Texas A&M Transportation Institute

Scenario Planning for COVID-19 and Other Uncertainties – Implications for Transportation and Air Quality Planning

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INTRODUCTION

BACKGROUND

The COVID-19 pandemic continues to present challenges in Texas. The pandemic has yielded profound impacts on all aspects of transportation, including passenger travel, freight, aviation, and public transportation (*1*). With current conditions in flux, there is still uncertainty over how short-term and long-term trends will play out in terms of future travel demand, and implications for air quality. There are other complicating factors, such as changing demographics and changes in how census data are collected, which can also impact transportation planning and funding in the coming years. In a study of potential COVID-19 impacts on air quality and transportation planning conducted in Fiscal Year 2020 (FY20), findings indicated that work-related trips have decreased during the pandemic and with no immediate trend of returning to the pre-pandemic level (*2*). The higher fraction of telecommuting (also known as remote working, work from home, or telework) employees and higher unemployment rates are major contributing factors to work trip reduction. This study builds on the previous findings, and includes expanded data and literature, including insights from discussions with stakeholders. This information is used to develop planning scenarios and analyzed for a regional network case study.

APPROACH

The major objective of this study is to (1) investigate the impact of COVID-19 on travel demand in Texas under various plausible future scenarios, and (2) analyze the implication of travel demand patterns on emissions and air quality. This study adopts a scenario planning approach to investigate this issue, focusing on three main aspects: the trajectory of COVID-19 outbreaks and their impact on transportation, economic conditions, and demographics.

In response to the large disruption of the COVID-19 pandemic, policymakers are seeking to adapt to change and adopt the best available policies to suit local conditions (*3*). Scenario planning is a powerful tool for agencies to provide essential information to policymakers and practitioners (*4*). Scenario planning is an approach to strategic planning that develops alternate narratives of plausible futures to make more informed choices and create plans for the future (*4*). In this study, the scenario analysis framework proposed by the Federal Highway Administration (FHWA) is adopted (*5*), consisting of the following steps:

1. **Define the scope of the work:** this study is focused on the impact of the ongoing COVID-19 pandemic on future traffic operation and air quality in Texas.
2. **Establish baseline analysis**: the current travel trends during COVID-19 in Texas and other socio-economic impacts of the pandemic are analyzed based on literature review and empirical data. Other factors, that may be impactful but cannot be quantified, are discussed, such as the potential impact of census operations, which had been greatly adjusted in 2020 due to the health and safety concerns during the pandemic *(6)*.
3. **Establish future goals and aspirations**: identify top issues/priorities regarding transportation and air quality impact of COVID-19 through literature review.
4. **Create a baseline and alternative scenarios**: develop plausible scenarios based on literature review and empirical data.
5. **Assess scenario impact**: perform travel demand and emission modeling to evaluate the potential impact of all scenarios.
6. **Craft comprehensive visions and identify strategic actions**: propose potential congestion mitigation and air quality improvement strategies under different scenarios based on the impact analysis results.

LITERATURE REVIEW

In this study, the team performed a comprehensive literature review on the impacts of the COVID-19 pandemic, covering studies performed in 2020, with data and observations therefore mostly reflecting the early stage of the pandemic. It covered three major aspects:

1. Existing impacts of COVID-19 on transportation
2. Existing impacts of COVID-19 on the environment and air quality
3. Implications for potential future scenarios

TRAVEL TRENDS DURING COVID-19 PANDEMIC

The findings on the latest travel trends during COVID-19 from the most recent studies are summarized in Table 1.

Table 1. Summary of Travel Trends during COVID-19 from Existing Studies

Transportation Sector	Location	Timeframe	Traffic Impacts
Roadway traffic	South Florida, United States	1st March- 22nd March 2020	Traffic volume dropped by 47.5% compar previous years.
	Detroit, Michigan	2020	Year-to-date average daily traffic was dow 19% for 2020 when compared to 2019
	Texas, United States	Week of April 11, 2020.	Change in the movement was its lowest c 38.92% compared to pre-COVID levels
	Texas, United States	March 2020	Movement was reduced by 15%
Air traffic	United States	By mid-summer between April and July 2020	73% reduction compared to previous year
	U.S. Domestic Departures	May 2020	71.5% reduction compared to the previou year
Transit	Washington DC Metro bus rail New York MTA	2020	• 66% reduction on Metrobus and 90% reduction on Metrorail compared to previous years. • Ridership reduction of MTA around 95 the spring and is still down around 78 from last year at the same time.
Railways	Amtrak, United States	2020	Amtrak provided 16.8 million customer tri FY 2020, down 47.4% with a year-over-yea decline of 15.2 million riders.
Ridesharing Service (e.g., Uber and Lyft)	United States	March-April, 2020	Ridership dropped between 70% and 80% compare to the pre-pandemic level

From Table 1, we can see most transportation sectors have experienced profound disruptions during the COVID-19 pandemic. Among various transportation sectors, air travel and public transportation have the largest travel reduction due to the social distance measures for disease prevention. Limited travel data collected in Texas suggested that the travel reduction in Texas followed the national trends, with roadway throughput reducing drastically during the early outbreaks (*9*, *10*). Those findings are consistent with findings in the previous TTI report (*2*), and demonstrated the continuing disruption of COVID-19 on transportation sectors nationwide. The following sections provide more detailed insights on different transportation sectors.

Roadway Traffic

The total vehicle travel nationwide dropped from mid-March to the end of June 2020 compared to total vehicle travel in February 2020, with the largest travel reduction of 48% being observed on April 9th, 2020 (*15*). In south Florida, the overall traffic volume dropped by 47.5% during March 2020 compared to previous years (*7*). In Detroit MI, the year-to-date average daily traffic was down 19% in 2020 compared to 2019 (*8*). Among total roadway traffic, the passenger and freight movements show different travel trends, which are discussed in the following sections respectively.

Stay-at-home orders were associated with reduced passenger movement in most counties during the early months of the COVID-19 pandemic (16). The nationwide passenger car volume was reduced by 77% in April compared to 2019 and recovered to an 11% reduction rate by the end of July 2020 after most stay-at-home orders expired (11). Working from home is another contributor to passenger travel reduction. Passenger traffic was still down in key metro areas around workplaces 9 months since COVID-19 was declared a global pandemic indicating that people are still working from home (9, 10). In Texas, the largest passenger movement reduction reached 38.92% in the week of April 11 compared to pre-COVID levels (9). In major counties like Harris county, Travis county, Dallas county & Bexar county the change in movement was -39.31%, -41.39%, -37.96% & -31.13% respectively the week of April 11 compared to pre-COVID levels. The direct consequence of automobile usage reduction and decrease in traffic includes millions of dollars in toll revenue loss across the nation (17).

On the other hand, changes in freight movement shows a more complex pattern compared to passenger travel(*18*). Long haul truck traffic dropped around 10% nationwide in early April 2020 compared to the 2019 level, and then reached a 5% increase in November 2020 (*19*). However, freight fleets in metro areas have seen a 25%

increase in early April and dropped back to 2019 levels by August. The trucks moving essential consumer goods and medical supplies were generally at capacity in March, due to the consumer panic-buying (*18*). Finally, with e-commerce gaining more momentum during the COVID-19 crisis (*20*), freight movement may continue to grow to meet increasing delivery demand.

Air Traffic

The aviation industry in the U.S. is heavily impacted by the ongoing pandemic. The travel behavior changes of passengers following the COVID-19 pandemic, travel restrictions, and economic crises have resulted in a dramatic drop in air travel demand (*21*). At the peak level of travel disruption, the number of air travelers dropped by 96% (*11*). The air travel reduction then shifted to 73% by mid-summer 2020 compared to the previous years. Another study (*12*) found that domestic departures declined 71.5% in May 2020 compared to last year, and the number of domestic U.S. markets declined 32.1%. Among all airports, large airports and airports in multi-airport cities had the greatest service reduction. Air travel is slowly recovering after this serious disruption, but the full recovery to the pre-COVID levels may still take 3-4 years under various plausible scenarios (*22*).

Public Transportation

Public transportation experienced massive ridership reduction during the COVID-19 crisis (*19*), due to concerns with possible coronavirus infection on public transit (*23*). As of early December 2020, the nationwide transit ridership was down by 64% compared to the 2019 ridership (*19*). In Washington D.C., there was a 66% reduction on Metrobus and a 90% reduction on Metrorail. New York Metropolitan Transportation Authority's (MTA's) commuter rail service showed some of the greatest declines in ridership, with a 95% reduction in the spring and the ridership is still down around 78-84% compared to the same time last year. Los Angeles Metro estimated a loss of $50 million in farebox revenue and the Bay Area Rapid Transit (BART) is budgeting for a more than $350 million drop in fare revenue in 2021 (*17*). In Dallas metro area, the monthly transit ridership in April 2020 is only about 40% of ridership in early 2020 (*24*), and Houston metro area has observed a similar ridership reduction (*25*). Regarding heavy rail service, Amtrak provided 16.8 million customer trips in the fiscal year 2020, with a 47.4% trip reduction and 15.2 million fewer riders compared to the previous year (*13*). Transit agencies are facing unprecedented challenges through this pandemic, and they need to develop effective funding and finance resiliency plans in response to changing costs and revenues (*26*).

Ridesharing Services

Like other transportation sectors, the transportation network companies (TNCs) such as Uber and Lyft were also impacted. Uber and Lyft experienced a ridership drop between 70% and 80% in the months of March-April 2020, and reported a revenue loss of $2.9 billion and $39.8 million respectively (*14*). The business models of those TNC companies are the key for the recovery, and rideshare services have temporarily adapted to a new business model during and after the pandemic to slowly return to pre-COVID services (*27*). The outcomes of the TNC company pandemic response strategies are yet to be revealed, with several plausible future scenarios projected by different groups. In the most optimistic case, the business will improve as states and countries open and remain open (*14*). However, there is a possibility that pooled ride demand will not recover if social distancing becomes a cultural norm and/or consumer anxiety over infectious diseases persist (*27*). Passenger ridership will also be depressed while cross-border and inter-state travel is limited, but relative competitiveness against public transport may also boost ridership (*28*). Another study suggests that the ridesharing business may continue to struggle according to a recent survey, where 28% of respondents said they expect to use taxis or ridesharing services less, and 11% expect not to use the services at all even after the economic activity resumes (*29*).

The rideshare services need to continue improving their revenue model in response to the new normal after the pandemic, such as last-mile delivery or providing subsidized services to public transportation (*27*). TNCs are also accelerating their business expansion to include more types of services, including food and goods delivery and job hubs (*28*). High levels of unemployment in many countries may help those TNCs with driver recruiting and market growth, despite the stress on its economic sustainability both before- and after-pandemic.

COVID-19's Impact on Environment and Air Quality

The social distancing strategies and travel reduction are likely to contribute to the emission reduction and improvement in air quality across the nation. The findings on observed air quality improvements during COVID-19 from the most recent studies are summarized in Table 2. The observed air pollutants decreased at the national level, especially during the lockdown period (March and April 2020). Given the large contribution of transportation sectors to major air pollutants (54.5% of NO_X, 44.3% of CO, 4.3% of $PM_{2.5}$) (*30*), the reductions in travel demand could possibly be associated with the observed emission reduction and air quality improvements.

Texas has experienced mixed air quality changes, with worsening $PM_{2.5}$ and ozone problems observed in Houston and San Antonio, respectively. The PM increase in the Houston area is likely caused by long-range transport of smoke from Latin American fires using satellite data and smoke transport analyses (*31*). Ozone levels in San Antonio decreased greatly during the early outbreak and lockdown period, followed by a sharp increase in ozone levels after the stay-at-home order expired (*32*). The ozone increase is likely contributed by rebounding traffic after lockdown and warmer weather.

Table 2. Summary of Air Quality Improvements during COVID-19 from Existing Studies

Location	Pollutants	Reduction Rate	Observation timeline	Reference
United States	• NO_2 • $PM_{2.5}$	• NO_2: 25.5% • $PM_{2.5}$: 4.5%	2020 compared to previous years	Berman and Ebisu, 2020 (*33*)
United States	NO_2	Decrease in NO_2 levels was between 24% (from satellite) and 27% (from ground stations	Period of March-May	Archer, 2020 (*34*)
United States	Annual greenhouse gas (GHG) from transportation	14.7%	Compare 2020 to 2019	Rhodium Group, 2020 (*35*)
California, U.S.	• NO_2 • CO • $PM_{2.5}$	• NO_2: 38% • CO: 49% • $PM_{2.5}$: 31%	(March 19–May 7) compared to before (January 26–March 18) in 2020	Liu, et al., 2021 (*36*)
Dallas-Fort Worth area, U.S.	NO_2 concentration	21% (from 7.7 ppb to 6.1 ppb)	End of April value compared to early March	North Central Texas Council of Governments, 2020 (*24*)
Houston metro area, U.S.	• NO_X • $PM_{2.5}$	• NO_X: 21% decreased • $PM_{2.5}$: 25% increased	Compare April 2020 to April 2019	(*37*)
San Antonio, TX	• Ozone level at 3 selected locations	• March 2020: 14.6% - 22% reduction • April 2020: 4.3% - 7.1% reduction • May 2020: 10.6% - 16.4% increase	Compare 2020 values to 2017-2019 average ozone level	Alamo Area Council of Governments, 2020 (*32*)

Potential Transportation Impacts in Future

From a transportation planning perspective, the impacts of COVID-19 are observed in the short- and medium-term. Possible changes in the longer term will only happen in the case of a "new normal", i.e. changes that have a lasting impact beyond the pandemic. These include possible shifts in work culture, economic disruption, and demographic changes. Experiences with COVID-19 also has the potential to impact traditional transportation decision-making processes, with new approaches proposed in response to emerging issues and concerns. This section will discuss how COVID-19 could potentially change transportation systems in the future, and how transportation planners and engineers are addressing emerging issues.

Disease Outbreak and Social Distancing Measures

Since the pandemic began, numerous epidemiologists are predicting short-term and long-term impacts of COVID-19 and have reached similar conclusions: (1) COVID-19 is here to stay, and (2) the future is largely uncertain due to various factors (*38*). Those uncertain factors include (1) if people can gain lasting immunity to the virus, (2) whether seasonality affects its spread, (3) the choices made by governments and individuals. Specifically, the adoption of social distance and behavior change can reduce the virus spread and change the course of future prediction. A pessimistic scenario projects the resurgence in COVID-19 outbreak could occur as far into the future as 2025, as a result of short immunity to the virus (*39*). In this scenario, social distancing will be needed during the seasonal outbreak (especially in winter). In terms of transportation demand and economic impact, we may either see a short-term intensive disruption to keep the outbreak quickly under control or long-term seasonal disruptions if entering the seasonal outbreak scenario over the next few years.

Work Culture

The work culture in the United States has significantly changed during the ongoing pandemic and some of the temporary changes will become permanent even after the offset of the pandemic (*40*). A great portion of employees adapted to work from home (also known as remote working or telecommuting) during the pandemic. During March 2020, about 62% of U.S. workers have worked remotely according to a recent survey on 2,276 employed U.S. adults (*41*). A recent survey performed in Austin, TX found that 65% of residents will work from home at least some of the time after the coronavirus pandemic (*42*). As a result, more companies and employees are embracing remote working as part of their new working culture. According to a national survey of 1200 full-time employees in the U.S., 43% of respondents suggested they prefer to work from home after the pandemic and 65% of respondents are confident that their employers will allow more flexibility (*43*). Also, many organizations will settle somewhere with a hybrid strategy that allows distanced operations where feasible and on-site work where needed *(44)*. For example, in a recent resolution, the Metropolitan Transportation Commission in San Francisco Bay Area voted to require people at large, office-based companies to work from home three days a week to reduce GHG emissions (45). It can be anticipated that the work from home culture could become a new norm after the pandemic, which will likely affect commute travel demand.

Economy

The COVID-19 pandemic created an economic crisis in the United States (*46*). According to the U.S. Bureau of Economic Analysis, the 2nd quarter of 2020 saw a 35% decrease in the gross domestic product (GDP) compared to the previous quarter (*47*). In 2020, the unemployment rate sharply raised from 3.5% in February to 14.7% in April, reaching the highest values in 17 years (*48*). As of October 2020, the unemployment rate remained at 6.9%, which caused a loss in work-related travel demand. In addition, the pandemic had a different level of impact on different types of businesses, with small retail businesses hit the hardest (*46*). In Texas alone, the retail sector could experience economic losses exceeding $2.0 billion during the eight months of restricted travel (*49*). In addition, with retail sales plummeting, the state will likely lose around $242.6 million in tax revenue. In dense urban areas, the office buildings will lose value due to more companies allowing remote working and less demand for office space (*50*). Retailers and restaurants in business districts could also be hurt, and demand for mass transit commuting options will fall. The loss of jobs and revenue will likely cause travel demand to shrink, as vehicle travel increases at similar rates as economic growth (*51*).

It is predicted that the recovery in the U.S. economy begins in 2021 (*52*). At the local level, for example, Houston would likely have come to the end of a moderate recession by the first half of 2021 (*52*). The full economic recovery in Houston and returning employment to pre-COVID levels will take another five quarters after the end of social distancing. Some economy sectors have already recovered, for example, the oil prices have rebounded significantly after an initial disruption and will soon reach the pre-March levels in the United States (*53*). Some sectors, such as e-commerce, may see long-term changes due to changing consumer behavior and retail sector transformation

(*20*). the growth of e-commerce will fundamentally change the current supply chain system and will impact the freight demand after the pandemic.

Demographics

The ongoing pandemic may also affect the demographic patterns in various ways. First, it may change the population growth. For example, Texas' steady population growth might be slowing down for the first year in more than a decade, and demographers predict the COVID-19 pandemic will harm the rate of population growth (*54*). The pandemic will also affect population migration, and the cities with more companies allowing remote work will see their employees moving out of the city centers and the demographics will change in regions or areas where the current employees and their families migrate to (*55*). The shifting demographic patterns will chang the population landscape and hence affect travel demand. Finally, the pandemic has greatly disrupted the workflow of the 2020 Census, which might affect the accuracy and reliability of Census results (*6*). The Census data is widely adopted in transportation studies, and the impact of Census results will affect the ongoing planning and decision-making process.

Transportation Decision-Making

According to a recent survey on transportation stakeholders (*3*), decision-makers could consider adopting the following adjustments in the long-term planning process:

- Enact new funding and pricing mechanisms (e.g., road pricing, value capture).
- Employ a customer-centric approach to transportation.
- Engage with employers during recovery.
- Incorporate environmental and social equity in all future actions and policies.
- Create new public transit business structures.
- Combine public transit and mobility services.

Those adjustments are closely related to the transportation impact (especially transit), economic impact, and work culture shifts discussed previously.

TRAVEL TRENDS FROM EMPIRICAL DATA

In this study, plausible scenarios in the future are developed based on observed travel trends during the pandemic. In other words, it is assumed the level of traffic impact will not exceed the observed traffic impacts during the largest disruption of the COVID-19 pandemic. The observed traffic data and socio-economic factors are collected from various sources to quantify the level of impacts in Texas.

PASSENGER VEHICLE TRAVEL TRENDS

The major data source used for analyzing passenger vehicle travel trends comes from the COVID-19 impact analysis platform developed and maintained by the University of Maryland (UMD) (*56*, *57*). This platform provides mobility, COVID-19 case, demographic information, and economic impact for every county and state within the U.S. since January 2020, using privacy-protected mobile device location data, integrated with COVID-19 case data and census population data. With comprehensive transportation, economic, and health data provided in this dataset, the UMD data is used as the primary data source for analyzing passenger travel trends.

This study adopts the Texas subset of UMD data from January to November 2020. The number of active cases and passenger miles traveled per person, along with the weekly average trend line, are provided in Figure 1 below. Based on Figure 1, the passenger miles per person started to decline around mid-March, when the COVID-19 cases began to rise. With the stay-at-home (SAH) order coming into effect in early April, the daily passenger miles per person were already close to the lowest level. However, the trends started to diverge by trip purpose since the middle of the SAH order and slowly growing back to normal level by the end of June. Since June 2020, the passenger miles per person fluctuated every month but didn't drop again, despite the peak COVID-19 cases during the summer and high infectious rate during the Fall.

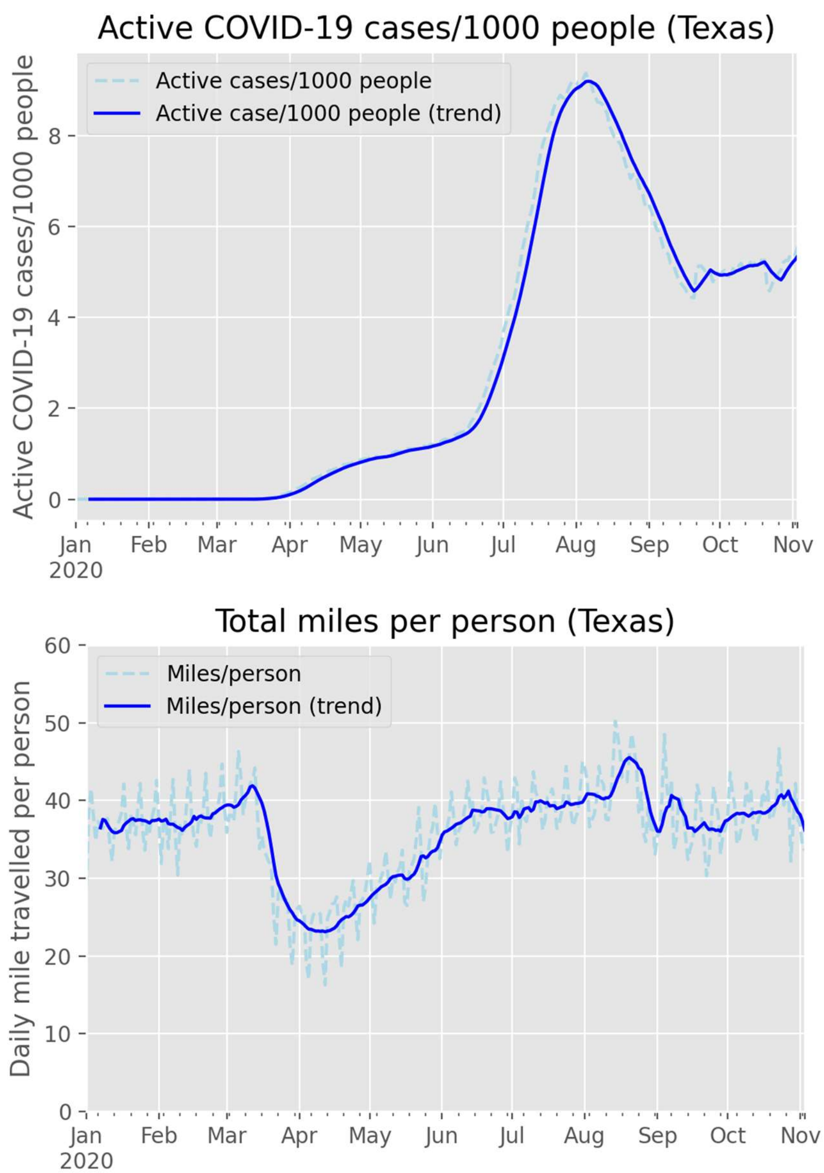


Figure 1 COVID-19 cases and passenger travel trends in Texas during COVID-19.

Next, the travel trends by travel purposes (work vs non-work) during the same period are illustrated in Figure 2 below. The non-work trip frequency follows a similar trend as total miles per person, with more people resuming their travel routine for non-work trips after Spring 2020. However, the work trips staying at a low level (~0.4 trips/person) with only a slight increment in the Fall. This suggests a large number of workers are not traveling to their work locations, potentially due to remote working policies or loss of jobs. In conclusion, the progress of the COVID-19 pandemic and the implementation of the SAH order shows a lasting impact on personal work trips but only a short-term impact on non-work trips and total miles per person in Texas.

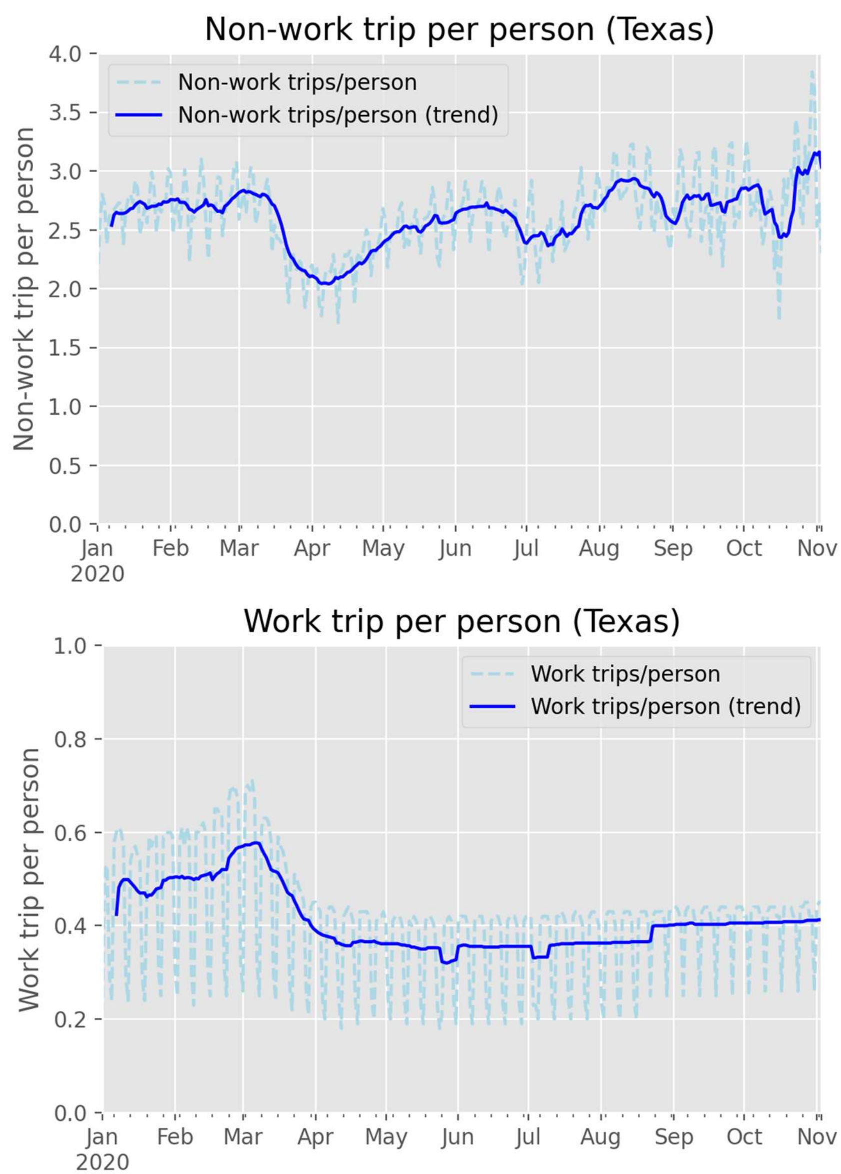


Figure 2 Trip frequency by travel purpose in Texas during COVID-19.

PUBLIC TRANSPORTATION TRAVEL TRENDS

Next, the transit travel trends in Texas during the pandemic are analyzed using the ridership data from the National Transit Database (NTD) (*58*). The NTD is the repository of data about the financial, operational, and asset conditions of the American transit systems. Transit agencies report data regularly on several key metrics such as Vehicle Revenue Miles, Passenger Miles Traveled, Unlinked Passenger Trips, and Operating Expenses. In this study, the transit ridership data during the past two years are collected for major Metropolitan areas within Texas. The ridership is represented using unlinked passenger trips and aggregated for bus and rail services respectively. The results are provided in Figure 3 below. According to Figure 3, the transit ridership starts falling in January 2020, and reached the lowest point in April 2020. The ridership level in late 2020 is almost half of the ridership in 2019 for all regions, and there is no trend of ridership recovery even near the end of 2020. In conclusion, the COVID-19 pandemic has severely disrupted transit ridership, and there is no immediate trend of recovery. This disruption will likely yield profound impacts on the revenue of local transit agencies and the operation of transit services in the long term.

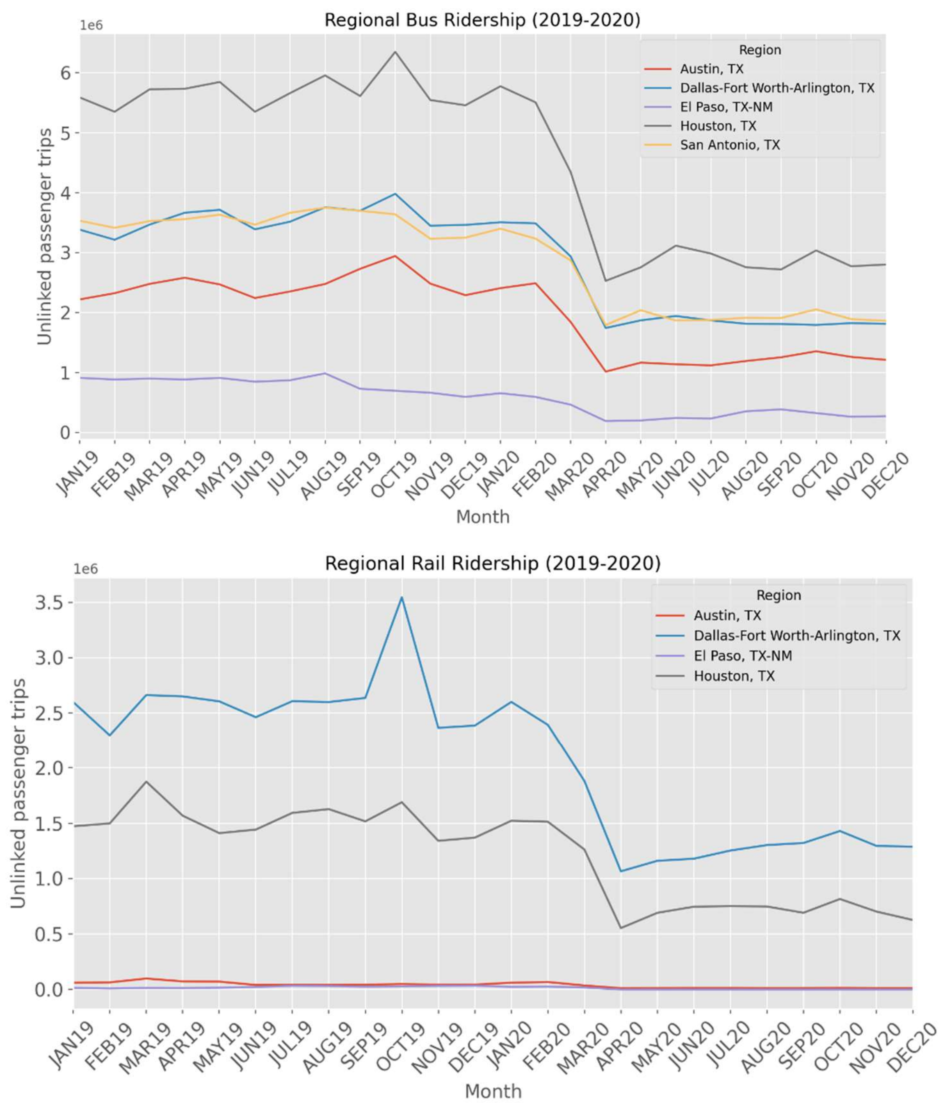


Figure 3. Transit Travel Trend (bus and rail)

Employment and Economic Trends

In previous works, it has been demonstrated that the work trip frequency is influenced by more people working from home during the pandemic and the unemployment rate (*2*). The recent trends of remote working and unemployment rates are collected from the UMD data and provided in Figure 4 below, and the summary statistics are provided in Table 3. Regarding the unemployment rate, after reaching the highest point in May 2020 (14%), the unemployment rate experienced some decline during summer and then rises to 10% around November 2020. The high unemployment rate suggests a very high toll of COVID-19 pandemic on Texas economy, compared to only a 3.5% unemployment rate in early 2020. Regarding the fraction of remote working employees, it reached the highest level of around 40% in June and July and -fell back to around 25% near the end of the year. This fraction is still much higher than the 5% before the pandemic started. In conclusion, the COVID-19 has largely changed the local economy and working culture, hence affected work-related trips throughout 2020. Some level of socio-economic impacts will likely remain after the pandemic.

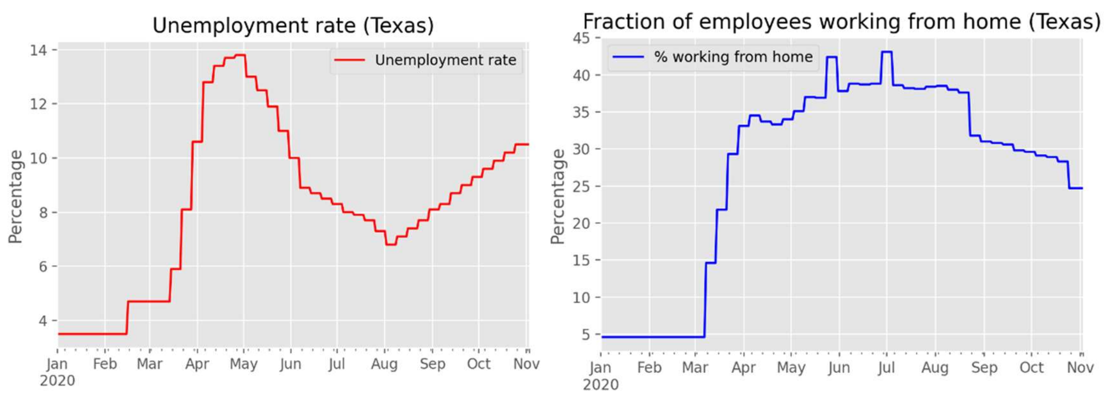
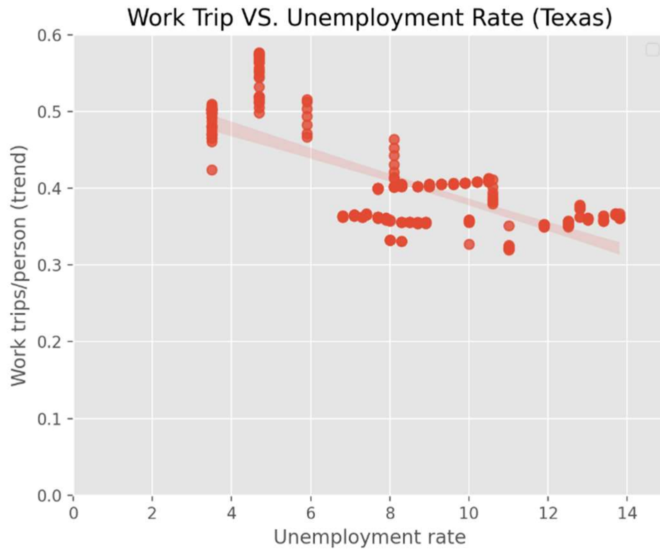


Figure 4. Trends of Remote Working and Unemployment

Table 3. Summary Statistics of Unemployment and Remote Working

Factors	**Before pandemic**	**During pandemic - high**	**During pandemic - low**
Unemployment rate	3.5%	14%	6.8%
% of work from home	4.6%	43.1%	24.7%

Finally, the relationship between the two factors and the work trip frequency are demonstrated using the scatter plots in Figure 5 below. With a higher unemployment rate and remote working fractions, the work trip frequency (trip/person) will drop significantly. These findings help explain the work trip reduction during the COVID-19 pandemic and can be used to predict the work travel trend under potential scenarios.



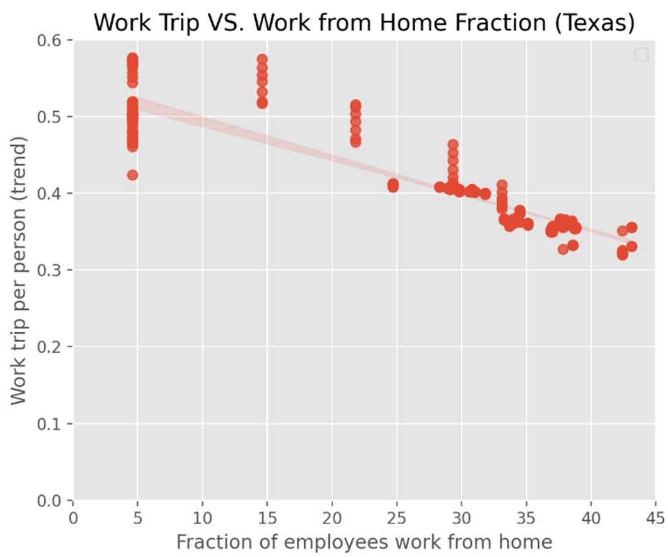


Figure 5. Work Trip Frequency by Remote Working Fractions and Unemployment Rates

CASE STUDY ASSESSMENT

In this section, a post-COVID scenario planning assessment is performed for San Antonio, Texas. The San Antonio Metropolitan area contains 5 counties, including Bexar County, Comal County, Guadalupe County, Kendall County, and Wilson County. Among those, Bexar County is designated as an ozone nonattainment area and is required to demonstrate transportation conformity for ozone precursors, VOC, and NO_X (*59*). The data from a recent conformity analysis (for sumemr and winter 2020) were used as key inputs, which were adjusted to the relevant analysis scenarios for this assessment. For the analysis, the TTI team developed several plausible scenarios based on observed trends and existing data and to reflect a wide range of travel demand changes. Next, the proposed scenarios were used as inputs to predict the travel demand changes and update the activity data used in the conformity analysis. Finally, using the new input sets under proposed scenarios, the emission modeling is performed using TTI's MOVES Utilities.

SCENARIO DEVELOPMENT

Combining findings from earlier chapters, and taking into account available data, four plausible scenarios were developed to represent post-pandemic conditions for which travel demand could be modeled. These scenarios, if extended to the long term, represent fairly extreme cases based on unemployment levels and telecommuting levels seen from the data during the pandemic. Also, due to lack of freight data, census data and other travel data, this scenario analysis may not reflect the travel demand changes of all sectors. A more comprehensive scenario planning exercise can be performed in coordination with stakeholders with more data as they become available.

- **Scenario 1: Baseline (Business as usual) -** In this scenario, it is assumed the economy will recover to pre-pandemic level and work practices around teleworking will also go back to pre-pandemic conditions. The assumptions in terms of analysis parameters are as follows: 3.5% unemployment rate and 4.6% of people work remotely.
- **Scenario 2: High Social Distance/Low Economic Disruption –** This scenario represents a strong economy, in whch the "new normal" is embraced in terms of sustained remote work. The assumptions in terms of analysis parameters are as follows: 3.5% unemployment rate and 24.7% of people work remotely.

- **Scenario 3: Low Social Distance/High Economic Disruption –** This scenario represents slow economic recovery and fatigue with social distancing, which manifests as a high unemployent rate and low levels of telecommuting as workers tire of social distancing. The assumptions in terms of analysis parameters are as follows: 10% unemployment rate and 3.5% of people work remotely.
- **Scenario 4: High Social Distance/High Economic Disruption –** This scenario represents a slow economic recovery combined with high levels of social distancing (seen in telecommuting). In this scenario, it is assumed that the economic crisis will continue and social distancing will remain in place due to the prolonged effect of the pandemic. The assumptions in terms of analysis parameters are as follows: 10% unemployment rate and 24.7% of people work remotely.

Methodology

In this study, the travel demand and air quality analysis are performed by modifying the regional conformity inputs in TTI MOVES Utilities. To assess the travel demand impact of four proposed scenarios, four steps were undertaken as shown in Figure 5 and described in the following sections.

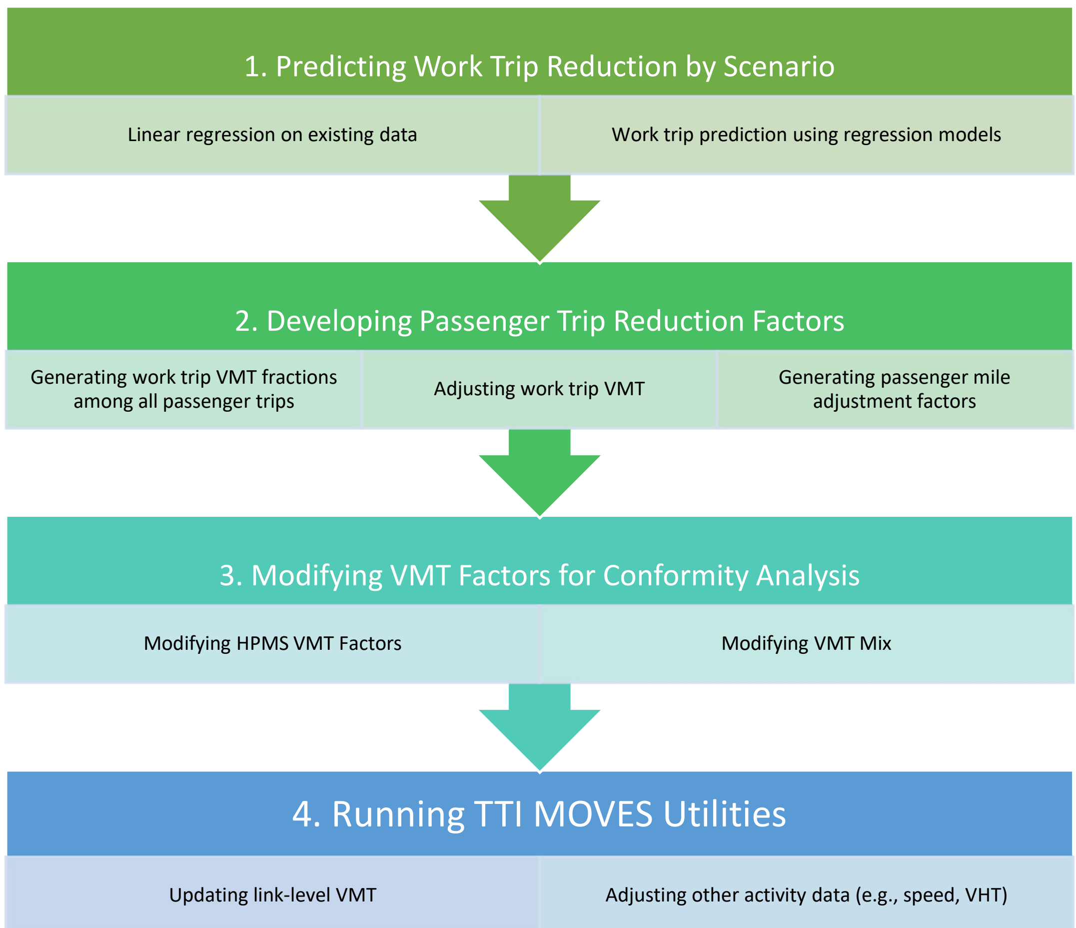


Figure 6. Methodology

Predicting Work Trip Reduction by Scenario

Similar to TTI's prior study (*2*), linear regression models are adopted to predict the work trip frequencies under all scenarios and the reduction rates compared to the baseline. The UMD county-level mobility data is used for model development and prediction, and the work trip reduction is performed for each county within the region. The travel trends from the UMD data are shown below. The travel trends in the San Antonio area are generally consistent with travel trends in Texas displayed in Figure 2 earlier in the report.

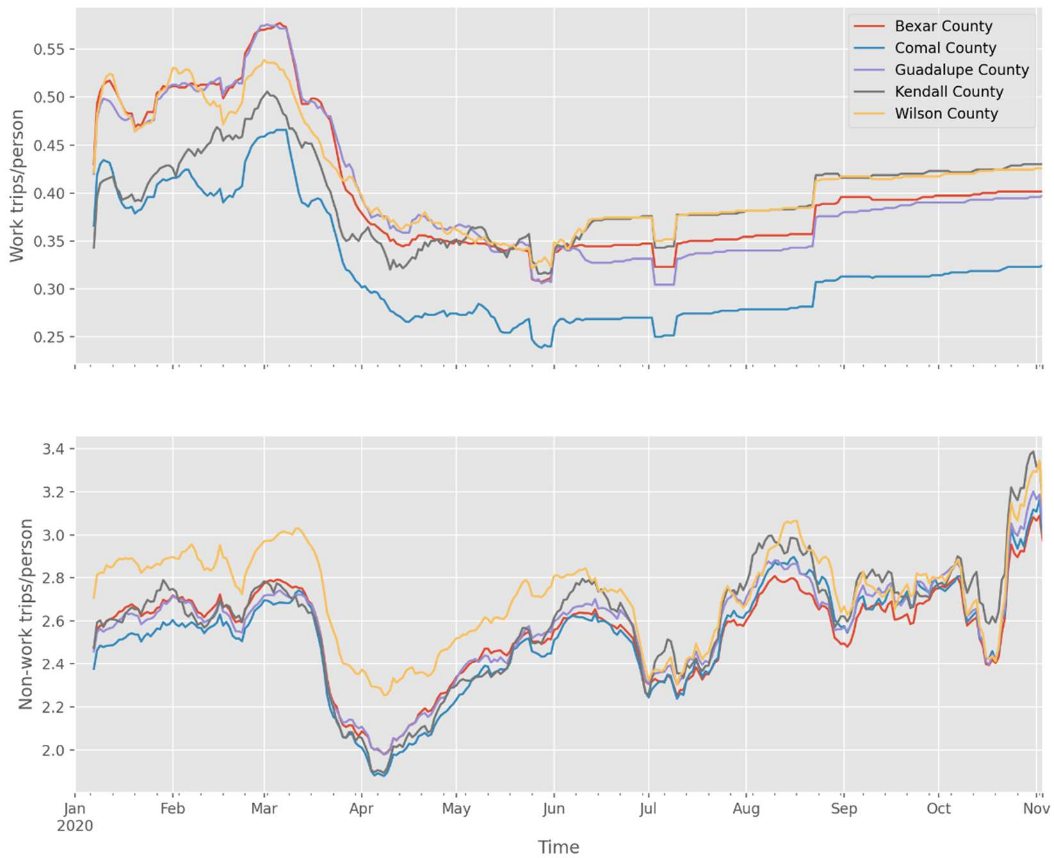


Figure 7. Trip frequency by travel purpose in San Antonio Area

To develop the linear regression model, the weekly average county-level work trip frequencies by county are used as the dependent variables. The state-level unemployment rate and work trip fractions are used as independent variables (the country-specific data are not available). The fitted parameters and model goodness-of-fit are summarized in Table 4 below. For most counties, the linear regression can predict the work trip trend well (R^2 >0.88)[1].

[1] For Kendall County, the selected independent variable and other variables in this dataset does not provide high R^2 values, and further work is needed to address this issue. For now, the model was used in the analysis for consistency of methodology.

Table 4. Linear Regression Model Results

County	% work from home coefficient	Unemployment rate coefficient	Intercept	R^2
Bexar County	-0.0046	-0.0034	0.56	0.90
Comal County	-0.00408	-0.0028	0.45	0.91
Guadalupe County	-0.0053	-	0.55	0.88
Kendall County	-0.0017	-0.0041	0.48	0.55
Wilson County	-0.0034	-0.0042	0.54	0.90

Using the values from the four scenarios introduced in Section 4.1, the work trip reduction rate can be generated for each county and each scenario. The work trip reduction results are summarized in Table 5 below.

Table 5. Predicted Work Trips by Scenario

Scenario	Baseline	High Social Distance/Low Economic Disruption		High Social Distance/High Economic Disruption		Low Social Distance/High Economic Disruption	
County	Trip /person	Trip /person	Reduction	Trip /person	Reduction	Trip /person	Reduction
Bexar County	0.53	0.43	18%	0.41	22%	0.50	4%
Comal County	0.42	0.34	19%	0.33	23%	0.41	4%
Guadalupe County	0.52	0.41	20%	0.41	20%	0.52	0%
Kendall County	0.45	0.42	8%	0.39	13%	0.43	6%
Wilson County	0.51	0.44	13%	0.42	19%	0.49	5%

Developing Passenger Trip Reduction Factors

Since passenger travel contains both work trips and non-work trips, it is essential to account for the work trip reduction among all passenger trips. To achieve this goal, the Texas subset of the 2017 National Household Travel Survey (NHTS) is used to develop the work trip fraction and generate final passenger travel adjustment factors (*60*). The NHTS Texas subset contains travel data from 24,464 households, 47,981 vehicles, and 178,579 trips. Among those trips, 101,155 trips are weekday driving trips and about 20% of those trips are work trips (20,294 work trips). In this analysis, the weekday driving trip data are used to generate the passenger travel vehicle miles of travel (VMT) adjustment factors. First, the weekday driving trip VMT was aggregated by trip purpose and travel demand model period. The four periods include AM- morning peak, MD- midday, PM – afternoon peak, and ON- overnight. The results are shown in Figure 8. The AM and PM periods have higher work trip fractions compared to the other two periods, which suggests higher demand reduction during rush hours will be observed for alternative scenarios.

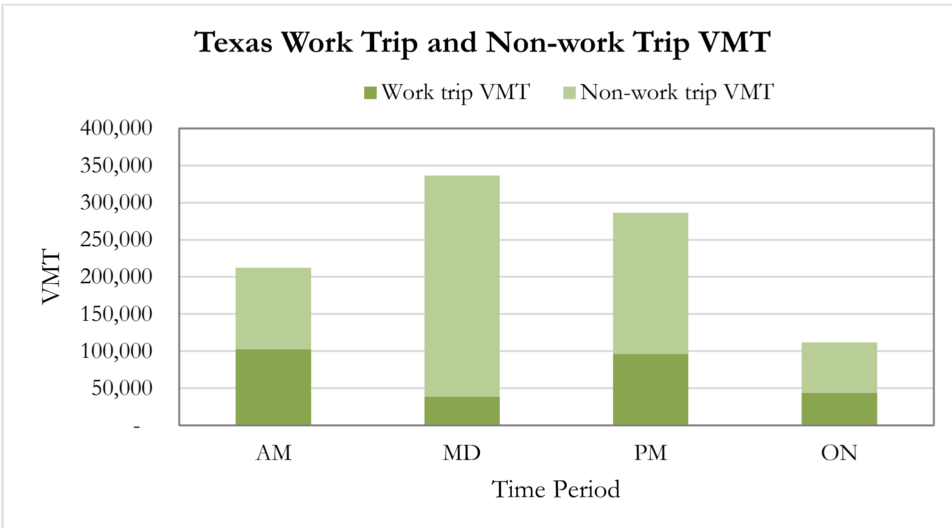


Figure 8. Driving Trip VMT by travel purpose and Time Period

Next, the county-level work trip reduction rates by scenario are used to generate the passenger driving VMT reduction by period. For each county, scenario and period, the passenger travel VMT adjustment factors f are computed as following:

Adjusted work trip VMT: $VMT_{work,adj} = VMT_{work,NHTS} * R$ (1)

Passenger travel VMT adjustment factor $f = \frac{VMT_{work,adj} + VMT_{non-work,NHTS}}{VMT_{work,NHTS} + VMT_{non-work,NHTS}}$ (2)

Where,

$VMT_{work,NHTS}$- work trip VMT from NHTS data

$VMT_{non-work,NHTS}$- non-work trip VMT from NHTS data

R- work trip adjustment factor from Table 5

The final passenger mile adjustment factors by county, period and scenario are provided in Table 6 below (by definition, the baseline adjustment factors equal to 1, i.e. no VMT adjustments are needed).

Table 6. Passenger Travel VMT Adjustment Factors

County	Period	High Social Distance/Low Economic Disruption	High Social Distance/High Economic Disruption	Low Social Distance/High Economic Disruption
Bexar County	AM	91.5%	89.4%	98.0%
	MD	98.0%	97.5%	99.5%
	ON	93.1%	91.4%	98.3%
	PM	94.0%	92.6%	98.6%
Comal County	AM	91.0%	88.9%	97.9%
	MD	97.9%	97.4%	99.5%
	ON	92.7%	91.0%	98.3%
	PM	93.7%	92.3%	98.6%
Guadalupe County	AM	90.2%	90.2%	100.0%
	MD	97.7%	97.7%	100.0%
	ON	92.0%	92.0%	100.0%
	PM	93.1%	93.1%	100.0%
Kendall County	AM	96.4%	93.5%	97.2%
	MD	99.1%	98.5%	99.3%
	ON	97.0%	94.8%	97.7%
	PM	97.5%	95.5%	98.0%
Wilson County	AM	93.5%	91.0%	97.4%
	MD	98.5%	97.9%	99.4%
	ON	94.7%	92.7%	97.9%
	PM	95.5%	93.7%	98.2%

Modifying VMT Factors for Emissions Analysis

In this study, the TTI MOVES Utilities are used to generate regional emission inventories to provide insight on potential regional impacts of the scenarios. The VMT adjustment factors developed in previous section need to be fitted into this modeling framework. TTI MOVES Utilities adopt link-level VMT for all vehicle types from regional travel demand models and apply several adjustment factors for emission calculation (e.g., the Highway Performance Monitoring System (HPMS) factor, Vehicle type and fuel type mix, etc.). In this study, the adjustment factors listed in Table 6 are used to adjust two major input factors in Utilities[2]: (1) HPMS VMT factors by county, and (2) the 5-county region VMT mix factors by vehicle type and time period. In addition, the baseline total VMT by vehicle types are used to generate the ratio between passenger travel VMT and other vehicles' VMT for each county.

For each season, county, and scenario, the HPMS VMT factors were updated using the following equations:

Reduced passenger VMT by county: $\Delta_{VMT,c} = \sum_{all\ periods} VMT_{passenger} * (1 - f)$ (3)

Total VMT adjustment factor $f_T = 1 - \frac{\Delta_{VMT,c}}{\sum_{all\ periods} VMT_{Total}}$ (4)

Adjusted HPMS VMT factor $f'_{HPMS} = f_{HPMS} * f_T$ (5)

Where,

$VMT_{passenger}$- total passenger vehicle VMT by county and period from baseline output (source type ∈ {21, 31, 32})

f- passenger travel VMT adjustment factors from Table 6

VMT_{Total}- total VMT by county and period from baseline output

f_{HPMS}- existing HPMS VMT factors

After adjusting the HPMS VMT factor at county-level, the VMT mix factors (a.k.a. VMX factors in the following sections) for the 5-county region (or TxDOT district 21) are also modified to reflect the reduced light-duty VMT among all vehicles. For each period and scenario, the adjusted VMT mix factors are computed as the following:

Reduced passenger VMT by period: $\Delta_{VMT,p} = \sum_{all\ counties} VMT_{passenger} * (1 - f)$ (6)

Ratio of baseline LDV VMT: $R_{LDV} = \frac{\sum_{all\ counties} VMT_{passenger}}{\sum_{all\ counties} VMT_{Total}}$ (7)

Ratio of baseline HDV VMT: $R_{HDV} = 1 - R_{LDV}$ (8)

Ratio of adjusted LDV VMT: $R'_{LDV} = \frac{\sum_{all\ counties} VMT_{passenger} - \Delta_{VMT,p}}{\sum_{all\ periods} VMT_{Total} - \Delta_{VMT,p}}$ (7)

Ratio of adjusted HDV VMT: $R'_{LDV} = 1 - R'_{LDV}$ (8)

[2] The input factors in Utilities does not support modifying passenger mile VMT directly. So multiple factors with the closest aggregation level were used in this study.

$$\text{Adjusted LDV VMX factors: } r'_{LDV\,VMX} = r_{LDV\,VMX} * \frac{R'_{LDV}}{R_{LDV}} \quad (9)$$

$$\text{Adjusted HDV VMX factors: } r'_{HDV\,VMX} = r_{HDV\,VMX} * \frac{R'_{HDV}}{R_{HDV}} \quad (9)$$

Where,

$r_{LDV\,VMX}$- Baseline light-duty vehicle VMT mix factor by source type, fuel type, and period

$r_{HDV\,VMX}$- Baseline heavy-duty vehicle VMT mix factor by source type, fuel type, and period

After generating the adjustment factors, the baseline and adjusted HPMS VMT factors and VMX factors for all four scenarios will be used to run TTI MOVES Utilities and assess the travel demand impact.

Running TTI MOVES Utilities

In this study, the TTI MOVES Utilities are used to account for the VMT reduction under various scenarios. The technical details of Utilities can be found in TTI's prior reports (*61*, *62*). In this study, the activity utility post-processes 2019 San Antonio travel demand model (TDM) outputs to produce hourly, on-road vehicle, seasonal and day-of-week specific, directional link VMT, and speed estimates. The link volumes were adjusted by the appropriate HPMS, seasonal, or other VMT factors. Hourly factors are then used to distribute the link VMT to each hour in the day. The TTI speed model is used to estimate the operational time-of-day link speeds for each direction. The total VMT and the reduction rate compared to baseline are summarized in Table 7. Under all alternative scenarios, the total VMT decreased compared to the baseline scenario. The highest VMT reduction is 6.1% under the high social distance and high economic disruption case.

Table 7. Total Vehicle VMT by Season and Scenario

Scenario	Baseline	High social distance, high economic disruptions		High social distance, low economic disruptions		Low social distance, high economic disruptions	
Season	**VMT**	**VMT**	**Reduction**	**VMT**	**Reduction**	**VMT**	**Reduction**
Summer	6.30E+07	5.92E+07	6.1%	5.99E+07	5.0%	6.23E+07	1.1%
Winter	6.30E+07	5.91E+07	6.1%	5.98E+07	5.0%	6.23E+07	1.1%

Next, the 24-hour VMT profiles by scenario and season are illustrated in Figure 9 below. As demonstrated in Figure 8 above, the AM and PM periods have higher work trip fractions. In Figure 9, higher VMT reductions are observed during rush hours, with fewer VMT reductions observed in other periods of the day. So, the VMT reduction caused by reduced work-related travel is likely to reduce more congestion during rush hours.

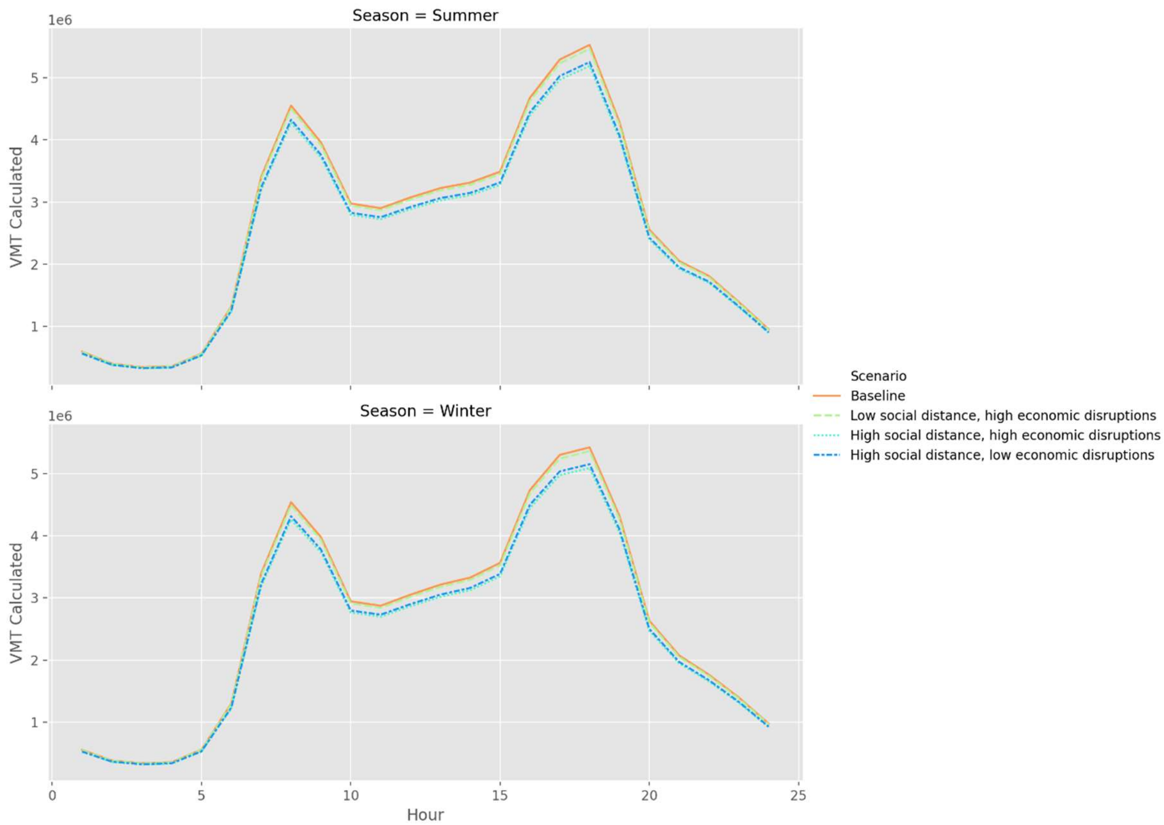


Figure 9. Hourly Total VMT by Season and Scenario

In the next section, the link VMT and speeds are selected as inputs for the emission analysis together with MOVES-based emissions factors, and results developed.

RESULTS

In this study, the TTI MOVES Utilities generates total emission inventory using MOVES emission rates, baseline and adjusted VMT inputs, and other off-network activities (e.g., idling, starts). The detailed methodologies are documented in the prior reports (*61*, *62*). The emission inventories generated include running, start, evaporative and heavy-duty vehicle idling emissions for CO, NOx, VOC, CO_2, PM_{10}, and $PM_{2.5}$. The total daily emission inventories from baseline and alternative scenarios are compared and summarized in Table 8 and Figure 10.

Table 8. Total Emission by Pollutant, Season, and Scenario

Pollutant	Scenario	Baseline	High social distance, high economic disruptions		High social distance, low economic disruptions		Low social distance, high economic disruptions	
	Season	Emission (g)	Emission (g)	Reduction	Emission (g)	Reduction	Emission (g)	Reduction
CO	Summer	3.30E+08	3.10E+08	6.1%	3.14E+08	5.0%	3.27E+08	1.1%
	Winter	2.46E+08	2.32E+08	5.5%	2.35E+08	4.5%	2.43E+08	1.0%
NOx	Summer	3.56E+07	3.45E+07	3.1%	3.47E+07	2.6%	3.54E+07	0.6%
	Winter	3.98E+07	3.86E+07	2.9%	3.88E+07	2.4%	3.96E+07	0.5%
VOC	Summer	1.78E+07	1.74E+07	2.3%	1.75E+07	1.9%	1.78E+07	0.4%
	Winter	1.25E+07	1.21E+07	3.2%	1.21E+07	2.6%	1.24E+07	0.6%
CO2	Summer	3.31E+10	3.13E+10	5.6%	3.16E+10	4.6%	3.28E+10	1.0%
	Winter	3.09E+10	2.92E+10	5.4%	2.95E+10	4.4%	3.06E+10	1.0%
PM10	Summer	4.73E+06	4.43E+06	6.4%	4.48E+06	5.3%	4.67E+06	1.2%
	Winter	4.75E+06	4.45E+06	6.4%	4.50E+06	5.2%	4.70E+06	1.2%
PM2.5	Summer	1.40E+06	1.35E+06	4.2%	1.36E+06	3.4%	1.39E+06	0.8%
	Winter	1.43E+06	1.37E+06	4.1%	1.38E+06	3.4%	1.42E+06	0.8%

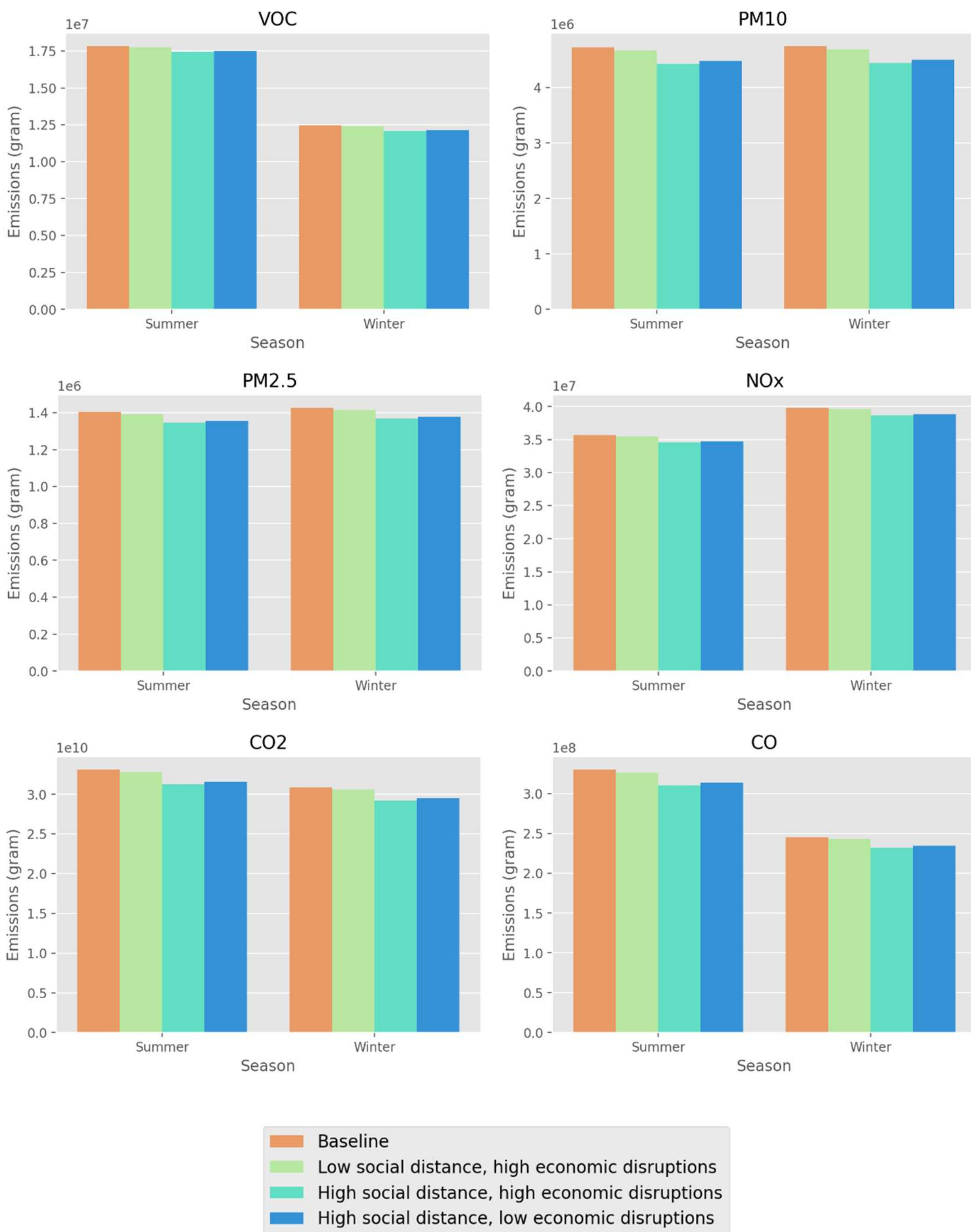


Figure 10. Daily Total Emissions by Pollutant, Season, and Scenario

Based on the results above, similar to VMT reduction, the emission inventories under all alternative scenarios are marginally lower than the baseline scenario. With the maximum demand reduction under high social distance and high economic disruption, the NOx and VOC reductions are around 3% and PM reductions are around 5%.

CONCLUDING REMARKS

In this study, a post-COVID scenario analysis is performed for a Texas case study to investigate potential travel demand impacts and air quality impacts of the 'new normal'. First, the existing studies and analyses on travel during the COVID-19 pandemic are reviewed to gain insights into potential post-pandemic travel patterns. Next, the travel trends in Texas are revealed using empirical data collected in Texas. Key factors that may affect passenger travel during COVID-19 are also identified in this process. Finally, a case study on San Antonio, Texas is performed using information from literature review and empirical data.

A baseline and three alternative scenarios are proposed to represent different levels of social distancing and economic disruption. The travel demand and emission impacts are analyzed using TTI MOVES Utilities and other local datasets. Under the largest travel demand disruption, the total VMT reduction at the regional level can reach around 6%. The maximum NOx and VOC reductions are around 3% and maximum PM reductions are around 5%. The findings from this study can be used to inform policymakers and practitioners about potential transportation and environmental outcomes under different trajectories of social distancing and economic recovery. This study also demonstrates a streamlined workflow to perform scenario planning related to COVID-19's disruption in transportation sectors.

The scope of this study is limited to passenger travel at county-level, due to limited data availability. In addition, only social distancing and economic factors are selected to develop potential scenarios, which can be expanded to include other factors as data become available. The scenario planning performed in this study reflect some immediate passenger travel trends and may not be representative of the long term. Some potential future directions include working with local stakeholders and conducting more refined analyses on: (1) collecting and analyzing data from other sectors, such as freight and transit; (2) investigating other influential factors on regional travel demand, such as population characteristics and land-use patterns; (3) integrating the scenario planning process into travel demand model instead of performing TDM post-processing to account for potential traffic assignment impacts, (4) combining trends expected from COVID-19 with other trends and changes to assess longer-term scenarios.

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