BOSTON REGION METROPOLITAN PLANNING ORGANIZATION

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TECHNICAL MEMORANDUM

DATE: **March 26, 2025**
TO: **TDM23 Users**
FROM: **CTPS Travel Model Development Team**
RE: **Exploration of Post-Pandemic Travel Behavior Changes**

1 INTRODUCTION

In June 2023, the Boston Region Metropolitan Planning Organization (MPO) formally adopted the Travel Demand Model, TDM23, as an integral component of the 2023 Long-Range Transportation Plan. The development of TDM23 spanned from spring 2021 through spring 2023, using a 2019 base year and projecting scenarios for the year 2050. The choice of base year implies that the travel patterns of 2050 would resemble those of 2019 more closely than any of those during the intervening pandemic years. This assumption was necessary as travel behavior was rapidly changing in response to travel restrictions, remote work policies, and safety concerns.

In the post-pandemic era, the travel landscape has undergone significant changes. The widespread adoption of remote work policies challenges the traditional base year assumption that individuals commute to work five days a week. This may lead to fewer work trips to central business districts (CBD), an increase in nonmandatory trips near home locations, and a decline in public transit usage. Confirming these expectations is crucial not only for determining whether a new post-pandemic scenario is needed but also for identifying which components of the model require updates.

With the results of the 2024–25 Massachusetts Travel Survey pending, data from Replica (Replica, 2025) offers a potential bridge to fill the current data gap while providing an opportunity to evaluate the validity and effectiveness for updating a travel demand model using Replica data. The analysis is further supported by data from Massachusetts Department of Transportation (MassDOT) Highway Performance Monitoring System (HPMS), the Massachusetts Bay Transportation Authority (MBTA), and the Massachusetts Vehicle Census.

The purpose of this memo spans three key objectives:

1. Explore shifts in mobility patterns in the post-pandemic era

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2. Evaluate the validity and effectiveness of Replica data for model recalibration
3. Identify aspects of the model that could be adjusted to better represent post-pandemic travel behavior

The analytical framework of this memo is structured around the core components of TDM23: Vehicle Availability, Trip Generation, Trip Distribution, Mode Choice, and Time of Day. This is followed by a system-level evaluation of Highway Vehicle-Miles Traveled (VMT). The memo is organized into multiple sections: Section 1 gives an introduction; Section 2 provides a detailed overview of the data sources used; Section 3 outlines the methodologies applied to each model component and explains core concepts used; and Section 4 presents a comparative analysis of expected versus observed changes in travel behavior, broken down by component. The final section lists references that support the analysis.

2 DATA SOURCE

While the geographic extent of TDM23 includes Rhode Island and southeastern New Hampshire, this study focuses exclusively on Massachusetts. We use a combination of datasets to analyze travel behavior changes between the pre-pandemic and post-pandemic periods.

The primary data source for general travel patterns and highway volumes is Replica data. Replica categorizes data by scenarios (Thursday and Saturday) and seasons (spring and fall) for each year. For this analysis, we selected Thursdays from the fall seasons of 2019 and 2022. The fall 2019 dataset serves as a baseline reflective of pre-pandemic conditions, while fall 2022 represents the early stabilization phase of post-pandemic travel behaviors. The choice of fall 2022, rather than a later season, is to avoid the discrepancies introduced by significant methodological changes implemented in the Replica model starting in 2023. Access to Replica data is through two parts: the front-end portal, which is equipped with filters, summaries, and predefined tables for enhanced accessibility for the trips data; and the backend database, which contains more information such as the vehicle ownership to be used in this study.

For analyzing Trip Generation, Trip Distribution, Mode Choice, and Time of Day, we used the “Trips” table in the Replica Portal, which can be accessed in the Places Studies section under the Dataset tab. The following attributes were used:

- *Trip Origin*
- *Trip Destination*
- *Primary Mode*

- *Trip Purpose (including "work from home")*
- *Previous Trip Purpose*
- *Trip Start Time*
- *Trip Distance*
- *Trip Taker Age*

For inspecting Highway VMT, the following attributes from the "Network Link Volumes" Table in the portal (located in Data Library) are used:

- *OSM ID*
- *Bidirectional*
- *AADT*

For assessing Vehicle Availability, the following attributes from the "Person" Table in the database are used:

- *person_id*
- *age*
- *household_id*
- *vehicles (vehicle counts)*

In addition, vehicle ownership trends are supported by data from the Massachusetts Vehicle Census (Massachusetts Department of Transportation, 2025). This resource provides biannual snapshots of vehicle registrations within the state, with selected data points from January 1, 2020, and January 1, 2023. These dates are those closest to the chosen Replica timeframes.

To supplement highway VMT estimates, we incorporate VMT data from MassDOT via the MassGIS Data Hub for 2019 (Massachusetts geoDOT, 2024a) and 2022 (Massachusetts geoDOT, 2024b). The VMT data is part of the Road Inventory and is used to prepare the yearly HPMS report to the Federal Highway Administration. This dataset provides daily average VMT estimates labeled with Federal Highway Functional Classification.

For transit ridership analysis, we use data from the MBTA accessed via the MBTA Open Data Portal (MBTA OPMI, 2024). This dataset includes monthly average weekday ridership data for various transit submodes such as heavy rail, light rail, commuter rail, and buses. The months of October 2019 and October 2022 have been chosen, also to align with the timeframe of the Replica data.

3 METHODOLOGY

The methodology explores changes in travel behavior across individual model components while assessing the validity of Replica data. Following the structure of TDM23, it examines core components—Vehicle Availability, Trip Generation, Trip Distribution, Mode Choice, and Time of Day—supplemented by system-level evaluations of Highway VMT. For each component, we establish assumptions based on recent research (Caros et al., 2023; Massachusetts Department of Transportation, 2024) and publicly available datasets on post-pandemic travel pattern trends. We then analyze the corresponding data from Replica to determine if Replica's estimated data aligns with our expectations. If alignment is found, we consider the Replica data to be potentially valid and a starting point for discussions on updating TDM23 components. In cases of discrepancies, further investigation may be conducted using alternative data sources.

Some core TDM23 concepts used in this analysis are explained below.

Vehicle Availability

TDM23 categorizes vehicle availability in relation to household composition:

- *Sufficient vehicles*: Vehicles ≥ Drivers
- *Insufficient vehicles*: Vehicles < Drivers
- *Zero vehicles:* Households without any available vehicles

Trip Purposes

Trips are classified as either home-based or non-home-based in TDM23, considering both ends of the trip made ("Trip Purpose" and "Previous Trip Purpose" in Replica), with specific classifications including

- *HBPB* (Home-Based Personal Business)
- *HBW* (Home-Based Work)
- *HBSR* (Home-Based Social/Recreational)
- *HBSC* (Home-Based School)
- *HBU* (Home-Based University)
- *NHBW* (Non-Home-Based Work)
- *NHBNW* (Non-Home Non-Work)

The conversions from Replica are illustrated in Table 1. For example, in TDM23, a trip is classified as "HBW" if one end of the trip is home and the other is work, regardless of the direction.

In Replica, trips in the "school" category, where the other trip end is "Home," correspond to the "HBSC" and "HBU" categories in TDM23. These are divided based on the school type and the age of the traveler. Trips are classified as "HBU" in TDM23 if the school type is undergraduate or graduate, or if the traveler is older than 20 years; otherwise, they are classified as "HBSC."

Table 1
Trip Purpose Conversions from Replica to TDM23

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="6">Previous Trip Purpose in Replica</th></tr>
<tr><th>Home</th><th>Work</th><th>Errands Shop</th><th>Eat Recreation Social</th><th>School</th><th>Other</th></tr>
<tr><th rowspan="6">Trip Purpose in Replica</th><th>Home</th><td>N/A</td><td>HBW</td><td>HBPB</td><td>HBSR</td><td>HBSC or HBU</td><td>N/A</td></tr>
<tr><th>Work</th><td>HBW</td><td>N/A</td><td colspan="4">NHBW</td></tr>
<tr><th>Errands Shop</th><td>HBPB</td><td rowspan="4">NHBW</td><td colspan="4" rowspan="4">NHBNW</td></tr>
<tr><th>Eat Recreation Social</th><td>HBSR</td></tr>
<tr><th>School</th><td>HBSC or HBU</td></tr>
<tr><th>Other</th><td>N/A</td></tr>
</table>

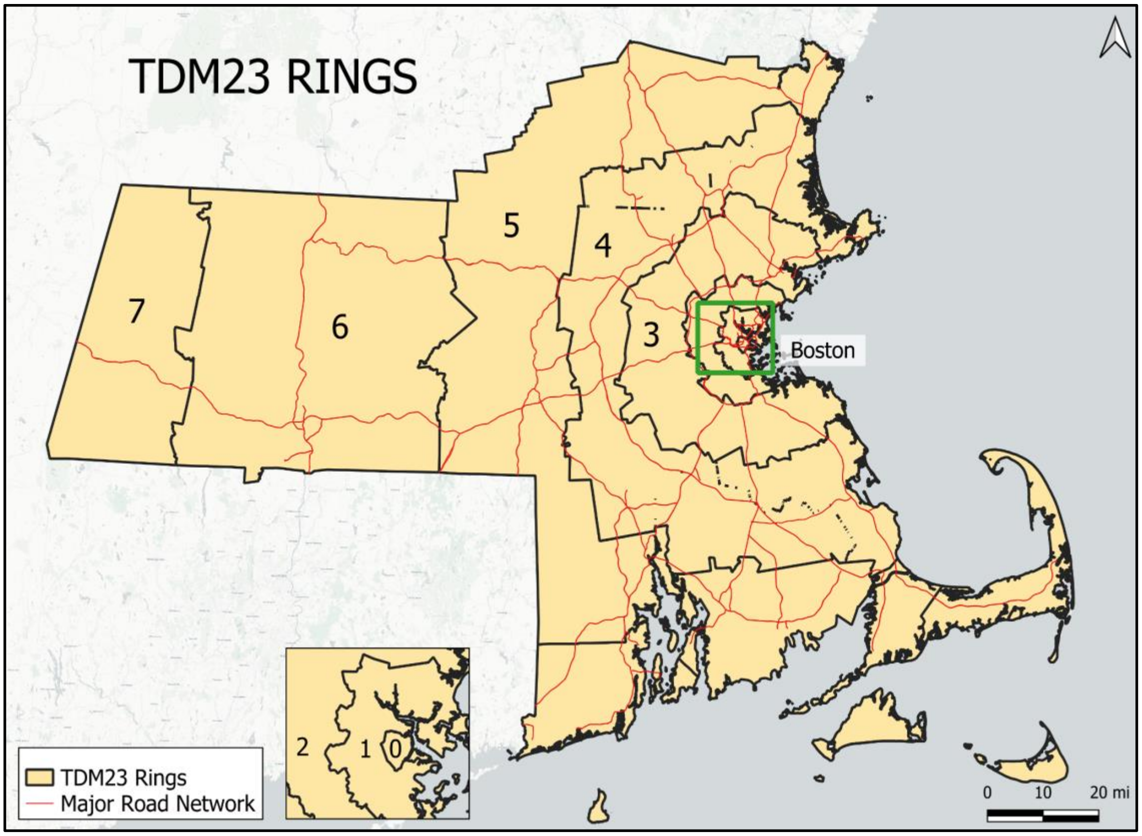
HBPB: home-based personal business. HBSC: home-based school. HBSR: home-based social-recreation. HBU: home-based university. HBW: home-based work. N/A = Not Applicable NHBNW: non-home based non-work. NHBW: non-home based work.

The analysis also considers the impact of remote work on **work-related** (**to-work** and **from-work**) and **non-work** trips.

Rings

For data summarization, areas are organized into concentric rings with downtown Boston as the center (Ring 0), extending out to Berkshire County (Ring 7). The ring spans are depicted in Figure 1, noting that this analysis only covers the Massachusetts portion.

Figure 1
TDM23 Ring Coverages



Time of Day
TDM23 divides an "average weekday" into distinct times of day:

- AM Peak: 6:30 AM–9:30 AM
- Midday: 9:30 AM–3:00 PM
- PM Peak: 3:00 PM–7:00 PM
- Night: 7:00 PM–6:30 AM

Highway VMT
Highway VMT is analyzed by facility type as defined in the TDM23 Structure and Performance Report. Our evaluation focused on five primary facility types: Freeway, Expressway, Major Arterial, Minor Arterial, and Collector. We align Replica highway links with those in TDM23, using the "OSM ID" attribute and validate with Bidirectionality ("Bidirectional"), to use only the matched data, ensuring consistency in our comparisons.

4 RESULTS

The results are organized by TDM23 components, starting with a summary of the expected changes, followed by the observed changes. Supporting graphs are provided to illustrate and validate the analysis. Finally, potential next steps, if feasible, are outlined for the development calibration of the post-pandemic base year.

4.1 Overview of Results

Table 2 summarizes the expected changes compared to the estimated changes by Replica, emphasizing cases where discrepancies occur.

Table 2
Expected and Replica Estimated Travel Behavior Changes by Component

Component	Expected Changes	Replica Estimated Changes
Vehicle Availability	Increase in private car ownership	Less than 1 percentage point increase in household share with 3+ vehicles
Trip Generation	**Decrease in total trips** Decrease in work trips Increase in non-work trips	**+ 12.3% total trips** - 14.5% work trips + 26.4% non-work trips
Trip Distribution	Lower share of work trips to CBD Higher share of non-work intra-ring trips	-7 and -5 percentage points work trips to CBD from Ring 1, 2 respectively +5 percentage points non-work intra-ring trips in **Ring 0 only**
Mode Choice	Higher auto share Lower transit share Higher share of nonmotorized trips	+ 2.0% auto share - 51.2% transit share + 3.1% nonmotorized share
Time of Day	Decrease in “To Work” trips during the AM peak Increase in “From Work” trips during the MD period, driven by more flexible schedules	- 3.6% “To Work” trips during AM + 4.2% “From Work” trips during MD
Highway VMT	Lower VMT, especially in CBD or on arterials	0.76 VMT Ratio (VMT 2022/ VMT 2019) in Ring 0 0.83 and 0.84 VMT Ratio for Major Arterial and Minor Arterial

CBD = Central Business District. MD = midday. VMT = vehicle miles traveled.

4.2 Vehicle Availability

Expected Changes

Given the impacts of the COVID-19 pandemic on public transportation—such as labor shortages, reduced operational reliability, and concerns over hygiene and safety, with the need to go to different places including non-urban areas, an increase in private car ownership is expected.

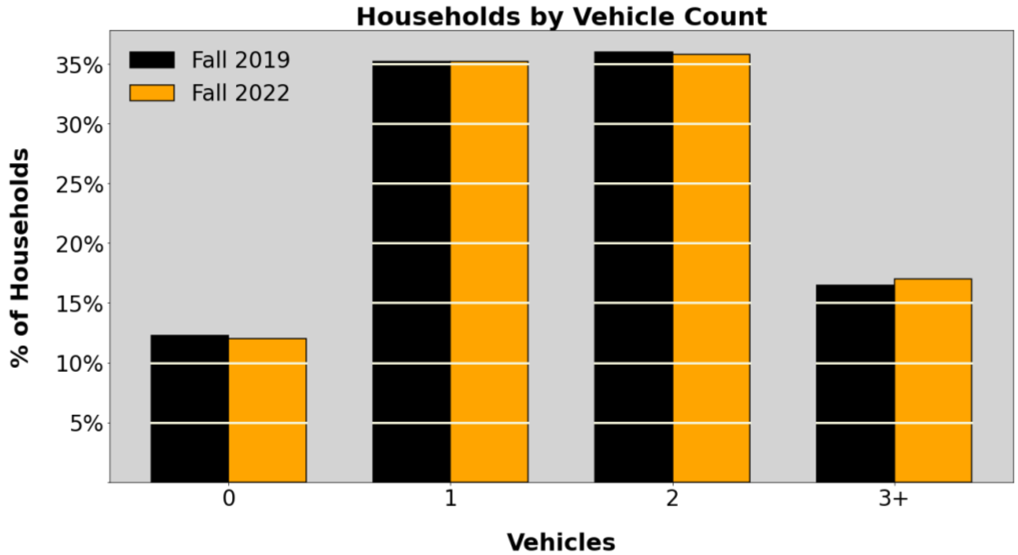
To assess this trend, we examined data from the Massachusetts Vehicle Census, which reports a 1.8 percentage points increase in the total number of registered vehicles statewide—from 4,710,159 on January 1, 2020, to 4,793,611 on January 1, 2023. While this confirms an increase, the magnitude is relatively small.

In TDM23, vehicle availability is categorized based on household vehicle ownership relative to the number of drivers. However, the Massachusetts Vehicle Census does not include household size information, meaning we cannot determine whether the observed vehicle increase reflects a shift from Zero Vehicles to Insufficient Vehicles, Insufficient Vehicles to Sufficient Vehicles, or simply more vehicles within already sufficient households. To gain further insights, we turned to Replica data.

Estimated Changes by Replica

Within the Replica dataset, vehicle ownership for households (excluding group quarters) is categorized into four groups: zero, one, two, and three or more vehicles. The analysis showed subtle shifts in ownership patterns, with a slight increase (less than one percent) in households owning three or more vehicles and a negligible decrease in households without any vehicles (Figure 2).

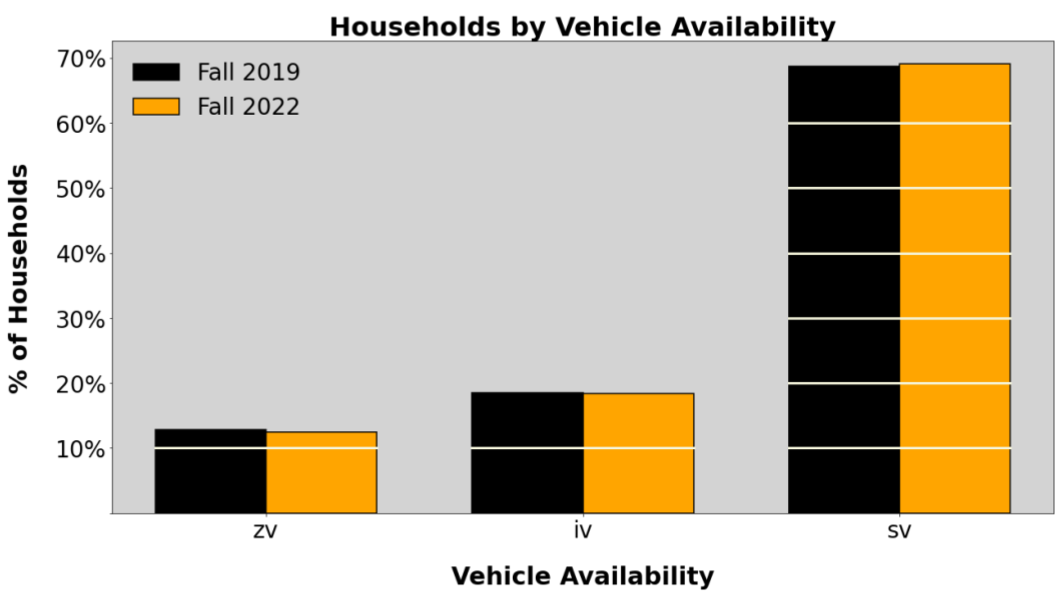
Figure 2
Percentage of Households by Vehicle Count



Source: Replica

By converting Replica's vehicle counts into TDM23’s vehicle availability categories for households with up to three drivers (due to data limitations), the analysis indicated that overall vehicle availability remained relatively stable (Figure 3).

Figure 3
Percentage of Households, With up to Three Drivers, by Vehicle Availability Using TDM23 Classification



iv = insufficient vehicles. sv = sufficient vehicles. zv = zero vehicles.
Source: Replica

Conclusion and Discussion

The Replica data indicate a slight increase in vehicle ownership, particularly in the category of households with three or more vehicles. However, putting the change in the TDM23 terms of vehicle availability, the observable change is less than one percent increase in the share of households with three or more vehicles. This change would not produce substantial changes in model results. Nevertheless, it will be important to continue monitoring these trends and pursue more granular and reliable data sources. As new socio-demographic data and survey results become available, the model's calibration targets can be refined to better reflect evolving vehicle ownership patterns and travel behaviors.

4.3 Trip Generation

Expected Changes

As remote work increases, the total number of trips is expected to decline. In a post-pandemic future, research projects that Massachusetts residents will work remotely an average of 1.69 days per week, up from 0.64 days in 2017 (Caros et al., 2023). Consequently, "To Work" and "From Work" trips will decrease as fewer people commute to traditional workplaces.

While work trips decline, non-work trips are expected to rise, reflecting greater flexibility in daily routines. Research shows that hybrid workers take the most non-work trips, balancing workplace commutes with personal activities, while fully remote workers take slightly fewer but still more than those who work fully in person. Fully in-person workers make the fewest non-work trips overall, as their schedules are more constrained by daily commutes (Caros et al., 2023). This shift is leading to more localized travel, particularly for grocery shopping, daycare drop-offs, recreation, and social engagements.

Estimated Changes by Replica

Data shows an overall increase in total trips, which was unexpected, despite the projected decline in work-related travel. While work trips fell by 14.5 percent, the 24.6 percent surge in non-work trips was greater than anticipated, ultimately driving total trip growth (Table 3). Approximately one-third of all remote work takes place in third places, such as cafés, co-working spaces, and libraries. However, Replica does not classify these trips as work related, instead recording them as non-work trips, which contributes to the observed increase.

Table 3
Total Number of Trips by Purpose and Time Period

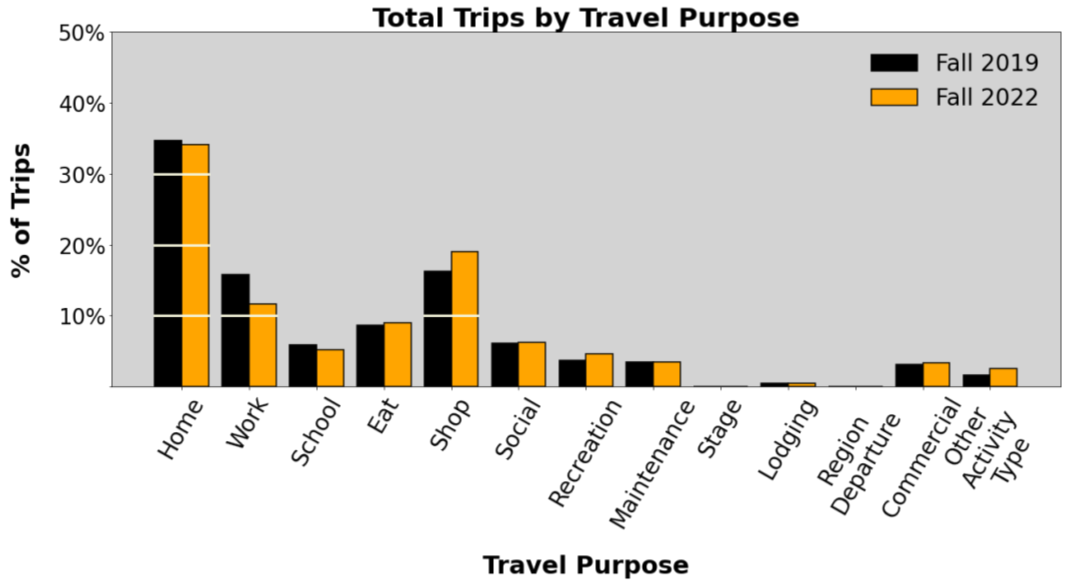
Trips	Fall 2019		Fall 2022		Absolute Change (pp)	Relative Change (%)
	Trips (mil)	Share (%)	Trips (mil)	Share (%)		
Work-Related	11.7	31.4	10.0	23.9	**- 7.5**	**- 14.5**
Non-Work	25.6	68.6	31.9	76.1	**+ 7.5**	**+ 24.6**
Total	37.3	100	41.9	100	-	**+ 12.3**

Source: Replica

Figures 4 and 5 illustrate shifts in trip composition, focusing on the destination end of trips. The share of work trips has declined by approximately four percentage points, reflecting the impact of increased remote work. In fall 2022, many universities adopted hybrid learning models, allowing students to attend some classes remotely. However, since most grade schools had resumed in-person instruction, the observed decline in school trips was unexpected.

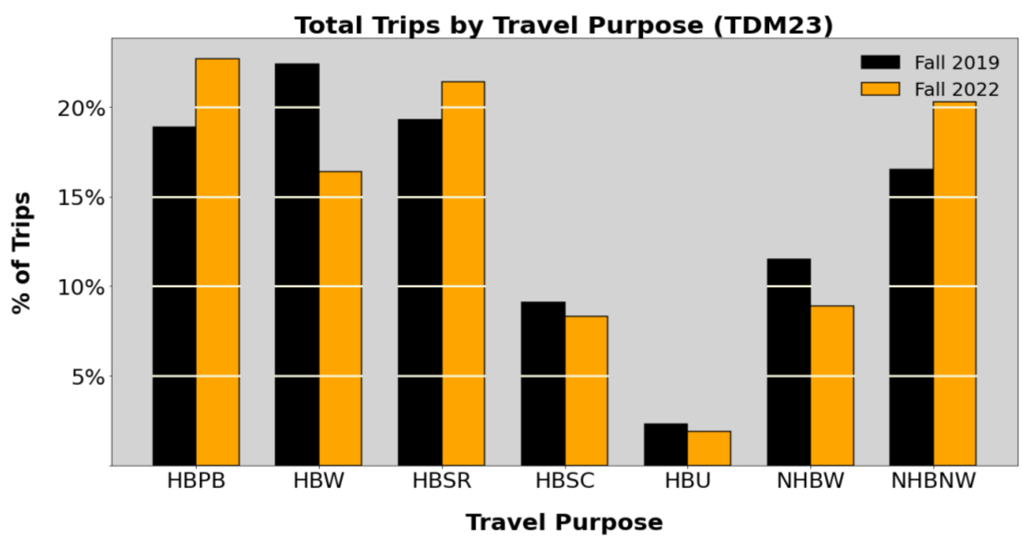
Meanwhile, discretionary trips—such as shopping, dining, and socializing—have increased significantly, likely driven by a rebound in activity following extended home isolation during the COVID-19 pandemic. In addition, not all nondiscretionary trips are home-based, as suggested by the rise in NHBNW (Non-Home-Based Non-Work) trips (Figure 5). This increase may be attributed to trip chaining of non-work activities, including remote work at third places, such as cafés and shared workspaces, which Replica categorizes as a non-work activity.

Figure 4
Percentage of Trips by Travel Purpose on a Statewide Level



Source: Replica

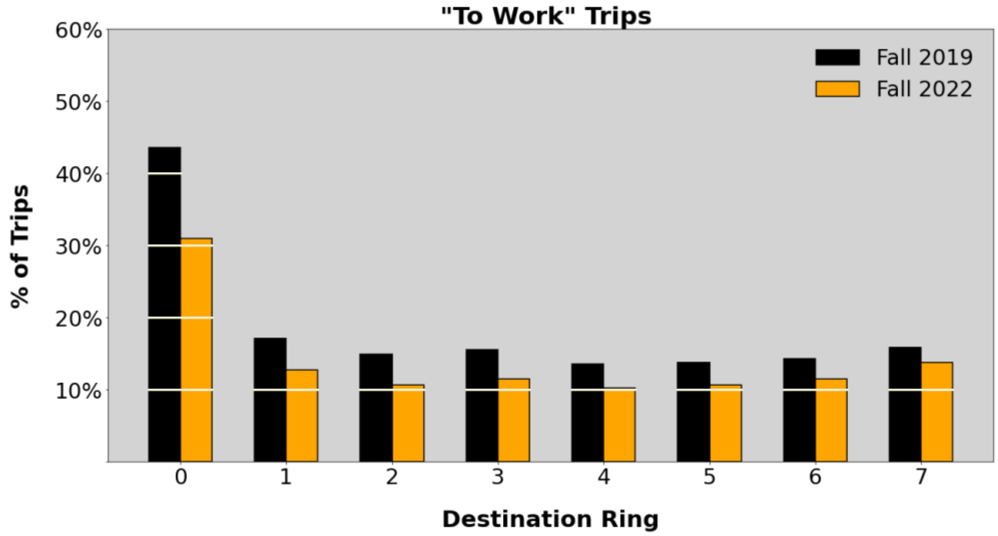
Figure 5
Percentage of Trips by Travel Purpose Using TDM23 Classification



HBPB: home-based personal business. HBSC: home-based school. HBSR: home-based social-recreation. HBU: home-based university. HBW: home-based work. NHBNW: non-home based non-work. NHBW: non-home based work.
Source: Replica

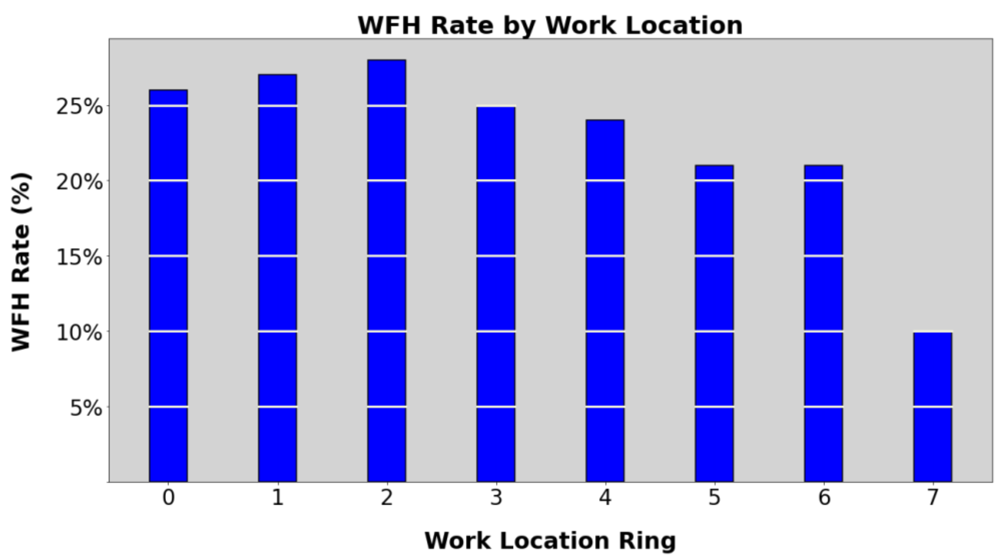
"To Work" trips have declined, particularly to Ring 0, underscoring its role as a central employment hub (Figure 6). This trend aligns with expectations, as downtown areas were anticipated to experience the largest reductions due to the higher prevalence of remote work in office-based industries. The larger percentage decrease in Rings 0, 1, and 2 also suggests that remote work adoption is higher for workplaces in denser development (Figure 7).

Figure 6
Percentage of “To Work” Trips Ending in Each Ring as a Share of Total Trips



Source: Replica

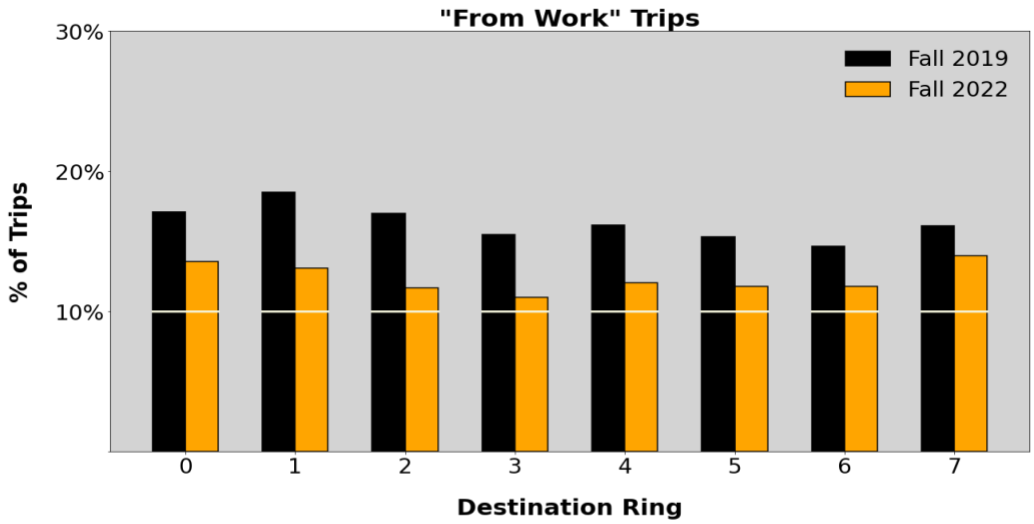
Figure 7
Work-from-Home Rate by Work Location Ring in 2022



WFH = work from home.
Source: Replica

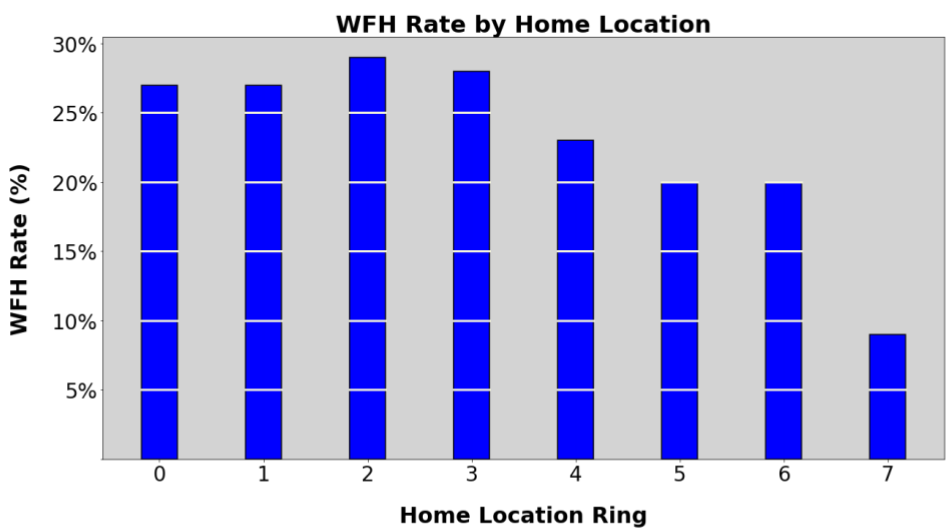
Similarly, “From Work” trips have decreased as well (Figure 8), reflecting the natural reduction in return trips due to fewer commutes to work. This trend is also complemented by the work from home rates by home location (Figure 9). Here again, we see the denser areas of the region (rings 0 through 3) with higher rates of remote work.

Figure 8
Percentage of “From Work” Trips Ending in Each Ring as a Share of Total Trips



Source: Replica

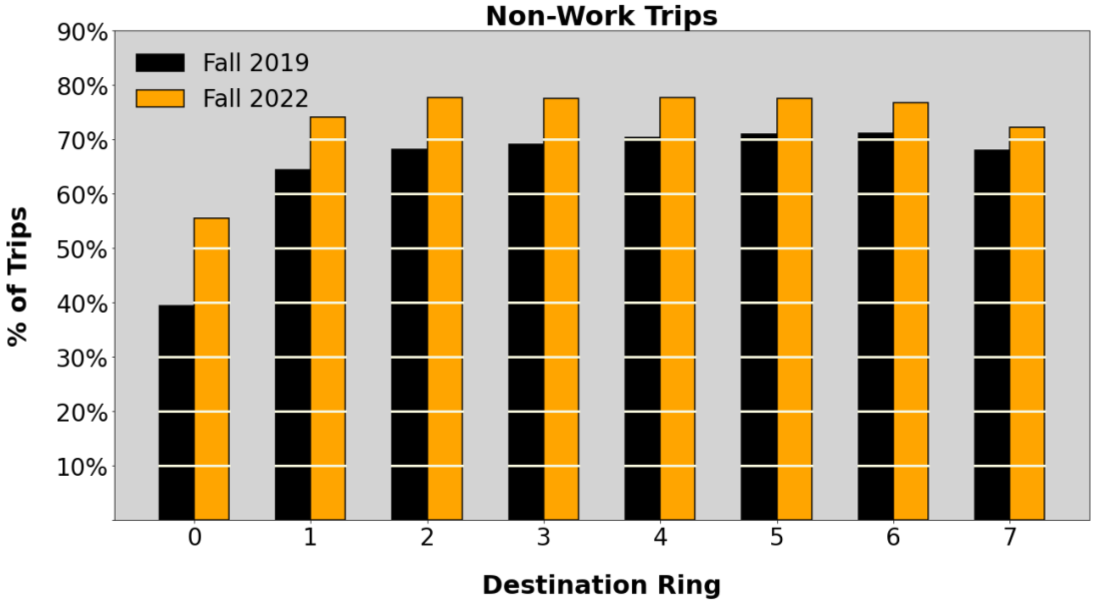
Figure 9
Work-from-Home Rate by Home Location Ring in 2022



WFH = work-from-home.
Source: Replica

Non-work trips have seen an uptick, as shown in Figure 10, indicating more local travel for shopping, dining, and socializing. This increase appears more pronounced, particularly in Ring 0, due to a significant reduction in work trips. This trend is consistent with expectations that increased remote work, and flexible schedules would shift travel demand towards local, discretionary activities.

Figure 10
Non-Work Trips Ending in Each Ring as a Share of Total Trips



Source: Replica

Conclusion and Discussion

The primary change observed in Trip Generation is a decrease in work trips and an increase in non-work trips. This shift aligns with the widespread adoption of remote work, which has resulted in fewer work-related trips, particularly to downtown areas. However, the noticeable increase in non-work trips deviates from expectations. These non-work trips may include personal errands, social activities, or recreational purposes. This increase could be attributed to remote work occurring either at home or in third places, such as cafés or shared workspaces.

Representing these substantial changes in activity patterns would require adjustments to the Trip Generation component of TDM23. One approach could involve adjusting work-from-home (WFH) rates. Since ring-level WFH rates are currently unavailable, trip generation patterns at the MPO or municipal level would be needed to establish a more refined basis for calibration.

To represent the increase in non-work activity, the production and attraction coefficients could be adjusted. However, the overall increase in trips requires further validation to ensure it isn't an anomaly in the data.

4.4 Trip Distribution

Expected Changes

Work trips to downtown, particularly from the outer rings, are expected to decline as remote work becomes more widespread. With fewer individuals commuting to traditional workplaces, the number of trips originating from the CBD is also likely to decrease.

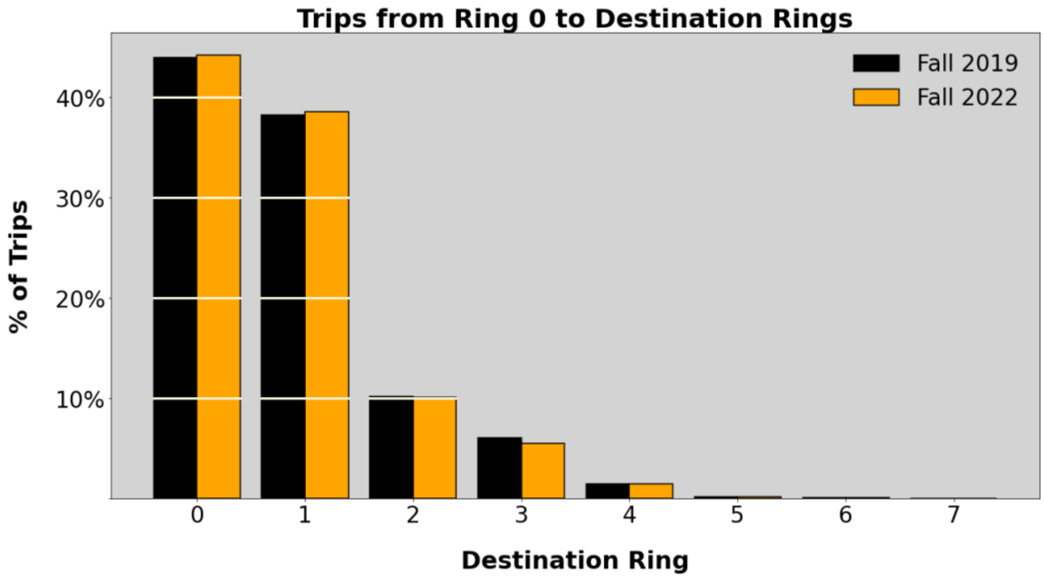
Non-work trips are expected to increase, particularly within suburban areas (intra-ring travel), as remote workers, whether at home or in third places, engage in more local travel. As previously noted, Replica does not classify trips to third workplaces as work trips. Since these trips are generally shorter than commutes to traditional workplaces, they further contribute to the rise in intra-ring non-work travel (Caros et al., 2023).

Estimated Changes by Replica

The Boston region and its inner commuting communities extend approximately to Ring 2, aligning with our expectations for Trip Distribution analysis. This area contains the largest share of the population and work locations, making it the most relevant for studying travel patterns. With accessible public transit and a reasonable distance from downtown, it provides a suitable framework for analyzing mode choices between public transit and car travel to the urban core. Since the majority of trips occur within these rings, they offer a comprehensive view of various trip types, and extending the analysis beyond Ring 2 did not yield any new insights.

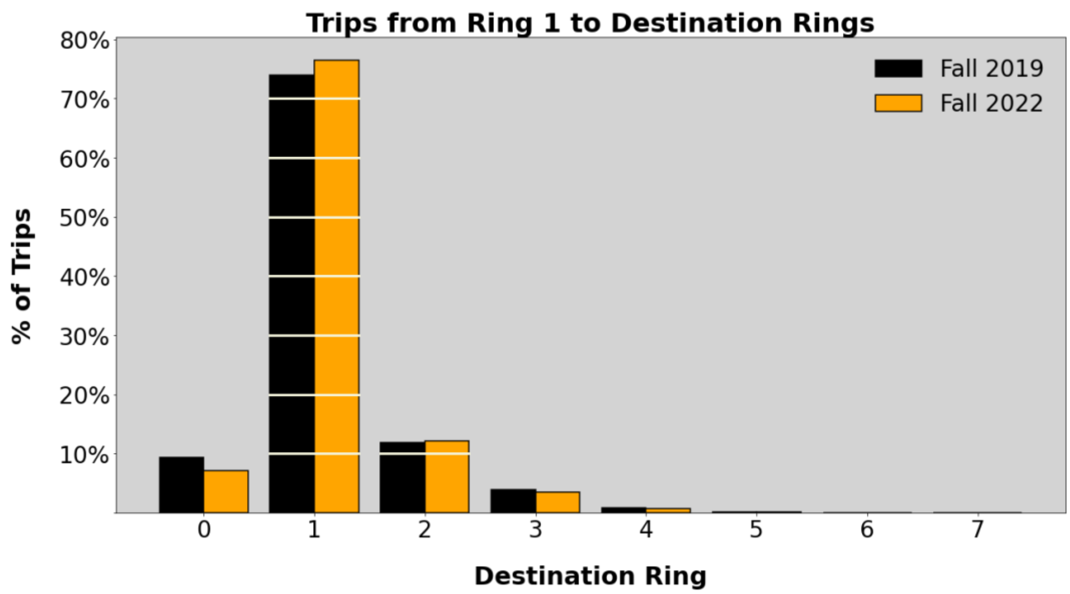
Estimated travel patterns show a decline in trips to Ring 0 from Ring 1 and Ring 2 (Figures 11, 12, 13), aligning with expectations. This reduction is largely driven by the widespread adoption of remote work, which has significantly reduced commuting to the CBD. Conversely, data show a higher share of intra-ring trips, reflecting a rise in localized travel, which also aligns with anticipated shifts in mobility patterns.

Figure 11
Percentage of Trips Originating from Ring 0 and Ending in Each Ring



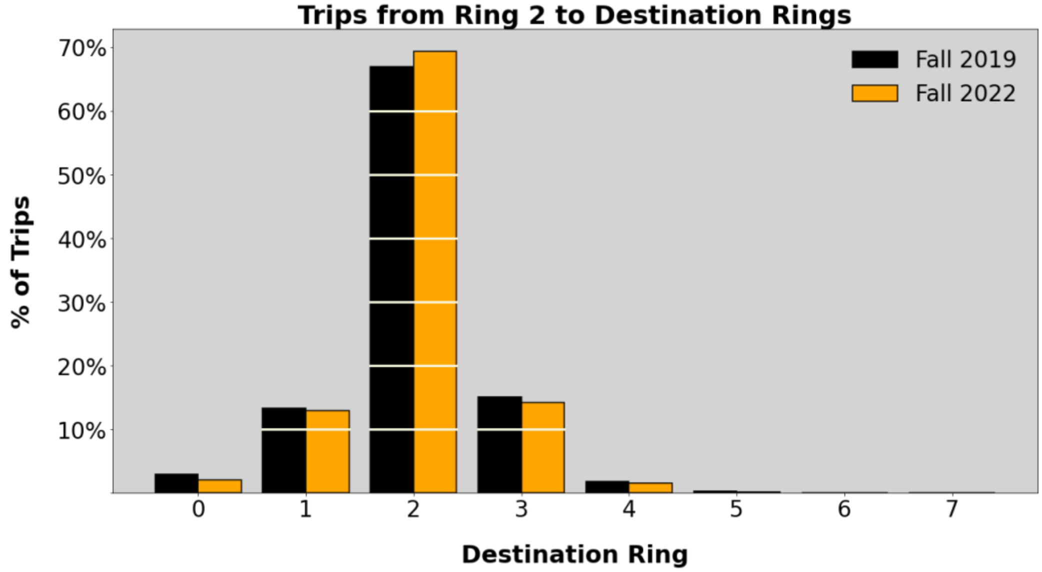
Source: Replica

Figure 12
Percentage of Trips Originating from Ring 1 and Ending in Each Ring



Source: Replica

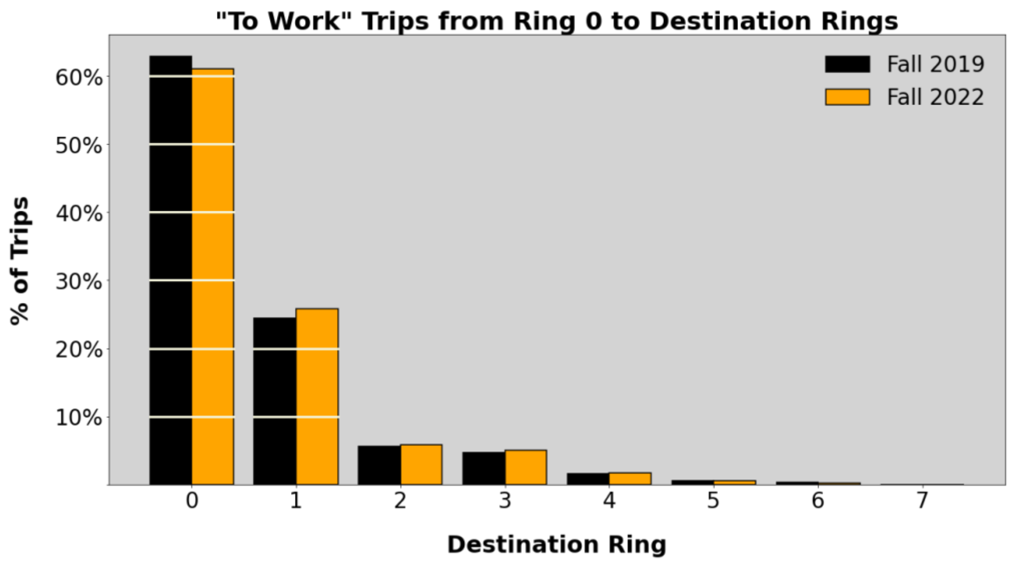
Figure 13
Percentage of Trips Originating from Ring 2 and Ending in Each Ring



Source: Replica

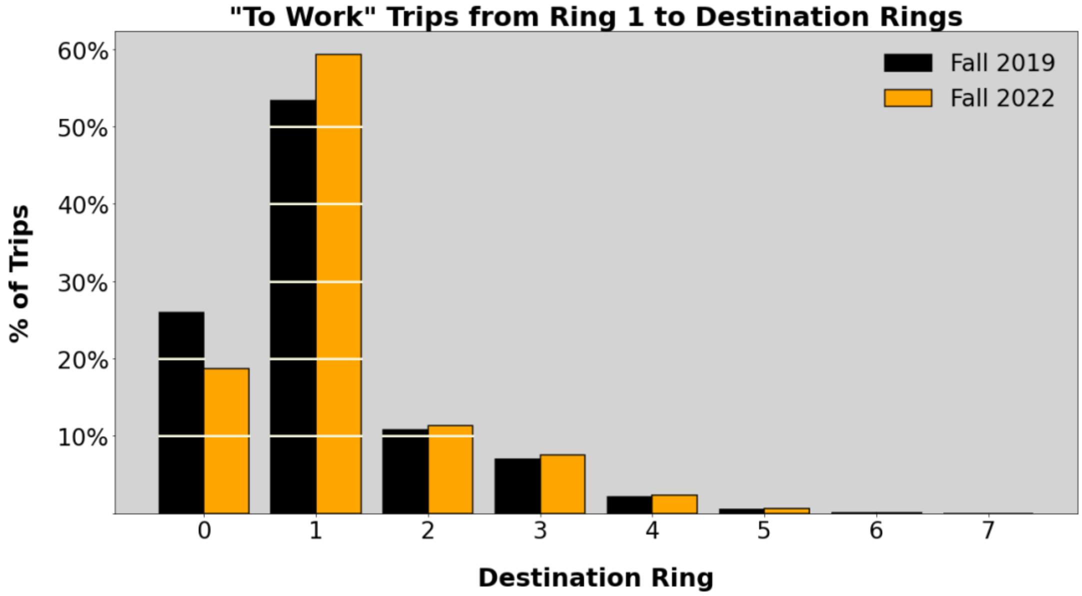
“To Work” trips to Ring 0 have significantly declined from Ring 0, Ring 1, and Ring 2, aligning with expectations as remote work reduces commuting to the urban core (Figures 14, 15, 16). The increase in intra-ring “To Work” trips within Ring 1 and Ring 2 is due to rebalancing.

Figure 14
Percentage of “To Work” Trips Originating from Ring 0 and Ending in Each Ring



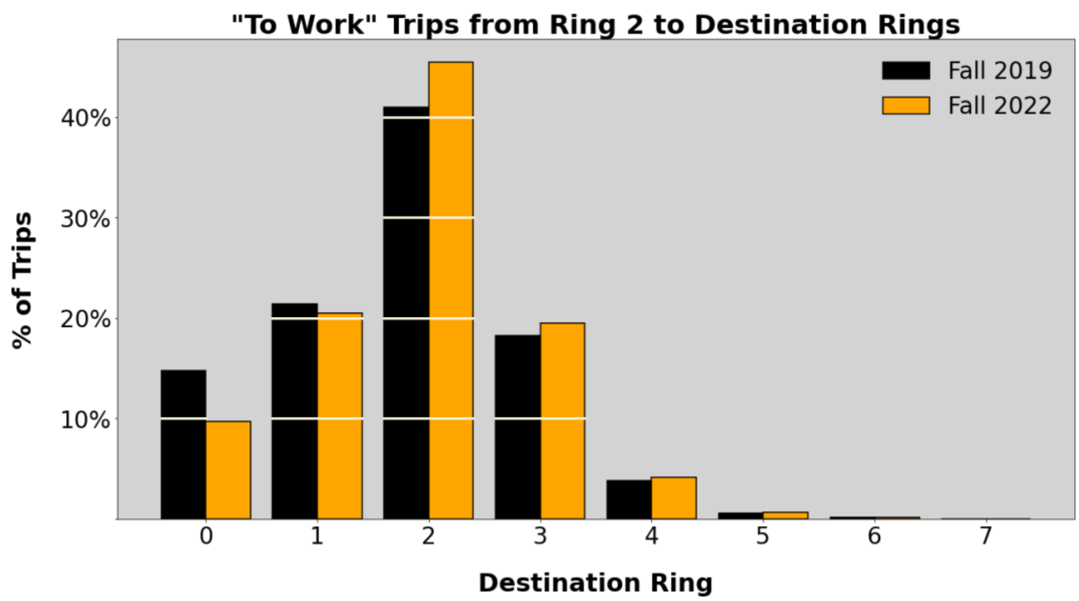
Source: Replica

Figure 15
Percentage of "To Work" Trips Originating from Ring 1 and Ending in Each Ring



Source: Replica

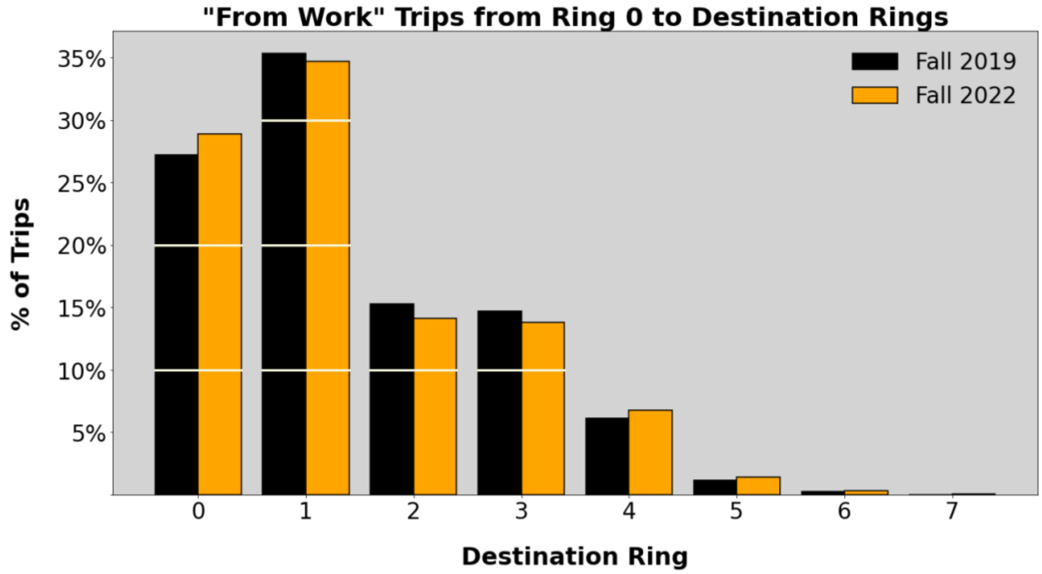
Figure 16
Percentage of "To Work" Trips Originating from Ring 2 and Ending in Each Ring



Source: Replica

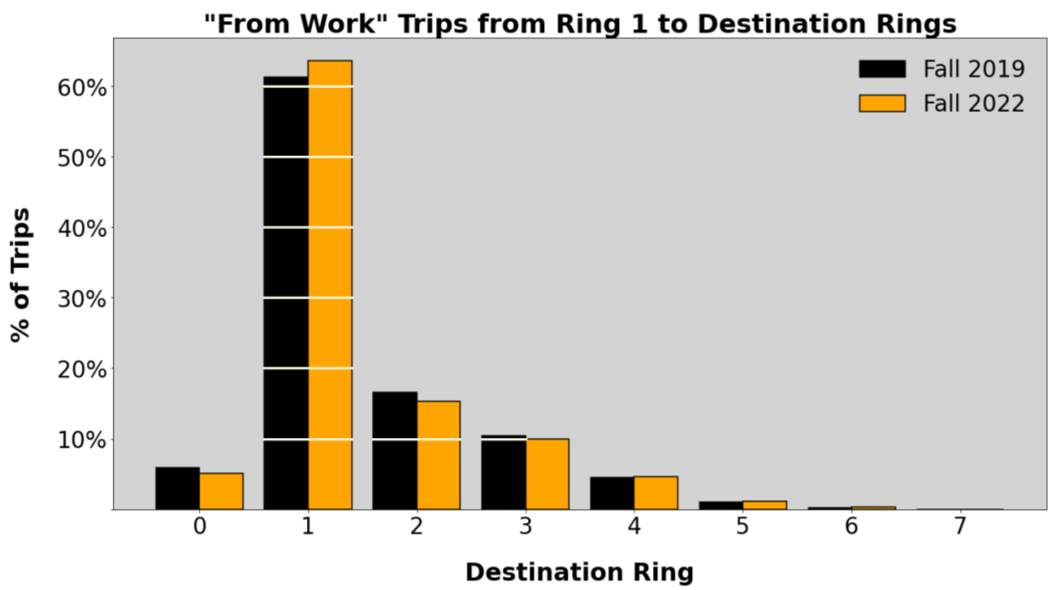
Similarly, "From Work" trips from Ring 0 to the outer rings have declined, reflecting reduced commuting to the CBD (Figure 17). In addition, a slight decline is observed in trips from Ring 1 and Ring 2 to other rings, indicating a broader shift in commuting patterns (Figures 18 and 19).

Figure 17
Percentage of "From Work" Trips Originating from Ring 0



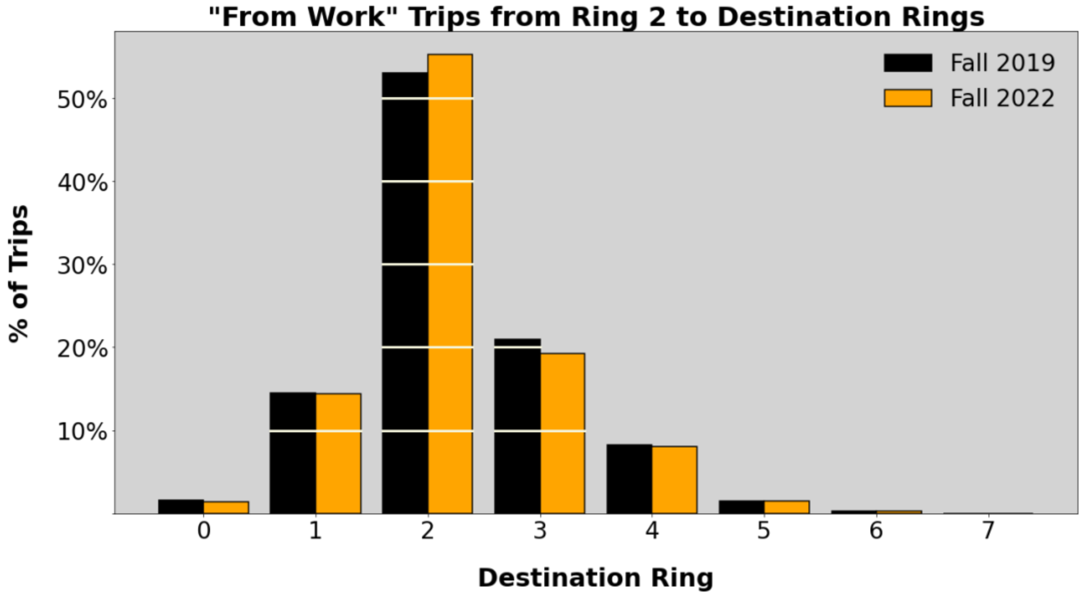
Source: Replica

Figure 18
Percentage of "From Work" Trips Originating from Ring 1



Source: Replica

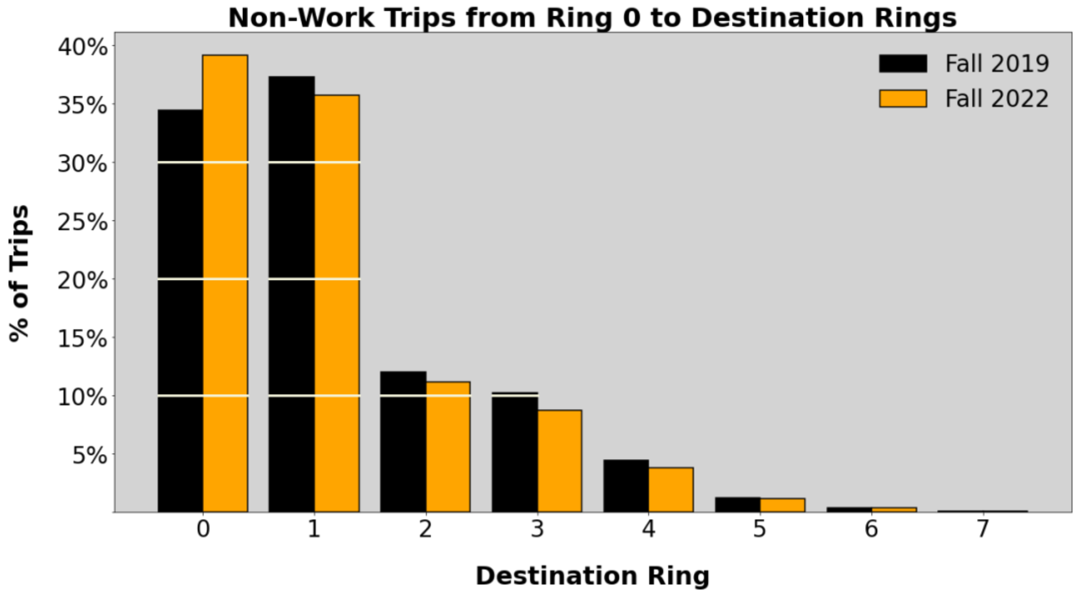
Figure 19
Percentage of "From Work" Trips Originating from Ring 2



Source: Replica

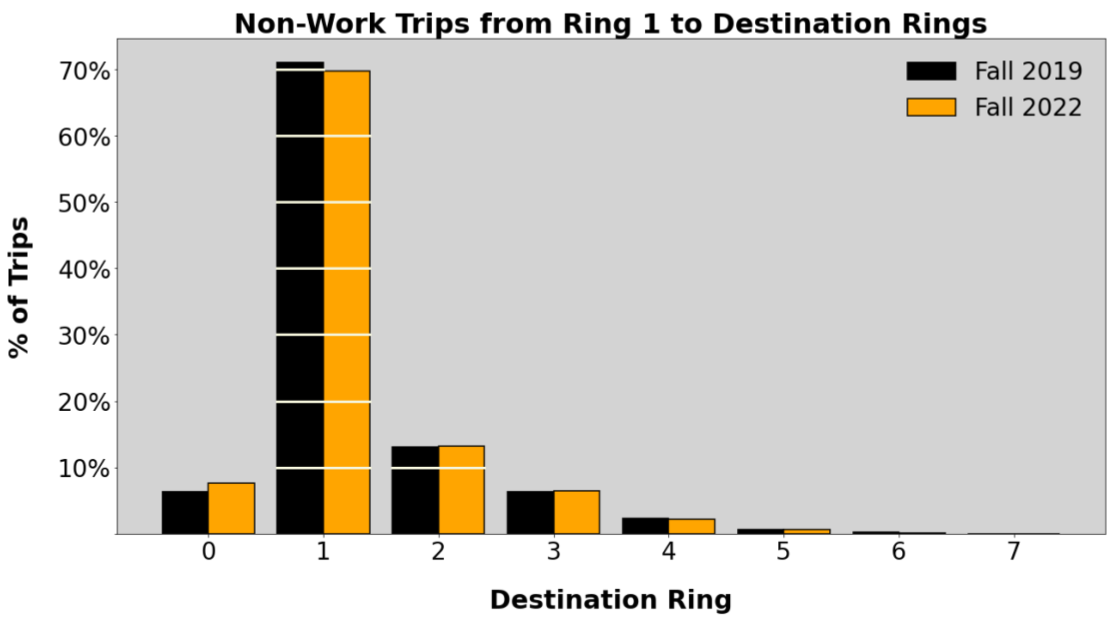
Non-work trips display varying trends across different urban rings. Notably, Ring 0 has seen an increased share of intra-ring non-work trips, as shown in Figure 20. This rise is likely driven by denser development, heightened commercial activity, and a shift towards more localized trips due to remote work practices. Conversely, Rings 1 and 2 have experienced a decrease in the share of intra-ring non-work trips, as illustrated in Figures 21 and 22. This observation defies initial expectations and may be explained by an increase in online shopping, which reduces the need for residents to travel locally for shopping or errands.

Figure 20
Percentage of Non-Work Trips Originating from Ring 0



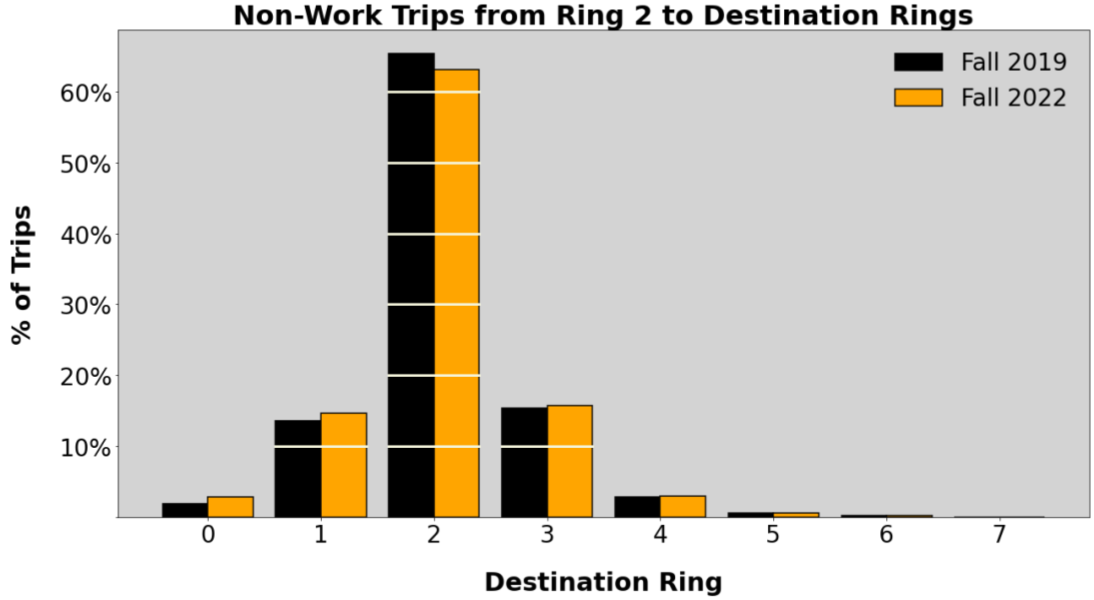
Source: Replica

Figure 21
Percentage of Non-Work Trips Originating from Ring 1



Source: Replica

Figure 22
Percentage of Non-Work Trips Originating from Ring 2



Source: Replica

Conclusion and Discussion

Observed travel patterns indicate a decline in trips to the CBD from outer rings and a rise in intra-ring travel.

More specifically, work-related trips to and from the CBD have significantly decreased, while intra-ring work trips in Ring 1 and Ring 2 have increased, which could potentially be attributed to rebalance or home and workplace relocations influenced by remote work arrangements.

Non-work travel trends are mixed: intra-ring activity within the CBD has increased, which could potentially be because of a large reduction in work trips, while suburban areas have seen a decline in localized non-work trips, contrary to expectations.

This analysis does not necessarily imply any changes needed to the distribution component of the model. Change in the travel patterns may be sufficiently represented through the change in trip generation of work and non-work purposes.

4.5 Mode Choice

Expected Changes

Travel patterns are expected to shift toward greater reliance on auto trips across all trip types, driven by reduced public transit service, health concerns, and the convenience of car travel. Research (Caros et al., 2023) suggests that since 2019, more people have transitioned from sustainable modes to driving or using taxis (6.8 percent) than the reverse (5.0 percent), reinforcing this anticipated trend.

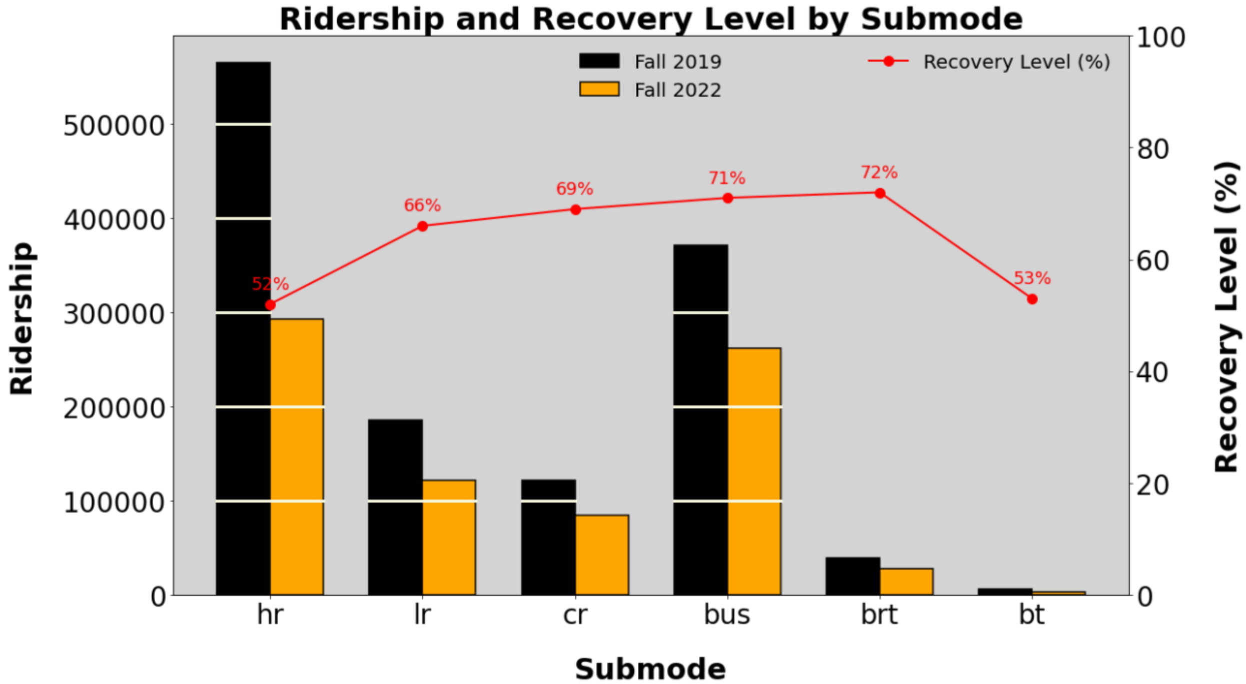
Both work and non-work trips are expected to follow this pattern, with non-work travel particularly influenced by flexibility and privacy, making driving the preferred choice for errands and leisure activities. This expectation is supported by research showing that more than 50 percent of the population already drives for non-work trips at least five times per week (Caros et al., 2023).

Public transit trips are expected to decline due to reduced service levels, health concerns in crowded spaces, and the rise of remote work, which has lowered commuting demand. This trend aligns with research findings showing that approximately 75 percent of people rarely or never use transit, walking, or biking for non-work trips (Caros et al., 2023).

Transit ridership trends were analyzed using data from the MBTA Open Data Portal. Average weekday ridership in October declined from 1.3 million in 2019 to 0.8 million in 2022, resulting in a 62 percent recovery level, which aligns with expectations.

Figure 23 illustrates ridership recovery levels across transit submodes, revealing notable variations. Heavy Rail and ferry services exhibited the lowest recovery levels at 52 percent and 53 percent, respectively, suggesting a slower return of commuters in these modes. This may be attributed to lingering health concerns, reduced service frequencies, or shifts in work locations. In contrast, bus and bus rapid transit services demonstrated the highest recovery levels at 71 percent and 72 percent, respectively, indicating stronger demand. This resilience may be driven by their accessibility and essential role in serving transit-dependent populations and essential workers.

Figure 23
Average October Weekday Ridership by Transit Submode



brt = bus rapid transit. bt = boat (ferry). cr = commuter rail. hr = heavy rail. lr = light rail.
Source: MBTA

Nonmotorized trips, such as walking and biking, are expected to increase overall, primarily in dense, walkable urban areas where daily needs can be met without a car. As remote work and shifting routines encourage more localized travel, active transportation becomes a more convenient option for short trips. However, in suburban and rural areas, where auto use remains dominant, nonmotorized travel is likely to decline or remain stable.

Estimated Changes by Replica

Table 4 shows that auto trips have remained the most prevalent mode of travel, with their share increasing from 75.5 percent in fall 2019 to 77.0 percent in fall 2022. However, Table 5 reveals a notable shift within this mode: while the share of auto drivers declined by 13.9 percent, this decrease was offset by a 57.7 percent increase in auto passengers, suggesting a shift toward more passenger-based car travel. This pattern was somewhat unexpected given the anticipated rise in vehicle ownership and could be a result of the large shift in trips from commuting with single-occupancy vehicle use to non-work activities that have a higher share of high occupancy vehicle travel. Nonmotorized modes saw a slight increase from 15.9 percent to 16.4 percent, though the growth was more modest than expected. The most significant change, however, is the 51.2 percent decline in public transit usage, a trend that aligns with expectations.

Table 4
Mode Share for Total Trips

Travel Mode	Share (%)		Absolute Change (pp)	Relative Change (%)
	Fall 2019	Fall 2022		
Auto	75.5	77.0	+ 1.5	+ 2.0
Nonmotorized	15.9	16.4	+ 0.5	+ 3.1
Public Transit	4.3	2.1	- 2.2	- 51.2
Commercial	3.2	3.4	+ 0.2	+ 6.2
Other	1.1	1.1	0.0	0.0

Source: Replica

Table 5
Disaggregated Mode Share for Total Trips

Travel Mode	Share (%)		Absolute Change (pp)	Relative Change (%)
	Fall 2019	Fall 2022		
Auto Driver	56.8	48.9	- 7.9	- 13.9
Auto Passenger	17.5	27.6	+ 10.1	+ 57.7
Biking	1.2	1.1	- 0.1	- 8.3
Walking	14.7	15.3	+ 0.6	+ 4.1
Public Transit	4.3	2.1	- 2.2	- 51.2
On Demand Auto	1.1	0.6	- 0.5	- 45.5
Commercial	3.2	3.4	+ 0.2	+ 6.2
Other	1.1	1.1	0.0	0.0

Source: Replica

The estimated patterns for work-related trips generally reflect the broader trends, as shown in Table 6. Private vehicles continued to account for the majority of these trips, with their share increasing from 79.0 percent to 82.0 percent, consistent with expectations. Nonmotorized modes, including walking and biking, increased by 10.6 percent, which is unexpected. The 56.4 percent decrease in public transit usage is slightly higher than the change across all trips, which is reasonable given the higher transit mode share for work related trips.

Table 6
Mode Share for Work-Related Trips

Travel Mode	Share (%)		Absolute Change (pp)	Relative Change (%)
	Fall 2019	Fall 2022		
Auto	79.0	82.0	+ 3.0	+ 3.8
Nonmotorized	12.3	13.6	+ 1.3	+ 10.6
Public Transit	7.8	3.4	- 4.4	- 56.4
Other	0.9	1	+ 0.1	+ 11.1

Source: Replica

Table 7 shows that auto trips have remained the dominant mode for non-work travel, with their share increasing slightly from 77.5 percent in fall 2019 to 79.0 percent in fall 2022—a change that aligns with expectations of increased reliance on car travel for errands and leisure activities. Nonmotorized modes experienced a 2.7 percent decline, which contrasts with the anticipated growth driven by projected increases in localized travel. The most notable shift is the 35.7 percent decrease in public transit usage, a trend that matches expectations.

Table 7
Mode Share for Non-Work Trips.

Travel Mode	Share (%)		Absolute Change (pp)	Relative Change (%)
	Fall 2019	Fall 2022		
Auto	77.5	79.0	+ 1.5	+ 1.9
Nonmotorized	18.5	18.0	- 0.5	- 2.7
Public Transit	2.8	1.8	- 1.0	- 35.7
Other	1.3	1.2	- 0.1	- 7.7

Source: Replica

Conclusion and Discussion

The analysis confirms the continuation of established travel behavior trends, with auto trips remaining dominant across all trip types and experiencing modest growth. Nonmotorized modes, such as walking and biking, showed slight variations, with a minor increase in work-related trips and a small decline in non-work trips. The most notable trend is the consistent decline in public transit usage across all trip types, reinforcing a broader shift away from transit, which aligns with expectations.

Adjusting the model to fit these mode shares may be realized through the alternative specific constant representation of unobserved attributes to represent the increased reluctance to use transit and preference for auto and nonmotorized modes.

4.6 Time of Day

As mentioned in the Introduction, TDM23 divides an “average weekday” into distinct times of day:

- AM Peak: 6:30 AM–9:30 AM
- Midday: 9:30 AM–3:00 PM
- PM Peak: 3:00 PM–7:00 PM
- Night: 7:00 PM–6:30 AM

Expected Changes

The AM peak is expected to see a lower share of trips due to remote work, as some individuals start their day at home instead of commuting early. Others may delay their departure and begin working from third places such as cafés, libraries, or co-working spaces later in the morning. Research (Caros et al., 2023) shows that commuting departure times have shifted later compared to 2019, with departures after 8:30 AM increasing while earlier departures have declined. Notably, late departures (after 11:00 AM) have risen from 9.5 percent to 16 percent, likely due to the growing use of third places for remote work.

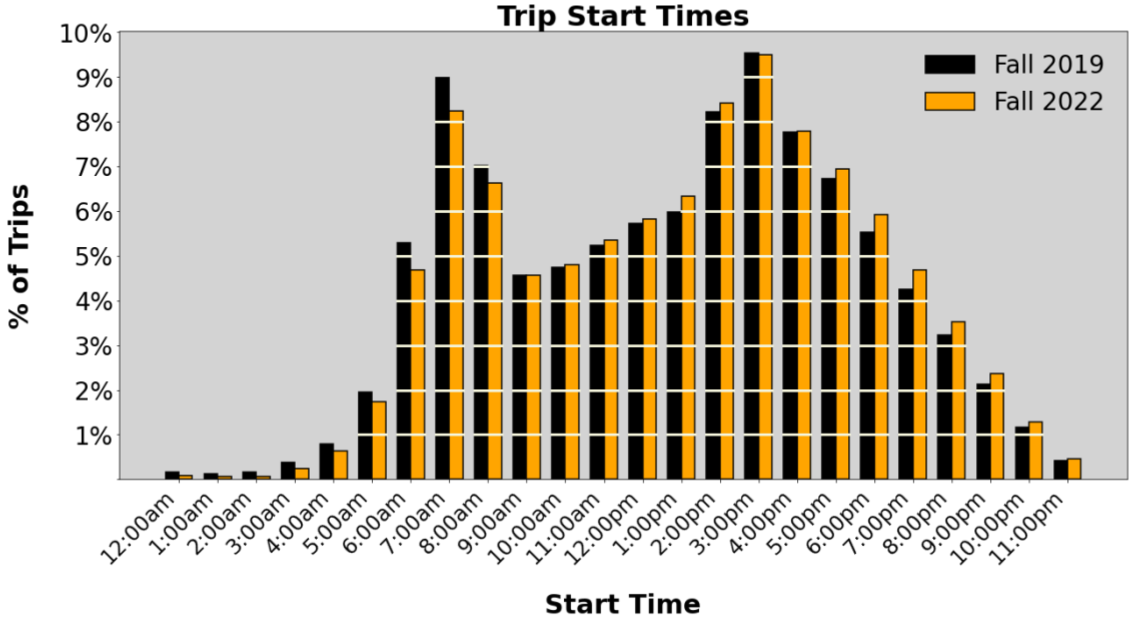
These shifts contribute to a rise in work-related travel during the midday (MD) period, as more individuals start their commutes later or leave workplaces earlier in the day, leading to a more dispersed commuting pattern. In addition, with fewer people commuting at fixed times, nonmandatory trips—such as errands, leisure activities, and social outings—are expected to increase, particularly during the MD period, when roads and services are less crowded.

Estimated Changes by Replica

Figure 24 illustrates the distribution of trip start times in fall 2019 and fall 2022, highlighting shifts in travel behavior. The AM peak (6:30–9:30 AM) experienced a 7.4 percent decline in trips, which aligns with expectations given the continued impact of remote work (Table 8). With fewer individuals commuting early in the morning, some delay their trips, either starting their workday at home or working from third places such as cafés or co-working spaces. This shift contributes to a more evenly distributed pattern of trips throughout the morning and midday, reflecting anticipated changes in travel demand.

During the midday period (9:30 AM–3:00 PM), trips increased by 2.5 percent, which aligns with expectations as more flexible schedules allow workers to arrive later or leave earlier (Table 8). The PM period (3:00–7:00 PM) experienced a modest rise, maintaining its role as a peak travel window despite slight shifts in trip distribution. Meanwhile, the nighttime period (after 7:00 PM) saw a small increase, reflecting an uptick in evening travel, likely for social or leisure activities. Overall, these trends indicate a more evenly distributed travel pattern, consistent with anticipated changes driven by flexible work arrangements.

Figure 24
Hourly Distribution of Trip Start Times



Source: Replica

Table 8
Total Trips by Time of Day

Time of Day	Share (%)		Absolute Change (pp)	Relative Change (%)
	Fall 2019	Fall 2022		
AM	21.6	20.0	- 1.6	- 7.4
MD	32.1	32.9	+ 0.8	+ 2.5
PM	29.5	30.1	+ 0.6	+ 2.0
NT	16.8	17.0	+ 0.2	+ 1.2

MD = Midday. NT = Nighttime.
Source: Replica

Table 9 shows a 3.6 percent decrease in the share of “To Work” trips during the AM period, aligning with expectations due to the impact of remote work. Similarly, the 3.4 percent increase in the MD period was anticipated, likely to reflect more flexible work arrangements that allow individuals to start later or leave earlier. However, the 14.3 percent increase in the PM period is less intuitive, suggesting a shift in commuting patterns that was not as expected.

Table 9
"To Work" Trips by Time of Day

Time of Day	Share (%)		Absolute Change (pp)	Relative Change (%)
	Fall 2019	Fall 2022		
AM	46.9	45.2	- 1.7	- 3.6
MD	23.6	24.4	+ 0.8	+ 3.4
PM	10.5	12.0	+ 1.5	+ 14.3
NT	19.0	18.3	- 0.7	- 3.7

MD = Midday. NT = Nighttime.
Source: Replica

Table 10 shows a 4.2 percent increase in the share of "From Work" trips during the MD period, which aligns with expectations as flexible work arrangements allow individuals to leave work earlier. Meanwhile, the 7.5 percent decrease in the PM period was also anticipated, as fewer people commuting to work naturally results in fewer return trips at the end of the workday.

Table 10
"From Work" Trips by Time of Day

Time of Day	Share (%)		Absolute Change (pp)	Relative Change (%)
	Fall 2019	Fall 2022		
AM	3.8	4.1	+ 0.3	+ 7.9
MD	38.4	40.0	+ 1.6	+ 4.2
PM	41.6	38.5	- 3.1	- 7.5
NT	16.1	17.4	+ 1.3	+ 8.1

MD = Midday. NT = Nighttime.
Source: Replica

Table 11 shows a slight shift in non-work-related trips by time of day, aligning with expectations. The share of trips during the peak period declined by 1.4 percent, while the share during the non-peak period increased by 1.4 percent. This suggests a small redistribution of non-work trips toward off-peak hours, likely due to increased schedule flexibility or changes in travel behavior, which is consistent with broader trends in travel demand.

Table 11
Non-Work-Related Trips by Time of Day

Time of Day	Share (%)		Absolute Change (pp)	Relative Change (%)
	Fall 2019	Fall 2022		
PK	50.9	50.2	- 0.7	- 1.4
NP	49.1	49.8	+ 0.7	+ 1.4

NP = non-peak. PK = peak.
Source: Replica

Conclusion and Discussion

The estimated patterns in time of day align with expectations driven by increased flexibility in work arrangements. The AM peak period has seen a decline in trips, consistent with the impact of remote work reducing the number of commutes to workplaces. In contrast, the midday period has experienced an increase, reflecting greater flexibility that allows individuals to arrive later or leave earlier. The PM period remains a key travel window, but the higher-than-expected increase in “To Work” trips suggests evolving commuting behaviors that may require further analysis.

Non-work-related travel has also shifted slightly, with a small decline in peak-period trips and an increase in non-peak trips. This redistribution is in line with expectations, likely influenced by greater flexibility in daily schedules.

These changes indicate a more evenly distributed travel pattern throughout the day. Reproducing these patterns would require changes to the Peak and Non-Peak Production-Attraction to Time-of-Day Origin-Destination rates in the model.

4.7 Highway VMT

Expected Changes

Overall, total VMT is expected to decrease, driven by the widespread adoption of remote work, which reduces the need for traditional commuting. To confirm this, we analyzed average daily VMT data from MassDOT via the MassGIS Data Hub for 2019 and 2022. To assess discrepancies in VMT changes, we use the VMT Ratio, defined as the VMT in 2022 divided by the VMT in 2019. Total VMT in 2022 is 96 percent of 2019 levels (Table 12), indicating a modest but persistent decline in driving activity post-pandemic.

Breaking this down by Federal Highway Functional Classification, we observed that major roadways, including interstates and principal arterials, experienced some of the most significant declines. Interstate VMT fell by five percent, while principal arterials saw an eight percent drop. Rural minor arterials and major collectors also showed reductions, suggesting that long-distance travel and commuting have yet to fully rebound. These declines align with the continued impact of remote work and changing commuting habits. In contrast, other freeways and expressways saw a five percent increase, which may indicate shifts in travel routes or changes in regional traffic demand. Local roads experienced a slight one percent increase, suggesting that neighborhood-level travel has remained stable, possibly due to more localized activity and flexible work arrangements. The sharp increase in VMT on minor collector roads, more than doubling between 2019 and 2022, is likely an anomaly in the data rather than a true shift in travel behavior. Given the typically low VMT on these roads, small variations in reporting or classification may have exaggerated the percentage change.

Table 12
Highway VMT from MassDOT by Federal Highway Functional Classification

Federal Highway Functional Class	VMT 2019	VMT 2022	VMT Ratio	VMT Change
Interstate	49,637,522	46,988,639	0.95	5%
Other Freeways & Expressways	18,618,262	19,514,937	1.05	+ 5%
Principal Arterial	35,803,736	32,814,384	0.92	- 8%
Rural Minor Arterial	35,599,807	33,203,918	0.93	- 7%
Major Collector	14,186,404	13,480,000	0.95	- 5%
Minor Collector	339,021	684,993	2.02	+ 102%
Local	23,598,472	23,944,576	1.01	+ 1%
Overall	177,783,224	170,631,447	0.96	- 4 %

MassDOT = Massachusetts Department of Transportation. VMT = vehicle miles traveled.
Source: MassDOT

These results are compared with Replica's estimates. For statewide VMT, Replica data indicates a nine percent decrease, a greater decline than the four percent decrease observed in MassDOT data. In 2019, the Replica-based VMT ratio was 0.85, declining to 0.81 in 2022 (Table 13). This suggests that Replica systematically reports lower VMT values.

Table 13
Highway VMT Comparison from Different Sources

Source	VMT 2019	VMT 2022	VMT Ratio	VMT Change
MassDOT	177,783,224	170,631,447	0.96	- 4%
Replica	151,101,413	137,830,934	0.91	- 9%
Replica/MassDOT Ratio	0.85	0.81		

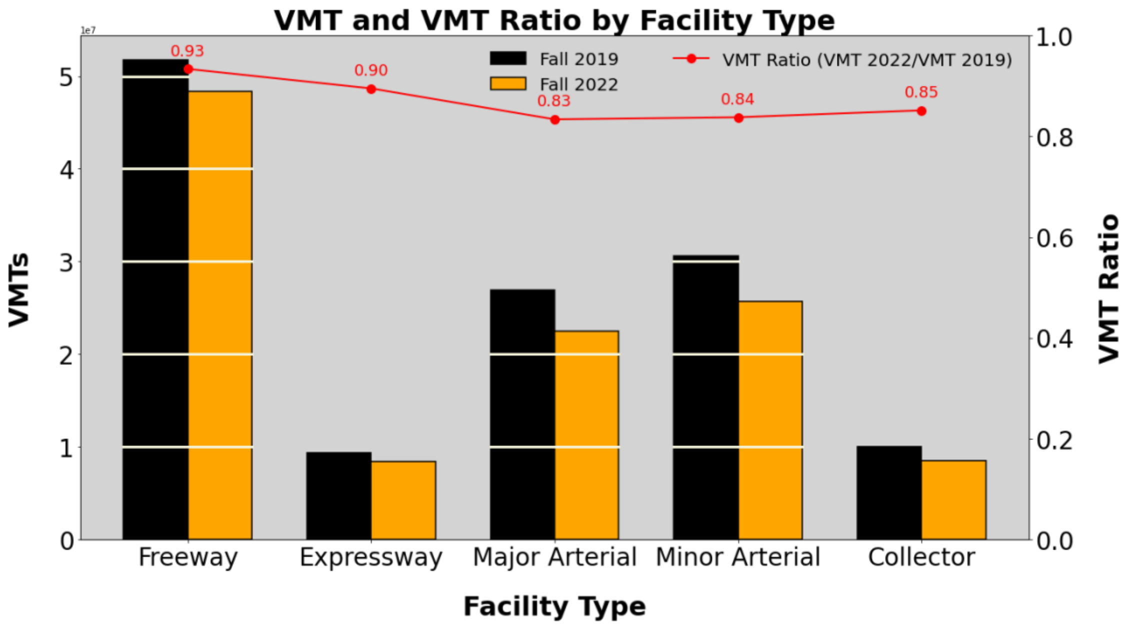
MassDOT = Massachusetts Department of Transportation. VMT = vehicle miles traveled.
Source: MassDOT and Replica

We further investigate the VMT data from Replica. Since TDM23 defines facility types differently from the Federal Highway Functional Classification, we converted Replica links to TDM23 facility types to examine VMT breakdown changes.

Estimated Changes by Replica

As discussed in the Methodology section, highway links in Replica are mapped to TDM23. Among the five facility types in TDM23, 75 percent of the links were successfully matched with corresponding data in Replica, with a VMT Ratio of 0.88, which is further lower than that in Table 13. Nevertheless, the observed VMT changes on matched links align with expectations, showing an overall decline, with the largest decreases occurring on Major and Minor Arterials (Figure 25).

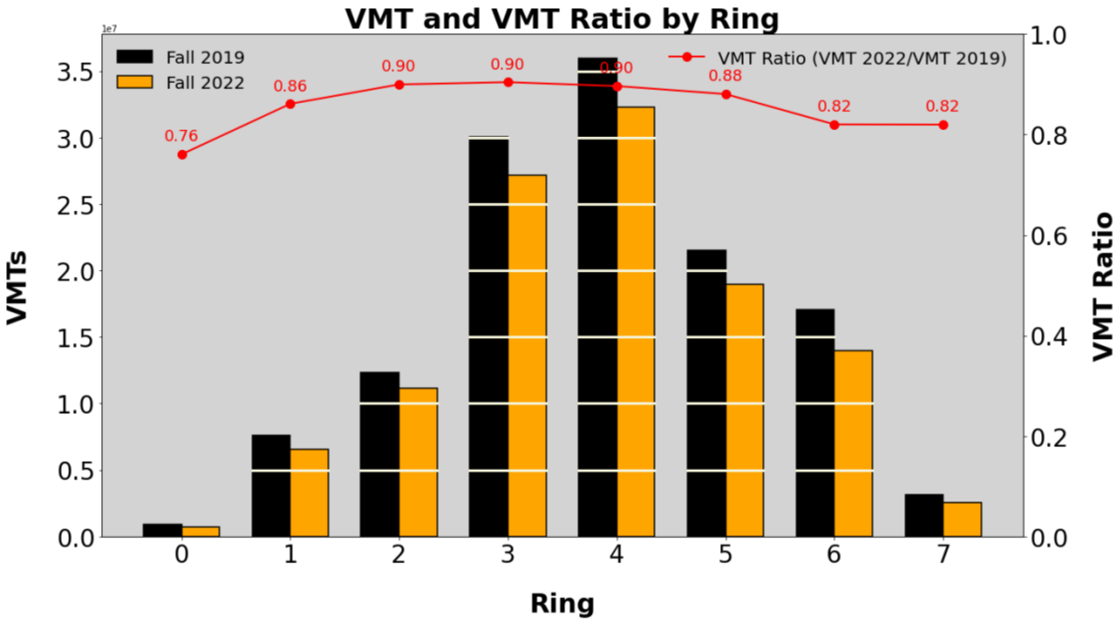
Figure 25
VMT and VMT Ratio by Facility Type (Replica 2019 vs Replica 2022), for Matched Links Only



VMT = vehicle miles traveled.
Source: Replica

We also analyzed VMT by ring, anticipating a greater decline within CBD, due to reduced work-related trips. In Ring 0, Replica estimates show a significantly lower VMT ratio compared to other rings (Figure 26), reflecting fewer trips to and from urban centers.

Figure 26
VMT and VMT Ratio (VMT 2022/VMT 2019) by Ring, for Matched Links Only



VMT = vehicle miles traveled.
Source: Replica

While Replica reports a lower VMT ratio than MassDOT data, we also observed that Replica reported higher total trip counts and a higher auto mode share in 2022 than in 2019 in earlier analyses. To further investigate the lower VMT ratio reported by Replica, we examined trip distances.

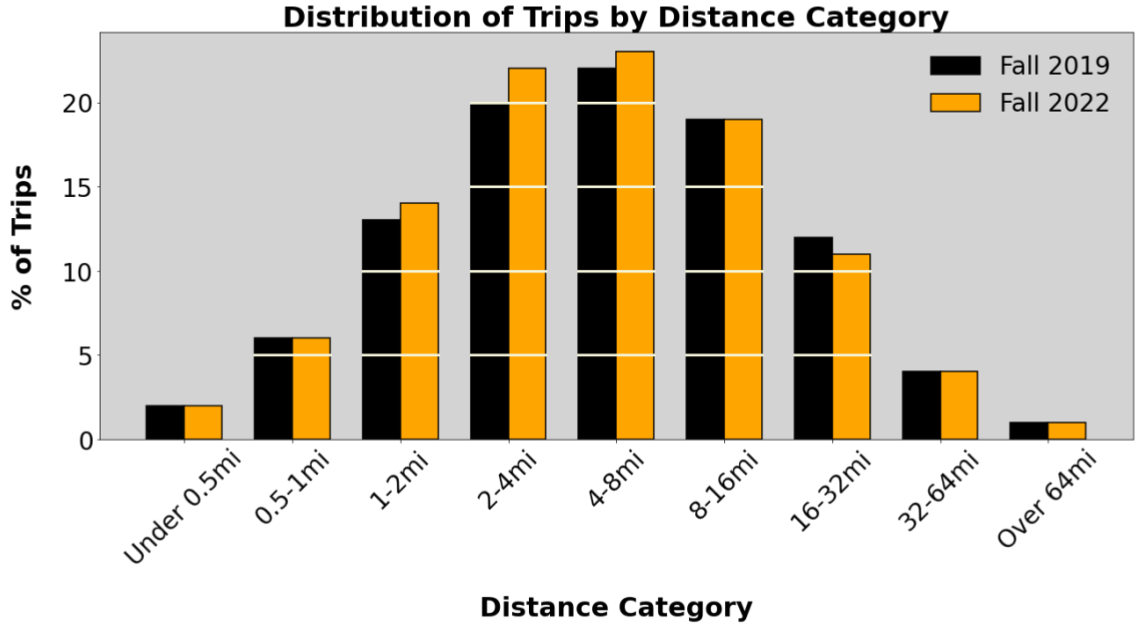
Further Investigation—Trip Distance

Post-pandemic travel patterns are expected to shift towards shorter average trip lengths due to an increase in localized activities and a decline in long-distance commute trips.

From Replica data, the average trip length decreased from 9.1 miles pre-pandemic to 8.6 miles post-pandemic, with the median trip length dropping from 5.1 miles to 4.8 miles. This shift indicates a notable trend toward shorter trips as expected. Note that the trip distance values discussed in this section is for all-mode, not highway-specific.

Due to data availability from the Replica portal, trip distance classification is used as the horizontal axis in Figure 27. Trips within the one to eight miles range accounted for 59 percent of all trips in 2022, up from 55 percent in 2019. This increase highlights a growing preference for shorter, local trips, potentially influenced by reduced commuting for work and an uptick in neighborhood-based activities.

Figure 27
Trip Distance Distribution



Source: Replica

This shift toward shorter trips in Replica data may help explain why total VMT in 2022 remains lower than in 2019.

Conclusion and Discussion

It is noticeable that Replica produces lower VMT estimates than those from MassDOT, warranting further investigation to understand the discrepancy. In addition, aligning Replica data with the existing network in TDM23 may present challenges. Nevertheless, Replica provides valuable insights. The data indicates that total VMT in 2022 was noticeably lower than in 2019, with the most pronounced drop observed in Ring 0 (i.e., the CBD) and average trip distance being shorter. When analyzed by facility type, major and minor arterials have recovered less than freeways and expressways.

The VMT check serves as a system-level validation for the Travel Demand Model. In a post-pandemic year, if the model is recalibrated, for example, by revising work-from-home parameters, time-of-day distributions, and utility function coefficients, VMT checks can indicate how the demand level changes result in system level differences.

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