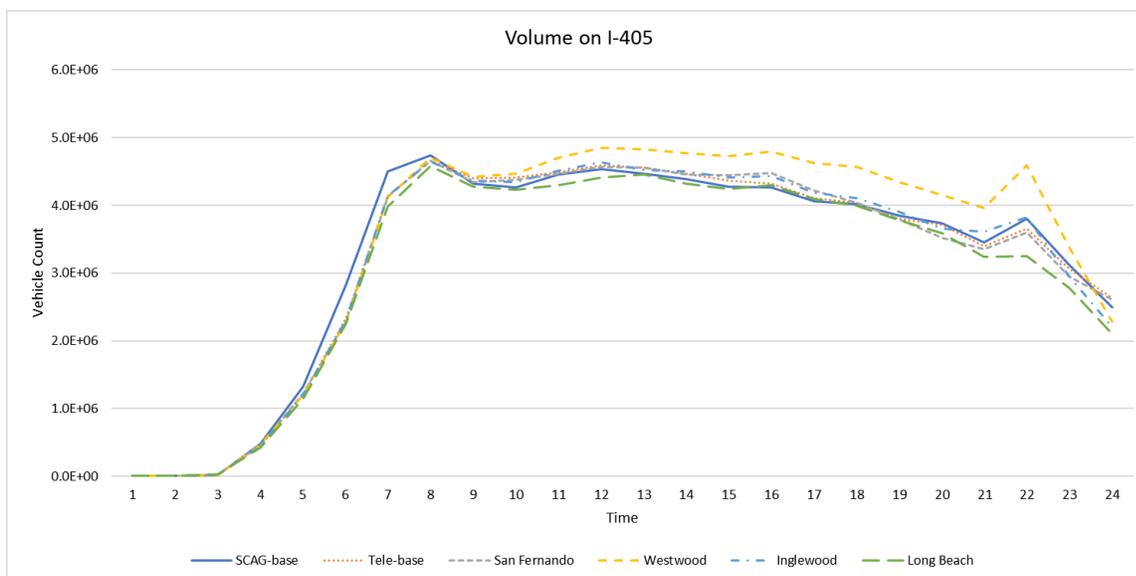


Fig 9. Temporal distribution of traffic volume on I-405

Fig 10 provides a more detailed spatial analysis by showing the traffic volume of different segments of the I-405 as defined in the experiment specification section. As seen in **Fig 10**, the growth in traffic volume due to the trip reduction in Westwood is more pronounced on Segment 2 and 3 of the I-405 than in other segments. This is because these two segments are closer to the Westwood area than the rest of the I-405. Out of the four freeway segments, segment 2 and segment 3 show the most significant deviation in volume across scenarios. This can be explained by the fact that segment 2 and segment 3 are located right in-between Westwood and Long Beach, and near some other densely populated communities such as Inglewood, Manhattan Beach, Torrance, and so on. In the meantime, these segments of the I-405 have more intersections with other freeways. Therefore, this part of the I-405 is more likely to be impacted by the activity pattern changes caused by the adoption of telework and teleservice. On the Segment 4, only the Long Beach scenario has a significant reduce in volume, which is resulted from the transfer to teleservices in local communities.

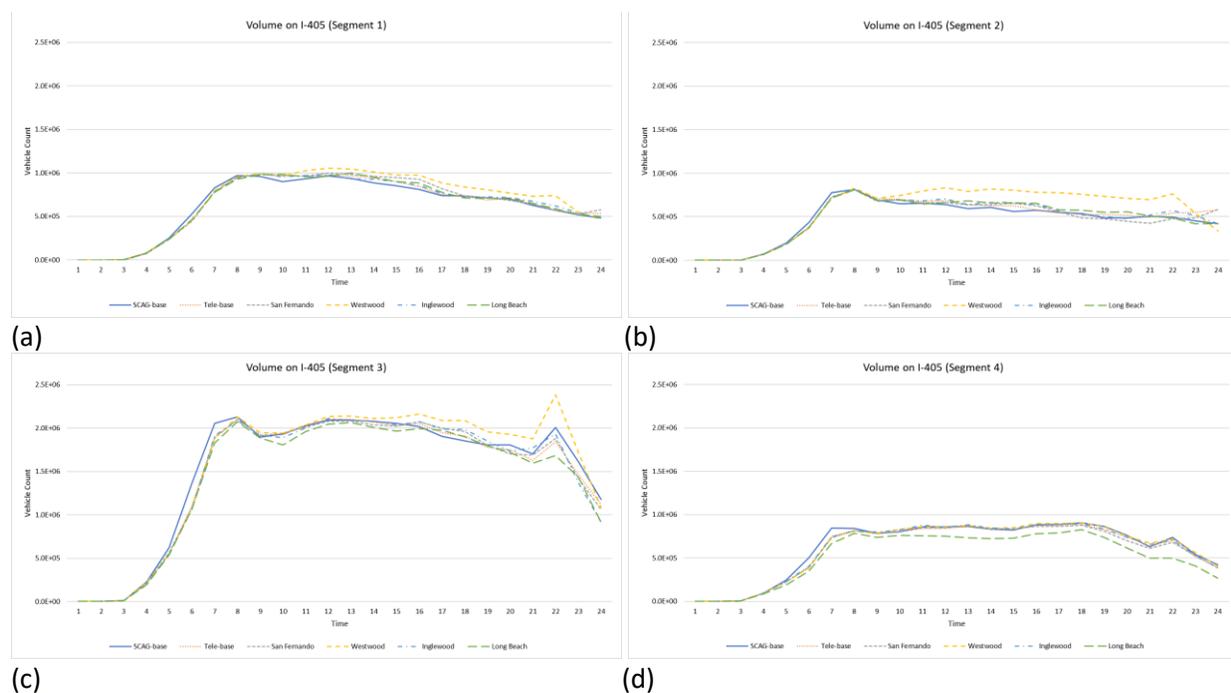


Fig 10. Temporal distribution of traffic volume on different segments of I-405

Traffic Speed Analysis

Fig 11 provides the temporal distribution of speed on I-405 across different scenarios. The speed patterns of the five test scenarios are close to the SCAG base scenario. The telework and teleservice updated scenarios all yield speed enhancement during the morning (8 to 10 AM) and afternoon (after 6 PM) peak hours. This indicates that the adoption of telework and teleservice contribute to reducing the level of congestion on the I-405. **Fig 12** illustrates the speed pattern on different freeway segments of the I-405. As seen in **Fig 12 (b)**, the Westwood scenario demonstrates the best enhancement of traffic speed compared to the SCAG baseline scenario and other test scenarios. The speed improvement on the second segment I-405 is

significantly pronounced after 5 PM. Compared to the SCAG baseline case, the speed increase of the Westwood scenario can reach as high as 60%. This can be regarded as another support for the volume increase discovered in the traffic volume analysis section.

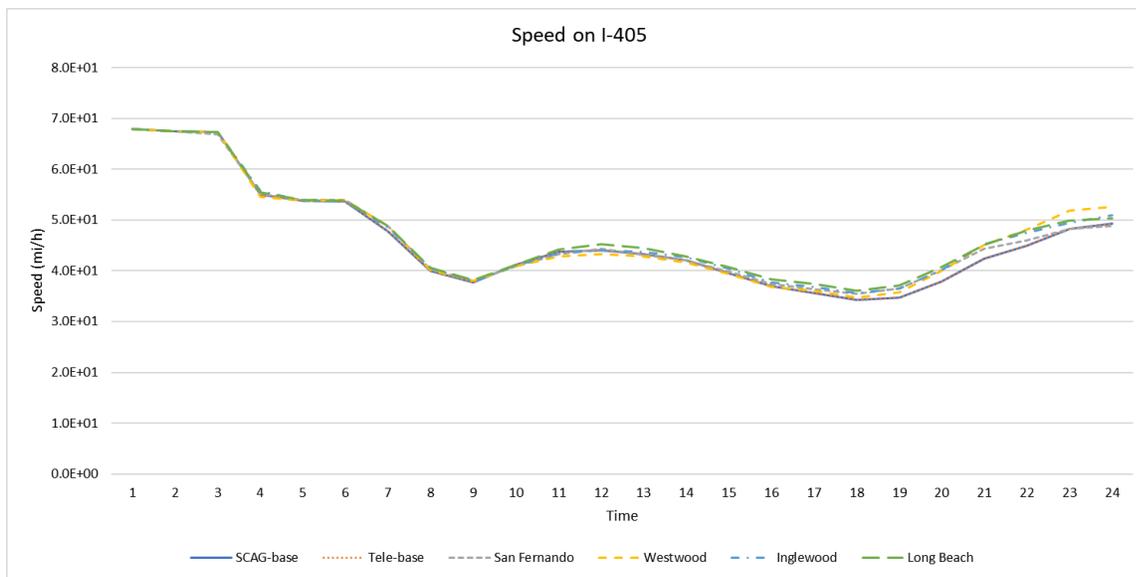


Fig 11. Temporal distribution of speed on I-405

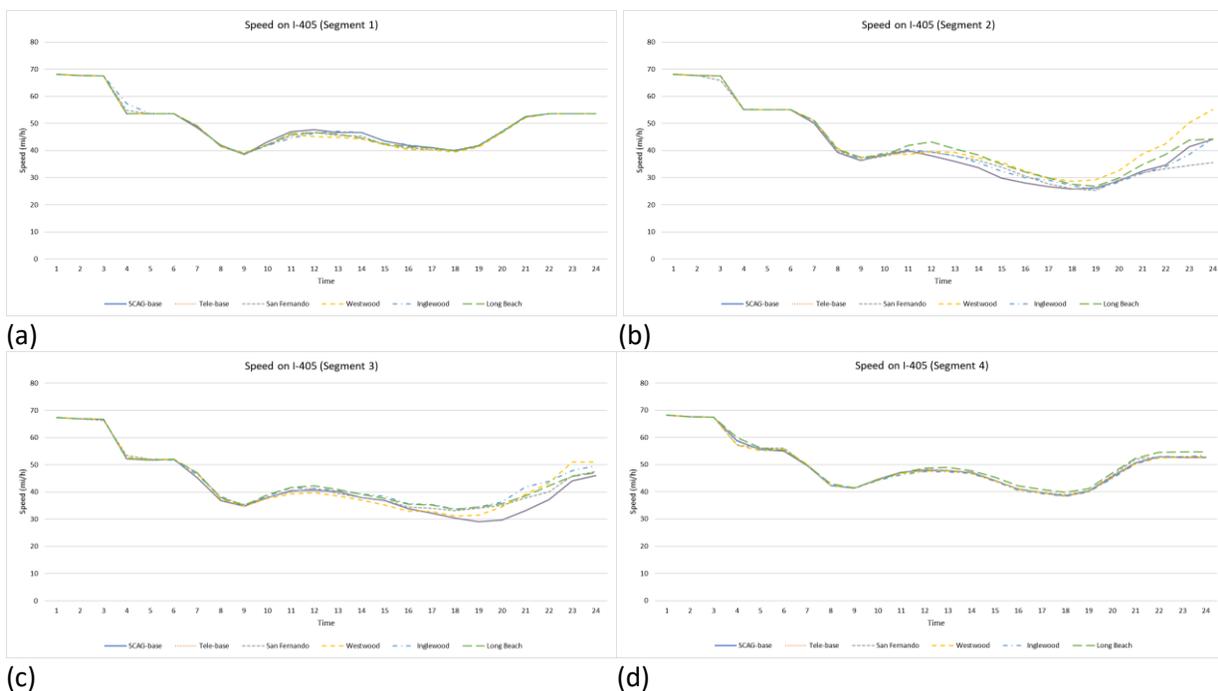


Fig 12. Temporal distribution of average speed on different segments of I-405

Emission Analysis

Besides the network-level emission analysis in the previous section, we also conducted a corridor-level emission analysis to investigate the emission impact of the test scenarios compared to the SCAG baseline scenario. **Table 14** provides a summary of the emission divided by emission type. As seen in **Table 14**, the scenario of tele-base yields around -0.1% to -0.2% emission reduction on I-405, slightly less than the emission reduction on the whole network (-0.4%). The SFV and Long Beach scenarios indicate that by reducing non-mandatory trips and performing these activities by teleservice, the emission generated on the I-405 can be reduced by 0.5% to 3%. On the other hand, the Westwood and Inglewood scenario demonstrates that reducing the school/university and non-mandatory trips near the middle segments of the I-405 corridor would add more emissions on the I-405, because this activity pattern change could induce more traffic volume and thereby more VMT on the I-405. **Table 15** provides a summary of emissions generated on different segments of I-405 under different test scenarios. **Fig 13** and **Fig 14** illustrate the emission change distribution of NOx and PM 2.5 in different test scenarios. We can find that the emission impact caused by teleservice pattern changes is more likely to occur on segments near the community where the teleservice test conducted. The general trend is that the promoting of teleservice is more likely to increase emissions near central and upper segments on I-405, while reduce emissions on the southern segments of I-405.

Table 14. Emissions generated on I-405 by pollutant type

Scenario	Air Pollutants		GHG
	NOx	PM2.5	CO2 equivalent
SCAG Base	1.76×10^6	9.53×10^4	3.99×10^9
Tele-Base	1.76×10^6 (-0.1%)	9.51×10^4 (-0.2%)	3.98×10^9 (-0.2%)
San Fernando Valley	1.76×10^6 (-0.5%)	9.48×10^4 (-0.6%)	3.96×10^9 (-0.6%)
Westwood	1.91×10^6 (8.4%)	1.03×10^5 (8.4%)	4.32×10^9 (8.4%)
Inglewood	1.77×10^6 (0.2%)	9.54×10^4 (0.1%)	3.99×10^9 (0.1%)
Long Beach	1.71×10^6 (-3.2%)	9.20×10^4 (-3.4%)	3.85×10^9 (-3.4%)

Table 15. Emissions generated on different segments of I-405

Pollutant	Scenario	I-405 Segments			
		1. San Fernando Valley	2. Westwood	3. Inglewood	4. Long Beach
NOx	SCAG Base	3.75×10 ⁵	3.74×10 ⁵	7.28×10 ⁵	3.17×10 ⁵
	Tele-Base	3.82×10 ⁵ (1.8%)	3.90×10 ⁵ (4.2%)	6.94×10 ⁵ (-2.1%)	3.08×10 ⁵ (-2.7%)
	San Fernando Valley	3.86×10 ⁵ (2.8%)	3.82×10 ⁵ (2.0%)	6.94×10 ⁵ (-2.1%)	3.05×10 ⁵ (-3.8%)
	Westwood	4.15×10 ⁵ (10.5%)	4.59×10 ⁵ (22.7%)	7.36×10 ⁵ (3.9%)	3.13×10 ⁵ (-1.0%)
	Inglewood	3.83×10 ⁵ (2.1%)	3.89×10 ⁵ (4.0%)	6.95×10 ⁵ (-1.9%)	3.11×10 ⁵ (-1.7%)
	Long Beach	3.84×10 ⁵ (2.2%)	3.88×10 ⁵ (3.5%)	6.76×10 ⁵ (-4.6%)	2.70×10 ⁵ (-14.6%)
PM 2.5	SCAG Base	2.04×10 ⁴	2.02×10 ⁴	3.83×10 ⁴	1.71×10 ⁴
	Tele-Base	2.07×10 ⁴ (1.8%)	2.10×10 ⁴ (4.1%)	3.74×10 ⁴ (-2.3%)	1.66×10 ⁴ (-2.8%)
	San Fernando Valley	2.10×10 ⁴ (3.0%)	2.05×10 ⁴ (1.9%)	3.74×10 ⁴ (-2.2%)	1.64×10 ⁴ (-4.0%)
	Westwood	2.25×10 ⁴ (10.6%)	2.48×10 ⁵ (22.8%)	3.97×10 ⁵ (3.8%)	1.69×10 ⁵ (-1.1%)
	Inglewood	2.08×10 ⁴ (2.1%)	2.09×10 ⁴ (3.8%)	3.74×10 ⁴ (-2.2%)	1.68×10 ⁴ (-1.8%)
	Long Beach	2.08×10 ⁴ (2.2%)	2.08×10 ⁴ (3.4%)	3.64×10 ⁴ (-4.8%)	1.46×10 ⁴ (-15%)
CO2	SCAG Base	8.51×10 ¹⁰	8.43×10 ⁸	1.60×10 ⁹	7.16×10 ⁸
	Tele-Base	8.66×10 ¹⁰ (1.8%)	8.78×10 ⁸ (4.1%)	1.56×10 ⁹ (-2.3%)	6.96×10 ⁸ (-2.8%)
	San Fernando Valley	8.77×10 ¹⁰ (3.0%)	8.59×10 ⁸ (1.9%)	1.57×10 ⁹ (-2.2%)	6.87×10 ⁸ (-4.0%)
	Westwood	9.41×10 ¹⁰ (10.6%)	1.04×10 ⁸ (22.8%)	1.66×10 ⁹ (3.8%)	7.08×10 ⁸ (-1.1%)
	Inglewood	8.69×10 ¹⁰ (2.1%)	8.76×10 ⁸ (3.8%)	1.57×10 ⁹ (-2.2%)	7.03×10 ⁸ (-1.8%)
	Long Beach	8.70×10 ¹⁰ (2.2%)	8.72×10 ⁸ (3.4%)	1.52×10 ⁹ (-4.8%)	6.09×10 ⁸ (-15%)

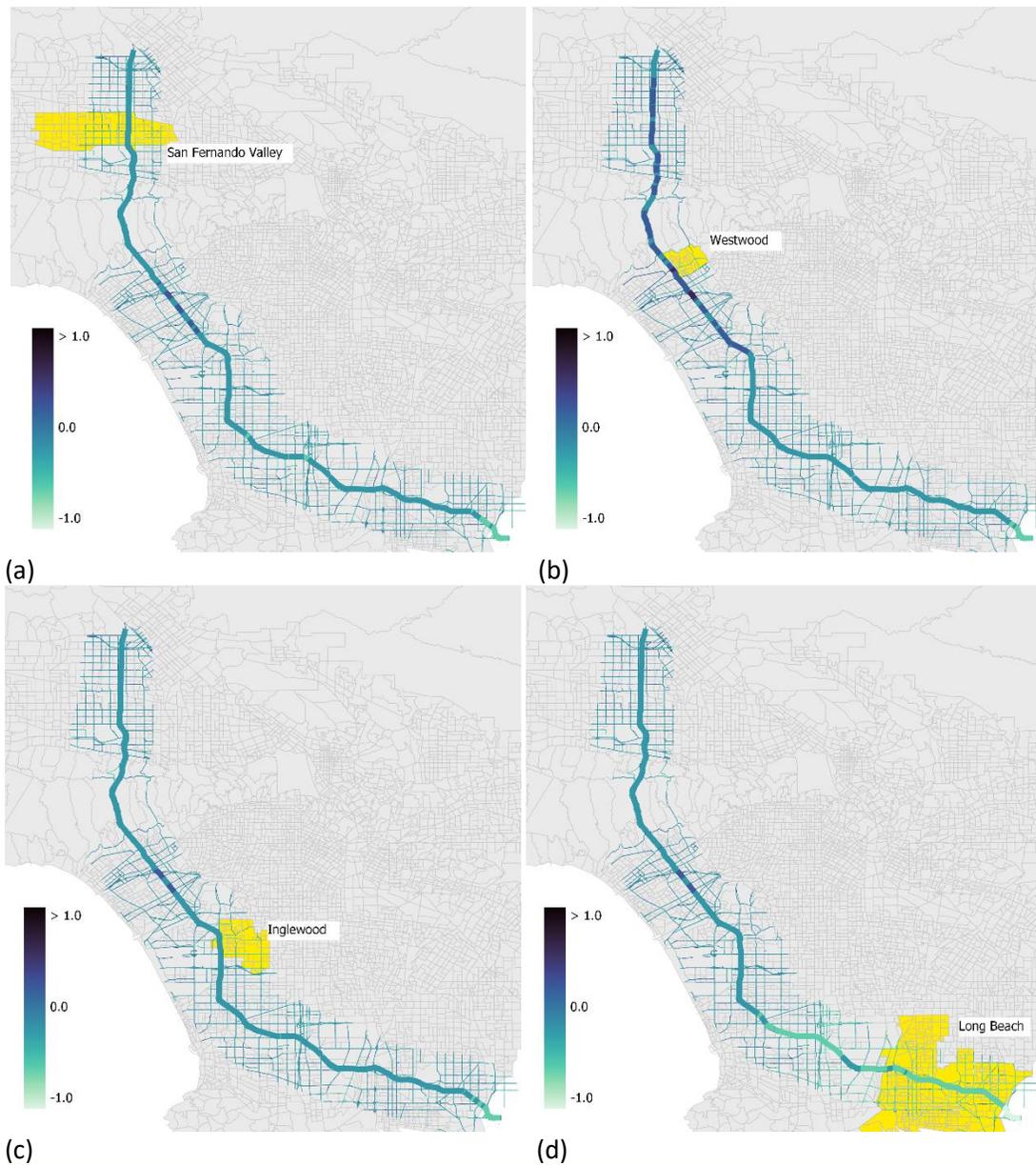


Fig 13. NOx percentage change relative to SCAG base scenario on I-405 for: (a) San Fernando Scenario; (b) Westwood Scenario; (c) Inglewood Scenario; (d) Long Beach Scenario

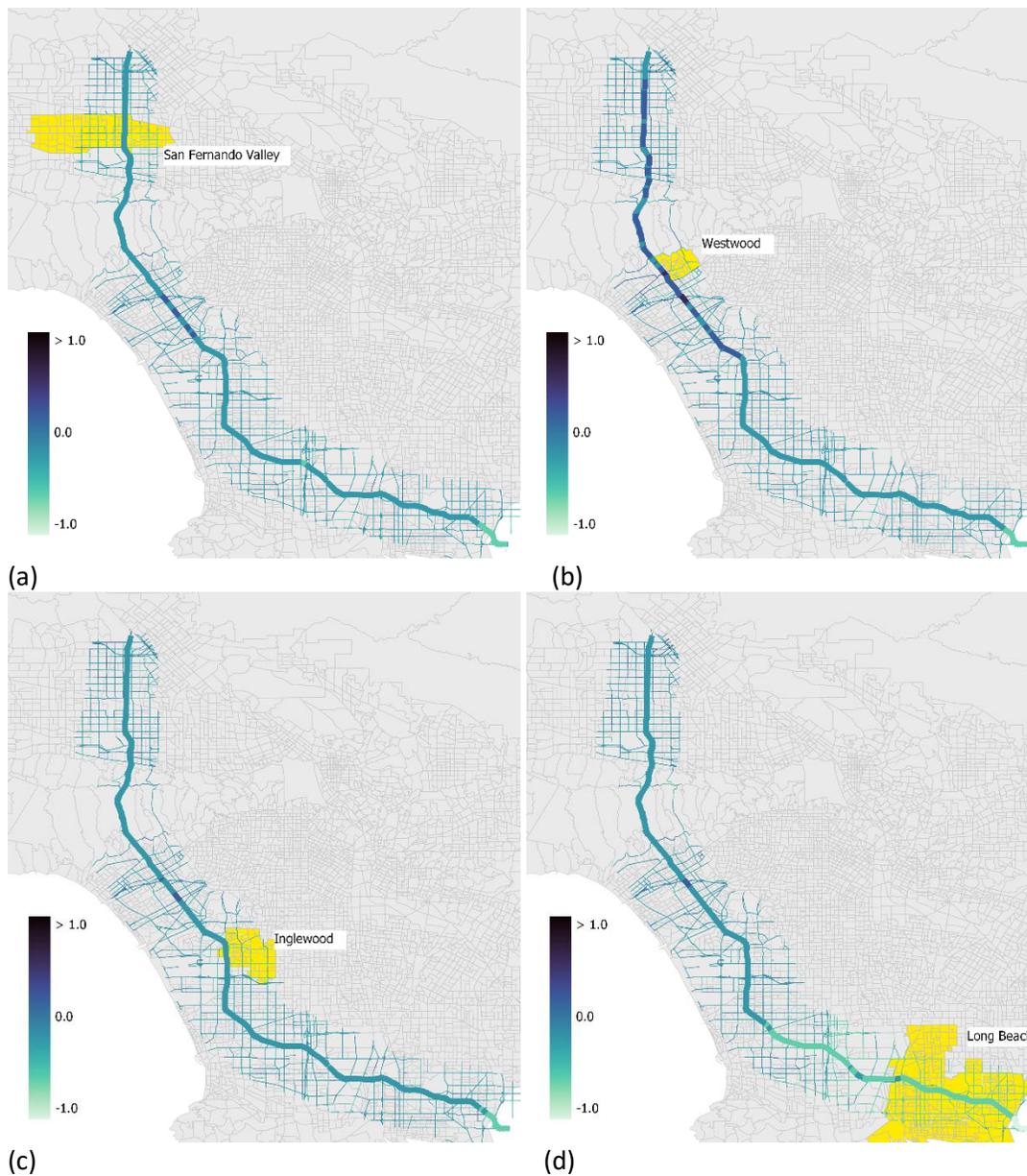


Fig 14. PM 2.5 percentage change relative to SCAG base scenario on I-405 for: (a) San Fernando Scenario; (b) Westwood Scenario; (c) Inglewood Scenario; (d) Long Beach Scenario

Conclusion

The outbreak of COVID-19 pandemic has caused significant impact in every aspect of people's everyday lives. People's activity preference and travel patterns have also been deeply affected, which could last for a relatively long period of time even after the pandemic ends. This study focuses on the impact of telework and teleservice on people's travel patterns and how these changes in travel patterns result in shift in the transportation system. This research collected people's travel preference data through an online survey, then estimated the changes in travel demand by updating the SCAG ABM with the survey data, and further conducted an agent base

mesoscopic traffic simulation to analyze how transportation system performs under the consideration of telework and teleservice. The study also designed a couple of test scenarios to demonstrate the performance of the transportation system when the telework or teleservice status changes. Selected findings from this study that can inform policymakers about the features of the post-pandemic travel and help them find solutions to enhance the transportation performance include:

- The post-pandemic activity frequency increases compared to the pre-pandemic era. While work trips in post-pandemic era decrease by 11% due to telework, non-work trips increase by 3%, resulting in a slightly change in total trips (about 1% growth).
- The adoption of telework and teleservice results in little decrease in VMT (1.5% lower than pre-pandemic era). While the non-work trips induced VMT barely changed (0.2%), the VMT drop in total trips is mainly contributed by work trips (-7.7%).
- The ground transportation generated emissions stay nearly the same by considering the adoption of telework and teleservices (NO_x -0.5%, PM_{2.5} -1.5% and CO₂ -1.5%). While the majority of the LA county shows slightly decreased emission compared to pre-pandemic era, some specific regions such as the north area to downtown LA produces more emission than before the pandemic because of induced non-work trips.
- Existing telework and teleservice adoption status would reduce the peak hour traffic by a small margin and maintain a close daily pattern in traffic volume and speed comparing to pre-pandemic era. However, further promoting teleservice in communities near the major freeway on corridor does have reasonable impacts on traffic and emissions on local areas.
 - The promotion of teleservice in communities near the central parts of I-405 (Westwood) would induce more traffic on the corridor. It is because trips to Westwood majorly originates from nearby areas of I-405 and highly depend on I-405. Eliminating those trips by teleservice would reduce pressure on I-405 and induce more traffic.
 - The promotion of teleservice in other communities (SFV, Inglewood, and Long Beach) would the same or slightly reduce the traffic volumes on the nearby segments of I-405, while wouldn't have a significant impact on the whole freeway.

This study can be extended in several ways. First, the network level analysis can further incorporate equity considerations to find out the disparity in travel across different communities. Second, the corridor level analysis can be conducted in a more detailed approach by extracting the trajectories of each vehicle and focus only on the trips that pass through a selected corridor.

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Data Management Plan

Products of Research

There are two types of data collected/generated from this research, including data collected from the online telework/teleservice survey and simulation data generated from the transportation and emission models. First, an online survey was distributed in LA County to collect people's socio-economic characteristics, attitudes and preferences to telework and teleservices, and travel behavior related choices regarding the adoption of telework and teleservices. Then, simulation data was generated from the integrated transportation and emission models under multiple scenarios designed under different purposes, including people's travel trajectories, hourly traffic volumes at the link level (road segment), average hourly travel speed at the link level, and emission estimation at the link level.

Data Format and Content

The survey data is in CSV file, including 1089 valid response. The content includes the socio-economic characteristics of respondents, choices of telework and teleservices, and travel behavior choices regarding the adoption of telework and teleservices. Details of the survey data content can be found in Appendix A.

The simulation data are in CSV and TXT formats.

The travel trajectories are saved in CSV format. Each row in the trajectory file represents a record of a trip, including person ID, trip ID, trip origin/destination, trip purpose, departure time, arrival time, and travel modes.

The traffic volume and travel speed data are in TXT format. Each row in the data represents a link in the road network of LA County, and attributes include link length (in meter), traffic volume per hour, and average travel time per hour.

The emission data are saved in CSV format. Different emission sources (e.g., PM 2.5, CO2) are saved in different files. Each row in the data represent a link in the road network of LA County, and attributes include estimated emission per hour.

Data Access and Sharing

The data is stored in both local hard drives at UCLA and online database. The general public can access the data by sending request to the UCLA team.

Reuse and Redistribution

The data of this project is restricted for research purpose only. The general public need to get the permission of UCLA team before they reuse and redistribute the data.

Appendix A: Survey Data Demographic Analysis

(1) Telework and teleservice adoption rate

Fig 15 provides an overview of the adoption rate for telework and teleservice, respectively. The results are based on the weighted responses of the two revealed preference questions, so that it can be regarded as the current telework and teleservice adoption status in LA county. Fig 15 (a) illustrates that 45% of workers are currently teleworking at least occasionally. This result is close to the estimation of teleworker rate (40%) during post-pandemic era by the California Center for Jobs & the Economy (2020). Fig 15 (b) shows that a little of more than half of the population (57%) accept teleservice in their daily lives. Although there's no exact data showing the percentage of people who accept teleservice, the results generated from this survey demonstrate similar trend with conclusions in existing literatures. A survey conducted by Shamshiripour et al. (2020) in Chicago indicates that 59 % expressed willingness to order their groceries online even far after the pandemic. Beck and Hensher (2020) reported the pandemic transferred the respondents' out-of-home activities such as social activity, dine-in, and shopping during pandemic to online activities by 80%, 76%, and 76%, respectively.

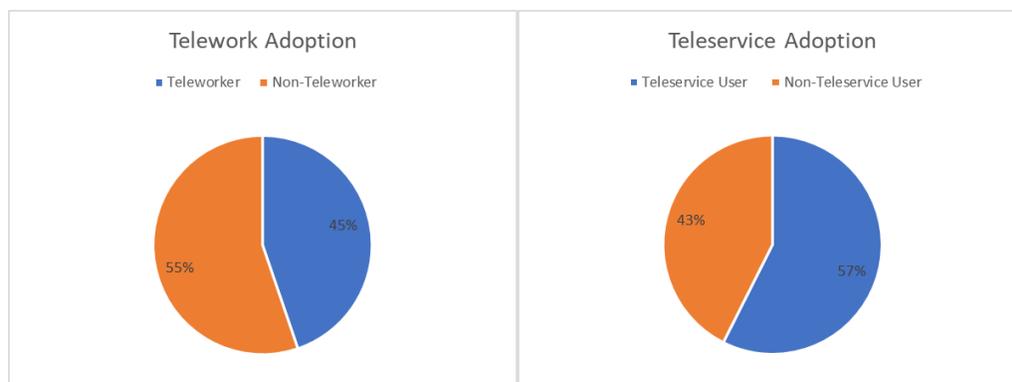


Fig 15. The adoption rate for: (a) Telework; and (b) Teleservice

(2) Demographic features of teleworkers and non-teleworkers

Fig 16 provides a summary of demographic attributes of teleworkers and non-teleworkers. Fig 16 (a) shows that the ethnicity group with the highest teleworker rate is the non-Hispanic White, where 40% of teleworkers are from the non-Hispanic White group. Meanwhile, among non-teleworkers, over 50% are from the Hispanic group, indicating that people of this ethnicity group is more likely to conduct work at workplace. Fig 16 (b) shows the distribution of education attainment among teleworkers/non-teleworkers. It can be seen that more teleworkers are from the higher education levels. People with at least associate degree and above takes up over 80% of teleworkers. Fig 16 (c) shows the industry distribution of teleworkers. As seen in Fig 16 (c), the industry with the most share of teleworkers are the information and business sectors. This can be explained by the fact that these jobs are more likely to be performed by computers through the Internet. On the other hand, the relatively

traditional industries such as agriculture, mining, and construction have much less share in teleworkers as these work mostly requires to be conducted onsite. Fig 16 (d) shows the share of teleworkers/ non-teleworkers among different income groups. It can be found that teleworkers are distributed mainly in the middle to upper income groups, while the non-teleworkers are from the lower income groups.

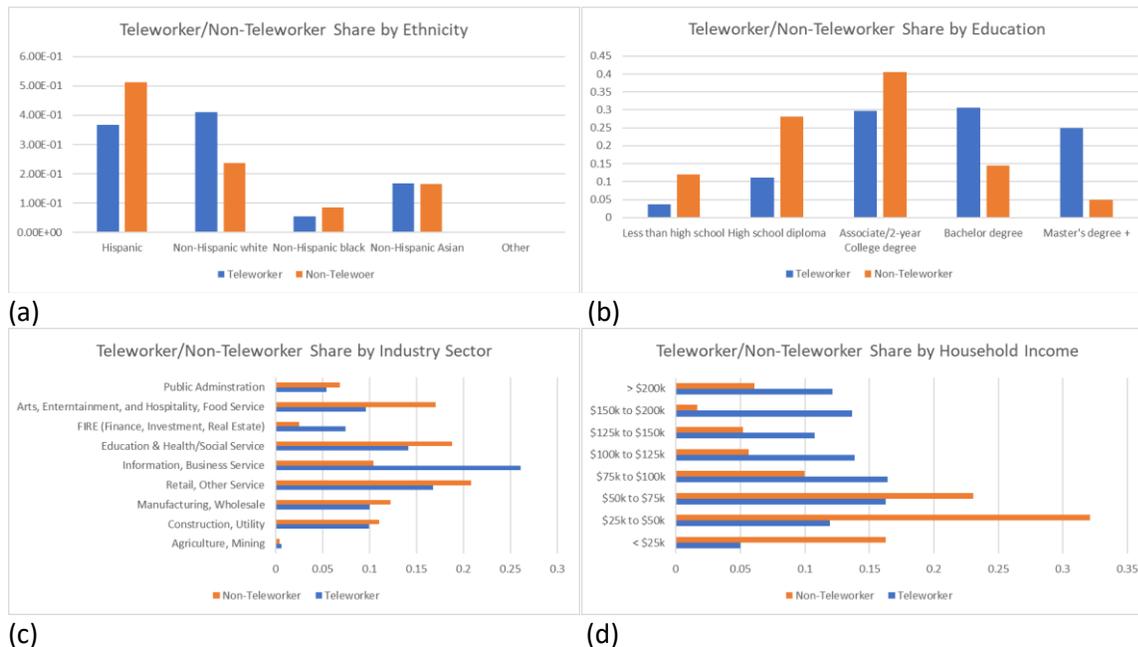


Fig 16. Teleworker/non-teleworker share by different demographic attributes: (a) Ethnicity; (b) Education; (c) Industry; and (d) Household income

(3) Demographic features of teleservice users and non-teleservice users

Fig 17 provides a summary of demographic attributes of teleservice users and non-teleservice users. Fig 17 (a) shows that the ethnicity group with the highest teleservice acceptance rate is the non-Hispanic White, where nearly 40% of teleworkers are from the non-Hispanic White group. Fig 17 (b) shows the distribution of education attainment among teleservice users and non-teleservice users. It is found that people with associate degree are more likely to adopt teleservice than people with either higher than or lower than this degree. For people who don't accept teleservice, the majority are from the less than high school group (37%). Fig 17 (c) shows the share of teleservice adoption status among different income groups. We can find that a large portion of teleservice users are from the 50k to 100k annual income group (55%), teleservice users from higher than 100k group are evenly distributed across different income categories. People who aren't teleservice users are mostly from the lower income groups, where lower than 25k population accounts for over 40% of non-teleservice users. Fig 17 (d) compared the share of teleworkers/non-teleworkers for teleservice adoption. It shows that more teleservice users are teleworkers (55%), meanwhile about three fourth of non-teleservice

users are non-teleworkers. This indicates that teleworker are more likely to accept teleservice as alternative for their daily activities.

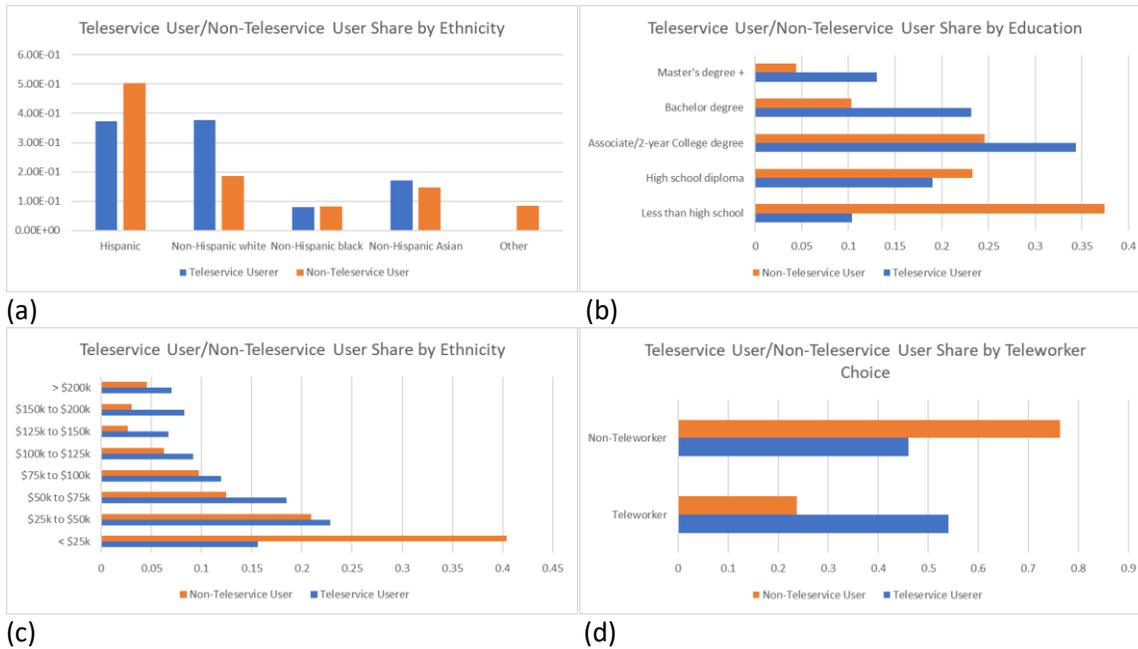


Fig 17. Teleservice user /non-teleservice user share by different demographic attributes: (a) Ethnicity; (b) Education; (c) Household income; and (d) Teleworker status

Appendix B: Activity Frequency Mapping for Teleservice Model

People’s weekly activity frequency choices are converted into daily activity frequency choices as follows. We assume that the activities predicted by the weekly activity frequency model for each person can be assigned to any day/days from Monday to Friday. The maximum number of activities can be assigned on one single day is constrained by the choice alternatives defined in SCAG ABM. For example, the maximum daily number of friends visiting activities per person is one, while the maximum daily number of personal discretionary activities is two. Let’s assume that there are n different patterns of distributing the weekly activity frequency on the weekdays, where each distribution pattern is denoted as B_i , and we have N different alternatives in the daily activity choice model, with each alternative denoted as A_j . For an individual with weekly activity choice alternative W , the probability of this choice alternative being mapped to the daily activity choice alternative A_j is given as:

$$P(A_j) = \sum_{i=1}^n P(B_i) \cdot P(A_j|B_i) \quad (10)$$

where, $P(A_j)$ is the probability that the choice is mapped to alternative A_j , $P(B_i)$ is the probability that the i th frequency distribution pattern occurs, $P(A_j|B_i)$ is the probability of the j th alternative being selected given the distribution pattern B_i .

Take the personal discretionary activity choice model as an example. The SCAG activity frequency choice alternatives are 0, 1, 2, meaning that the maximum number of activities to be distributed on a day is two. Therefore, for each weekly activity frequency choice alternative, we can enumerate all possible activity distribution ways across weekdays and calculate the corresponding probabilities of each distribution pattern for each daily frequency alternative, as illustrated in Fig 18. With the probabilities for each daily frequency alternatives under different weekly frequency alternative, we can select the portion of people to be mapped to daily choice alternatives accordingly.

Table 16. Alternative Mapping probabilities for discretionary activity

Weekly frequency alternative	Probability of being selected on the typical day (alternative = 2)	Probability of being selected on the typical day (alternative = 1)	Probability of not being selected on the typical day (alternative =0)
1	0.0	0.2	0.8
2	0.07	0.27	0.66
3*	0.13	0.33	0.54

4	0.16	0.49	0.35
5 or more	0.19	0.62	0.19

*See detailed calculation process in Fig 18 for weekly frequency = 3

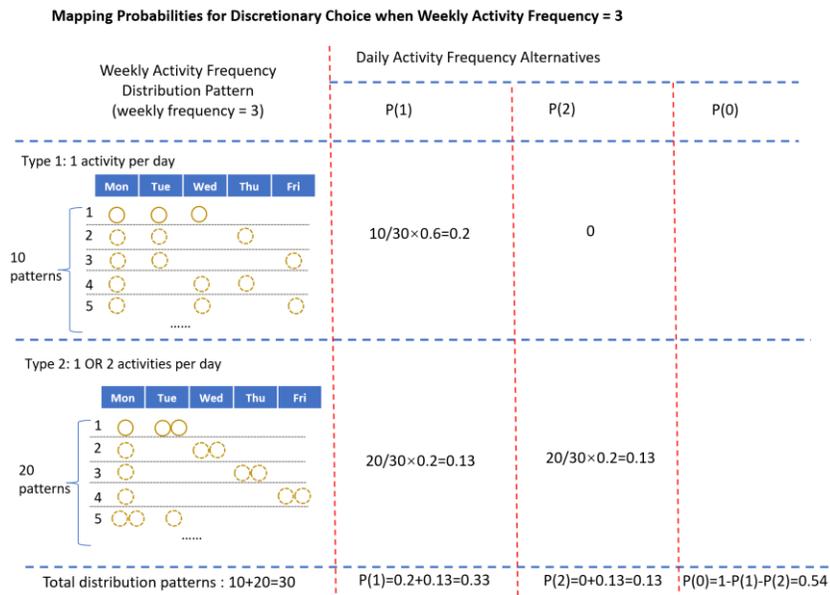


Fig 18. Illustration of mapping probability calculation for people with weekly frequency equals three for discretionary activity choice model