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Longitudinal and spatial analysis of Americans’ travel distances following COVID-19

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ABSTRACT

Travel has become less common due to COVID-19. While prior research has discussed recent travel changes for Americans in multiple ways, few have examined the adjusted travel that has been sustained since March 2021. In addition, little is known about changes in Americans’ travel patterns in trips by distance.

In this research, we asked two questions: 1) How have the numbers of trips by distance changed since 2019? and, 2) What are the geospatial patterns of the changes? Data from mid-March to mid-September 2021 indicates a 7% decrease in the number of trips and a 14.5% increase in people staying home. People traveled less except for those in the middle U.S. states, from North Dakota to Texas, as vertically aligned. Staying home more seemed to occur mainly in the South. Trips between 50 and 500 miles increased nationwide. COVID-19 has had different levels of impact on trips of different distance ranges.

1. Introduction

Since the first case of COVID-19 was reported in China in December 2019, the COVID-19 pandemic has become a major public health disaster sweeping the world. The pandemic has lingered for two years prior to the time when this paper was written. Facing the continuous challenges of the pandemic, people have changed their lifestyles and behaviors worldwide in multiple ways that have been described in many studies (Cancello et al., 2020; Mouratidis et al., 2021; Politis et al., 2021; Osorio et al., 2022; Ton et al., 2022).

As the daily travel data from the U.S. Bureau of Transportation Statistics (BTS) suggests, Americans had a considerable drop in the numbers of daily trips during 2020. They have changed to quite a steady travel trend (referred to as the adjusted travel trend) since around mid-March 2021 to the last updated data in February 2022, except for an expected travel increase during the 2021 winter holiday seasons. This adjusted travel trend was lower than before the pandemic in 2019 (BTS, 2022a). The trend suggests that less travel and staying home more often may have become a constant in American society.

Compared to the large amount of research that traced people’s travel behavior shortly after the pandemic outbreak, few studies have investigated the adjusted travel trend that has lasted for nearly one year and may still be sustained. Additionally, prior studies tended to analyze Americans’ overall travel changes across the country or by specific areas (Fatmi, 2020; Gao et al., 2020; Shamshiripour et al., 2020), yet they do not specify the changes in trips of different distances. This leaves us with a question about how far people need to travel, or from the perspective of time geography, how large the potential path areas could be to satisfy the daily needs of people.

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of people. Moreover, most existing studies use the early months of 2020 as their baseline, and this excludes seasonal differences in travel. The daily travel data from 2019 substantiates that the average number of trips during January and February was approximately 80% of the number of trips during the rest of the year (BTS, 2022a).

To fill the gaps, our research explores the changes in the number of people who stay at home and the number of trips ranging from less than one mile to over 500 miles in the U.S. over time and space since 2019. Our spatial analysis specifically focuses on the adjusted travel trend from mid-March to mid-September 2021. We used daily travel data from mobile devices during 2019–2021 and used the data from 2019 as the baseline. Noticeably, we began our data analysis for this paper in September 2021 when the adjusted travel trend had lasted for about half a year. Therefore, the data used in this paper ends on September 18, 2021.

We asked two questions in this research: 1) How have the numbers of trips by distance changed in the period from 2019 to 2021? and, 2) What are the geospatial patterns of the changes in the numbers of trips by distance and people staying home across the country, based on the adjusted travel trend?

This research contributes to the existing studies in two ways. First, it explores the changes in the number of trips across ten distance ranges (from trips less than one mile to trips over 500 miles) over time, at both the national and state levels. Second, it provides the spatial patterns of the changes people made from staying home and then taking trips of different distance ranges at the county level based on the adjusted travel trend. These changes in the patterns of travel behavior demonstrate whether or not the facilities and services are well planned, as well as the geographical inequity of services across the country. The findings of this research can be connected to studies on travel activities to better understand which types of travel are critical in human lives even under considerable societal changes. From a resilience perspective, the research sheds light on Americans’ travel behavior following the two-year, seemingly medium- to long-term impact of COVID-19. This can serve as an indication of the public’s sustained lifestyle changes when responding to the health disaster.

2. Literature review

2.1. Studies on prior epidemics and travel since 2000

Since 2000, a series of epidemics have erupted in human society before COVID-19, such as SARS-CoV (2003), H1N1 Virus (2009), and Ebola (2014). Limited by real-time data tracking technology, there are substantially fewer travel-related studies during these diseases than during COVID-19; comparably, most studies that use mobile phone data show up after 2010. The number of these studies has surged after 2015. During these early epidemics, the major purposes of investigating travel behavior have included such topics as exploring disease transmission (Ruan et al., 2006; Bajardi et al., 2011; Bogoch et al., 2015) and the diseases’ effects on the tourism industry (Dombey, 2004; Lee et al., 2012; Novelli et al., 2018). However, few studies have analyzed people’s daily behavioral changes.

The prior studies largely rely on the aggregated health or travel reports presented after the events. Their data mainly comes from 1) global and national health organizations (John et al., 2005; Wilder-Smith, 2006), 2) tourism agencies (Min et al., 2011), 3) flight organizations (Ruan et al., 2006; Goubar et al., 2009), and 4) surveys (Mukherjee et al., 2010; Neatherlin et al., 2013). Inevitably, a delay exists in the studies, and the survey data greatly relies on people’s memory. Overall, there are not many conclusions about the extent to which public travel behavior, including travel distances, have been affected by prior epidemics.

2.2. Travel changes in the early pandemic phase

In the current research, we refer to the year 2020 as the early pandemic phase. A large body of literature regarding travel behavioral changes has come to light since the start of COVID-19, and especially during the early pandemic phase. The travel-related studies during this pandemic not only focus on disease transmission but also examine lifestyle changes. Planning for individuals’ environments is also reevaluated. Researchers who investigate travel pay attention to the changes in travel activities (Fatmi, 2020; Shamshiripour et al., 2020), modes of transportation (Laverty et al., 2020; Pawar et al., 2020), and travel distances (e.g., Gao et al., 2020; Huang et al., 2020; Warren & Skillman, 2020). Moreover, benefiting from the advances in technology, researchers have applied “big data” from multiple sources. Among the COVID-19 research in the U.S. context, publicly available mobility data mainly includes: 1) places of interest (POIs) from Google (2022), SafeGraph (2022), and Foursquare (2021) companies; 2) travel distance data from the Descartes Labs (Warren and Skillman, 2021), Meta (2022), Unacast (2021) companies, and governmental agencies (e.g., BTS, 2022a); 3) travel mode requests from Apple (2022); 4) geolocation data from social media (e.g., Twitter); and 5) surveys. Notably, these datasets vary in baseline periods and aggregation units, and many of them have stopped releasing data for COVID-19 since late 2021.

Specific to travel distances, existing literature primarily examines the overall trend of Americans’ travel changes nationwide or by area. In the early pandemic phase, using the median of the maximum travel distance data, Warren and Skillman (2020) conclude that Florida and Texas residents reduced their travel distance by 70% from March 2 to March 23, 2020, while residents in California, Illinois, New York, and Washington reduced their travel distance by over 80%. Based on the same dataset, Gao et al. (2020) reveal that Americans reduced the median of the maximum travel distance by 59.6% on March 31, 2020, and 6.6% on May 1, 2020, compared to the baseline between February 17 and March 7, 2020. Through geotagged Tweets, Huang et al. (2020) find that Americans’ single-day maximum distance traveled, and cross-day distance traveled, were each reduced by around 30% and 55% at the end of March 2020, compared to the baseline from January 13 to February 29, 2020. Based on Google mobility data, Jacobsen & Jacobsen (2020) discover that Americans decreased the number of visits in six destination categories (i.e., retail and recreation, parks, grocery and pharmacy, transit stations, workplaces, and residential places) by about 30% in 25 states without a Stay at Home (SAH) order and 40% in 26 states where a SAH order had been instituted by March 29, 2020, relative to the median visitation data from January 3 to February 6,
2020. Taken together, both the number of trips and the travel distance decreased due to COVID-19. The decrease of the former is around 30–40 % shortly after the pandemic outbreak.

2.3. Travel changes in the later pandemic phase

In this research, we refer to the year 2021 and afterwards as the later pandemic phase. As could be expected, fewer studies track the quantity and spatial patterns of travel behavior during the later pandemic phase compared to studies during the early pandemic phase. To better understand the medium- to long-term impact of COVID-19 on travel, we checked the travel data of 2021 from some of the major publicly available data sources mentioned above. For example, Google’s Community Mobility Reports (2021) describe people’s visits to six destination categories (i.e., retail and recreation, grocery and pharmacy, parks, transit stations, workplaces, and residential). Yet they only provide concrete data of the visiting change rates on the most recently reported day and the associated trends to that day. Based on an observation of the visiting trends of the Google mobility data, we speculate that by early December 2021, there was an approximately 20 % decrease in visits to transit stations and workplaces, a 10 % decrease in visits to parks and retail and recreation, a marginal increase in visits to residential places, while visits to grocery stores and pharmacies almost stayed the same relative to the baseline from January to February in 2020. Additionally, based on the public’s requests for directions in Apple Maps, Apple’s Mobility Trend Reports (2022) indicate that walking, driving, and transit modes were all heavily (<-40 %) affected in the early pandemic phase compared to the baseline volume on January 13, 2020. However, walking and driving rebounded to the baseline rates and stayed above it after April 2021, while transit initially returned to the baseline in July 2021 and maintained a slight fluctuation. The last updated mobility data in late September 2021 from the Unacast company (2021) demonstrates that there remained a reduction of 25–40 % in Americans’ average distance traveled and a reduction of 55–60 % in their non-essential visits. These results indicate that the pandemic still has a sustained impact on public travel in late 2021, but the impact varies in different modes of transportation and visits to different destinations.

The literature suggests that prior epidemics has not shed much light on the public’s travel behavioral changes, while COVID-19 provides an opportunity to understand these changes. This research can complement the current literature by filling in the inadequately studied topics of 1) the adjusted travel trend that has lasted and may still be sustained, and 2) mobility changes, especially spatial analysis, of different travel distance ranges. We use the 2019 daily travel data as the baseline and this helps obtain more accurate comparison results.

3. Methodology

3.1. Study area and data

Our study area includes the entire U.S. territory except Puerto Rico, for which no data was available. We acquired daily travel data collected by mobile devices from the BTS, part of the U.S. Department of Transportation. This is the preeminent source of statistics on commercial aviation, multimodal freight activity, and transportation economics (BTS, 2019). The data was provided by the Maryland Transportation Institute and Center for Advanced Transportation Technology Laboratory at the University of Maryland. The raw data originated from an anonymized national panel of mobile device data from multiple sources, suggesting that more than one operation system is represented in the sample (BTS, 2022b).

The data’s validation report shows its mobile phone penetration rate (i.e., the percentage of mobile devices from the national effective data pool over population) is 14.6 %. The report also indicates that the penetration rate was distributed quite evenly among groups near the national median household income. Most counties fall into the range of 25 k-125 k, within which the penetration rate varies from 14.1 % to 15 %.

The dataset we use includes the number of people staying home and trips of ten distance ranges from less than one mile to over 500 miles from 2019 to 2021 on a daily, weekly, and monthly basis, at all national, state, and county levels. The dataset was updated frequently until February 5, 2022. All modes of transport are included due to the counting algorithm that captures movements as trips. It is worth noting that the data only represents the straight-line distances between points, and the trip-counting algorithm uses a ten-minute threshold to break movements into trips. For example, if a person goes for a run where both starting and ending points are the same location, and does not stop along the way, this is not counted as a trip. The straight-line counting algorithm suggests that the actual distance travelled is highly likely to be underestimated in the dataset. In addition, home locations are examined for each device every week based on where the device is located. For longer distance trips, the algorithm tries to chain all the divided trips as one long trip based on the locations of destinations and origins of those trips (BTS, 2022b). However, our dataset does not provide further information about which modes of transport are used for the trips, the purpose of the trips, or the time or durations of the trips. Therefore, some later discussion that briefly touches on those topics represents only speculation based on information from other datasets or relevant research.

3.2. Study period

Our study spanned the period from March 14, 2019 to September 18, 2021. We proposed three specific periods for a comparison goal, including: 1) Baseline Period, from March 14 to December 31, 2019; 2) considerable restriction (CR) period, from March 14 to December 31, 2020; and 3) post considerable restriction (PCR) period, from March 14 to September 18, 2021 (Fig. 1). The “restriction” here does not refer to governmental interventions but just describes the changes in the public’s travel behavior. The period division
was based on the trend of Americans’ daily mobility data released by the BTS. The trend indicates that the daily number of trips taken by Americans plunged beginning on March 14, 2020, immediately responding to the declarations of COVID-19 as a Coronavirus Global Pandemic on March 11, 2020 (WHO, 2020) and a U.S. National Emergency on March 13, 2020 (The White House, 2020). The immediate response was also demonstrated by the daily maximum travel distance data from the Descartes Labs (Warren and Skillman, 2020), showing that both the number of trips and the distance traveled dropped dramatically since March 14, 2020. The trend remained at a considerably lower level to the end of 2020 compared to that of 2019. Therefore, we defined the period from March 14, 2020 to the end of 2020 as the CR period.

Following that, the trend had an upward momentum in early 2021 and stayed quite steady from March to April 2021. We defined the steady period as the PCR period. To make our comparisons easier, we set the PCR period as beginning on March 14, 2021, the same day as the CR period started in 2020, to September 18, 2021, when the adjusted travel trend had lasted for half a year. Finally, we set the period from March 14, 2019 to the end of 2019 as the baseline, which also corresponds to the starting and ending dates of the CR period one year later.

3.3. Study design

We conducted a three-step analysis of travel including at national, state, and county levels. First, we compared the national-level changes of the number of trips per capita of ten distance ranges between the CR/PCR periods and the baseline period. Second, we compared the changes in the number of trips and people staying home among all U.S. states between CR/PCR and the baseline. Third, we presented the geospatial patterns of the changes during PCR at the county level. We borrowed the division of the ten distance ranges from the BTS (Table 1). Based on the similarities shared by some trips in the results part, we featured the trip lengths as walkable trips, short-distance trips, medium-distance trips, and long-distance trips, to provide clearer implications about different travel distances. Noticeably, trips less than one mile were also considered as one kind of short trip, yet we wanted to emphasize their walkable features. Additionally, the walkable trips we refer to do not necessarily mean that they were conducted on foot – as stated previously, information about the travel modes of the data was not available. For all the research, we conducted statistical analysis in RStudio (Version 2021.09.2 + 382) and spatial analysis in ArcGIS Pro (Version 2.8.2).

3.4. Data normalization

To normalize the data of different areas and scales, we investigated per capita travel data of all the ten distance ranges and compared their percentage changes. $N^T_j$ represents the average number of trips per capita per day during the time period $T_j$, where $T_j$ is an aggregate of individual day $i$ and $|T_j|$ denotes the length of the period (i.e., the number of days). For a comparison goal, $T_1$, $T_2$, and $T_3$ represent the baseline, CR, and PCR periods, respectively. Similarly, $S^T_{jk}$ represents the number of trips in each state, $k$, among the 50 U.S. states and D.C., and $C^T_{jl}$ represents the number of trips in each county, $l$, among the 3,143 counties or equivalents (U.S. Census, 2020) (Formula 1–3). Notably, some county data are missing because no data were reported for a county if it had fewer than 50 mobile devices in the sample on any given day (BTS, 2022b). Next, we defined that $V^T_j$ represents the variation, or percentage changes, of the travel data during $T_j$ compared to that of $T_1$. Formula 4 shows an example of computing the percentage changes of the national average trip numbers during $T_j$. A negative result indicates that the number of trips decreased compared to the 2019 baseline, and vice versa. This computation also applies to state- and county-level data.

$$N^T_j = \sum_{i \in T_j} N_i / |T_j|, \quad j \in \{1, 2, 3\}$$  \hspace{1cm} (1)

$$S^T_{jk} = \sum_{i \in T_j} S_{ik} / |T_j|, \quad j \in \{1, 2, 3\}, \quad k \in \{0, 1, \ldots, 51\}$$  \hspace{1cm} (2)

Fig. 1. Daily travel data of Americans from 2019 to 2021 (Adapted from the BTS, 2022a).
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4. Results

4.1. Travel distance changes at the national level

Table 2 summarizes the percentage changes of people staying home and the number of trips at the national level. Fig. 2 shows the comparisons between the 2020 CR period and the 2019 baseline (x-axis), as well as the comparisons between the 2021 PCR period and the 2019 baseline (y-axis). The size of the dots represents the individual shares of numbers out of all individual trips. The red triangle represents the average changes of all trips in the U.S.

To better understand the changes, we take the national average and the origin as points of reference for discussion. From the x-axis, if a decrease in trips is lower than the national average during CR, we recognize it as a considerable decrease; if the number of trips is above the average during CR but still below the origin, we recognize it as a moderate decrease; if the number of trips is above the origin, then it is an increase. In terms of the y-axis, if the changes in trips fall below the origin, the trips remain lower than the travel trend of 2019; if the changes fall above the origin, the trips rebound. For example, trips from 250 to 500 miles show an increase in both periods while trips over 500 miles show considerable declines in both periods.

Overall, we find an average of approximately a 30 % decrease in the number of trips during CR in 2020 and a 7 % decrease during PCR in 2021. Meanwhile, there is still an over 30 % increase in people staying home during CR and a 14.5 % increase during PCR. Specifically, walkable trips less than one mile moderately decrease (-28.0 %) in 2020 but have rebounded (+8.5 %) since the start of 2021. By comparison, other short trips between 1 and 25 miles decrease considerably (-30.0 %) due to COVID-19 and stay lower (-10 %) in 2021. A noticeable finding is that medium-distance trips between 50 and 500 miles start increasing from mid-April 2020, only after a one-month hiatus in public travel.

After a seemingly natural decrease in winter, those medium-distance trips rebound and remain above the 2019 baseline (+11.3 % for trips between 50 and 100 miles, +35.9 % for trips between 100 and 250 miles, and +9.1 % for trips between 250 and 500 miles) since March 2021, and the 35.9 % increase for trips between 250 and 500 miles is especially high during PCR compared to the baseline period. Not surprisingly, long-distance trips over 500 miles experience a catastrophic fall in the number of trips and remain at less than half during both CR (-55.5 %) and PCR (-51.4 %) relative to the number during 2019.

Additionally, we find that the number of short trips, less than 25 miles, dominate in quantity by taking up over 90 % of all trips. In particular, the number of walkable trips less than one mile and short trips between one and three miles each comprise 25 % of all trips. Therefore, the changes in overall trips are mainly attributed to the short trips, less than 25 miles. Though medium-distance trips show a considerable increase, they do not greatly affect the national average because they comprise less than 3 % of the total trips. Despite travel changes due to COVID-19, the shares of the distances do not vary a lot among the years. Minor changes include walkable trips that are less than one mile, which increase from less than 25 % during the baseline period to above 25 % during PCR, and long-distance trips, which decrease from above 0.1 % in 2019 to lower than 0.1 % in 2021.

4.2. Travel changes at the state level

Similarly, we construct a set of coordinates that show travel changes by distance among the U.S. states. Fig. 3 shows the comparison of the overall trip changes per capita among the states. We identify outliers as those states that have a Studentized Residual above 2 or below –2. We also highlight the eight U.S. states without statewide SAH orders after the COVID-19 outbreak. The New York Times (Mervosh et al., 2020) reports that only three states had the order in parts of the state, including Wyoming (WY), Utah (UT), and Oklahoma (OK), while five states never had an order, including North Dakota (ND), South Dakota (SD), Iowa (IA), Arkansas (AR), and Nebraska (NE).

We obtain three major results from Fig. 3 and the figures of different distance ranges. First, people in the eight states without the SAH order show voluntary travel restrictions. There are no distinguishing features that make those states stand out among all the U.S. states in terms of travel behavior among residents. Though we do not provide all sets of figures regarding different trips, we confirm
Table 2
Percentage changes of the number of trips per capita by distance (Unit: mile, = 1.6 km).

| Period               | At home | All trips | <1  | 1-3 | 3-5 | 5-10 | 10-25 | 25-50 | 50-100 | 100-250 | 250-500 | >500 |
|----------------------|---------|-----------|-----|-----|-----|------|------|------|-------|--------|---------|------|
| 3/14/2019–12/31/2019 | Baseline|           |     |     |     |      |      |      |       |        |         |      |
| 3/14/2020–12/31/2020 | +34.2%  | -31.9%    | -28.0% | -32.8% | -34.2% | -36.0% | -37.2% | -26%  | +3.6%  | +28.1%  | +14.0%  | -55.5% |
| 3/14/2021–9/18/2021 | +14.5%  | -7.0%     | +8.5% | -12.1% | -10.1% | -11%  | -16.4% | -11.7%| +11.3% | +35.9%  | +9.1%   | -51.4% |
that those states are not exceptional during either the CR or PCR period, or in any travel distance range. Second, California (CA) acts as an outlier that decreases the national average of trips. Specifically, it is a remote outlier for all the short trips less than 25 miles. CA also has the highest increase of people staying home during CR and PCR. Third, travel changes during CR and PCR are highly correlated \( r = 0.86 \), indicating a quite consistent travel behavior in individual states over time. That being said, people in the states with greater trip decreases during CR are more likely to continue to travel less during PCR, and vice versa.

4.3. Geospatial patterns of travel distance changes at the county level

Further, we present spatial patterns of the travel changes during PCR relative to the baseline data (Fig. 4). We divide the percentage changes across the U.S. into five classifications based on the Jenks Natural Breaks algorithm in ArcGIS Pro (Version 2.8.2). This algorithm groups similar values together and maximizes the differences between classes. The features of the groups are divided into classes whose boundaries are set where there are relatively big differences in the data values (ESRI, n.d.). Then, we adjust the ranges of the two classes that were close to zero to distinguish positive and negative changes more clearly; the other three classes keep the same ranges as divided by the algorithm. Next, we label positive changes in warm colors (either red or yellow), and negative changes in blue. Our descriptions of U.S. regions (i.e., Northeast, Southeast, Midwest, Southwest, and West) are based on the classification of regions by the National Geographic Society (2009). Notably, due to the travel changes that vary considerably among different travel distance groups, we do not set the ranges the same throughout Fig. 4A-H. The classifications of the ranges and their associated color codes have different meanings in individual figures.

The results show that the 14.5 % increase in people staying home during PCR mainly exist on the West Coast, the east half of Texas, and the Southeast (Fig. 4A). It is interesting that Texas (TX) shows a mixed pattern, where people in the east half of the state stay home for an increased time while those in the west half do not. Though we do not present the figures of mobility changes during CR, we recognize that the pattern of staying home increase nationwide during 2020, and this situation has largely recovered during PCR. The overall 7 % decrease in trips during PCR indicates that people still travel less across the county, except for those in the states that are vertically aligned in the middle U.S. regions. These states are colored red in Fig. 4B. The states are primarily located next to the Rocky Mountain regions and include North Dakota (ND), South Dakota (SD), Nebraska (NE), Kansas (KS), Oklahoma (OK), and Texas (TX). Since, as mentioned previously, the National Geographic Society does not define the regions specifically, we name them the middle regions in this research.

Specifically, walkable trips less than one mile increase in the middle regions, the Midwest, and the Northeast (Fig. 4C). Other short
trips between 1 and 25 miles share a pattern like the overall pattern of trip changes, which shows that people in the middle regions increase these short trips. This reaffirms that the national travel trend is primarily attributed to short trips less than 25 miles. As two examples, Fig. 4D presents the pattern of the changes in the number of short trips between 3 and 5 miles, and Fig. 4E exhibits the changes for trips between 10 and 25 miles, both of which show the increase of number of trips in the middle regions. Fig. 4F shows the pattern of the most increased medium-distance trips between 100 and 250 miles. The results suggest that medium-distance trips increase almost across the country, except for some areas in the middle regions and the West. Fig. 4G shows that the increase of medium-distance trips between 250 and 500 miles mostly remains in the South. Not surprisingly, long-distance trips over 500 miles decrease almost all over the country (Fig. 4H). By observing the figures, we find that trips of different distance ranges may compensate each other to satisfy people’s needs for travel. For example, people in the South show increases in both staying home and the numbers of medium-distance trips between 100 and 500 miles. Likewise, people in the middle regions enjoy increases in short-distance trips between 10 and 25 miles, yet they have fewer of medium-distance trips between 100 and 250 miles.

5. Discussion

At the beginning of this study, we ask two research questions regarding the changes in Americans’ travel behavior and their spatial patterns. The first question is, “How have the numbers of trips of ten distance ranges changed along the period from 2019 to 2021?” To summarize, COVID-19 has led to an average of over a 30 % decrease in the number of trips per capita across all distance ranges during the CR period. Then, the effects of COVID-19 have been sustained as a 7 % average decrease in the number of trips during the PCR period. Among all the trips, only trips less than one mile and trips between 50 and 500 miles increase during PCR compared to the baseline. Considering that the numbers of trips less than one mile include a quarter of all trips, and trips between 50 and 500 miles total less than 3 %, the increased trips during PCR are mainly comprised of walkable trips. In fact, even though our data shows an increase in walkable trips, the actual number is probably higher because the data’s counting algorithm does not include trips that start and end at the same locations without an over ten-minute stop in between, such as walking nearby home. We speculate that the increased walkable trips are likely due to recreational walking (and biking). In support of this theory, Apple’s mobility reports (2021) suggest that walking is the most increased mode since early 2021 compared to driving and transit. Further, Hunter et al. (2021) show that Americans’ recreational walking has recovered and even has surpassed pre-pandemic levels as early as June 2020, though Americans’ utilitarian walking has dramatically declined during the period from February to June 2020. Through surveys and secondary mobility data, respectively, Matson et al. (2021) and Bliss et al. (2020) show evidence that COVID-19 causes more frequent trips by walking and

Fig. 3. Percentage changes in the number of trips among U.S. states.
biking for leisure purposes. However, as we state earlier, we do not know the travel mode for our data. Recreational walking (and biking) are simply possible explanations for the increase in the number of walkable trips less than one mile, as our results reveal.

Regarding the increased medium-distance trips between 50 and 500 miles, they have strongly rebounded since mid-April 2020, and

Fig. 4. Changes in travel behavior between PCR and baseline periods in eight categories: A) percentage of people staying home; B) number of trips per capita; C) number of trips less than one mile per capita; D) number of trips between three to five miles per capita; E) number of trips between 10 and 25 miles per capita; F) number of trips between 100 and 250 miles per capita; G) number of trips between 250 and 500 miles per capita; H) number of trips over 500 miles per capita.
have remained quite high during PCR. This shows that COVID-19 only suppresses the public’s medium-distance travel immediately after the pandemic outbreak but prompts these types of trips afterwards. The increased medium-distance trips are also likely to be recreational trips. To illustrate, the 2001 National Household Travel Survey (NHTS) shows that over half (56 %) of the trips of 50 miles or more are made primarily for pleasure purposes, while business trips come in second (15.9 %), and commute trips come in third (12.7 %) (BTS, 2017a). As the latter two have dropped considerably due to COVID-19 (Levere, 2022; Currie et al., 2021), recreational trips should be the key contributor to the increase of medium-distance trips.

Statistics on rising tourism since 2020 support our assumption about the increase of medium-distance recreational trips. For example, some national parks have seen record numbers of visitors during 2021, including Yellowstone and Grand Teton National Parks (Warthin, 2022; Adams, 2022). As early as late July and early August 2020, the number of visitors to Yellowstone surpassed that of August 2019 (Warthin, 2020). Additionally, Airbnb’s 2021 revenue has exceeded the 2019 level from the first quarter, and revenue from the third quarter in 2021 achieved the highest quarter profits ever (Airbnb, 2021). Possible reasons for the surge in tourism include increased flexibility due to working from home, increased unemployment, pandemic aid (e.g., unemployment insurance, stimulus checks), and the public’s compensatory consumption (Miao et al., 2021). The increase of medium-distance trips and the return of national park visits also imply that Americans may actively avoid crowded gathering in cities and do not mind taking longer trips to areas of lower population density. In other literature about post-pandemic travel, this behavior is also identified as “voluntary de-crowding” (Miao et al., 2021). Taken together, the increase in Americans’ walkable trips and medium-distance trips are probably for leisure.

By comparison, trips between 1 and 50 miles and long-distance trips over 500 miles stay lower during PCR than before the pandemic. One thing to notice here is that trips between 10 and 25 miles decrease by 16.4 %, which is the second largest decrease during PCR among all trips. This is lower only than the decrease of long-distance trips over 500 miles. One important reason for this could be the transition from working in an office to working from home since the start of COVID-19. The Pew Research Center (Parker et al., 2022) indicates that in January 2022, about one quarter of all US workers are working from home all or most of the time. Meanwhile, the 2019 American Community Survey (ACS) data suggests that Americans’ average one-way commute time is 27.6 min and commute distance is 18.8 miles (U.S. Census, 2021). Therefore, many decreased commute trips are likely to fall into the 10–25 miles category. The decreases in this category may represent a long-term consistency because 60 % of workers with jobs that can be done from home claim that they would like to work from home or most of the time (Parker et al., 2022). What is noteworthy is that people who can continue to work from home are more likely to be in jobs that pay higher salaries while certain other jobs could only be done remotely temporarily.

Finally, long-distance trips over 500 miles, which are most impacted by COVID-19, remain at less than half of their pre-pandemic volume during PCR. The 2001 NHTS data shows that personal vehicles and air travel are the top two modes selected by long-distance travelers (BTS, 2017b). The longer the trips, the more likely travelers are to choose flying. For trips between 500 and 999 miles, over 80 % of travelers still select personal vehicles, while for trips over 2000 miles, nearly 80 % of the travelers choose flights. Based on the airline data, until the end of 2021, the number of monthly airline passengers (domestic and international) is slowly returning from the lowest point in April 2020 and has approached 86.5 % of the passenger numbers in December 2019 (BTS, 2022c). During the PCR period from March to September 2021, the data increases all the way from March to August, and a fluctuation follows in September. The average passenger number during PCR is roughly 50 % of the 2019 baseline (BTS, 2022c), echoing our results that the number of trips over 500 miles during PCR remains at half the pre-pandemic volume. Since we do not find specific data for long-distance driving, we assume that driving over 500 miles also averages a 50 % decrease during PCR. Additionally, though the latest airline data in December 2021 appears to close the difference from the pre-pandemic normal, emerging variants may keep causing delays in the recovery of the airline industry. Prior research shows that airline consumers in both the U.S. and Europe (e.g., Dutch) plan to travel less by airline even after the pandemic because they do not feel safe or comfortable sharing space with others (de Haas et al., 2020; Shamshiripour et al., 2020). As a result, even though it has been over two years since the initial COVID-19 outbreak, it is still unclear when airline travel will return to the pre-pandemic level.

There are two major findings to the second question, “What are the geospatial patterns of the changes in the numbers of trips by distance and people staying home across the country, based on the adjusted travel trend?” First, the overall change in trip pattern suggests that people in the middle regions increase the number of trips while other regions do not (as in Fig. 4B). According to the urban–rural classification for U.S. counties by the National Center for Health Statistics (Center for Disease Control and Prevention [CDC], 2013), the middle regions are mostly noncore counties, which are defined as having a small population. Most areas of this region are not even included in U.S. micropolitan or metropolitan statistical areas. Therefore, the public’s travel is less suppressed in the middle regions overall, likely due to their lower population density and high rates of travel by automobile, which lead to lower perceived threats of infection and less fear of travel.

Second, the increase of people staying home during PCR exists mainly in the South (as in Fig. 4A). Residents in the South show a mixed picture on walking for shorter distances (Fig. 4C) and an increase in the number of medium-distance trips between 100 and 500 miles (as in Fig. 4F and Fig. 4G). This seems to be a little contradictory to our first finding as explained above, because the South is generally recognized as less dense than the North. One explanation could be that our study period for the spatial analysis is from mid-March to mid-September, which spans the summer season. The South is hot, and residents may prefer to stay in the air-conditioned comfort of their homes, or to travel to cooler places that are between 100 and 500 miles from home. People in the South may have stayed home longer because they had an increase in the number of cases beginning in the summer during each year. A second possible explanation could be that cities in the South are generally more sprawling and less urbanized, and may not have sidewalks and other infrastructure to support short distance travel. It has been long established that compact cities, which feature high density, mixed land use, and well-connected street pattern, encourage the public’s walking behavior (Burton, 2000; Bibri et al., 2020). Historically,
residents in the South show higher rates of physical inactivity and obesity compared to residents in other U.S. regions, based on data from the Behavioral Risk Factor Surveillance System (BRFSS) survey (CDC, 2022a; CDC, 2022b). Our results also suggest that walkable trips less than one mile (as in Fig. 4C) and trips between one to three miles increase in the Midwest and Northeast, which feature higher density, a greater mix of land use, and cooler temperature during summer when compared to the South.

Moreover, as for the increase of walkable trips in the Midwest and Northeast, income can also be a contributor. The map of the median household income for Americans shows that higher incomes are more concentrated in the Midwest and Northeast, and some areas of the West Coast (U.S. Census, 2018). Prior research shows that Americans in high-income areas substituted utilitarian walking activities for more leisurely walking in 2020 after the start of the pandemic, sometimes reaching higher levels of walking than before the pandemic (Hunter et al., 2021). This result may be attributed to the idea that high-income individuals have more opportunities for social distancing, such as working from home, and they also may have more free time and opportunities to engage in leisure walking (Hunter et al., 2021).

This research demonstrates that people in diverse geographic regions responded to COVID-19 by changing their travel patterns and the distance of their travel as they adjusted their daily activities. Collectively, the revealed patterns of public’s travel changes provide practical implications for urban planning. First, while people in the Midwest and Northeast increase short trips less than three miles, people in the South stay home longer. The results highlight the importance of providing infrastructure for walking and other supportive environments for physical activity, including walkable streets and open public spaces around neighborhoods. Specifically, as we mentioned earlier, this suggestion is consistent with CDC’s environmental suggestions based on their studies on Americans’ physical inactivity and obesity.

Additionally, the trips between 10 and 25 miles may show a consistently lower volume relative to its pre-pandemic normal due to the long-term trend of working from home, which has its own distinct regional patterns. COVID-19 may have accelerated the rate of movement from downtown office locations to remote work for certain types of jobs and it may have permanently changed the nature of downtown employment in many cities (Badger & Bui, 2021; Parker et al., 2022). The increase in telework leads to changes in people’s commute travel and the uncertainty of the recovery of downtown workplaces. Future researchers and practitioners will need to pay attention to these changes when developing regional transportation models, transit development plans, and other aspects of transportation planning that placed the trip to work in downtown office locations as the predictable trip in space and time. Researchers will also need to remember that remote work will be more available to certain groups of workers in certain employment sectors.

Furthermore, due to the increased medium-distance trips, especially the trips between 100 and 250 miles across the country, planners may need to consider the networks of transport options on the scale of half-day driving distance from cities, to better correspond to the public’s intercity travel. Tourism researchers will also need to reevaluate if the facilities and services of the destinations within a half-day driving radius of cities meet travelers’ increased demands.

6. Conclusion

This research unveils the percentage changes of Americans staying home and the numbers of trips of ten travel distance ranges during 2020 and 2021 after the pandemic outbreak, as well as the spatial pattern of those changes during the sustained adjusted travel trend from March to September 2021. The travel change results were compared with Americans’ daily travel data in 2019 as the baseline. Overall, COVID-19 resulted in an approximately 30 % decrease in the number of trips after March 2020 and a 7 % decrease from March to September 2021. The sustained travel pattern shows that Americans still travel less overall, mostly due to the decrease in short trips less than 25 miles, except for those in the states that aligned vertically in the middle U.S. from North Dakota, South Dakota, to Texas.

There was a 30.3 % increase in people staying home nationwide after March 2020, and a sustained 14.5 % increase from mid-March to mid-September 2021, mainly in the South. Specific to the adjusted travel trend, walkable trips less than one mile rebounded to a little above the baseline (+8.5 %). Meanwhile, the demand for medium-distance trips between 50 and 500 miles greatly increased (e. g., +35.9 % for trips between 100 and 250 miles) across the country, probably for leisure. By comparison, other short trips between 1 and 25 miles, likely commute trips, and long-distance trips over 500 miles, which would have required air travel, stayed lower than before the pandemic.

Major concerns of this research include the underestimation of travel distances, and the representativeness of the dataset. The captured travel distances of our dataset only represent straight-line distances between points, while the actual distances traveled are probably longer. As for data representativeness, first, the raw data is limited to those who have mobile devices and to areas with relatively larger number of users. Sample sizes less than 50 on one day are not reported for small counties. Yet, according to the dataset’s validation report, the 14.6 % mobile device penetration of the dataset is better than some other commercial sources.

Second, not all movements are observed. The dataset excludes trips that start and end at the same points, and those during which the travelers do not stop for over ten minutes. Those features suggest that the excluded trips are more likely to be short trips near the traveler’s home. A related limitation is the number of people staying home in the dataset, who do not make a non-home trip more than one mile away from their home. However, these people may have traveled within a one-mile radius near their home without a stop of more than ten minutes. Additionally, the number of long-distance trips may also be underestimated, due to the trip-counting algorithm that may have failed to chain longer trips as one trip, especially for multi-day trips.

Third, the data is not equally representative across all U.S. counties and socio-demographic groups. However, some features of the data may have weakened this limitation. For example, as we mentioned above, the variation of the sample penetration rates regarding household income does not vary much for the dataset. We also did not see great differences in the sampling rates between urban and rural areas, though these areas were not examined statistically, only visually compared using the sampling rate pattern and the U.S.
urban–rural classification by the National Center for Health Statistics (CDC, 2013).

To sum up, there may be some limitations in the data. For example, the captured travel distances in our research may be shorter than Americans’ actual travel distances, areas with small populations may be underrepresented, the number of shorter trips and long-distance trips are both likely to be underestimated, and the number of people staying home may be overestimated. Overall, the research conducts descriptive analysis of changes in Americans’ travel patterns following COVID-19 and provides some possible reasons. Further research can apply statistical methods to analyze the contributors to the patterns more rigorously considering social and physical environments across the country.

CRediT authorship contribution statement

Kanglin Chen: Conceptualization, Methodology, Formal analysis, Software, Visualization, Writing – original draft, Writing – review & editing. Ruth Steiner: Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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