massDOT
Office of Transportation Planning

Impact of Teleworking: Evaluating Travel and Economic Effects for the Commonwealth

June 2024

Contents

List of Figures

List of Tables

1.0 Disclaimer

While this study was funded by the Federal Highway Administration (FHWA), the report contents do not necessarily reflect the official views or policies of the FHWA nor do the reports constitute a standard, specification, or regulation of FHWA.

2.0 Introduction

This report for the Massachusetts Department of Transportation (MassDOT) Office of Transportation Planning (OTP) evaluates a range of potential outcomes as increasingly more workers have greater opportunities to conduct their work without needing to be physically present at a traditional office or workplace.

The COVID-19 pandemic was a significant shock to the world affecting all aspects of life, including travel behavior, societal norms and acceptance of new ways of working—perhaps most notably teleworking. As the number of commute trips fell in the immediate term, several profound changes in regional travel occurred: peak hour travel patterns changed and the land use relationship between a place of work and housing location became more fluid as workers reduced or even eliminated their need to commute.

2.1 Objective

The goal of this project is to develop and assess plausible scenarios for how teleworking in Massachusetts may affect land use patterns, travel behaviors, and the Commonwealth's economy in the post-pandemic future. The report examines how anticipated increases in teleworking and changes in the distribution of growth (residential and employment) may change household vehicle miles traveled (VMT) and commute VMT, along with the macro-economic impacts associated with these changes.

2.2 Summary of Approach

This report provides a detailed summary of the study's analysis, which:

- Defined teleworking and established pre-pandemic travel patterns.
- Conducted a residential survey on teleworking and expectations for the future.
- Modeled statewide travel behavior using four scenarios exploring how changes in the rate of teleworking may change land use and travel behavior.
- Assessing the economic implications across the scenarios.

3.0 Understanding Teleworking Behavior to Inform Scenario Modeling

3.1 Defining Teleworking

In this report, 'teleworking' refers to a day spent working that excluded a physical commute trip.[1] This includes all work undertaken remotely, whether at the home or a location other than the workplace (e.g., a coffee shop) or at a location that serves as an *alternative* to the *dominant* workplace. This definition applies to those who sometimes commute to a workplace, and those who only work at home. A review of the literature and existing data sources found that a wide cross-section of terms describing various detailed subcategories are bundled together under the concept of teleworking – and that definitions vary by the supplier of the data.

Key Data Sources Reviewed

Three national studies provide important sources of insight on teleworking trends over time: the National Household Travel Survey (NHTS), the U.S. Census American Community Survey (ACS), and Bureau of Labor Statistics (BLS) Reports. These national sources of data are complemented by custom surveys initiated to track the travel behaviors associated with the COVID-19 pandemic including a national panel survey conducted by Resource Systems Group, Inc. (RSG) with over 30,000 respondents.

The literature and the data indicate that there are two primary groups of workers who may work from home, and it is important to distinguish which

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[1] Working at home after a day which included a commute is *not* included here as an example of teleworking; nor is any day which includes a commute to a workplace, or a unit of work undertaken on a day not normally including a commute trip.

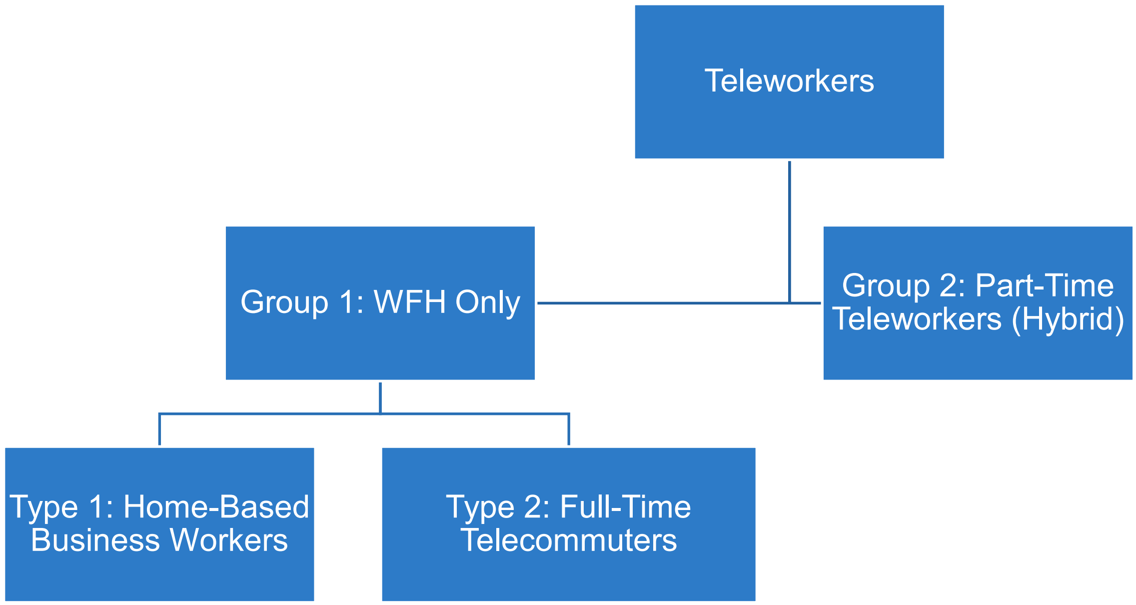
types are being referred to in the various data. Specifically, the NHTS divides workers into the following groups:

- **Group 1: Work From Home Only (WFH Only).** This group is a category of telework which includes workers who only telework and do not commute to a place of work. There are two main types of WFH Only workers.
    - **Type 1: Home-Based Business Workers**. This group is a subcategory of the NHTS category called "WFH Only," describing those that have their employment address matching their home address.
    - **Type 2: Full-Time Telecommuters**. This second subcategory describes workers who use technology to replace a physical commute to a place of work. Their home is not the same address as their place of employment, although they may do their work from their home. A subset of this group may also work in a third location, such as a library, coffee shop, or shared working environment.
- **Group 2: Part-Time Teleworkers (Hybrid).** This group is a category of teleworkers which includes workers who telework any amount less than full-time. This includes all workers who commute to a workplace some days and work from home some days.

The remaining workers outside of Group 1 and Group 2 are classified in Group 3 – those always commuting and working outside of the home (i.e., non-teleworkers).

The terms "teleworking," "telecommuting," and "working from home" (WFH) are interchangeable and used throughout this report. Both terms refer to Group 1 and Group 2 workers. The NHTS defines the WFH Only workers (Group 1) as those who "did work in the last week for pay or profit" and did not have a regular workplace outside the home. Therefore, the WFH Only classification does not include "hybrid" workers, or workers who work from a non-home workplace any number of days per week. The WFH Only classification encompasses the Type 1 home-based workers and the full-time Type 2 teleworkers as shown in *Figure 1*.

Figure 1: NHTS Telework Classification Subcategories



RSG COVID-19 Transportation Insights Survey

RSG initiated a national longitudinal panel survey during the early months of 2020 to track and better understand the quickly evolving nature of travel. By the spring of 2022, RSG had completed 10 waves of surveys and collected data from over 30,000 respondents from across the United States. This survey provided detailed information on occupation status, working status, travel behavior, and the degree to which teleworking was available and used by workers.[2]

2021 MassDOT Impacts of Teleworking Resident Survey

A survey of employed Massachusetts residents was designed and fielded to better understand past, present, and future teleworking and travel behaviors among workers across the Commonwealth.

A questionnaire asked residents for details about their job (including industry, occupation, commute mode, commute distance, and office location) and household (including members, demographics, vehicles, spending patterns,

[2] RSG COVID-19 Transportation Insights Survey. https://rsginc.com/covid-19-transportation-insights-survey/

and moving plans). It also asked about expectations for teleworking in a post-pandemic future.

A total of 1,101 responses were collected between November 1 and December 2, 2021, using an online panel provider. The dataset was cleaned, weighted to county-level demographics (age, income, gender), and then adjusted to account for county-wide population levels. This process resulted in 972 cleaned and weighted survey responses used in the analysis.

3.2 Potential Teleworking Implications for Regional Travel

Teleworkers' Travel Compared with Other Workers

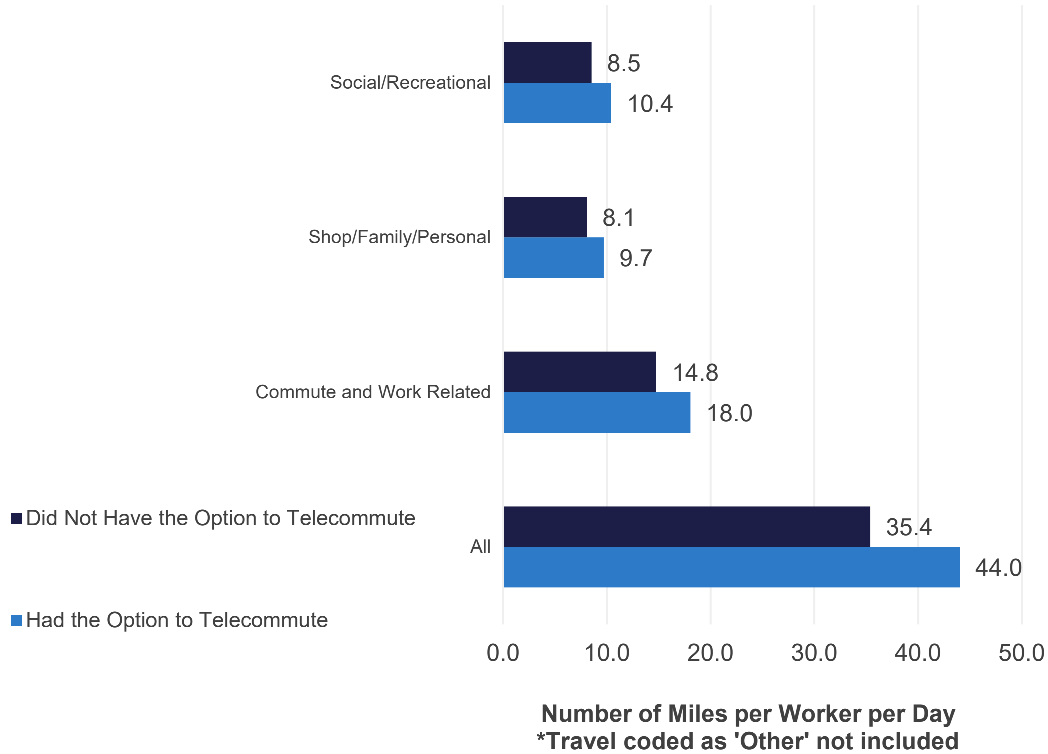
The aforementioned national data sources and surveys provide valuable insights into the characteristics of teleworkers and their travel behavior.

Compared to all workers nationally, workers who had the option to telework were more likely higher-income professionals in larger metro areas. The average miles traveled per day for *all purposes* was greater for workers who had the option to telework compared to workers who did not. For instance, the NHTS indicates teleworkers traveled longer distances to work (when they commuted) on average compared to other workers; 18 miles per day for teleworkers compared to 14.8 for others, as shown in *Figure 2.*

The NHTS data revealed differences in national pre-pandemic travel rates, including:

- Home-based business workers (Type 1) traveled nearly as many miles per day as other workers. That is, they traveled fewer miles commuting but traveled more miles for other purposes.
- Workers with the option to telework pre-pandemic had longer commute distances compared to workers without that option.
- Teleworkers were likely to be workers in large metro areas with higher incomes, and these workers also traveled more for other purposes compared to workers who could not telework.

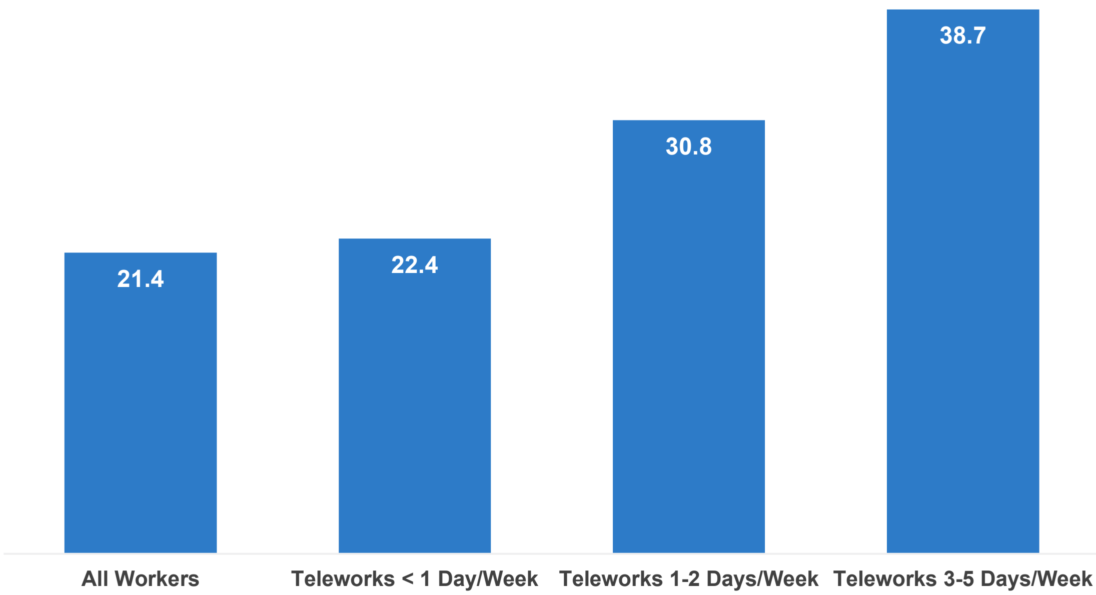
Figure 2: Miles per Day of Travel for Pre-Pandemic Workers Nationwide Who had the Option to Telework and Those that Did Not



Source: NHTS 2017

Consistent with the above trend on commute distance, those who telework more frequently appear to live further from the workplace locations, as shown in *Figure 3*, with those teleworking more than 3 days a week living an average of 39 miles away, while those teleworking only 1 day live an average of 22 miles from their workplace.

Figure 3: Distance to Work by Telework Frequency Pre-pandemic Nationwide



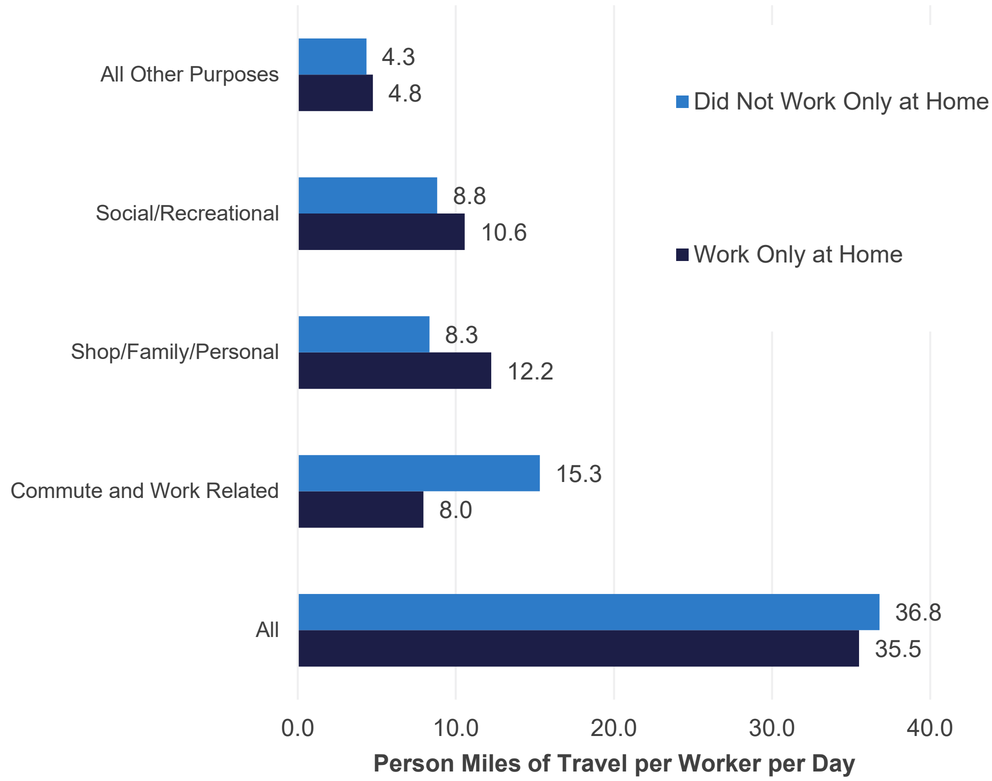
Source: NHTS 2017

Land use and housing location changes are much slower to occur than travel decisions made by household members. The trends identified by the NHTS are cross-sectional observations with limited ability to show trends over time.

Figure 4 compares the daily miles of travel by purpose for workers who worked *only* from home against all other workers in the sample. The chart summarizes the daily travel demand on the survey workday for these two groups of workers. The 2017 NHTS found that workers who usually worked *only* from home traveled 1.3 fewer miles per day than workers who did not work only from home.

These findings indicate that those who telework may live further from work with longer distances to other non-work activities. But those who are full-time working from home were observed to drive somewhat fewer miles in total than those who traveled to an outside place of work.

Figure 4: Miles per Day of Travel for Workers Who Worked only from Home and Those that Did Not



Source: NHTS 2017

Although demographics, such as age and gender, impacted travel rates, the overall pattern was similar: home-only workers appeared to travel more miles daily for household errands and social/recreational travel, while traveling less for commute and work-related reasons.

Commute Trips in Context

While commute work trips are a major influence on the configuration, design, and capacity of the transportation system, they represent only about 30% of miles generated[3], and perhaps 25% of individual trips (depending on various definitions of the work trip).[4]

This means that a hypothetical shift towards 14% more workers teleworking full-time (relative to the pre-pandemic base case) would result in a decrease of only 4% total household VMT. This simplified example assumes no changes to non-work trip activity with the change in household VMT only due to an eliminated commute trip.

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[3] https://rosap.ntl.bts.gov/view/dot/68751

[4] NHTS 2017

3.3 Pre-pandemic Trends in Teleworking

In 2017, the National Household Travel Survey (*Table 1*) showed that full-time teleworkers (categorized as "Teleworking Only") reported teleworking an average of 3.85 days a week. Hybrid teleworkers ("Commute with Some Teleworking") were teleworking about 1.15 days a week pre-pandemic. Given that most (71%) workers in 2017 were categorized as "Commute Only," in 2017 telework accounted for only about six tenths (0.64) of one day per week for workers as a whole (which represents about 13% of all employed time).[5]

Table 1: NHTS 2017 Results Recalculated for Percentage of Days of Employment

Metric	Percentage of Sample in Category	Days per Week Teleworking
Commute Only	71%	0
Commute with Some Teleworking	17.5%	1.15
Teleworking Only	11.5%	3.85
Total	100%	–
Days per Week Equivalent for Teleworking	–	0.64
Teleworking Days as % of All Employment Days	13%	–

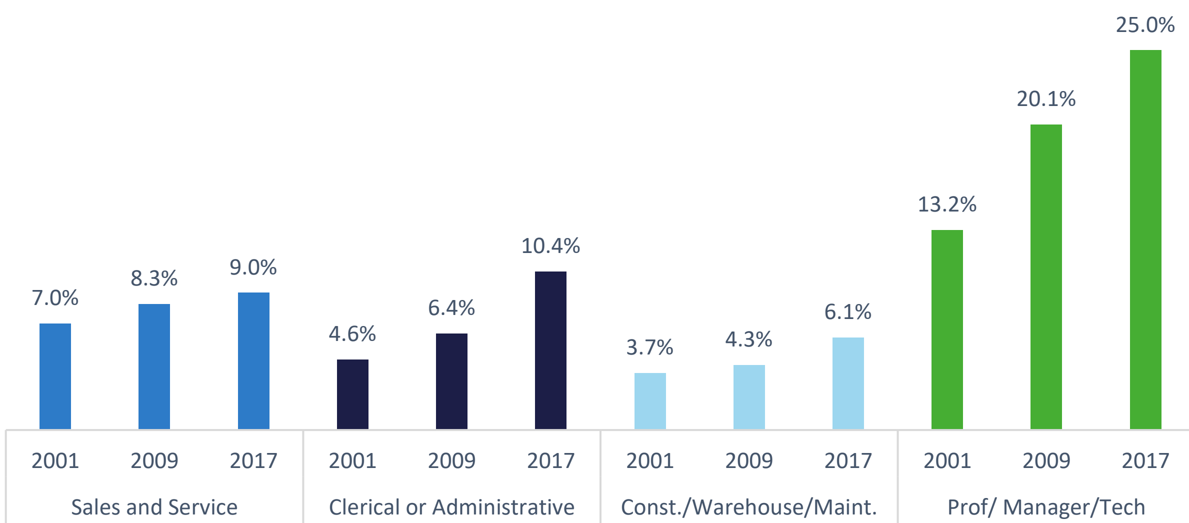
Source: NHTS 2017 (adapted by RSG)

[5] There are issues regarding what is defined as a "working day" across the surveys, and how each survey process was able to answer whether when the worker remained home, was that worker replacing a commute or a home-based employment location?

Occupation Matters

By 2017, national data indicated that a quarter of high-income workers and workers in professional/technical/managerial occupations had the option to telework compared to just 8% of lower income workers and 10% or less of workers in other occupations, as shown in *Figure 5*.

Figure 5: Pre-pandemic Nationwide Trends in Teleworking Usage on day of Survey by Occupation



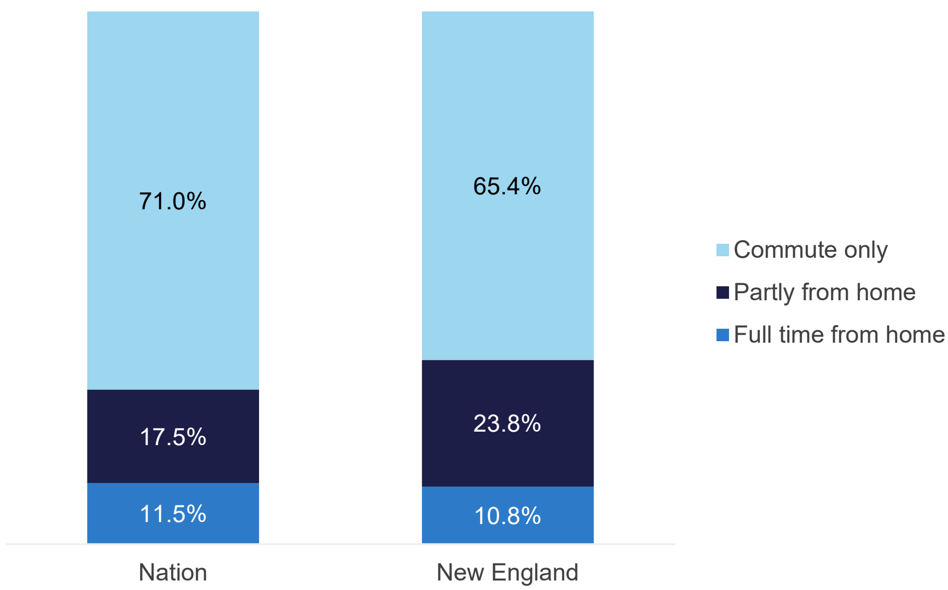
Source: RSG analysis of NHTS Data Series 2001 – 2017

Massachusetts in context - New England Teleworkers

Teleworking pre-pandemic was more prevalent in New England than in other parts of the country. This is likely due to the fact that New England has a higher share of workers that are in professional/technical/managerial occupations: 57% compared to 48% nationwide, providing greater opportunities for teleworking.

Figure 6 shows NHTS data organized into three categories comparing pre-pandemic teleworking rates for New England compared with the nation.

Figure 6: Pre-pandemic Percent of Workers Teleworking—New England vs. National

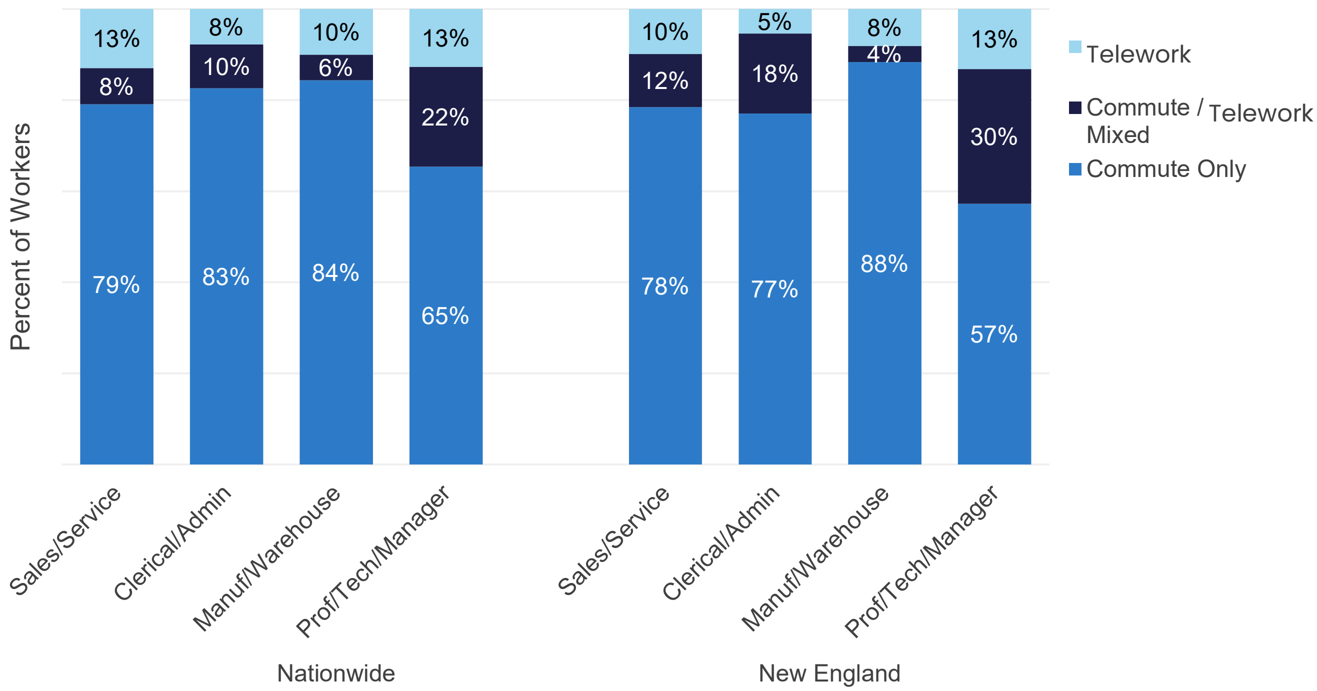


Source: NHTS 2017

Figure 7 further breaks down the New England work from home rates with greater distinction between occupations and the propensity to commute, work from home part-time, and full-time work from home.[6]

[6] The New England region consists of Massachusetts, Connecticut, Rhode Island, Maine, New Hampshire, and Vermont

Figure 7: Variation in Commute Type New England and Nationwide, by Occupation (Pre-Pandemic)



Source: NHTS 2017

3.4 COVID-19 Paradigm Shift

The onset of the COVID-19 pandemic in March 2020 rapidly accelerated the previously gradual emergence of improved network, security, and video conference technologies. This COVID-plus-capability paradigm shift led to substantial increases in the share of workers teleworking. There was significant growth in those able to work from home who began doing so full-time (Group 1 Type 2 in Figure 1), leading to dramatic changes in travel locally, regionally, and nationally.

Those changes were not evenly distributed across workers. The pre-pandemic teleworking trends based on workers' occupations were mirrored by the general degrees of teleworking observed in surveys conducted during the COVID-19 pandemic period. The three job groups of "remote," "mixed," and "onsite" were developed to define groups of occupations with similar teleworking travel behaviors.

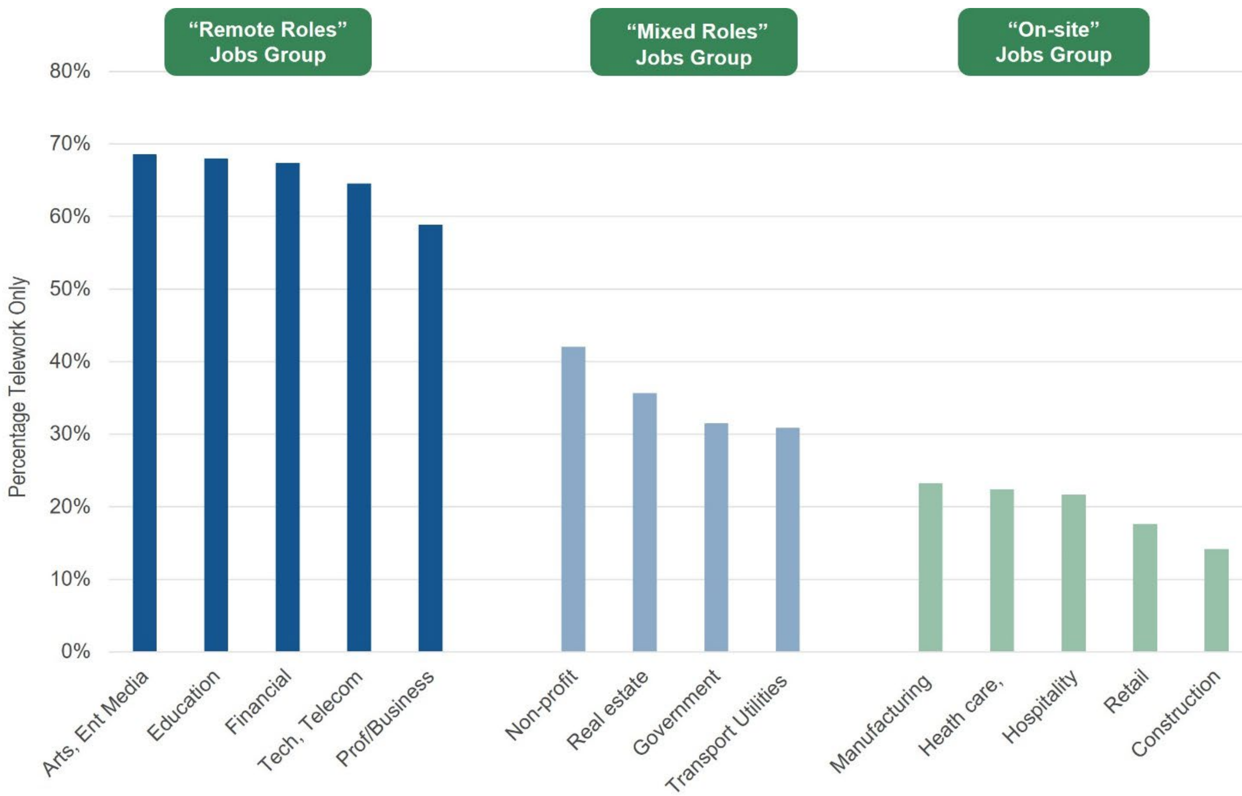
These categories are defined based on this study's literature review, the COVID-19 Transportation Insights Survey and an extensive analysis of a longitudinal household travel survey in Ohio using an rMove^{tm} dataset made available by Ohio DOT for use in this study.[7] Occupational data (i.e., BLS Standard Occupational Classification) was found to have a stronger relationship with teleworking as compared to industry classification (i.e., NAICS), however, occupational data is less frequently sampled than industry data.

The grouping of occupations into the three job group categories is a convenient way to monitor changes over time and were used in the modeling of future changes in travel behavior as a consequence of increases in teleworking.

Figure 8 shows occupation categories sorted into the three job group categories, which are based on the rate of workers teleworking in mid-2020. The occupations with the highest rate of telework only workers are categorized in the "Remote Roles" jobs group, the middle rates of telework only employees are sorted into the "Mixed Roles" jobs group, and the occupations with the lowest rates of telework are categorized as "On-site." Similar patterns, although different scales, of teleworking are observed in the national NHTS teleworking trends shown in Figure 5.

[7] rMove is a survey application used by RSG to conduct household travel surveys. https://rsginc.com/rmove/

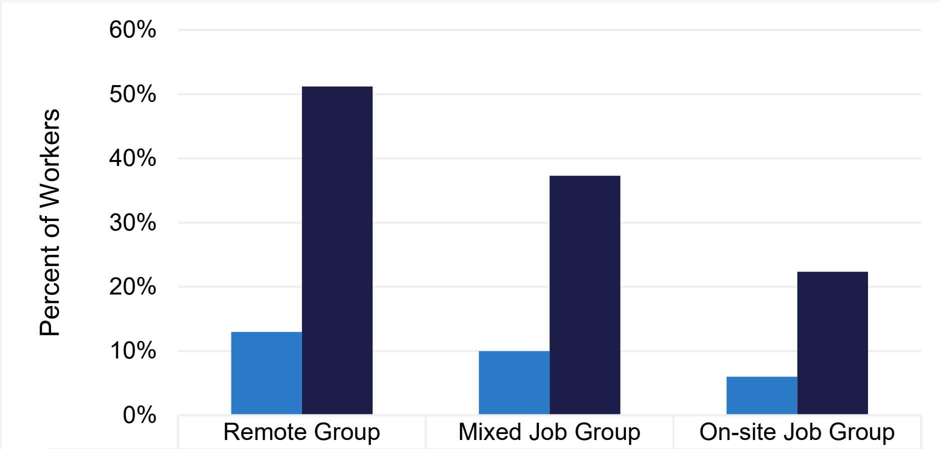
Figure 8: Teleworking Only Percentages by Teleworking Category and Occupation during Peak COVID-19 (mid-2020) Pandemic Teleworking Rates



Source: RSG COVID-19 Transportation Insights Survey

At the onset of the COVID-19 pandemic, the number of days spent teleworking increased across all job groups, but in different magnitudes. *Figure 9* shows the variation in national teleworking rates among the three categories pre-pandemic (2019) and for the peak during the pandemic (around mid-2020).

Figure 9: Nationwide Teleworking Rates 2019 and Mid-2020 by Jobs Group



	Remote Group	Mixed Job Group	On-site Job Group
2019	13%	10%	6%
Mid-2020	51%	37%	22%

Source: RSG COVID-19 Transportation Insights Survey

3.5 Post-Pandemic Teleworking Prevalence

The survey of Massachusetts residents conducted for this study provides a sense of the potential future trajectory of teleworking in the Commonwealth.

The expected degrees of teleworking by county are shown in *Figure 10*. They range from an average of 0.79-2.23 days that residents expect to telework (or work from home) each week in a post-pandemic future, with a statewide average of 1.69 days a week.

Figure 10: Average Expected Future Teleworking Days per Week for Massachusetts Residents, 2021

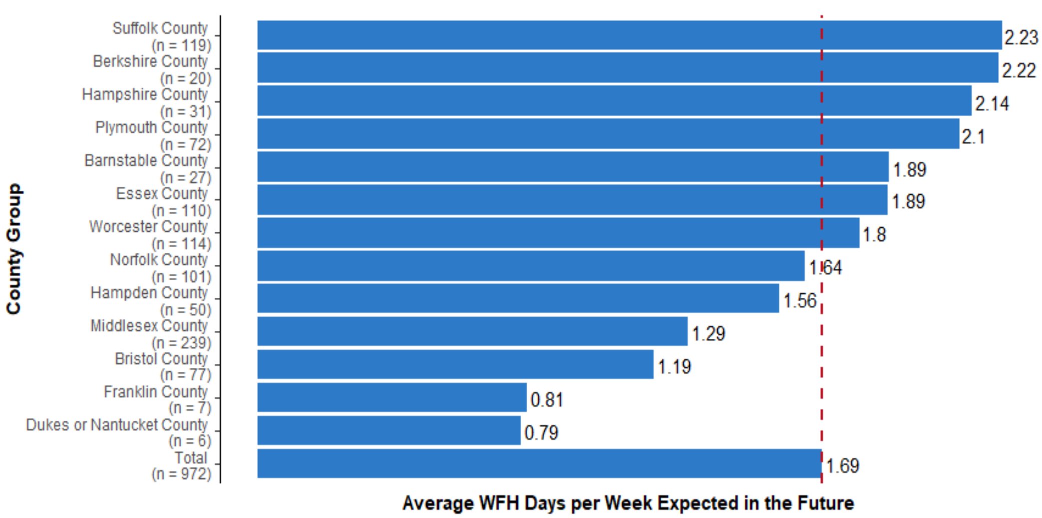


Figure 11 shows teleworking rates from the resident survey at different points in time, pre-pandemic and during 2020 and 2021. The occupations comprising the "remote" job industry group saw the most substantial increase from 29% of days being teleworked pre-pandemic to 50% in November 2021. The mixed group increased from 19% to 29% and on-site increased by 4 percentage points.

The results reinforce the relative flexibility some occupations have towards teleworking relative to certain on-site occupations where there is little current opportunity for teleworking. It is noted that in all cases, workers anticipate increasing their degree of teleworking relative to pre-pandemic rates.

Figure 11: Massachusetts Reported and Expected Teleworking Rates by Jobs Group

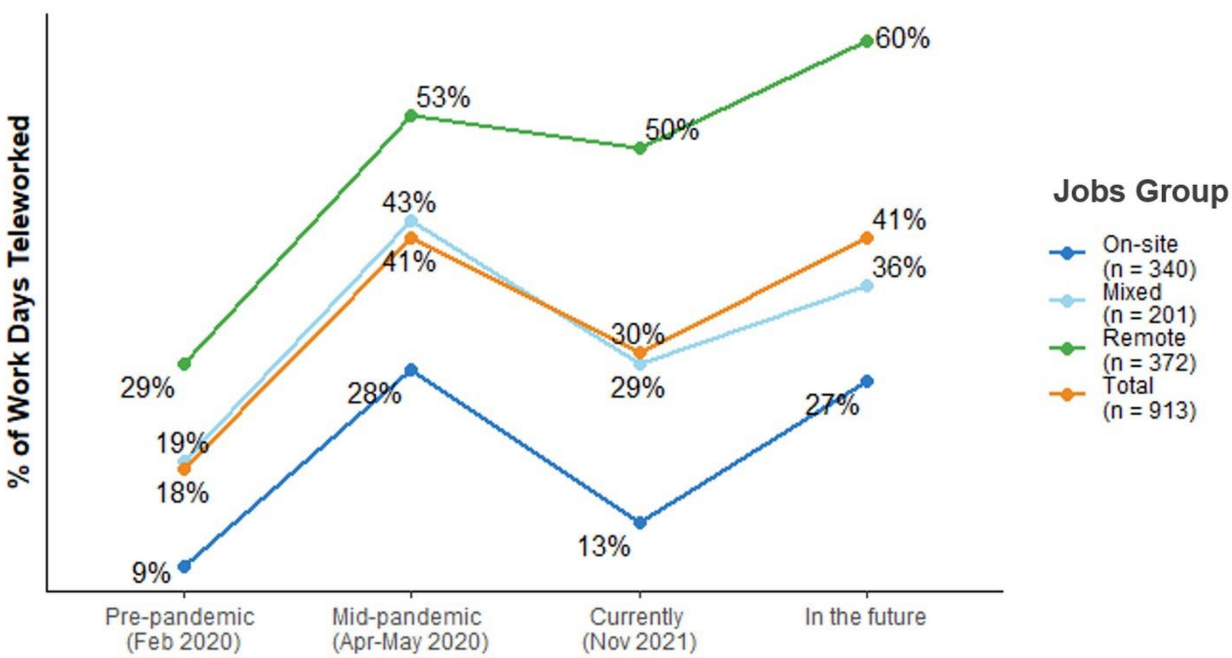
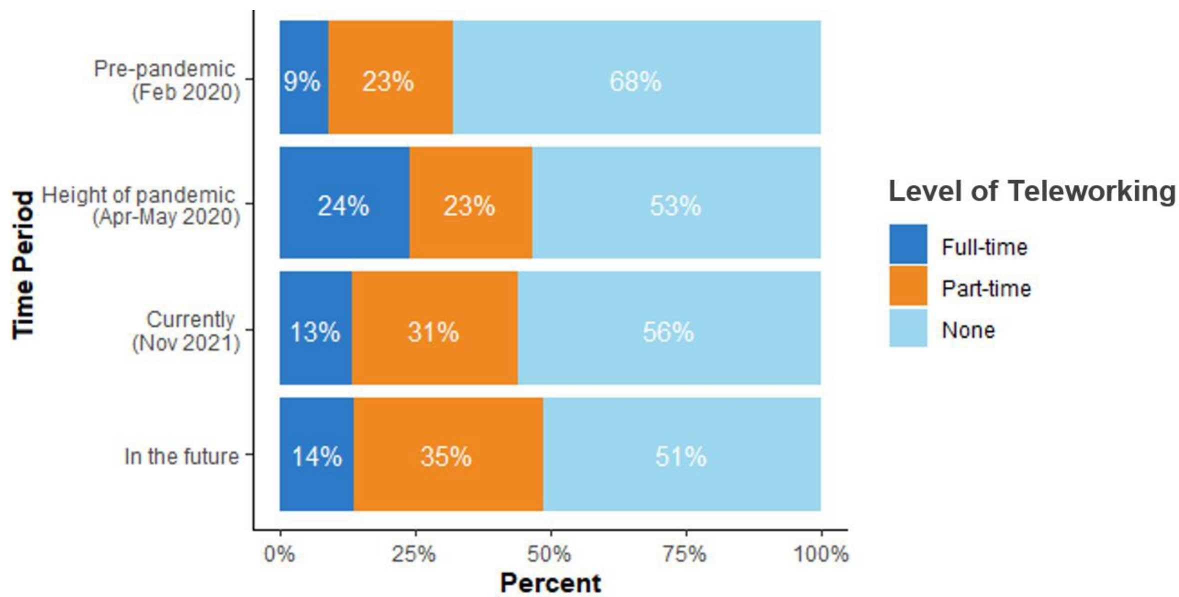


Figure 12 shows the aggregated portion of work weeks that individual workers teleworked and anticipate teleworking over time. There were small increases in the amount of full-time teleworking compared to pre-pandemic, with larger increases seen in the proportion of workers teleworking part-time (e.g., hybrid schedule).

Figure 12: Massachusetts Workers Level of Teleworking by Time Period



Over time, teleworking rates may stabilize, given changes in social norms, worker expectations, and the technological capabilities that exist to enable a remote workforce. While there is uncertainty in the exact rates of teleworking, the data suggest that these rates will be higher than pre-pandemic levels.

Key Findings for Massachusetts Residents

The following Massachusetts-specific findings were most critical for the development of the scenarios and transportation modeling described in Chapter *4.0*.

- Remote industries have seen a significant increase in teleworking over the last several years; mixed industries have seen a slower and steadier increase; and on-site industries, although clearly having reacted to the pandemic in the late spring of 2020, are currently close to near pre-pandemic levels. In all cases, the future propensity to telework is expected to be higher than it was before the pandemic.

- Regardless of industry and occupation types, workers in Massachusetts expected their future propensity to telework to be higher than it was before the pandemic.
- Each job group (remote, mixed, on-site) has followed similar trajectories at different magnitudes, with workers in the "remote" group seeing a slightly smaller drop-off in teleworking after the height of the pandemic. In the future, on-site industries expect a three-fold increase in teleworking compared to before the pandemic (9% to 27%) while mixed and remote industries' teleworking rates are expected roughly to double.
- The shift to teleworking is most prominent among younger residents of Massachusetts, who expect to telework in the future at least 2 days per week. This is a change from pre-pandemic conditions, when older workers were teleworking more frequently than younger workers.
- Residents of households with higher incomes ($75,000 or more annually) expect to telework at higher rates than those with lower incomes.
- Expected future teleworking rates are highest among individuals living in households with 4 or more people and lowest among individuals living alone.
- Respondents with 2 or more household vehicles expect to work remotely around 2 days per week in the future. Those without access to a household vehicle expect to work from home only 1.2 days per week.
- Respondents with longer commutes expect to telework more in the post-pandemic future compared to those with shorter commutes. The exception is those who have very short commutes (less than 5 miles) who also expected relatively high rates of teleworking, expecting to work remotely an average of 1.65 days per week in the future.

4.0 Modeling Future Telework Scenarios

4.1 Overview

Scenario testing is a means to explore and test a range of possible future outcomes. The scenario design was informed by the literature and data reviewed, which suggested strong connections between the residence location of workers and the rate of teleworking. The findings summarized in Chapter 3.0 informed enhancements to this statewide travel modeling exercise to better account for the effects that teleworking has on daily household travel and commute travel.

4.2 Statewide Travel Modeling

The VisionEval strategic model was used to evaluate the effects of teleworking on travel behavior. The VisionEval-State (VE-State) model analyzes travel behavior and is used in the evaluation of how increased levels of teleworking may affect travel behavior and how land use may influence the resulting demand for travel.

VE-State is a strategic travel demand model used to evaluate transportation policy impacts. It is one of three models built on the VisionEval open source programming framework. VE-State, like the other VisionEval models, may be described as a "disaggregate demand/aggregate supply" travel demand model. It combines the demographic and socioeconomic detail of simulated households with aggregate treatments of travel (multimodal travel and congestion without using a coded transportation network). By creating a simulated (i.e., synthetic) set of individual households—each associated with specific annual household income, vehicle ownership, and other characteristics—strategic travel demand models can examine equity effects, the impacts of fuel prices and other pricing policies, changes in population demographics and employment, and other factors on mode choice and travel behavior.

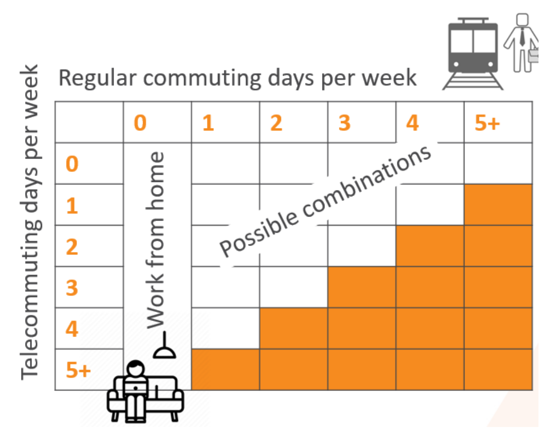
The VE-State model is estimated using nationally available datasets, including U.S. Census ACS Public Use Microdata Sample (PUMS), National

Household Travel Survey (NHTS), Highway Performance Monitoring System (HPMS), National Transit Database (NTD), and the US Environmental Protection Agency's Smart Location Database (SLD).

The VE-State model includes a base (2015) and future reference year (2050). Beyond the reference model for 2050, four additional future year scenarios are tested in this study. The model years were selected to leverage a previous earlier generation strategic planning model developed for Massachusetts, the MassDOT Emissions Reduction Policy Analysis Tool (EERPAT) that uses the same model years.[8] EERPAT and VE-State are within the same family of strategic planning models, and there are many similar and overlapping inputs between the two models.

The VE-State model for Massachusetts was enhanced as part of this effort to include additional information on the employed residents, (i.e., workers) to better account for the effect that teleworking has on their travel behavior. A new "work from home" module within VE-State accounts for the teleworking category of the worker's occupation and then estimates the number of days that the worker may telework (full-time 5-days a week down to one day a week part-time). *Figure 13* shows the combinations of teleworking and the results, given how many days commuting vs teleworking. Each individual worker is modeled, and each has a different propensity to telework given their individual attributes (commute distance, age, income, household members, etc.).

Figure 13: Teleworking Rates



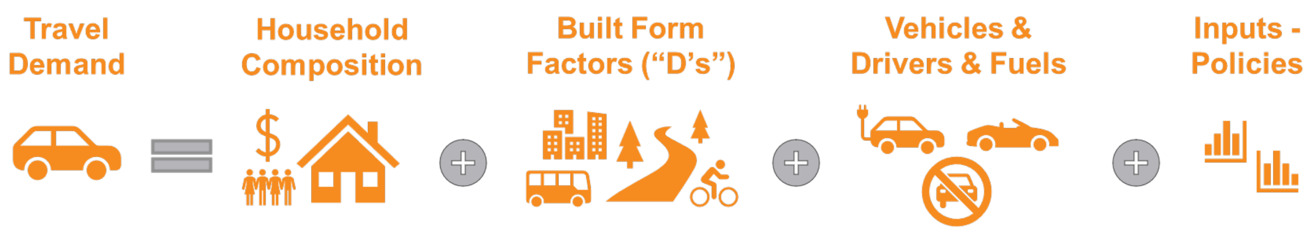
Source: Atlanta Regional Council adapted by RSG

Strategic models are designed to model travel behavior at the household level (although some attributes are modeled for each individual within the

[8] https://www.mass.gov/service-details/modeling-ghg-reduction-policies

household, as noted above). Each household in Massachusetts is described by the number of occupants, the household income, whether the occupants are employed or not, and the travel options and surrounding land use characteristics (the "D's" of density, diversity, design) of the household. Each of those attributes are known to influence the amount of travel that the household generates. The concept is shown in *Figure 16*.

Figure 14: VE Household Travel Demand Concept



The teleworking and land use scenarios developed and analyzed evaluate the changes in travel behavior only through shifts in housing location, work location, and rates of teleworking among the teleworking categories. The resulting changes in household travel demand are summarized for each of the teleworking scenarios. VE-State's geographic resolution produced several outputs at the sub-county-level (referred to as "bzone" level), which is approximately the size of census block groups. Each of these bzones were aggregated up to the county-level used within this report. In addition to the sub-county input levels there are land use classifications referred to as Area Types in VE-State. These include Urban, Town, and Rural designations that are defined by the U.S. Census classifications of Urbanized Areas, Urban Clusters, and all other areas primarily defined by the population and population density of the area. For this study's scenario design and development, the "Town" area type was classified as "Exurban."

Additional details on the selection of VE-State for this study can be found in *Appendix A: Transportation Model Selection Process*.

4.3 Future Reference Scenario

The Future Reference Scenario reflects the expected "business as usual" conditions forecast for 2050 starting from 2015. The Future Reference Scenario was developed using statewide forecasts for Regional Planning Associations for the 2040 MassDOT Long Range Transportation Plan "We Move Massachusetts" and is consistent with the demographic forecasts used in the 2050 Massachusetts Decarbonization Roadmap completed by the Executive Office of Energy and Environmental Affairs (EEA) in 2020.[9] Given it was created in 2015, this scenario does not account for any changes due to the COVID-19 pandemic, nor more recent updates on population or economic changes.

The Future Reference Scenario is the baseline by which all other scenarios for the year 2050 are compared (sometimes referred to as the "Base" model because it retains pre-pandemic assumptions of the future). The Future Reference Scenario assumes a growth of 626,672 persons and 429,236 jobs across the Commonwealth (see *Table 2*). Note that all other scenarios maintain this overall change in population and jobs; they are simply distributed differently in spatial terms based on the amount of land use change the scenario considers.

Table 2: Growth Totals for the Future Reference Scenario

	Base Year 2015	Future reference 2050	Change
Population	6,784,259	7,410,931	626,672
Jobs	3,180,245	3,609,481	429,236

[9] https://www.mass.gov/info-details/ma-decarbonization-roadmap#:~:text=EEA%20has%20developed%20a%20roadmap,pathways%20to%20net%2Dzero%20emissions.

For the 2050 Future Reference Scenario, teleworking rates were set to align to the best extent possible with pre-pandemic rates described in Section 3.3. This translated to:

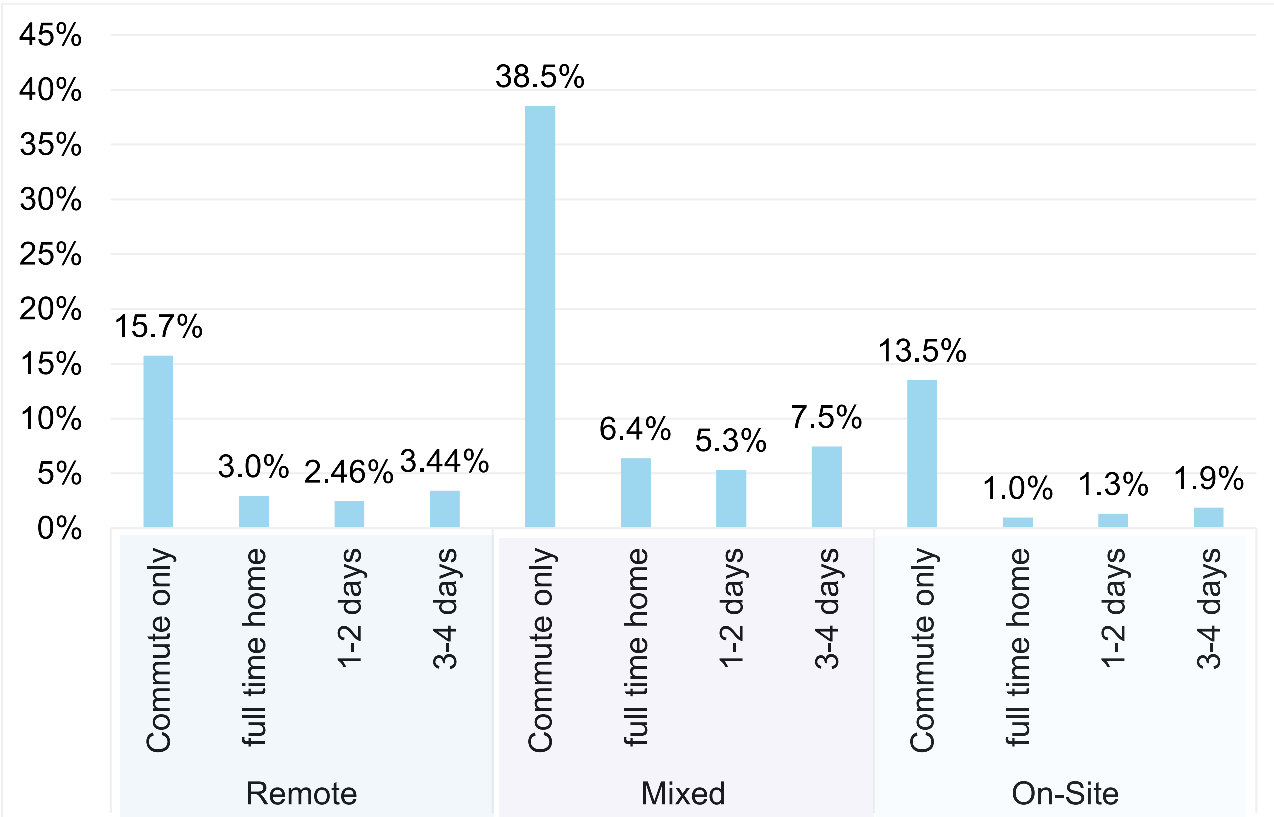
- 67.8% of workers are full-time commuters (Group 3)
- 10.3% are full-time home workers (Group 1 reflecting those who telework and those who do not have an outside the home place of work)
- 21.9% workers are hybrid (Group 2 part-time teleworking and part-time commuting)

The Future Reference Scenario expects a 38% increase in daily household VMT and 19.5% increase in the commute daily VMT from 2015 base conditions. The reasons for the increase are multifaceted. Beyond simple population and employment growth the simulated households in the VE-State model include attributes of changes in real household income, changes in land use density and diversity, proximity to transit and other alternative modes, fuel and energy price assumptions, and the underlying age and cohort effects (all the components included in Figure 14). If any of these assumptions were to change, then the Future Reference Scenario values would change. In the design of the four scenarios tested, all these future conditions are held constant, focusing only on the two dimensions that *do* change – residential and workplace location and the rate of teleworking.

Scenario	Household DVMT Percent Change from 2015	Commute DVMT Percent Change from 2015
Future Reference Scenario	38.0%	19.5%

Figure 15 shows the overall travel patterns for workers in Massachusetts in the Future Reference Scenario, weighted by the share of workers in each of the three teleworking categories.

Figure 15: Workers' Teleworking Rates for Future Reference Scenario, by Job Group



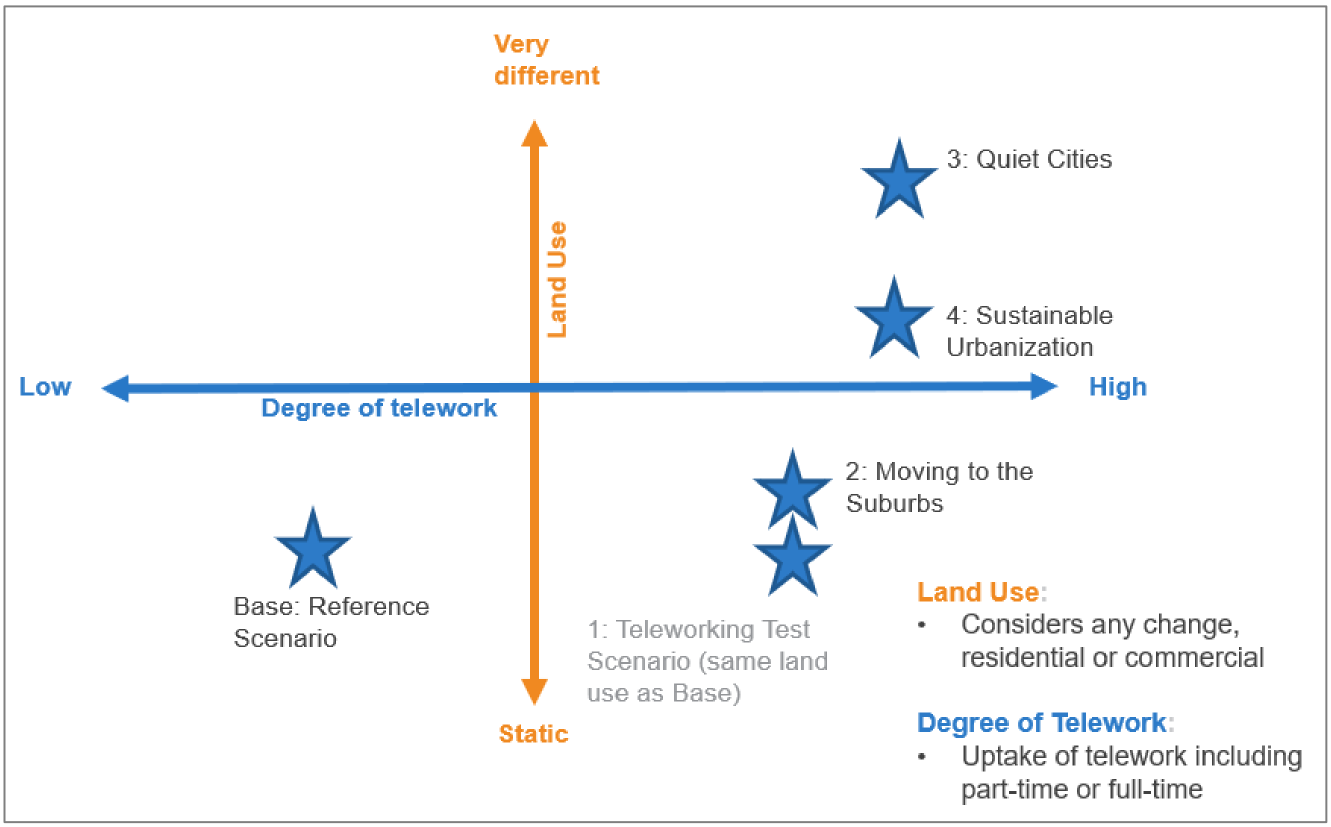
4.4 Scenario Design

Dimensions of Change

Figure 16 shows the two dimensions of land use and teleworking explored in the scenarios. "Land use" refers simply to the degree of change in the residence location and/or work location relative to the future reference condition. The degree of telework change refers to the overall rate of teleworking (part-time and full-time) relative to pre-pandemic levels used in the Future Reference Scenario. Commute distance, commute frequency, and mode choice are accounted for in the VE-State model and are affected by the land use / teleworking nexus.

The scenarios are based on changes between the present day and the future year of 2050. The change in population and employment from today to the future year 2050 is accounted for in the Future Reference Scenario. One of the assumptions across all scenarios is that all counties in the state will have at least as many residents or jobs as today. The scenarios simply shift the total expected growth in residents and jobs between different parts of the Commonwealth, with the shifts in growth occurring both within and between counties.

Figure 16: Scenarios - Land Use / Teleworking Relationship



The dimensions of change for each scenario are further described in *Table 3* which shows the four scenarios along with the amount of growth (low to high) for urban employment, urban residential, exurban/rural employment, exurban/rural residential, and the rates of part-time vs full-time telework. All shifts in growth and telework rates represent increases from the pre-pandemic trend unless otherwise specified as "less than pre-pandemic trend".

Table 3: Growth Trends for the Scenarios

Scenario	Urban Land Use Changes		Exurban / Rural Land Use Changes		Rate of Teleworking among Eligible Workers	
	Urban Employment	Urban Residential	Exurban/ Rural Employment	Exurban/ Rural Residential	% Teleworking Part-Time	% Teleworking Full-Time
Future Reference Scenario	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**
Scenario 1: Teleworking Model Test	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**High**	Low
Scenario 2: Moving to the Suburbs	**Pre-pandemic trend**	**Less than pre-pandemic trend**	**Pre-pandemic trend**	**Med-High**	**High**	Low
Scenario 3: Quiet Cities	**Less than pre-pandemic trend**	**Less than pre-pandemic trend**	**High**	**High**	**High**	**High**
Scenario 4: Sustainable Urbanization	Low	**High**	**High**	**Med**	**High**	**High**

Scenario Details

This section describes how each scenario's land use changes and teleworking rates translate into changes within the VE-State model.

Scenario 1: **Telework** uses the 2050 Future Reference Scenario's land use assumptions and varies only the number of workers who are teleworking.

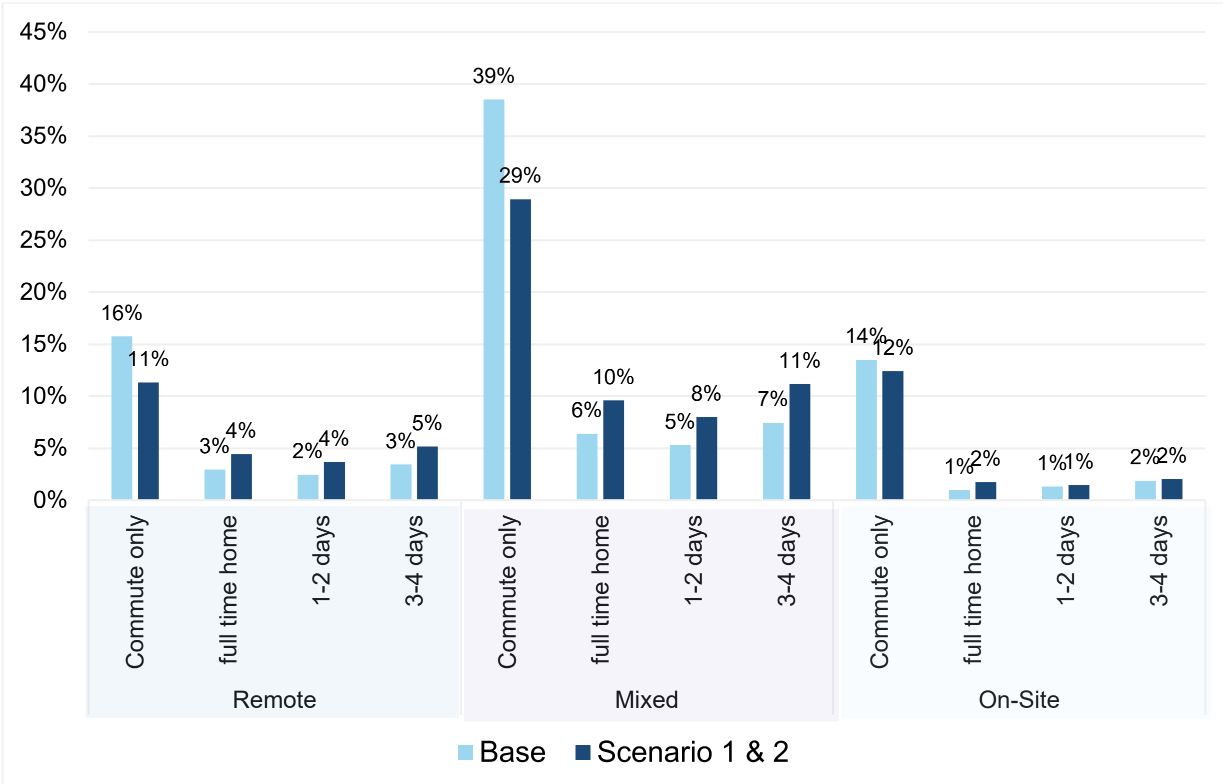
Figure 19 shows the changes in teleworking rates between the base pre-pandemic levels used in the Future Reference Scenario and Scenarios 1 & 2 (which use the same teleworking rates).

Relative to the 2050 Future Reference Scenario (Base), Scenario 1 has:

- 22% fewer daily full-time commuters (presume 5 days commuting)
- 53% more full-time home workers (only 16% of overall workers)
- 44% increase in the number of workers hybrid teleworking 1 to 4 days a week (32% of overall workers)

These changes increase the average number of days teleworking from 1.1 in the base scenario up to 1.6 days in Scenarios 1 & 2.

Figure 17: Workers' Teleworking Rates for Base and Scenarios 1 & 2, by Job Group



Scenario 2: **Moving to the Suburbs** has a greater share of eligible workers teleworking part-time relative to the 2050 baseline, using the same teleworking rates as Scenario 1. This scenario shifts the residential location of workers further away from denser urban cores into less dense town locations. Some growth moves further into rural/exurban locations. This pattern of moving away from density was observed in some of the Massachusetts survey responses. Part-time teleworking requires a physical commute at least one day a week to a workplace, which limits the viable residential location to work distance.

Figure 17 shows the changes in teleworking rates between the base and Scenarios 1 & 2 (which use the same teleworking rates). Relative to the 2050 Future Reference Scenario, Scenario 2 has:

- 22% fewer daily full-time commuters
- 53% more full-time home workers (still only 16% of workers)

- 44% increase in the number of workers hybrid teleworking 1 to 4 days a week
- Residential
  - 4.4% decrease in the households in urban areas, 38% increase in households in town areas, and 54% increase in households in rural areas.

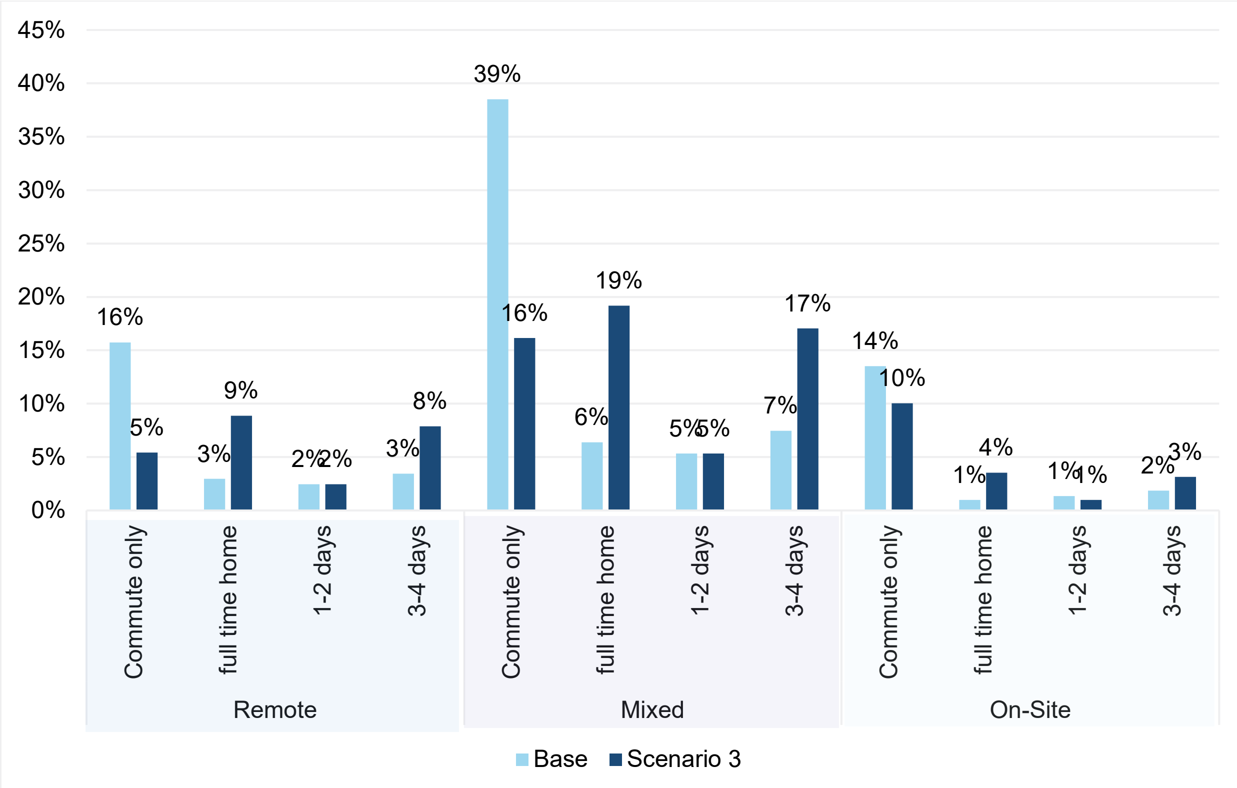
Scenario 3: **Quiet Cities** uses high rates of teleworking, both full-time and part-time, and correspondingly reduces employment in urban locations (dense employment centers). In this scenario, employers shift workplaces out of urban cores into more predominantly residential areas closer to the workers. The growth in city cores slows, while land use change accelerates in town and rural/exurb areas. Traditional residential locations see an increase in mixed use, rather than primarily residential growth.

Figure 18 shows the changes in teleworking rates between the base and Scenario 3. Relative to the 2050 Future Reference Scenario, Scenario 3 has:

- 53% fewer daily full-time commuters
- 3x more full-time home workers (remains only 32% of workers)
- 68% increase in the number of workers hybrid teleworking
- Residential
  - 79% of Urban Growth remains in Urban Areas. 55% of Urban Growth shifts which urban area it is tied to. For example, 100,000 of Suffolk population growth is estimated to move to other counties. However, other counties' population may still experience movement to Suffolk.
  - Town growth increases 265% and Rural growth by 243%
- Employment
  - 91% of Urban job growth remains in Urban Areas. 5x growth in Town areas and 29x more Rural jobs (although remains only 7% of overall statewide job growth)

These changes increase the average number of days teleworking from 1.1 in the base scenario up to 2.6 days in Scenario 3.

Figure 18: Workers' Teleworking Rates for Base and Scenario 3, by Job Group



Scenario 4: **Sustainable Urbanization** uses high degrees of teleworking, particularly part-time, that concentrates land use changes and growth in areas that are already primarily urban in nature. In this scenario, urban cores become more spatially diverse by attracting greater shares of residents and jobs.

Figure 19 shows the changes in teleworking rates between the base and Scenario 4. Relative to the 2050 Future Reference Scenario (base) Scenario 4 has:

- 42% fewer daily full-time commuters
- 2x more full-time home workers
- 80% increase in the number of workers hybrid teleworking
- Residential
    - 2% growth in Urban households. Town growth decreases by 8% and Rural growth decreases by 25%.
- Employment
    - 2% less growth in Urban jobs. 69% growth in Town areas and 63% more Rural jobs (although remains only 4% of overall statewide job growth).

These changes increase the average number of days teleworking from 1.1 in the Future Reference Scenario up to 2.1 days in Scenario 4.

Figure 19: Workers' Teleworking Rates for Base and Scenario 4, by Job Group

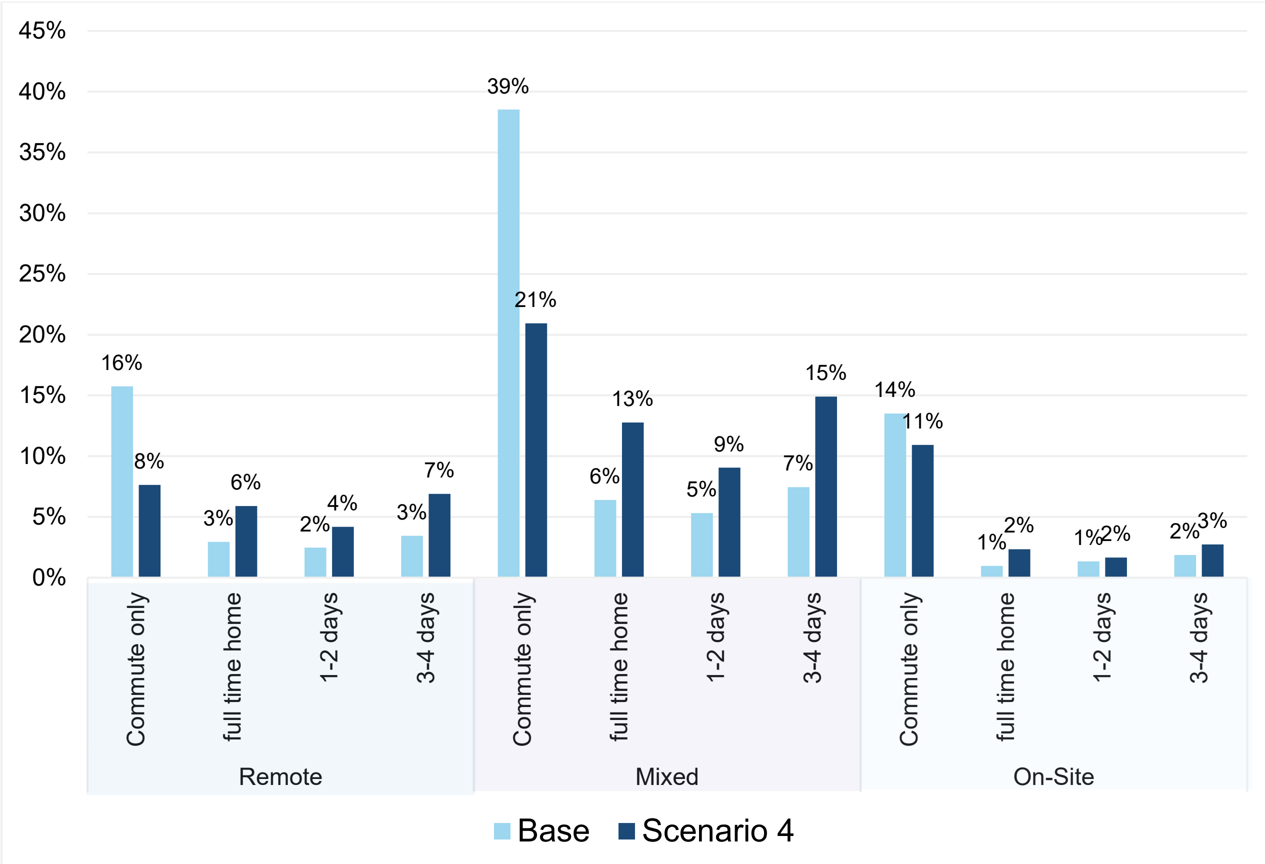
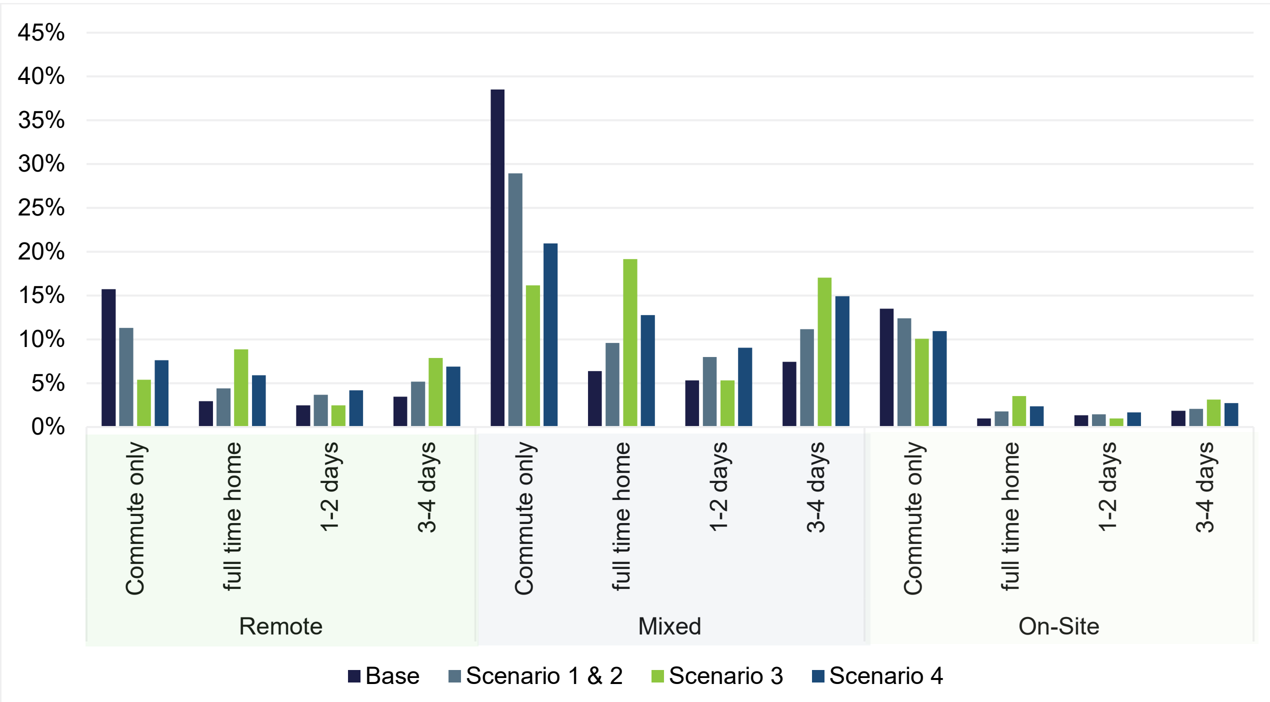


Figure 20 shows the variation in teleworking and commute rates for each of the four scenarios. The chart shows the decrease in commute rates relative to the base and changes in part-time vs full-time teleworking rates between the scenarios.

***Figure 20**: Workers' Teleworking Rates for 4 Scenarios, by Job Group*



4.5 Findings by Scenario

Overall Summary

Each of the four teleworking scenarios produces changes in household daily vehicle miles of travel (DVMT) and changes in commute travel in the year 2050. The scenario results are compared both to the existing base condition of 2015 and the future year 2050 reference scenario. The Future Reference Scenario represents the changes in travel demand between 2015 and 2050 in the absence of changes associated with an increase in teleworking.

Daily Household Travel

Table 4 shows the percent change in household DVMT by scenario.

Table 4: Household VMT Change by Scenario

Scenario	Household DVMT Percent Change from 2015	Household DVMT Percent Change from 2050 Future Reference Scenario
Future Reference Scenario	38.0%	0%
Scenario 1: Telework	36.7%	-0.90%
Scenario 2: Moving to the Suburbs	37.2%	-0.55%
Scenario 3: Quiet Cities	35.4%	-1.83%
Scenario 4: Sustainable Urbanization	34.3%	-2.65%

The scenarios indicate that overall, daily household VMT is expected to grow between 34-38% from 2015 by the year 2050. Shifts in land use and teleworking rates are associated with lower growth in household VMT—all scenarios show a small reduction in household VMT below the reference case in 2050. Scenario 4, with its urban intensification and greater mix of residential and non-residential uses, results in the greatest reduction of daily household VMT below the reference scenario.

The reductions from baseline do not necessarily mean that total VMT in 2050 will be below the baseline forecast, as only household VMT was modeled in this study. Total VMT includes freight traffic and commercial traffic and this study has not modeled the effects that changes in telework, and associated changes in land use and household VMT, could have on these other components of total VMT.

Daily Commute Travel

Table 5 shows the percent change in commute DVMT by scenario.

Table 5: Household Commute VMT Change by Scenario

Scenario	Commute DVMT Percent Change from 2015	Commute DVMT Percent Change from 2050 Future Reference Scenario
Future Reference Scenario	19.5%	0%
Scenario 1: Telework	9.9%	-8.06%
Scenario 2: Moving to the Suburbs	10.9%	-7.20%
Scenario 3: Quiet Cities	-15.4%	-29.22%
Scenario 4: Sustainable Urbanization	-1.2%	-17.33%

The Future Reference Scenario forecasts an increase of 19.5% in daily commute VMT. The change from the 2050 Future Reference Scenario shows that each of the four scenarios will reduce the daily commute VMT. Scenarios 1 and 2 reduce the magnitude of that growth while Scenarios 3 and 4 show that the combined increases in teleworking rates and changes in land use patterns would reduce overall commute VMT in the year 2050 below 2015 levels of commute VMT.

Scenario 3, with its high rate of full-time teleworking, results in the greatest reduction in commute VMT. Scenario 4 also significantly reduces commute VMT due to the urban intensification and greater mix of residential and non-residential uses.

It should be noted that changes in household commute VMT do not always translate into reductions in overall household VMT. This is partially because commute VMT only accounts for a fraction of household VMT, but also the shift to teleworking may free up available time for other trip making (not commute related) or changes in residential location may increase the distance required for other household activities. The VE-State model was enhanced to reflect empirical travel behaviors of teleworkers. In addition to reflecting the travel behaviors of teleworkers, the VE-State model includes feedback loops to account for induced travel that may occur as initial teleworking results in capacity and congestion benefits. Over time, those initial travel time saving benefits may lead others to drive, therefore limiting the net congestion and travel benefits.

Scenario 1 – Telework

The dimensions of change for each scenario were initially described in *Table 3.* Table 6 shows the Scenario 1 specific trends along with the Future Reference Scenario trends.

Table 6: Scenario 1 Growth Trends

Scenario	Urban Land Use Changes		Exurban / Rural Land Use Changes		Rate of Teleworking among Eligible Workers	
	Urban Employment	Urban Residential	Exurban/ Rural Employment	Exurban/ Rural Residential	% Teleworking Part-Time	% Teleworking Full-Time
Future Reference Scenario	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**
Scenario 1: Teleworking	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**High**	**Low**

Travel Behavior Changes for Scenario 1

Relative to the Future Reference Scenario, Scenario 1 sees a statewide reduction of 0.9% in daily household VMT (see *Table 4*). *Figure 21* shows the geographic variation in total household daily VMT changes in Scenario 1 relative to the 2050 Future Reference Scenario. The steepest household VMT declines are in three of the counties immediately adjacent to Suffolk County.

Figure 21: Map of Scenario 1 County-Level Household DVMT Absolute Change relative to 2050 baseline

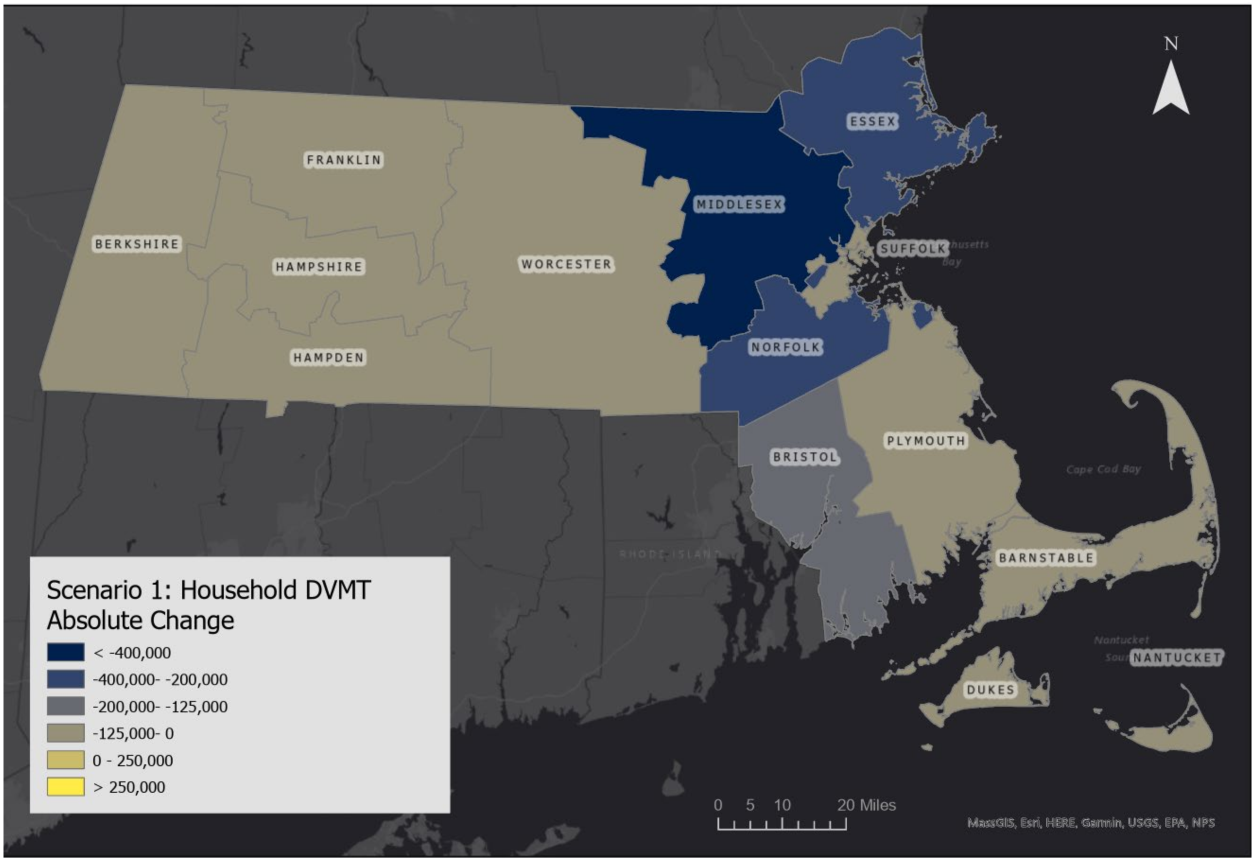
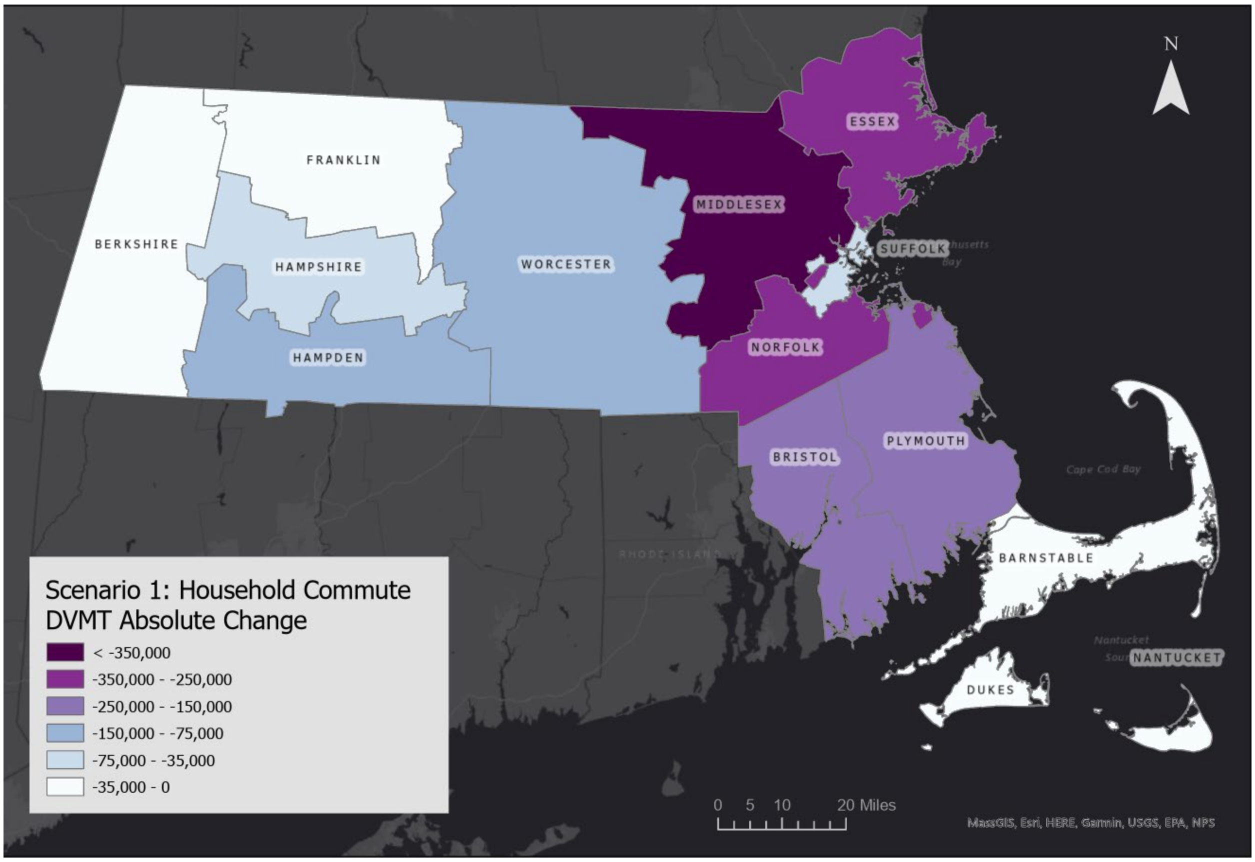


Figure 22 shows the geographic variation in commute VMT changes in Scenario 1 relative to the 2050 Future Reference Scenario. There is a statewide reduction of 8.1% in commute VMT relative to the 2050 Future Reference Scenario.

Figure 22: Map of Scenario 1 County-Level Household Commute DVMT Absolute Change relative to 2050 baseline



Scenario 2 – Moving to the Suburbs

Scenario 2 trends include low growth in urban land use, medium to high growth in exurban and rural land use, high rates of part-time telework, and low rates of full-time telework, as show in *Table 7*.

Table 7: Scenario 2 Growth Trends

Scenario	Urban Land Use Changes		Exurban / Rural Land Use Changes		Rate of Teleworking among Eligible Workers	
	Urban Employment	Urban Residential	Exurban/ Rural Employment	Exurban/ Rural Residential	% Teleworking Part-Time	% Teleworking Full-Time
Future Reference Scenario	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**
Scenario 2: Moving to the Suburbs	**Pre-pandemic trend**	**Less than pre-pandemic trend**	**Pre-pandemic trend**	**Med-High**	**High**	**Low**

Travel Behavior Changes for Scenario 2

Scenario 2 results in an estimated reduction of 0.5% in daily household VMT relative to the 2050 Future Reference Scenario. This is a smaller reduction compared to Scenario 1 (which uses the same degree of teleworking but no land use changes relative to the baseline), suggesting that the shift in residential growth from urban areas to exurban/rural areas increased household VMT.

While this scenario still sees a statewide reduction in household VMT relative to the baseline, there are areas (particularly Essex County and Plymouth County) that are expected to see increases in daily household VMT relative to the reference forecast, as seen in *Figure 23*, likely due to increased residential growth leading to longer commutes.

Figure 23: Map of Scenario 2 County-Level Household DVMT Absolute Change relative to 2050 baseline

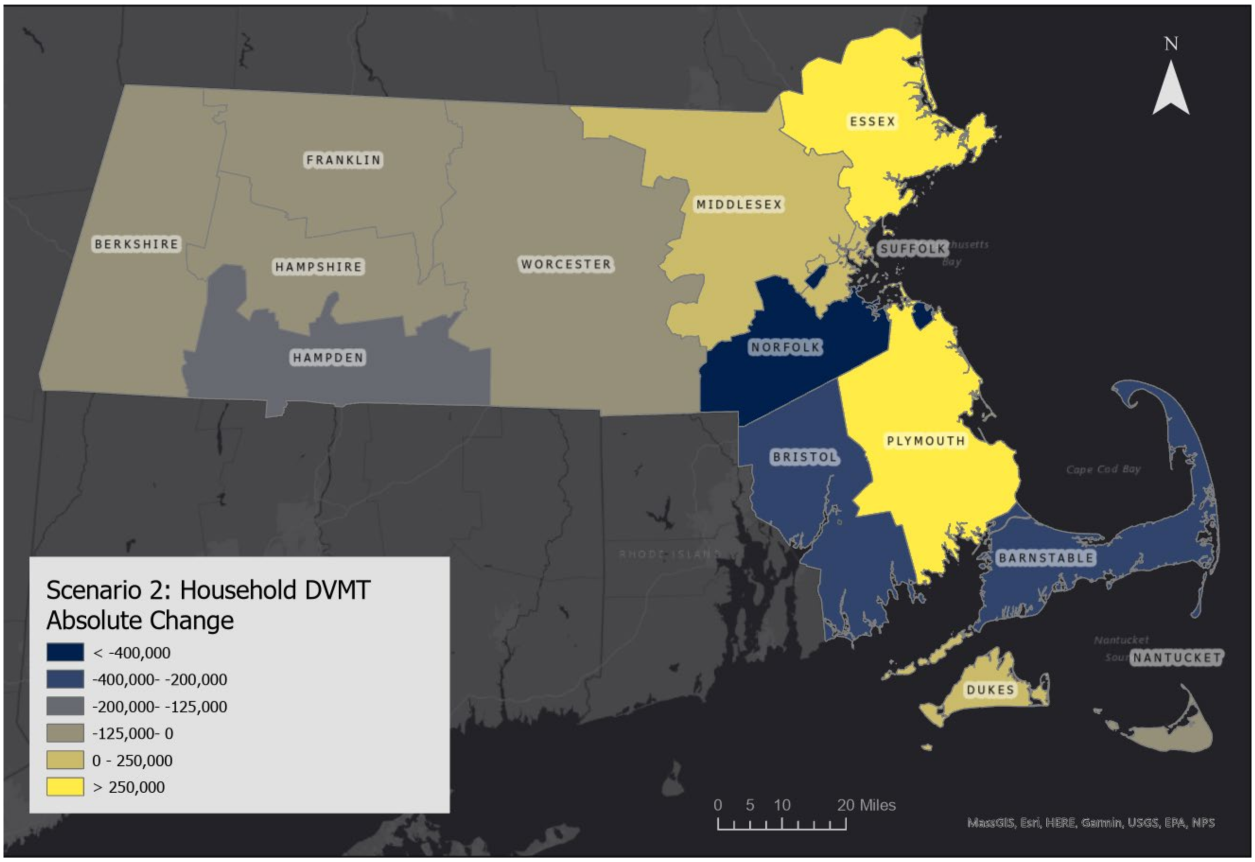
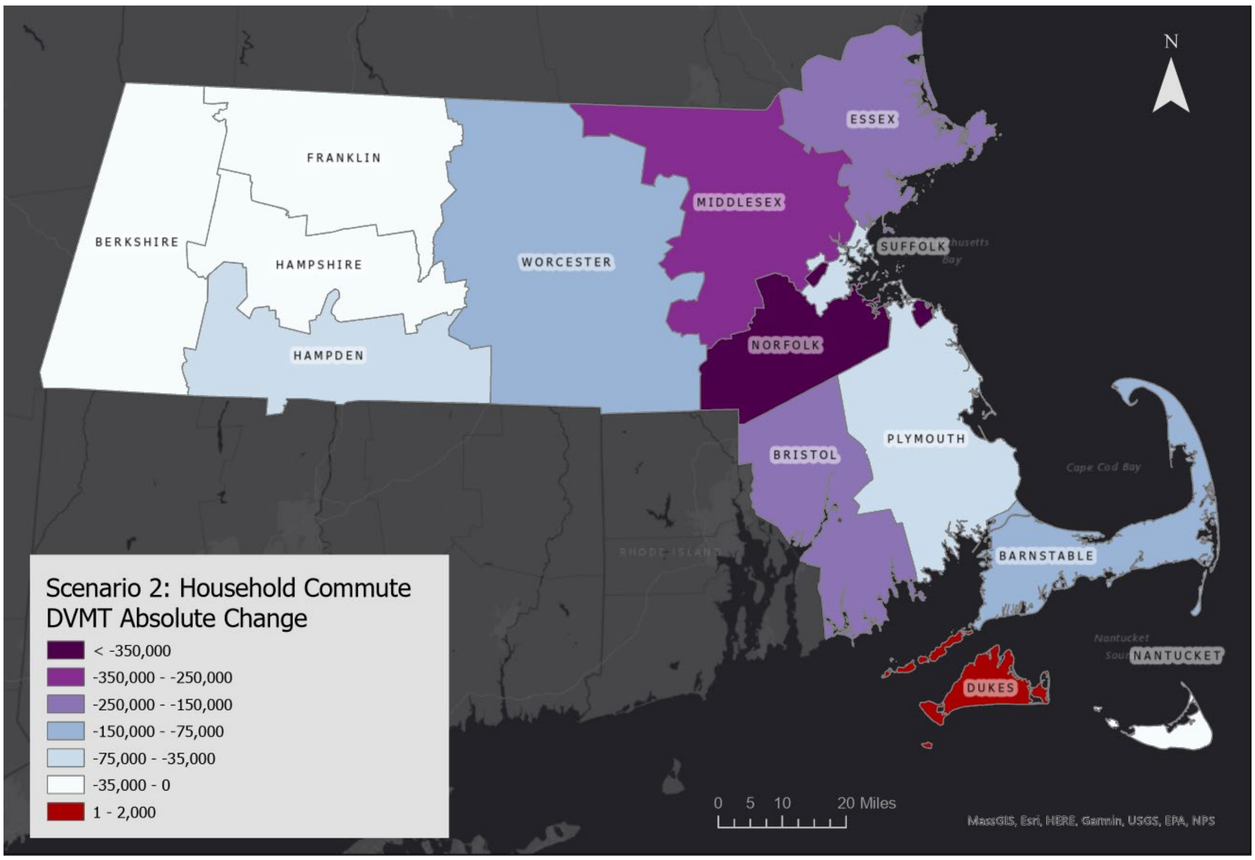


Figure 24 shows the geographic variation in commute VMT changes in Scenario 2 relative to the 2050 Future Reference Scenario. There is a statewide reduction of 7.2% in commute VMT relative to the 2050 Future Reference Scenario.

Figure 24: Map of Scenario 2 County-Level Household Commute DVMT Absolute Change relative to 2050 baseline



Scenario 3 – Quiet Cities

Scenario 3 trends include zero or low urban land use growth, high exurban and rural growth, and high rates of teleworking, as shown in *Table 8*.

Table 8: Scenario 3 Growth Trends

Scenario	Urban Land Use Changes		Exurban / Rural Land Use Changes		Rate of Teleworking among Eligible Workers	
	Urban Employment	Urban Residential	Exurban/ Rural Employment	Exurban/ Rural Residential	% Teleworking Part-Time	% Teleworking Full-Time
Future Reference Scenario	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**
Scenario 3: Quiet Cities	**Less than pre-pandemic trend**	**Less than pre-pandemic trend**	**High**	**High**	**High**	**High**

Travel Behavior Changes for Scenario 3

Scenario 3 results in an estimated reduction of 1.8% in daily household VMT relative to the 2050 Future Reference Scenario. This larger reduction (compared to Scenarios 1 & 2) indicates that elevated rates of full-time teleworking combine with a more heterogenous land use mix in which employers relocate to exurban/rural locations, potentially resulting in shorter commute distances due to the proximity to exurban/rural residences.

Figure 25 shows the areas where the daily household VMT is forecast to decline and increase under this scenario relative to the baseline. There are steep declines in household VMT relative to the Future Reference Scenario within the I-95 ring immediately surrounding Boston and more household VMT growth within Essex, Plymouth, and Worcester County.

Figure 25*: *Map of Scenario 3 County-Level Household DVMT Absolute Change relative to 2050 baseline

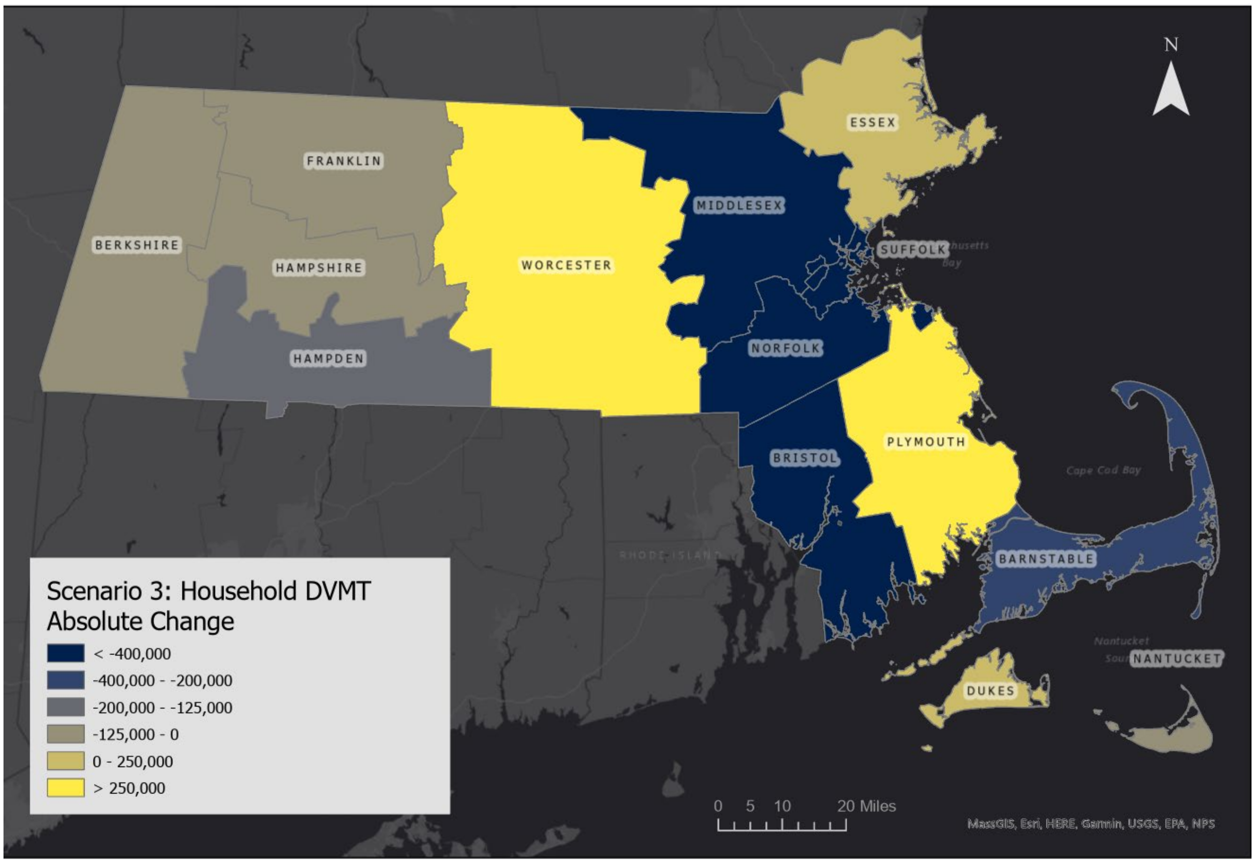
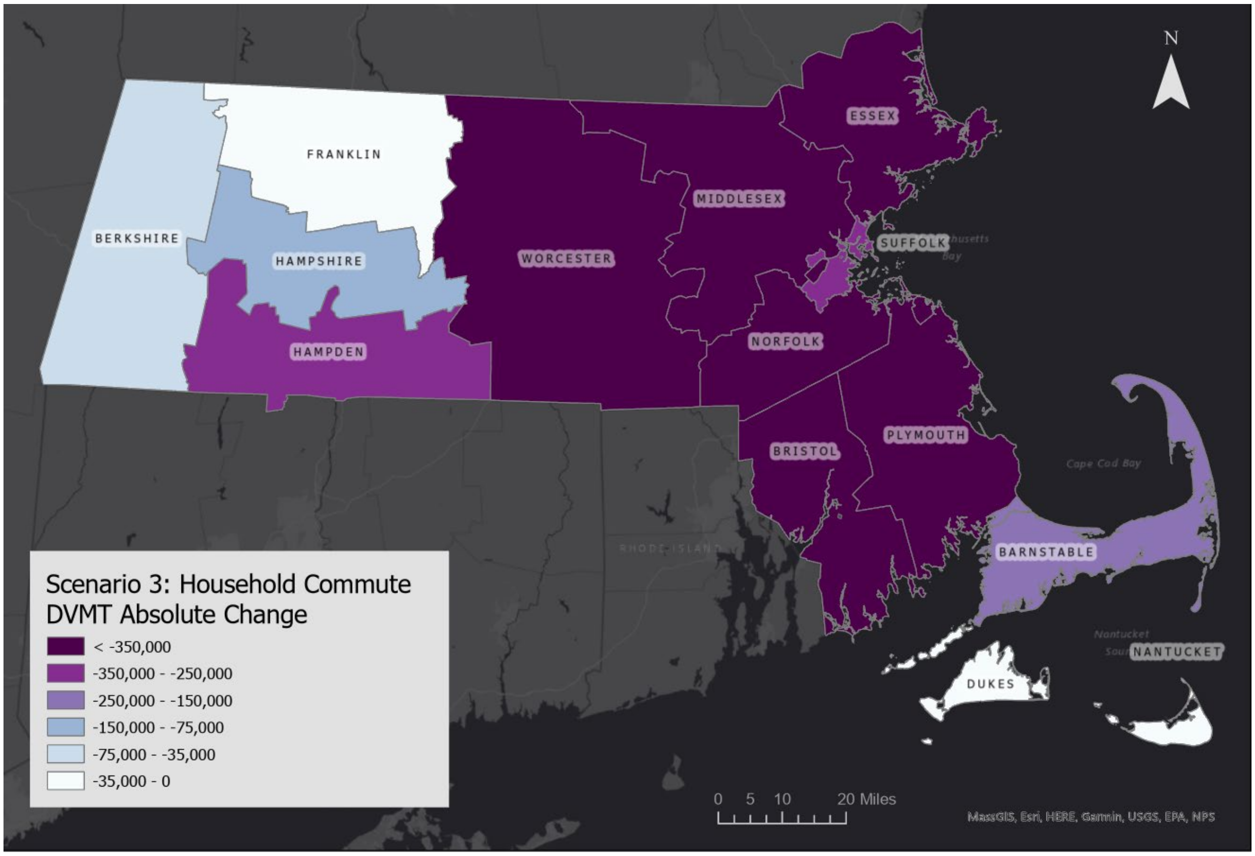


Figure 26 shows the variations in commute VMT relative to the Future Reference Scenario. Overall, Scenario 3 forecasts a statewide reduction of 29.2% in commute VMT relative to the 2050 Future Reference Scenario.

***Figure 26**: Map of Scenario 3 County-Level Household Commute DVMT Absolute Change relative to 2050 baseline*



Scenario 4 – Sustainable Urbanization

Scenario 4 trends include low urban employment growth, high urban residential growth, high exurban/rural employment growth, high exurban/rural residential growth, and high rates of teleworking, as shown in *Table 9*.

Table 9: Scenario 4 Growth Trends

Scenario	Urban Land Use Changes		Exurban / Rural Land Use Changes		Rate of Teleworking among Eligible Workers	
	Urban Employment	Urban Residential	Exurban/ Rural Employment	Exurban/ Rural Residential	% Teleworking Part-Time	% Teleworking Full-Time
Future Reference Scenario	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**	**Pre-pandemic trend**
Scenario 4: Sustainable Urbanization	Low	High	High	Med	High	High

Travel Behavior Changes for Scenario 4

Scenario 4 results in the greatest reductions in daily household VMT: an estimated reduction of 2.6% in daily household VMT relative to the 2050 Future Reference Scenario. Scenario 4 includes an intensification of pre-pandemic trends toward urban agglomeration increasing both residency and employment in urban areas. Combined with higher rates of teleworking, the scenario is expected to reduce overall household VMT relative to the Future Reference Scenario. The increased residential growth in urban areas (i.e., via office-to-residential conversion) leads to higher household VMT in these areas, most notably Suffolk County.

Figure 27 shows the changes in daily household VMT due to the changes in population and employment relative to the Future Reference Scenario.

Figure 27: Map of Scenario 4 County-Level Household DVMT Absolute Change relative to 2050 baseline

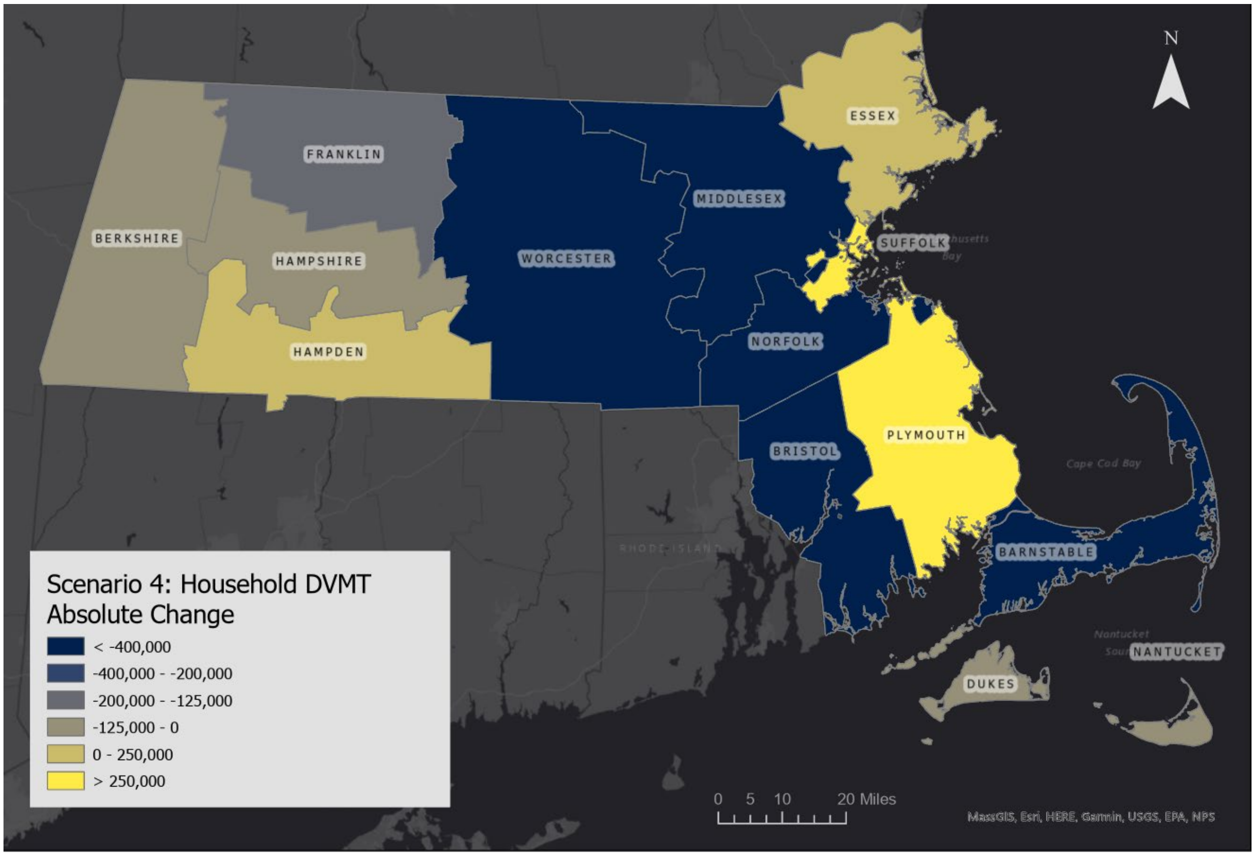
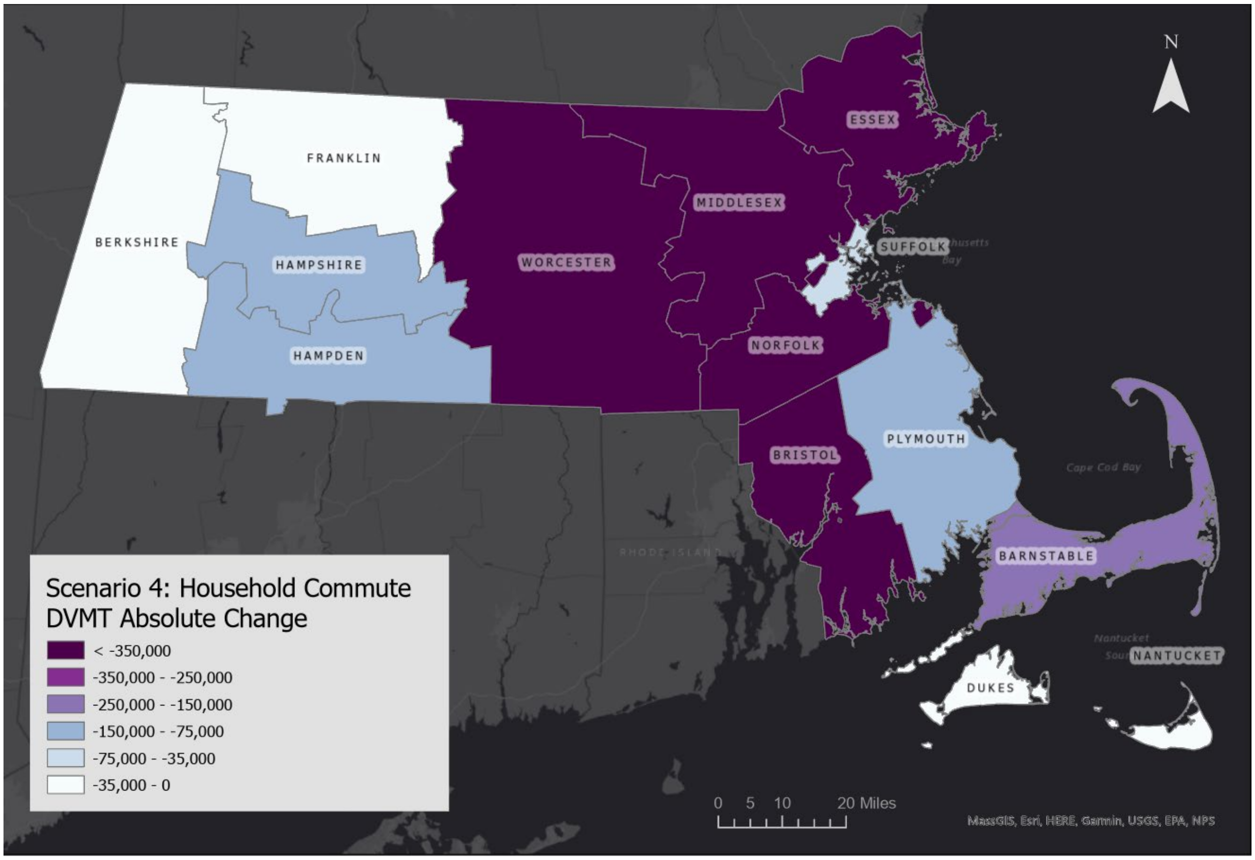


Figure 28 shows the declines in household commute VMT across the Commonwealth. Scenario 4 forecasts a statewide reduction of 17.3% in commute VMT relative to the 2050 Future Reference Scenario.

Figure 28: Map of Scenario 4 County-Level Household Commute DVMT Absolute Change relative to 2050 baseline



Key Results by County

The transportation modeling results found significant variations in household VMT between the counties of Massachusetts.

Table 10: Household VMT – Percent Change by Scenario from 2015 Base

County	2015 Base Scenario HH VMT	2050 Future Reference Scenario	Scenario 1: Telework	Scenario 2: Moving to the Suburbs	Scenario 3: Quiet Cities	Scenario 4: Sustainable Urbanization
Barnstable	4,564,766	-9.1%	-9.7%	-16.2%	-16.3%	-20.6%
Berkshire	2,462,858	25.7%	25.2%	22.8%	22.2%	21.0%
Bristol	10,238,872	28.7%	27.3%	25.2%	21.6%	20.6%
Dukes	298,136	67.4%	66.8%	75.0%	76.3%	62.1%
Essex	13,661,865	34.7%	33.0%	38.1%	36.2%	36.1%
Franklin	1,466,269	20.4%	20.0%	18.2%	18.0%	9.7%
Hampden	7,246,342	45.9%	44.8%	43.9%	43.3%	47.0%
Hampshire	3,445,243	21.6%	20.7%	19.7%	21.2%	20.2%
Middlesex	25,794,615	50.5%	49.0%	50.9%	47.2%	44.1%
Nantucket	196,235	49.8%	49.6%	49.0%	49.1%	44.6%
Norfolk	12,064,625	50.6%	48.9%	44.1%	39.9%	40.6%
Plymouth	8,750,752	38.9%	37.5%	41.8%	42.6%	42.2%
Suffolk	9,373,970	24.3%	23.9%	25.1%	18.6%	28.4%
Worcester	14,628,593	40.8%	40.0%	40.8%	45.1%	37.1%
Percent Change		**38.0%**	**36.7%**	**37.2%**	**35.4%**	**34.3%**

5.0 Economic Impact of Teleworking

5.1 Overview

The economic impacts of teleworking were conducted through an Economic Impact Analysis (EIA) based on travel demand model data to evaluate the long-term impacts of teleworking on the Commonwealth's economy, for Scenarios 2, 3, and 4 (all of which included land use changes)[10]. Key drivers of these economic impacts were changes to commuting times, household cost allocations, and businesses' transportation costs and productivity. The EIA compares these quantified predicted impacts for each scenario to the modeled baseline scenario.

The EIA leveraged TREDIS, a toolkit for economic impact, benefit-cost, and other financial analyses across passenger and freight travel modes. The methodology and the TREDIS model are described in detail in Chapter 5.2.

The analysis estimated the net benefits for each scenario by comparing them to a future baseline scenario. In 2050 under this baseline scenario, local business sales will be $1,947 billion, there will be $790 billion generated in local income, and there will be 5,705,899 jobs.

Compared to the baseline scenario, these scenarios provide the following economic benefits in 2050:

- Scenario 2 – Moving to the Suburbs will increase local business sales by $1.1 billion, generate $546 million in net new local income, and create and support 5,700 net new long-term jobs annually in the region that would otherwise not occur.
- Scenario 3 – Quiet Cities will increase local business sales by $4.8 billion, generate $2.3 billion in net new local income, and create and support 23,500 net new long-term jobs annually in the region that would otherwise not occur.

[10] Scenario 1 was not included in the initial set of scenarios run for VE-State and was therefore not modeled in TREDIS.

- Scenario 4 – Sustainable Urbanization will increase local business sales by $2.2 billion, generate $1.0 billion in net new local income, and create and support 11,300 net new long-term jobs annually in the region that would otherwise not occur.

5.2 Modeling Approach

Overview of Economic Modeling

Economic analysis uses information on passenger and vehicular travel to evaluate how transportation changes affect society and the economy. In this case, the analysis forecasts impacts in the future year 2050, based on the transportation patterns driven by work and home location decisions in each scenario.

Transportation performance metrics from the VE-State model capture changes in travel time, distance, and congestion. These serve as inputs to two types of economic analysis:

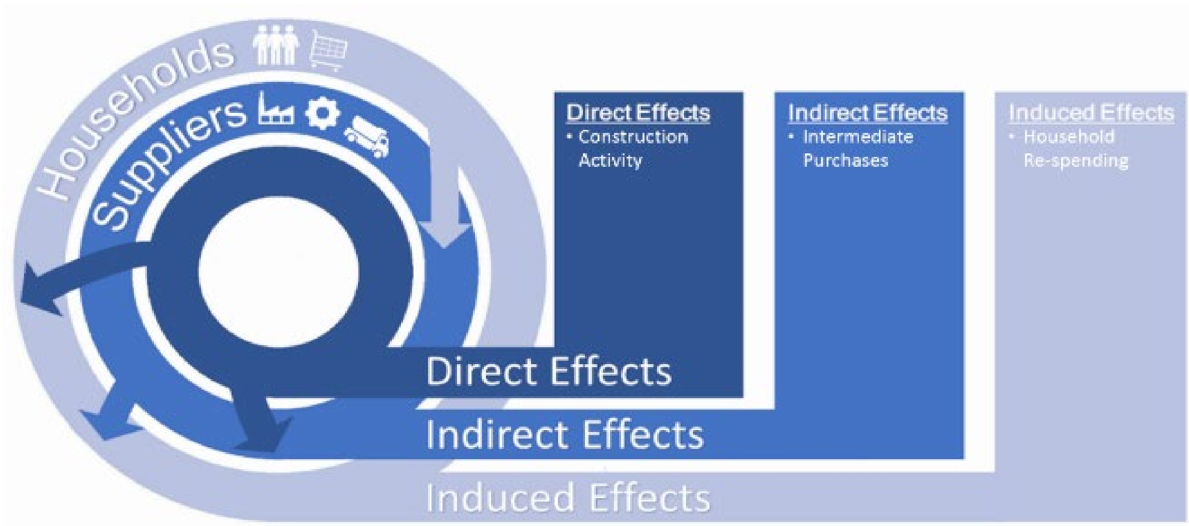
- **Societal Benefits**: The first type of economic analysis quantifies societal benefits stemming from improvements to travel, expressed in monetary (dollar value) terms. This valuation reflects both market costs of travel (for example, the costs of operating a vehicle or paying a truck driver) and social welfare valuation of other factors such as personal travel time or emissions that are important but do not directly translate into monetary flows in the economy. The analysis used valuation factors that are consistent with USDOT guidance and reflect people's "willingness to pay" for improved travel.
- **Impacts on the Economy**: The second analysis assesses how businesses in the region will respond to changes in travel costs, as expressed in the growth of the economy. Different scenarios result in higher or lower congestion and travel times; this could mean fewer wasted hours for workers and trucks spent stuck in traffic, and lower fuel costs. As a result, businesses can be more productive and competitive, leading to growth in jobs and business activity.

These are separate ways of evaluating economic performance, but they are linked in the same economic model runs and are based on the same measures of transportation performance.

Summary of Economic Impact Methodology

The underlying economic impacts are derived from long-term transportation efficiencies. Total economic impacts are comprised of direct, indirect, and induced impacts, as shown in *Figure 29*.

Figure 29: Components of Total Economic Impacts



These components are defined in more detail as follows:

- **Direct effects** represent the initial economic activity and transactions that are supported by the construction, operations, and maintenance activity associated with transportation changes. They also include the ways in which businesses and households in the region are affected by cost savings and productivity changes due to fluctuations in transportation efficiency. These direct impacts in turn stimulate additional demand for local goods and services due to indirect and induced effects—sometimes called "multiplier" or "spinoff" effects.

- **Indirect effects** represent the additional economic activity associated with business-to-business purchase of goods and services, or supplier impacts. One example is a business saving money on trucking costs that is able to expand operations and therefore require more materials and services from its suppliers.
- **Induced effects** are the additional household spending from worker income on items such housing, retail purchases, and services. Those expenditures support jobs in associated industries, whose workers then spend their salaries in the state.

Economic Performance Metrics

Economic activity and growth are measured using four key metrics:

- **Jobs**. Headcount of full and part-time jobs. This includes construction, operations and maintenance expenditures, additional household expenditures due to net new income, increased sales from local suppliers, and the transportation efficiencies that provide local businesses with improved access and reduced costs.
- **Business Output**. Value of goods and services produced (revenue or sales). This is a measure of gross business sales and incorporates the value of intermediate goods and services used in production, resulting in a higher measure than Gross Regional Product (GRP).
- **Value Added**. Also known as GRP, this is the value of goods and services produced (business revenue) minus the cost of "intermediate consumption" (i.e., non-labor inputs). Value added is the sum of (1) income paid to workers and (2) income kept as business profit within a specified area. GDP, GRP & GSP are essentially measures of value added (at national, regional or state spatial levels).
- **Labor Income**. Value of compensation paid to workers (a portion of value added). Income covers total compensation for work, including gross wages, salaries, proprietor incomes, employer provided benefits, and taxes paid to governments on behalf of employees.

Note that business output, value added, and labor income are different metrics that can be used to quantify the same overall level of economic activity. They are nested concepts, where value added is a subset of business output, and labor income is a subset of value added. As such, they should never be added together.

5.3 Economic Impact Analysis Statewide Results

The total economic impacts of the teleworking shift statewide are presented below in terms of value added, jobs, and labor income. Key drivers of these economic impacts were changes to commuting times, household cost allocations, and businesses' transportation costs and productivity.

Summary of Results

Table 12 presents results by scenario in 2050 compared to the Future Reference Scenario. In 2050 under this baseline scenario, there will be $1,217,705 million value added, 5,705,899 jobs, and $790,421 million in labor income.

Scenario 3 – Quiet Cities experienced the largest gain in jobs due to time savings in commuting by car and significant truck cost savings.

Scenario 2 – Moving to the Suburbs has the lowest job growth since it offers more limited transportation time and cost savings. It has modest car commute time savings but increases in personal car travel.

Scenario 4 – Sustainable Urbanization yields job growth that is between those of Scenarios 2 and 3. This is the only scenario with some additional costs imposed on freight according to the VE-State modeling. However, other efficiencies outweigh these costs.

The increments across all scenarios are small (<1%) compared to statewide value added, jobs, and labor income.

Table 11: Statewide Economic Impact Analysis Results by Scenario for 2050 - Net Change Compared to Baseline Scenario

Scenario	Value Added ($M)	Jobs	Labor Income ($M)
Scenario 2: Moving to the Suburbs	703	5,708	546
Scenario 3: Quiet Cities	2,935	23,516	2,281
Scenario 4: Sustainable Urbanization	1,368	11,331	1,049

Scenario 2 – Moving to the Suburbs

Table 13 shows the statewide economic impacts of teleworking under Scenario 2 for 2050. The services industry sees the most job growth in 2050 in this scenario, with 30% of jobs added in 2050.

Table 12: Statewide Economic Impact Analysis Results by Industry for Scenario 2 for 2050 - Net Change Compared to Baseline Scenario

Industry	Jobs	Value Added ($M)	Percent of Jobs	Percent of Value Added
Other Services	1,744	106.0	30.6%	18.5%
Professional & Business	1,107	199.0	19.4%	31.8%
Retail Trade	870	55.9	15.2%	8.3%
Education & Health	722	77.4	12.6%	13.3%
Financial Activities	545	126.3	9.5%	9.8%
Rest of Industries	720	137.9	12.6%	18.3%
Total	**5,708**	**702.5**	**100%**	**100%**

Scenario 3 – Quiet Cities

Table 14 shows the statewide economic impacts of teleworking under Scenario 3 for 2050. Scenario 3 has the highest job growth of all the scenarios, with 23,516 jobs created by 2050. Like Scenario 2, job growth is concentrated in the services industry.

Table 13: Statewide Economic Impact Analysis Results by Industry for Scenario 3 for 2050 - Net Change Compared to Baseline Scenario

Industry	Jobs	Value Added ($M)	Percent of Jobs	Percent of Value Added
Other Services	7,204	440.4	30.6%	18.7%
Professional & Business	4,527	816.8	19.3%	31.3%
Retail Trade	3,558	229.3	15.1%	8.2%
Education & Health	2,933	314.9	12.5%	13.0%
Financial Activities	2,225	518.5	9.5%	9.6%
Rest of Industries	3,069	615.3	13.1%	19.3%
Total	**23,516**	**2,935.2**	**100%**	**100%**

Scenario 4 – Sustainable Urbanization

Table 15 shows the statewide economic impacts of teleworking under Scenario 4 for 2050. The jobs generated are concentrated in both the professional & business and services sectors.

Table 14: Statewide Economic Impact Analysis Results by Industry for Scenario 4 for 2050 - Net Change Compared to Baseline Scenario

Industry	Jobs	Value Added ($M)	Percent of Jobs	Percent of Value Added
Other Services	3,211	183.9	28.3%	15.3%
Professional & Business	2,252	400.1	19.9%	33.3%

Retail Trade	1,718	106.0	15.2%	8.2%
Education & Health	1,586	171.2	14.0%	15.3%
Financial Activities	1,143	267.0	10.1%	10.6%
Rest of Industries	1,421	239.8	12.5%	17.3%
Total	**11,331**	**1,368.0**	**100%**	**100%**

Key Takeaways

The economic benefits measured across the three scenarios modeled in TREDIS were found to be positive and modest relative to the baseline forecast.

Across all three scenarios, the industries most likely to experience job growth are Professional & Business, Education & Health, and Other Services. Professional & Business services already dominate the Massachusetts economy, and they see the greatest job gains. Education & Health is Massachusetts' next largest industry and is impacted directly by commuter efficiencies. Other Services also benefits from general economic growth.

6.0 Conclusion

The transportation modeling results indicated that under all the scenarios considered, increased levels of teleworking compared with pre-pandemic levels will lead to small reductions in household VMT in 2050, when compared to the Future Reference Scenario. This occurs in the context of substantial household VMT growth in Massachusetts between the present and 2050, regardless of scenario. This was found to be the case even in scenarios where household commute VMT decreased in absolute terms.

These results also suggest that there will be potential benefits to households from telework due to reduced travel costs, which is supported by the economic modeling. This modeling found modest but positive economic impacts for each of the scenarios modeled due to reduced commuting times, household cost reallocations, and businesses’ reduced transportation costs.

The geographic variations in household VMT and commute VMT growth between the different scenarios further suggest a small reduction in statewide demand for investments that cater to demand from household VMT relative to future baseline levels of telework. There may be increased demand for investments catering to household VMT demand in certain areas, given the county-level increases in household VMT in some scenarios relative to the Future Reference Scenario associated with the changes in land use patterns

7.0 Appendix A: Transportation Model Selection Process

Tool Selection

There is rarely a perfect tool – often modeling and analysis needs to balance limitations somewhere in the process to achieve insights on the most pertinent qualities for the task at hand. This section of the report summarizes the process that led to the selection of VE-State for the statewide travel demand modeling.

The goal of the transportation modeling effort is to provide outputs that can account for the variation in possible futures and provide insights and direction to the type and degree of changes that may occur as a function of changes in teleworking.

The following process is used to identify the preferred modeling approach and tools to evaluate these effects.

- First: outline the goals and outputs that should be produced by the model and tools.
- Second: identify the sensitivity of the model and preferred attributes that are necessary to account for the scenarios created during Task 2.
- Third: determine the range of applicable tools and models that can achieve the study goals with the sensitivity and attributes required.
- Fourth: define evaluation criteria and evaluate the model candidates.

The following top-level goals and outputs are essential to assessing and understanding the impact that teleworking has on the transportation system:

- **Travel demand**: understanding the degree to which travel is desired by various segments of the population, measured in VMT or person miles traveled (PMT). Peak period (historically influenced by commuters) or total daily travel may change in magnitude.
- **Modal and trip impacts**: identifying how changes in teleworking may influence the mode choice for the physical travel that occurs.

- **Land use sensitivity**: changes in urban form and the relationship between the types of land use and the proportion of workers relative to households. This ratio is often an explanatory variable informing the mix between residential and commercial uses; teleworking may change that balance in some cases.
- **Spatial awareness**: understanding why certain areas are more or less impacted by changes in teleworking, given that the land use changes noted may not occur evenly.

Model Sensitivity

The analysis of teleworking in Massachusetts requires a broad scope to capture the myriad interacting relationships between the nature of the work issues (location, type, sector, income, etc.), the home (how many people at home, how many are employed, number of vehicles, etc.) and the spatial relationship between home and work.

Two elements of the impact of teleworking will be considered:

- **Spatially**: how does the geography around the workplace change as the number of teleworkers changes? There are primary and secondary effects of changing the number of workers in an area. The spatial configuration of where workers work and the related supporting industries (i.e., coffee shop or restaurants) are affected by the location where people conduct their work. New flexibility in physically commuting may have primary changes associated with residential location and also secondary impacts that make additional services (i.e., shopping, child care) in higher demand closer to home.
- **Temporally**: how does the location of one's workplace and home change over time as teleworking becomes more or less ubiquitous? Over time, expectations of one's physical presence at work may change with changes in cultural norms, technology, and other policies or influences (i.e., saving energy by reducing travel).

These two elements are related by the degree to which teleworking permeates and impacts travel and land use decisions. It is important that analysis tools consider both the spatial configuration of where people live and work as well as how those changes may unfold over time.

Desirable Model Attributes

The goals for the modeling of teleworking impacts on the transportation system combined with the additional considerations from the literature review indicate the following desired attributes to be used in the evaluation of travel models used in this research effort.

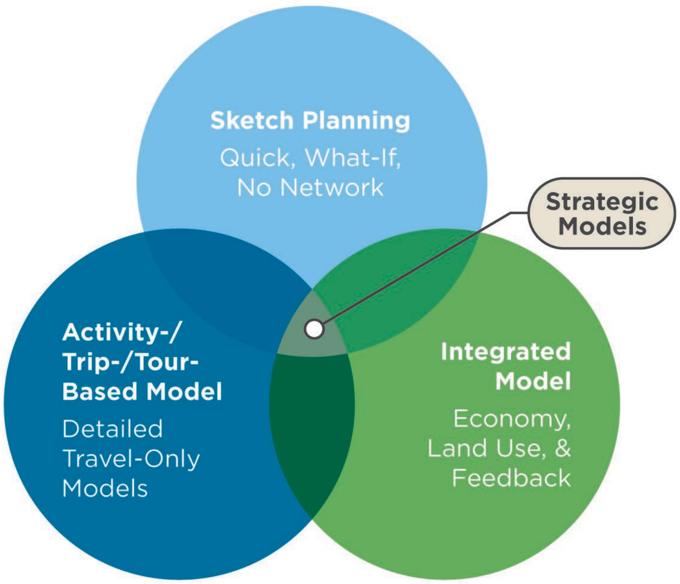
The literature review identified several additional insights beyond the potential changes both spatially and temporally. The following attributes are critical to understanding the degree to which teleworking will affect travel behaviors:

- Job sector of the employed persons (NAICS codes).
- Occupation type of the employed persons.
- Willingness of the employer to allow teleworking.
- Income of employed persons.
- Number of days teleworking (full-time vs. part-time).
- Cohort and age effects (are cultural norms different between generations).

Model Types

Transportation models can take on many forms, from simple regression formulas to complex system dynamic models. Figure 30 visually conveys the degree of commonality the primary model types have with each other and the unique niche that VE-State and strategic models have.

Figure 30: Primary Modeling Types



Source: Oregon DOT, 2019 (adapted by RSG)

Each of the primary model types have advantages and disadvantages as summarized in Table 16.

Table 15: Advantages and Disadvantages of Primary Model Types

MODEL TYPE	ADVANTAGES	DISADVANTAGES
Sketch	• Relatively quick to build and run. • Spatially can expand to cover large geographies with fewer inputs required compared to other models. • A large number of scenarios can be tested relatively quickly and easily.	• Aggregate representations of the population limits flexibility of specific scenarios. Trip generation is often applied at a land use or place type level. Limited feedback in the models to account for interactive effects. • Various models are often used to capture specific points of view or perspectives. These models often limit the level of customization to represent a specific locality.

Trip based	• Disaggregate representations of supply with a detailed assessment of the transportation system both spatially and temporally. • Mode choice as a function of land use, urban form and spatial configuration making it sensitive to land use changes.	• Trip generation is fixed using zonal attributes of household types, numbers of vehicles (often using a cross-class matrix) without sensitivity to employment information. • Trip attraction balances trip generation across employment sectors. No awareness of employment or other demographic information on the households. • Trip generation is a hard dial in these models making testing policies and incentives challenging.
Integrated	• Detailed representations of feedback loops and interconnections between transportation, land use, environment, health, etc. • Often helpful to inform long-term effects of various actions.	• Most integrated models use a blend of trip-based generation methods or more disaggregate trip generation estimates. • Given the complexity and run times of some integrated models, certain simplifications are made and each model has to be evaluated on its own. • Each integrated model is unique in its design and function.
Activity	• Disaggregate representations of both supply and demand. Demand is often at a household or small group of households level. • Travel network is assessed in a detailed manner, mode choice using user and trip specific attributes. • Results can be summarized across users, geographies,	• As very sophisticated models they require significant time to run and are calibrated for a specific point in time. Limitations may exist such as the degree to which employment is treated and assumptions on how trip generation is estimated. • Changes in model structure and decision-making processes may

	travel behaviors, time of day, etc.	require extensive model changes.
Strategic	• Disaggregate representation of demand (at household level) using a zonal representation of supply provides detailed insight on travel demand. • Models can test hundreds of options and variable combinations. Modular structure and open source code allows for changes and enhancements.	• Aggregate representation of supply doesn't assign trips to the network. • Limited data on the hourly profile of demand as the models forecast daily travel demand. • There are spatial limitations and assumptions, especially on the statewide level using population, employment, and land use features to guide travel making patterns rather than asserted spatial configuration.

Source: RSG

One main requirement for a transportation model was that it needed to have statewide coverage with sub-state sensitivity, to be able to assess changes at a statewide level with a degree of insights at a more granular level. Other criteria and their weights are shown below in Table 17.

Table 16: Model Evaluation Criteria Weighting

Evaluation Criteria	Weight
Statewide	100%
Travel demand (measured by VMT or PMT)	38.6%
Account for and output travel pricing and costs	8.5%
Land use sensitivity to residential and employment changes	10.2%
Spatial awareness between home and work	3.8%
Demographics sensitive to key teleworking factors	27.6%
Account for changing travel behaviors and norms (over time and generations)	2.7%

Based on the evaluation criteria, the recommended model was VE-State, a strategic model used to evaluate transportation policy impacts.

Model Design

These variables include:

- Occupation type – this impacts the ability to telework. The occupation type can be an occupation or a sector of the economy as certain types and sectors have different likelihoods of telework. The distinction between those who are home-based workers (self-employed) and those who are choosing to telework is important.
- Whether all workers in the home are able to telework full-time – this could lead to different residential location choices. This includes some degree of insight as to whether the employer and industry are inclined to allow the employee to telework.
- The number of full-time vs. part-time workers in a household – this impacts VMT and land use (part-time teleworkers live further from work).
- Income – this impacts the ability to telework, with higher incomes more likely to telework. Likely correlations between job type but data is more readily available.
- Overall employment by job sector – it is important to ensure employment levels in various sectors are accounted for moving forward.

A critical element to each of the above variables is the ability to represent households in the model.

Industries vs Occupation

To connect industries to occupations, Table 18 was developed to show how each NAICS code correlates to survey and COVID Panel codes and definitions and displays how each industry correlates to a work from home category.

- Remote industries: Industries in which most employees can perform 100% of their work from home.
- On-site industries: Industries in which most employees must be at their physical work location to perform their work.
- Mixed industries: Industries in which employees can perform some of their work from home but would occasionally need to go into their physical work location to perform some tasks; or industries with a mix of both remote and on-site positions.

Table 17: Crosswalk Table of NAICS and Survey Codes, Definitions, and WFH Categories

NAICS Code	NAICS Definition	Survey Code (MA)	Survey Definition (MA)	COVID Panel Code	COVID Panel Definition	WFH Category
11	Agriculture, Forestry, Fishing and Hunting					On-site
21	Mining, Quarrying, and Oil and Gas Extraction	4	Energy (e.g., oil, gas, coal)	6	Energy (oil, gas, and coal)	On-site
23	Construction	2	Construction	14	Construction	On-site
31-33	Manufacturing	9	Manufacturing	12	Manufacturing	On-site
				3	Capital goods (aerospace & defense, electrical, machinery)	
42	Wholesale Trade	17	Wholesale trade			Mixed
44-45	Retail Trade	14	Retail	11	Retail	On-site
48-49	Transportation and Warehousing	16	Transportation and utilities	13	Transportation and utilities	On-site
22	Utilities					
51	Information	10	Media/Information	18	Media	Remote
				17	Technology and telecommunications	
52	Finance and Insurance	5	Financial services	1	Financial services	Remote

53	Real Estate and Rental and Leasing	13	Real estate	2	Real estate	Mixed
54	Professional, Scientific, and Technical Services	12	Professional, scientific, and technical services (e.g., consulting, legal, IT)	4	Professional and business services (consulting, legal, marketing)	Remote
55	Management of Companies and Enterprises					
56	Administrative and Support and Waste Management and Remediation Services			21	Landscaping	On-site
61	Educational Services	3	Education	7	Education	On-site
62	Health Care and Social Assistance					
621	Ambulatory Health Care Services	7	Health care	8	Health care	On-site
622	Hospitals					
623	Nursing and Residential Care Facilities					
624	Social Assistance	15	Social assistance	9	Social assistance	Mixed
				19	Childcare	On-site
71	Arts, Entertainment, and Recreation	1	Arts and entertainment	10	Arts and entertainment	Mixed
				20	Sports/fitness	On-site
72	Accommodation and Food Services	8	Hospitality (e.g., restaurant, hotel)	5	Hospitality (e.g., restaurant, accommodation)	On-site
81	Other Services (except Public Administration)					
811	Repair and Maintenance					On-site
812	Personal and Laundry Services			23	Personal services	On-site
813	Religious, Grantmaking, Civic, Professional, and Similar Organizations	11	Non-profit	16	Non-profit	Mixed
814	Private Households					On-site
92	Public Administration	6	Government	15	Government	Mixed

				22	Military	On-site

8.0 Appendix B: Economic Modeling Additional Details

Economic Modeling Methodology

The TREDIS Model

The economic modeling was conducted using TREDIS. TREDIS is a decision-support system for transportation planners that spans benefit-costs analysis, economic impact analysis, and freight and trade impact analysis. It is used to evaluate economic outcomes of projects, programs, and policies. TREDIS is multimodal and each TREDIS license is calibrated to a specific local, regional, or state economy – in this case the economy of Massachusetts.

TREDIS consists of several model elements including:

- A *travel cost module* that translates changes in mode split, traffic volumes, vehicle occupancy, speed, distance, reliability, and safety into travel efficiency changes and direct cost savings for household and business travel.
- A *benefit-cost module* that calculates benefits and costs over time. Valuation follows international best practice, including the benefit-cost guidance of USDOT modal agencies.
- An *economic adjustment module* that incorporates a dynamic, multi-regional economic-demographic model to estimate economic impacts over time from changes in transportation system performance. The model accounts for changes in productivity, capital investment, labor supply and demand, employment and wage shifts, and population migration. Changes in supply, demand, and prices redirect spending patterns to different industries and affect their relative profitability and competitiveness. In this way various transportation changes can affect the magnitude of economic growth.

Data Sources

VE-State produced travel estimates for each scenario, including VMT and vehicle hours traveled (VHT). TREDIS takes this travel data as inputs. VE-State produced travel data for 2015 and 2050 for each scenario.

Travel demand data was reported for daily trips and was annualized for use in TREDIS using an annualization factor of 365. Modes modeled include passenger cars, passenger buses, trucks, and pedestrian trips. Car travel is split between business, commute, and personal trips. Bus and pedestrian travel is split between commute and personal travel.

VE-State produced travel data at the metropolitan area level, which was combined into statewide numbers for TREDIS modeling. After TREDIS modeling was complete, travel was allocated to metropolitan areas. Employment data was used from VE-State for each region in the state. New jobs were allocated from TREDIS to regions within the state based on the original distribution of jobs in VE-State.

Additional Economic Modeling Results by Urban Area

The economic modeling found that Urban Location Type areas capture the majority of total statewide employment and therefore collect the largest number of jobs across scenarios despite some shifts in growth patterns to non-urban areas. Towns and Rurals areas continue to have smaller impacts than Urban areas. Of all counties, Middlesex County Urban is expected to add the most jobs across all scenarios and years.

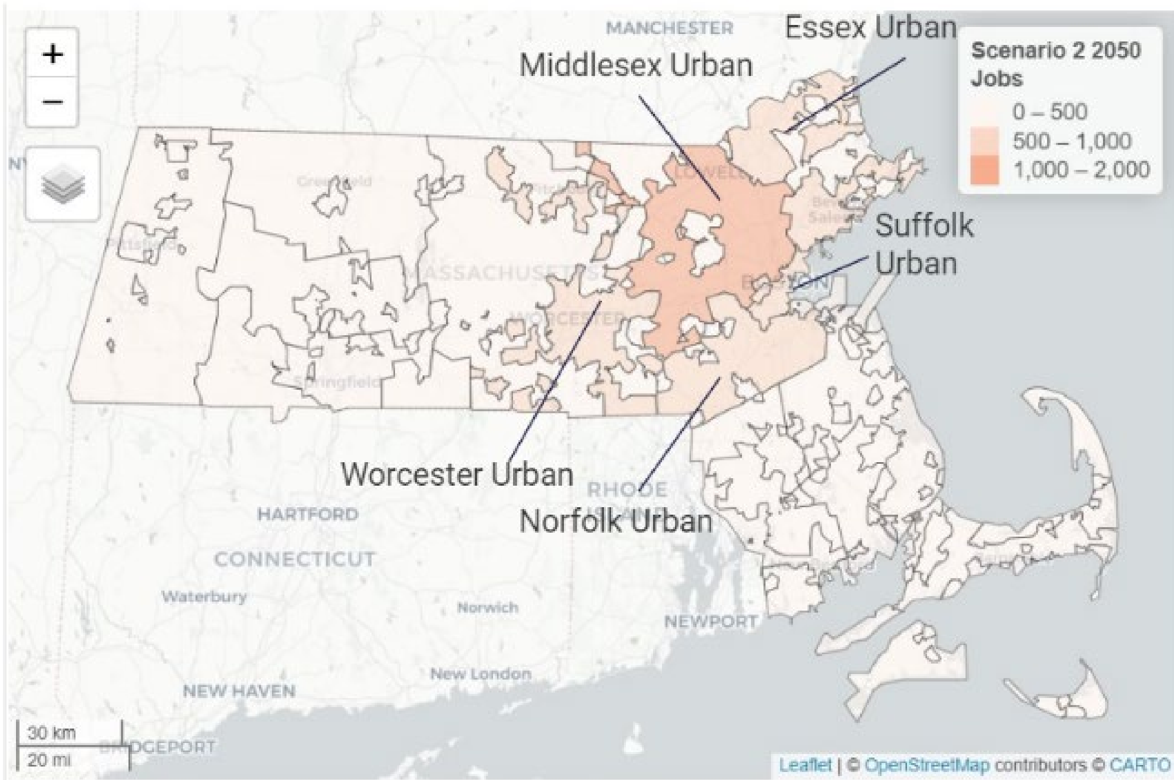
Scenario 2 – Moving to the Suburbs

Table 19 shows the shares of job growth by county urban areas under this scenario for the year 2050. Most job growth happens in Middlesex Urban areas in 2050, as shown in Figure 33.

Table 18: Shares of Job Growth by Urban Area under Scenario 2 by 2050

Urban Area	2050
Middlesex Urban	26%
Suffolk Urban	15%
Worcester Urban	11%
Norfolk Urban	10%
Essex Urban	9%

Figure 31: Scenario 2 Regional Results for Jobs, 2050



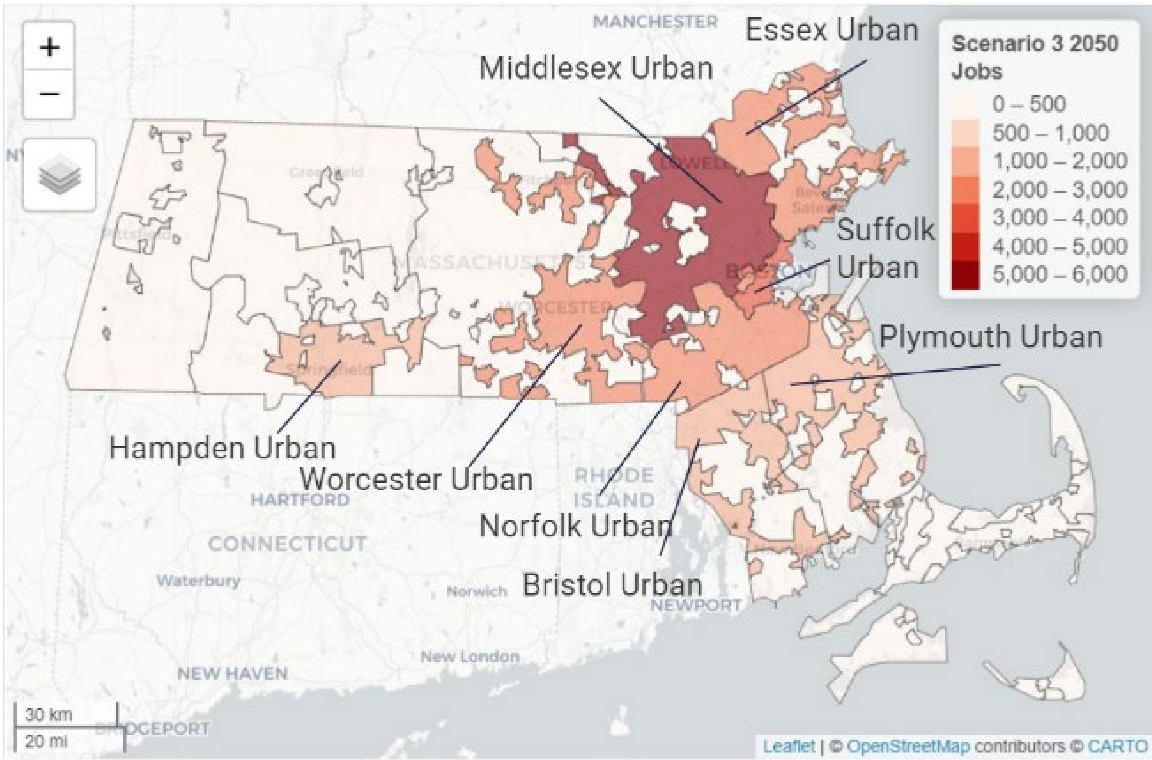
Scenario 3 – Quiet Cities

Table 20 and Figure 34 show job growth by county and urban classification under this scenario. About one-quarter of job growth occurs in Middlesex Urban areas.

Table 19: Shares of Job Growth by Urban Area under Scenario 3 by 2050

Urban Area	2050
Middlesex Urban	25%
Suffolk Urban	14%
Worcester Urban	12%
Norfolk Urban	10%
Essex Urban	10%

Figure 32: Scenario 3 Regional Results for Jobs, 2050



Scenario 4 – Sustainable Urbanization

Table 21 and Figure 35 show the shares of job growth by county and urban classification under this scenario. Like in other scenarios, job growth is most significant in the areas with the most baseline jobs, with about 25 percent of jobs in the Middlesex Urban area.

Table 20: Shares of Job Growth by Urban Area under Scenario 4 for 2025 and 2050

Scenario	2050
Middlesex Urban	25%
Suffolk Urban	16%
Worcester Urban	11%
Norfolk Urban	10%
Essex Urban	10%

Figure 33: Scenario 4 Regional Results for Jobs, 2050