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A Better Understanding of Shopping Travel in the United States

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16. Abstract - How we shop in the US is changing, with an increasing reliance on online shopping and delivery services. The transportation and environmental implications of this shift are unknown—these services could ultimately improve outcomes through batching of trips to multiple residences, or they could worsen transport outcomes by replacing short trips to the store with much longer trips to central warehouses, utilizing heavier vehicles. The convenience of online shopping may also lead to additional shopping events relative to the disutility of traveling to a store. A key piece of information in understanding the implications of the shift to online shopping is understanding what the transport impacts of the status quo of in-person shopping are. Most existing studies either add up the total mileage of trips to shopping destinations, or assume each shopping trip generates a round-trip from home. However, a significant fraction of shopping occurs on the way to or from other destinations. This research quantifies how much marginal vehicle mileage these trips induce, by comparing actual travel days with hypothetical travel days with shopping trips removed. We find that the marginal vehicle mileage generated by shopping trips is, coincidentally, comparable to mileage calculated by measuring only trips to shopping locations and approximately half the distance calculated by assuming round trips from home to each shopping location.

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ABSTRACT

How we shop in the US is changing, with an increasing reliance on online shopping and delivery services. The transportation and environmental implications of this shift are unknown—these services could ultimately improve outcomes through batching of trips to multiple residences, or they could worsen transport outcomes by replacing short trips to the store with much longer trips to central warehouses, utilizing heavier vehicles. The convenience of online shopping may also lead to additional shopping events relative to the disutility of traveling to a store.

A key piece of information in understanding the implications of the shift to online shopping is understanding what the transport impacts of the status quo of in-person shopping are. Most existing studies either add up the total mileage of trips to shopping destinations, or assume each shopping trip generates a round-trip from home. However, a significant fraction of shopping occurs on the way to or from other destinations. This research quantifies how much marginal vehicle mileage these trips induce, by comparing actual travel days with hypothetical travel days with shopping trips removed.

We find that the marginal vehicle mileage generated by shopping trips is, coincidentally, comparable to mileage calculate by measuring only trips to shopping locations, and approximately half the distance calculated by assuming round trips from home to each shopping location.

Keywords (up to 5):
shopping, online shopping, trip chaining, in-person shopping

EXECUTIVE SUMMARY

Online shopping and home delivery are growing rapidly in the US, potentially leading to a fundamental shift in how we shop. A shift to online shopping will have potentially large impacts on travel demand, as in-person travel to the store is replaced with (or potentially supplemented by) trucks delivering goods to people's homes. A number of authors have built simulation models of the transport impacts of delivery vehicles, but in order to understand how travel demand might change given increased online shopping, it is also important to understand the transport impacts of the status quo of in person shopping.

Figuring out exactly how much travel is attributable to shopping is difficult, because many shopping trips happen on the way to or from another destination. If someone stops at the store on the way home from work, how much of that trip should be attributed to shopping? Previous research has generally either summed up the mileage of the trips with a shopping destination, or assumed every shopping trip generates a round trip to the store. The former method will undercount mileage when a store was the only destination, while the latter will overcount mileage when the store was visited on the way to another destination.

This research uses detailed travel survey data from the Research Triangle region of North Carolina to estimate the marginal distance traveled for shopping. We construct counterfactual days without shopping for respondents who went shopping on the travel day, and compare these to the distance traveled on the actual travel day, to create an estimate of the *marginal* miles traveled by shopping.

We find that the households travel an average of 8.2 kilometers (5.1 miles) by car for shopping each day. This is roughly half the distance estimated by assuming round trips from home to the store. It is quite close to the distance estimated by adding up all trips to shopping destinations (7.8 kilometers). This latter finding is coincidental, but does suggest that existing research conducted using this technique for estimating distance is more or less sound.

Not all researchers will have access to detailed travel survey data when building their models. Some researchers have used the much simpler home-to-store round trip estimation method, but multiplied by a constant factor to account for trip chaining. This is a reasonable approach in light of a lack of more detailed data. We estimate this factor to be 0.42 for the Research Triangle region. More research is needed to understand how this factor varies between locations or households within a region.

1.0 INTRODUCTION

Shopping is major driver of the economy. Shopping also drives significant travel demand, as people need to travel to a store to undertake in-person shopping, still by far the most prevalent form of retail, well ahead of e-commerce (US Census Bureau, 2022). However, we do not have a good idea of how much travel shopping actually induces, because much shopping occurs on the way to or from another activity.

In order to evaluate the transport implications of the continuing acceleration of e-commerce, it is important to understand not only how e-commerce affects transport, but also how the alternative of in-person shopping affects transport. This research aims to fill the latter gap, and provide a methodology and estimates of marginal shopping travel—how much travel is directly attributable to shopping, rather than other trips on the same tour. We do this by using travel survey data to construct "counterfactual" travel diary information based on what would have happened had shopping stops not been made.

1.1 OBJECTIVE

This project has three primary objectives. First, it introduces a new method for computing the vehicle mileage attributable to shopping. Second, it provides new, more accurate estimates of shopping travel mileage in the Research Triangle region of North Carolina. Third, it compares the results of this new methodology with the results of other methodologies prevalent in the literature.

1.2 SCOPE

This project was originally intended to have national scope by leveraging multiple surveys stores in the Transportation Secure Data Center (Gonder et al., 2015). Unfortunately, technical difficulties led to delays in processing the full dataset available there. This report thus covers the Research Triangle region of North Carolina, using data from the 2016 Triangle Travel Survey. The methods developed are transferable to any travel diary worldwide.

2.0 LITERATURE REVIEW

Many researchers have considered the impacts of e-shopping on travel outcomes, with inconsistent results (Le et al., 2022). A common method is to perform simulations of freight vehicle activity under different assumptions about e-shopping adoption, but this requires a baseline of in-person shopping to compare against.

Some create this baseline by assuming round-trips from home to the store (Wygonik & Goodchild, 2018). The downside to this approach is that it does not account for the possibility that shopping trips will be chained, either with other shopping trips or other trip purposes altogether.

Others proportionally allocate travel to shopping based on the total number of stops in the tour (Jaller & Pahwa, 2020). This is more likely to accurately capture travel for shopping, but assumes that all stops on a tour contributed equally to total tour mileage—which may not be the case when stopping at the store on the way home from work, for example.

Others multiply round trips by a factor less than one to account for potential trip chaining (Brown & Guiffrida, 2014). This factor was empirically determined, similar to this study, but was based on a relatively small sample size at a few specific suburban big-box stores, whereas the current study uses large sample household travel surveys and all of the shopping experiences that respondents reported. If the factor is accurate, this method will produce reliable results.

Another common method is to divide trips by their destination purpose, and report the total travel to each destination (e.g., McGuckin & Fucci, 2018). This approach is easily applied with travel survey data, but will underestimate shopping travel for any round-trip shopping trips, as it will discount the trip home. For on the way shopping trips, it may under- or over-estimate, depending on the sequence and relative locations of the stops.

Understanding the distance traveled for in-person shopping is a necessary but not sufficient condition for understanding how online shopping may affect travel demand. In addition to substituting for in person trips, online shopping may be a complement to in-person shopping (e.g. by allowing additional research), or may have other modification effects on in-person shopping behavior (e.g., Couclelis, 2004; Le et al., 2022; Suel & Polak, 2018). How these trends interact is not yet known, and is beyond the scope of this project. However, this is a topic of ongoing research for many.

3.0 METHODOLOGY

This project used data from the 2016 Triangle Travel Survey in the Research Triangle region of North Carolina. This survey covered 4,184 households, 9,232 individuals, and 38,170 trips. It used an address-based sample. It asked demographic questions as well as asking respondents to record their travel on a specified weekday; weekends were not included.

The survey contains demographic information about households and a record of all trips they took on an assigned travel day. These trip records include the purpose of the trip, who was on the trip, and, importantly, the exact latitude and longitude of the origin and destination.

To understand how much shopping contributed to overall travel, we first break this dataset into home-to-home tours. We then create two sets of "counterfactual" tours. One contains all the stops except shopping, while the other contains only the shopping stops.

We then estimated the travel distance of each of these trips. We created a network based on OpenStreetMap data for the whole state of North Carolina,[1] and used the OSRM routing package to estimate network distances (Luxen & Vetter, 2011).

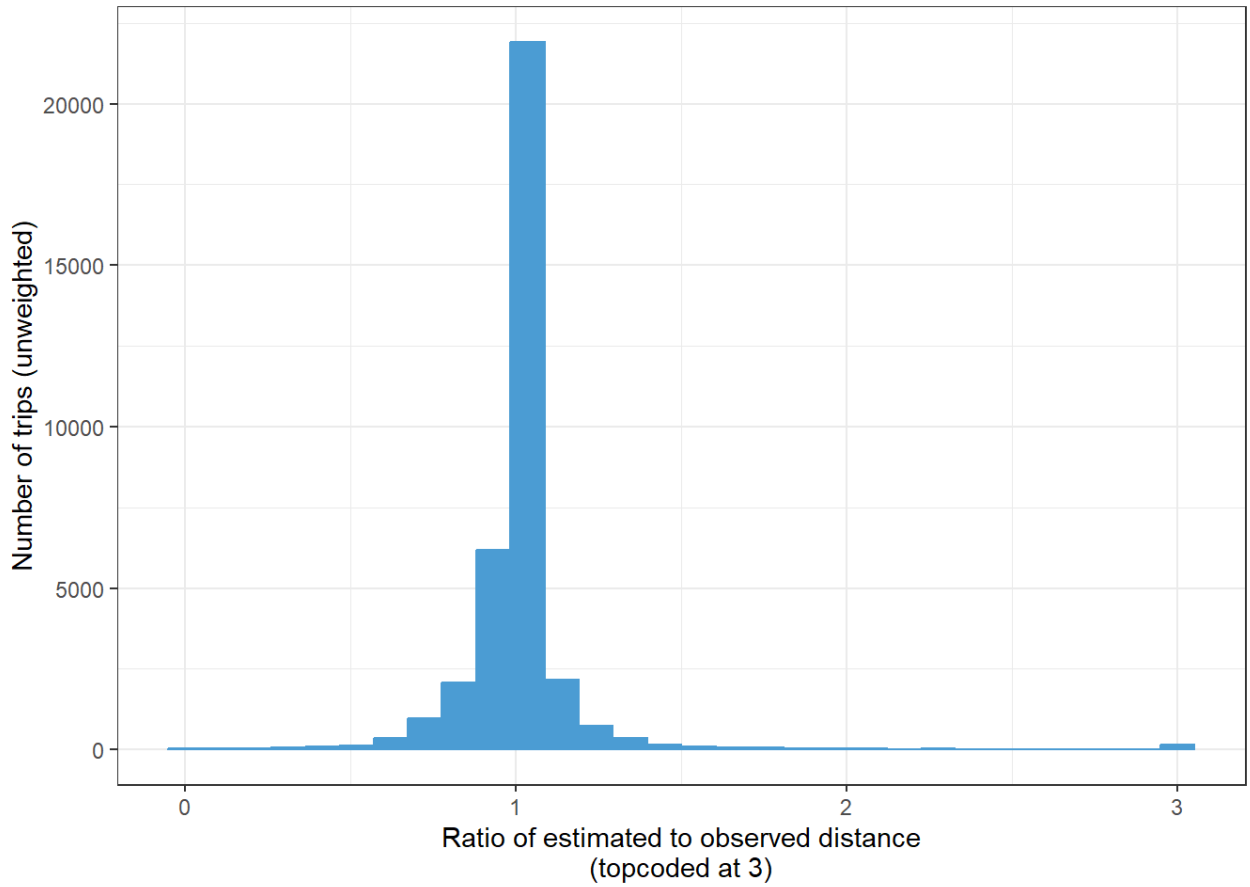

FIGURE 1: RATIO OF COMPUTED TO OBSERVED TRIP DISTANCE (UNWEIGHTED)

We calculated the distances for the original trips as well as the counterfactual trips, to ensure that comparisons use a consistent set of assumptions. While the original trips include travel

[1] Due to data availability, this network is based on 2023 data. While there have been some changes to the network since the survey was conducted in 2016, notably the construction of the I-885 East End Connector, we do not believe this materially affects the results.

distance information, we do not use this in the main analysis. However, our estimated travel distances track closely with reported travel distances, as shown in Figure 1.

We additionally computed travel distances for a home-to-shopping round trip for each shopping destination, to compare our results with literature that computes in-person shopping mileage in this way. We term this the "round trip" distance calculation method.

We then classified all tours into one of four categories, which determined how marginal shopping mileage was calculated. Tours that contained no shopping were the simplest, as they contribute 0 miles of shopping travel. Tours that contained only home and shopping were similarly simple, as they contribute the computed mileage for the actual trips.

70% of tours involving shopping chained the shopping trip(s) with another trip purpose. We classified tours that mixed shopping and non-shopping activities as primarily shopping or primarily non-shopping. Tours that were primarily non-shopping were any that included trips to work, school, medical visits, personal business (e.g. attorney), passenger pick-up/drop-off, and religious, civic, or volunteer activities. Other tours were considered primarily shopping.

For tours where shopping was the primary purpose, the marginal mileage attributed to shopping was the calculated mileage of the tour with non-shopping stops removed. This is demonstrated for a hypothetical tour in Figure 2. The original tour is shown in blue, and traveled from home to a home improvement store, then to a post office, then to a restaurant, and finally to a drugstore before returning home, traveling 38 km. Since shopping is the primary purpose of this tour, the mileage attributed to shopping is the full length of the tour with non-shopping results removed. Removing the non-shopping stops (post office and restaurant) results in the route shown in yellow, which is 24 km.

A common way of calculating travel distances for different trip purposes is to simply sum the total mileage of trips to a particular activity. We term this method the "shopping destination" method. Estimating shopping travel distance using only trips to the store or round-trip distances from home to each store estimate 12 and 35 km in this example, respectively. This demonstrates how summing only trips to the store can underestimate travel distance, while treating every shopping trip as a round trip overestimates distance.

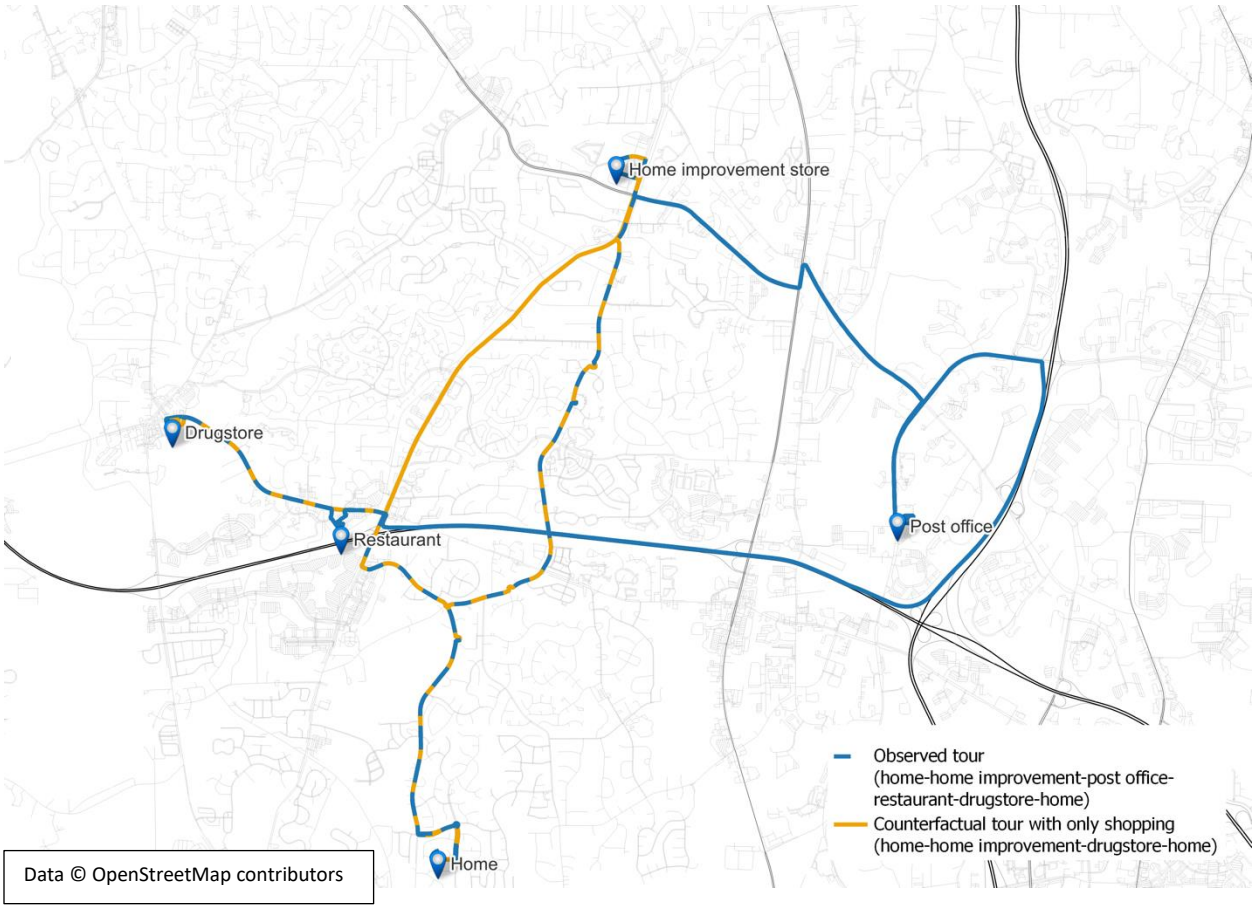

FIGURE 2: CALCULATION OF MARGINAL SHOPPING TRAVEL DISTANCE FOR A TOUR WHERE SHOPPING WAS THE PRIMARY PURPOSE (LOCATIONS ARE HYPOTHETICAL TO PRESERVE RESPONDENT PRIVACY)

For tours where shopping was *not* the primary purpose, we calculated marginal mileage contributed by shopping as the calculated mileage of the overall tour minus the calculated mileage of the tour with the shopping trips removed. Figure 3 demonstrates. As before, the original tour is in blue, traveling from home to work, then to a hardware store and department store before returning home, totaling 36 km. A tour with the shopping stops removed (i.e. a round trip to work) totals 32 km, shown in yellow. Thus, the shopping stops only added 4 km to the work tour.

Summing trips to the store results in an estimated shopping distance for this tour of 13 km, showing that method can also overestimate marginal shopping travel—in this case due to including a long leg from work as a “shopping” trip. The round trip distance estimate is 31 km, because the shopping locations are near the middle of the commute trip. Visiting them separately requires significant travel.

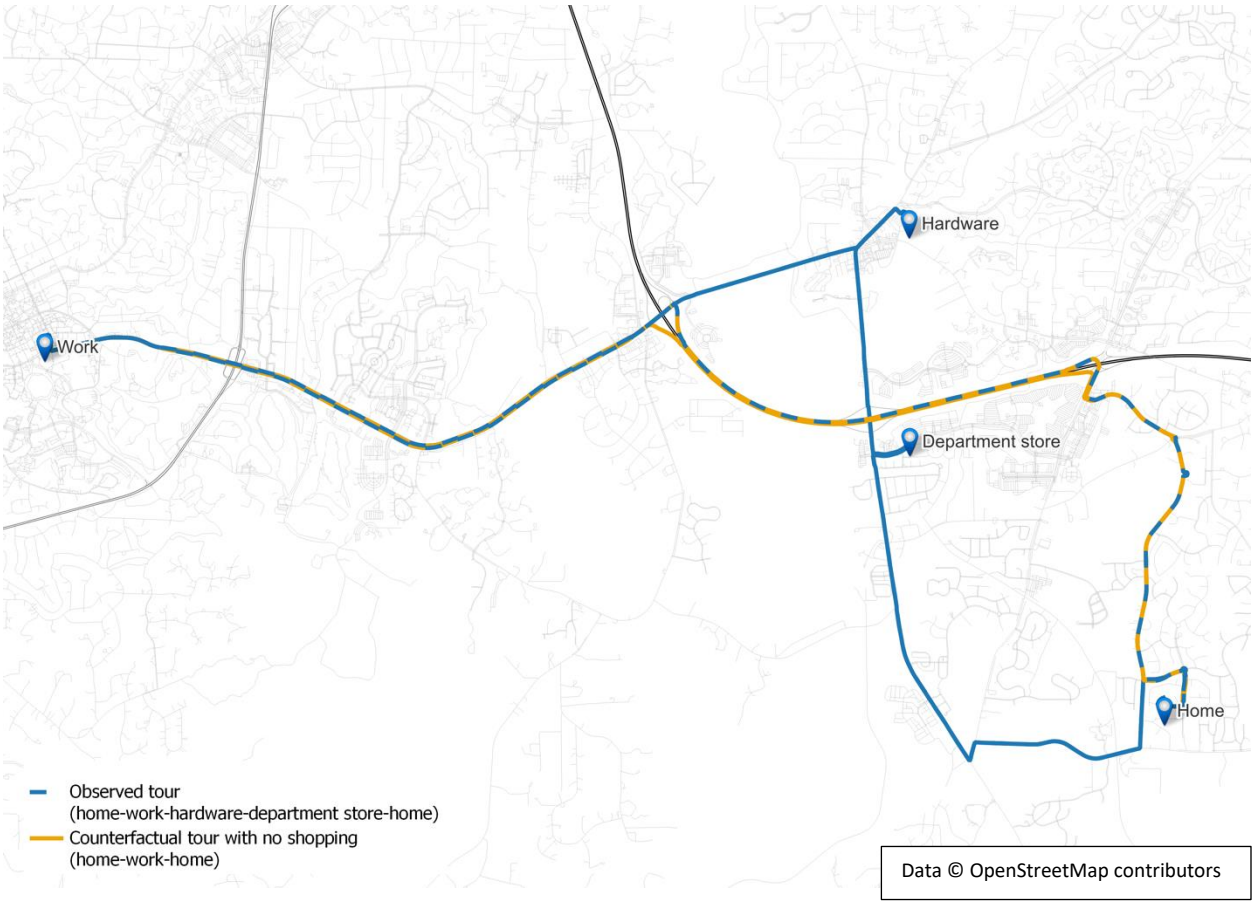

FIGURE 3: A TOUR WHERE SHOPPING IS A SECONDARY PURPOSE (LOCATIONS ARE HYPOTHETICAL TO PRESERVE RESPONDENT PRIVACY)

One limitation of this approach is that only shopping trips are removed. If a respondent also stopped at a restaurant in a shopping plaza for a snack before shopping, the travel distance to that shopping plaza will still be included, even though it may not have been visited had the shopping trip not occurred.

Oftentimes, multiple household members traveled together on a tour, and thus the tour was reported multiple times in the dataset. Deduplicating these is non-trivial, because in some cases travelers traveled together for part of a tour and then split up (e.g. one household member picks up another from the bus stop and then they go to dinner together). In other cases, different household members reported slightly different versions of the same trip (e.g. one member reported leaving at 10:22 and another at 10:25). Rather than attempt to remove these duplicate trips, we divided the mileage of each trip by the number of household members on the trip, so that vehicle miles were allocated proportionally among travelers. If the number of household members on the tour changed at an intermediate stop that was removed when generating counterfactual trips, we assumed the counterfactual trip would have the same number of household members as the trip to the removed stop. We only counted household members as being on a trip if they reported any trips on the travel day—i.e. if person 1

reported a trip where they traveled with persons 2 and 3, but person 3 did not report any trips, we consider only two people to be on that trip.

Some tours including shopping included both automobile and non-automobile travel (for instance, drive to work, walk to shopping, drive home). For these tours, we removed any kilometers associated with non-auto travel. When removing intermediate stops, we assumed that the mode that was used for the trip to the removed stop would be used for the full trip to the next stop.

A small subset of tours get longer when stops are removed (for instance, because removing a stop in a downtown area means it is faster to bypass downtown on a longer but faster freeway). This can lead to negative marginal shopping travel distances; in this case, we set marginal shopping travel distance to 0 for that tour. For similar reasons, marginal shopping travel distance may be longer than total tour distance; in this case, we set marginal shopping distance to the total tour distance. This situation can also arise when the trip to a removed stop on a tour is by car, but the next trip is not.

We exclude any households of which any member traveled outside of North Carolina on the assigned travel day, as well as any households with any trip longer than 100 miles. Some respondents reported working, shopping, etc. at home; we recoded these activities to generic in-home activities to avoid misclassifying tours (e.g. when someone was working at home and took a round trip to the store midday, that is not a chained work and shopping tour).

We calculated the daily shopping travel using the marginal distance method described above. For comparison purposes, we additionally calculated shopping travel by summing all trips with stores as destinations and by computing home-to-store round trips for every shopping trip. For the round-trip distance estimation, we removed any households where any shopping stop was more than 100 miles network distance from home (for instance, people who are traveling within North Carolina on the travel day). We summarized these to household-level average and 75th percentile daily shopping travel (the median is 0 as most households do not shop by car on any given day, or only make shopping trips that do not add any additional travel distance).

In addition to overall results, we also disaggregated the results along five dimensions: income, household size, number of workers, whether the household received any deliveries on the travel day (a rough proxy for online shopping), and geography.

4.0 RESULTS

4.1 What are shopping trips being chained with?

A first step was to identify how often shopping trips are chained with other trip purposes, and what those trip purposes are. For each shopping trip, we evaluated what other purposes occurred on the same tour. The results are shown in Figure 4.

Approximately 70% of shopping tours contain at least one other purpose. 24% of shopping tours contain work-related activities. 27% contain multiple shopping activities; respondents often shop at several stores in a single outing. If these stores are near each other (perhaps even in the same shopping plaza), assuming round-trip travel to each store will overstate travel distance.

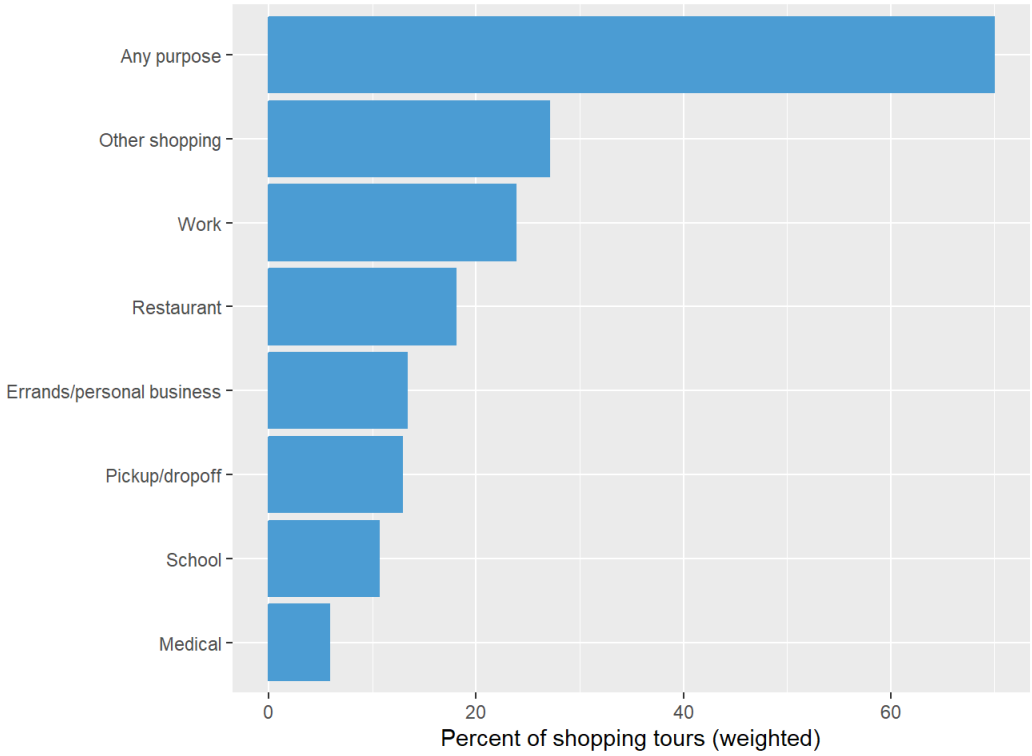

FIGURE 4: PERCENT OF SHOPPING TOURS THAT ALSO CHAINED WITH ANOTHER CHAINED PURPOSE (WEIGHTED)

4.2 Marginal shopping travel

The main results of the study are shown in Table 1, for the marginal shopping approach used in this project. The third and fourth columns present comparisons using the "shopping destination" and "round trip" approaches described above.

Using the marginal shopping approach, we find that households in the Research Triangle region drive an average of 8.2 kilometers (5.1 miles) per day to support in-person shopping. Summing trips by trip purpose leads to a slightly lower estimate of 7.8 kilometers. Given the prevalence of trip chaining, the round-trip distance is more than twice the marginal distance. The 75th percentile demonstrates similar patterns.

Households in the Research Triangle region drive an average of 76.6 kilometers per day, meaning that shopping travel constitutes 10.7% of overall travel in this region. Shopping is a

significant fraction of overall travel; planners should closely monitor changes in shopping travel patterns.

Means are sensitive to outliers. To evaluate whether outliers are affecting the results, we repeated the analysis with varying cutoffs for excluding households based on the length of their longest trip including shopping travel. The most restrictive cutoff, dropping any household with a trip longer than 50 kilometers, reduces the estimates by about 12%, but preserves the relationships between them.

TABLE 1: PER-HOUSEHOLD DAILY SHOPPING TRAVEL RESULTS, FULL SAMPLE, WEIGHTED

	Vehicle travel for shopping			
	Marginal shopping	Shopping destination	Round trip	Number of households[1]
Mean	8.2	7.8	19.5	4,010 / 4,004
75th percentile	7.9	9.5	21.6	4,010 / 4,004
Mean, households with longest trip not longer than…				
50 km	7.2	6.8	16.4	3,699 / 3,691
100 km	7.7	7.6	18.1	3,959 / 3,950
150 km	8	7.8	19.2	4,003 / 3,998
200 km	8.2	7.9	19.6	4,019 / 4,013
250 km	8.3	8	20.0	4,034 / 4,029
300 km	8.5	8.1	21.0	4,045 / 4,041
350 km	8.6	8.2	21.5	4,049 / 4,047
400 km	8.6	8.2	21.9	4,050 / 4,049

[1] Number on left is for marginal shopping and shopping destination methods, number on right for round trip method, as households who had any shopping destination over 100 miles from home are additionally excluded.

The round trip distance is consistently significantly longer than the actual distance traveled for shopping. Researchers should use a marginal distance approach when comparing e-shopping to in person shopping, or they will overstate the benefits and understate the drawbacks of e-shopping.

Brown and Guffrida (2014) used the round-trip approach to estimate shopping travel distance, but multiplied the estimates by an empirically derived factor of 0.64 to account for trip chaining. The equivalent estimate from this data is 0.42. There are several possible reasons for this discrepancy. We have a larger sample than they did, and their dataset focused on trips to big-box stores, which may not be trip-chained at the same rate as other shopping trips. Since they conducted their own survey, they were able to specifically ask respondents which other destinations on their tours they would have visited even if not making the trip to the store, rather than inferring based on trip purpose. Their survey also focused on the midwestern United States, whereas the Research Triangle is in the southeast; patterns may differ geographically.

Calculating marginal shopping distance as done in this project requires access to detailed travel survey information, including exact latitude/longitude coordinates. This data is justifiably kept carefully secured with limited access, due to its confidential nature. For projects where such data are not available, the approach of multiplying round trip distance by a factor to account for trip chaining is an alternative. It would be valuable in future research to develop factors based on characteristics of the household (for instance, workers may trip chain more often because they can run errands along their commute).

The distance calculated by summing trips to shopping destinations is relatively close to the distance estimated by the marginal distance approach. This is purely coincidental; this approach will underestimate the distance for round trips from home to a store, and may overestimate distances when a stop is on the way to or from another destination. At least in the Research Triangle region, these two effects roughly cancel out, though the same may not be true elsewhere. This is heartening, as it suggests the large volume of research done using the simple method of summing trips by trip purpose has not wildly missed the mark on how much shopping travel is occurring.

4.3 Disaggregation of results

In addition to calculating sample-level averages, we were also curious how marginal shopping mileage varied over the population. We disaggregated along four dimensions: income, household size, number of workers in the households, and whether any packages were delivered to the home on the travel day (a rough proxy for online shopping).

4.3.1 Income

Table 2 shows the mean daily household shopping travel for various income groups. The lowest-income group has somewhat lower shopping travel than the other groups, but changes are almost nonexistent among higher income groups. The Research Triangle region is heavily car-oriented, so most households own cars (94% of the survey sample). In much of the US, this region included, cars provide vastly superior mobility to other modes, and most people who can afford a car have one (King et al., 2019). Since car ownership largely consists of fixed costs, there is not much marginal cost to driving to a shopping destination for a household that owns a car, which may lead to the relatively small differences in shopping travel between income levels.

TABLE 2: MEAN DAILY HOUSEHOLD SHOPPING TRAVEL, KILOMETERS, BY INCOME (WEIGHTED)

	Vehicle travel for shopping			
Income	Marginal shopping	Shopping destination	Roundtrip	Number of households[1]
Under $25,000	7.1	6.5	18.5	378 / 378
$25,000-$49,999	8.1	8.2	20.1	663 / 663
$50,000-$74,999	8.1	7.7	18.2	686 / 685
$75,000-$99,999	8.9	8.4	21.8	555 / 555
$100,000 or more	7.9	8.3	19.2	1,277 / 1,272
Refused	10.2	8.2	20.1	451 / 451

[1] Number on left is for marginal shopping and shopping destination methods, number on right for round trip method, as households who had any shopping destination over 100 miles from home are additionally excluded.

Income is a variable almost universally used in travel demand models. Understanding relationships between income and travel (including that those relationships are small) is important in applying this research to long-range planning

4.3.2 Household size

Larger households are likely to have more shopping travel overall, but less per person, due to economies of scale. Table 3 shows the results disaggregated by household size. Somewhat surprisingly, there is relatively little variation in total shopping travel by household size. One-person households drive to shop substantially less than 2 person households, and somewhat less than larger households, but differences are not large, and are flat or declining by household size for households with two or more individuals. This suggests economies of scale in shopping for different household sizes are very significant.

TABLE 3: MEAN DAILY HOUSEHOLD SHOPPING TRAVEL, KILOMETERS, BY HOUSEHOLD SIZE (WEIGHTED)

	Vehicle travel for shopping			
Household size	Marginal shopping	Shopping destination	Roundtrip	Number of households[1]
1	7.0	6.8	15.6	1,160 / 1,158
2	9.3	8.4	22.2	1,726 / 1,722
3	8.1	8.3	18.4	552 / 552
4	8.5	8.7	21.5	401 / 401
5 or more	7.4	7.0	20.3	171 / 171

[1] Number on left is for marginal shopping and shopping destination methods, number on right for round trip method, as households who had any shopping destination over 100 miles from home are additionally excluded.

Household sizes have long been declining worldwide, which has led to increased per-capita energy consumption through increased home sizes per person (Ellsworth-Krebs, 2020). This results suggests another avenue for increased energy consumption as household sizes decline: the additional smaller households will travel much more for shopping than they would if they were members of larger households.

4.3.3 Number of workers

Since work is the destination most often chained with shopping, one might expect workers to have lower overall marginal shopping travel distances, as they may stop at locations very close to their normal route home. You might also expect them to have higher-than-normal travel distance as computed by the shopping-destination method, because their trips to stores may include large portions of their commutes. You might also expect round-trip distance estimations to be higher, because they may shop at far-away stores close to their place of work rather than their place of residence.

TABLE 4: MEAN DAILY HOUSEHOLD SHOPPING TRAVEL, KILOMETERS, BY NUMBER OF WORKERS (WEIGHTED)

	Vehicle travel for shopping			
Number of workers	Marginal shopping	Shopping destination	Roundtrip	Number of households[1]
0	11.4	8.5	21.9	1,063 / 1,060
1	7.7	7.8	18.6	1,525 / 1,522
2	6.4	7.5	18.9	1,322 / 1,322
3 or more	9.5	7.6	19.8	100 / 100

[1] Number on left is for marginal shopping and shopping destination methods, number on right for round trip method, as households who had any shopping destination over 100 miles from home are additionally excluded.

The results are shown in Table 4. Households with workers travel significantly less for shopping, suggesting that chaining shopping with work is a significant contributor to reduced VMT.

4.3.4 Package delivery

The Triangle Travel Survey additionally asked respondents how many packages were delivered to their home on the travel day. We use this as a rough proxy for online shopping, to understand how online shopping is related to vehicle travel for in person shopping. To preserve sample sizes, we split the sample into households that received one or more packages, and those that received none. Results are shown in Table 5. Ultimately, there is only a small difference in shopping travel between households that did and did not receive packages on the travel day. This suggests that online retail may not be serving as a substitute for shopping travel by private vehicle. However, this measure of online shopping is crude, as it only measures outcomes on the travel day, and more research is needed to understand the relationship between online shopping and in-person shopping travel.

TABLE 5: MEAN DAILY HOUSEHOLD SHOPPING TRAVEL, KILOMETERS, BY PACKAGE DELIVERIES (WEIGHTED)

	Vehicle travel for shopping			
Received delivery?	Marginal shopping	Shopping destination	Roundtrip	Number of households[1]
No	8.2	7.7	19.6	3,119 / 3,113
Yes	8.1	8.4	19.0	891 / 891

[1] Number on left is for marginal shopping and shopping destination methods, number on right for round trip method, as households who had any shopping destination over 100 miles from home are additionally excluded.

4.3.5 Geography and density

The distance to nearby stores and amenities varies by location within the region, with more central areas having lower average shopping travel. Figure 5 shows the average household shopping travel in the region, disaggregated by Census tract of residence (to reduce variance and protect respondent privacy, Census tracts with fewer than five households are suppressed). The central parts of Raleigh and Durham, as well as the college town of Chapel Hill, have lower shopping travel, while more outlying areas have higher travel. This is consistent with expectations; central areas are closer to shopping opportunities, and residents need not drive as far.

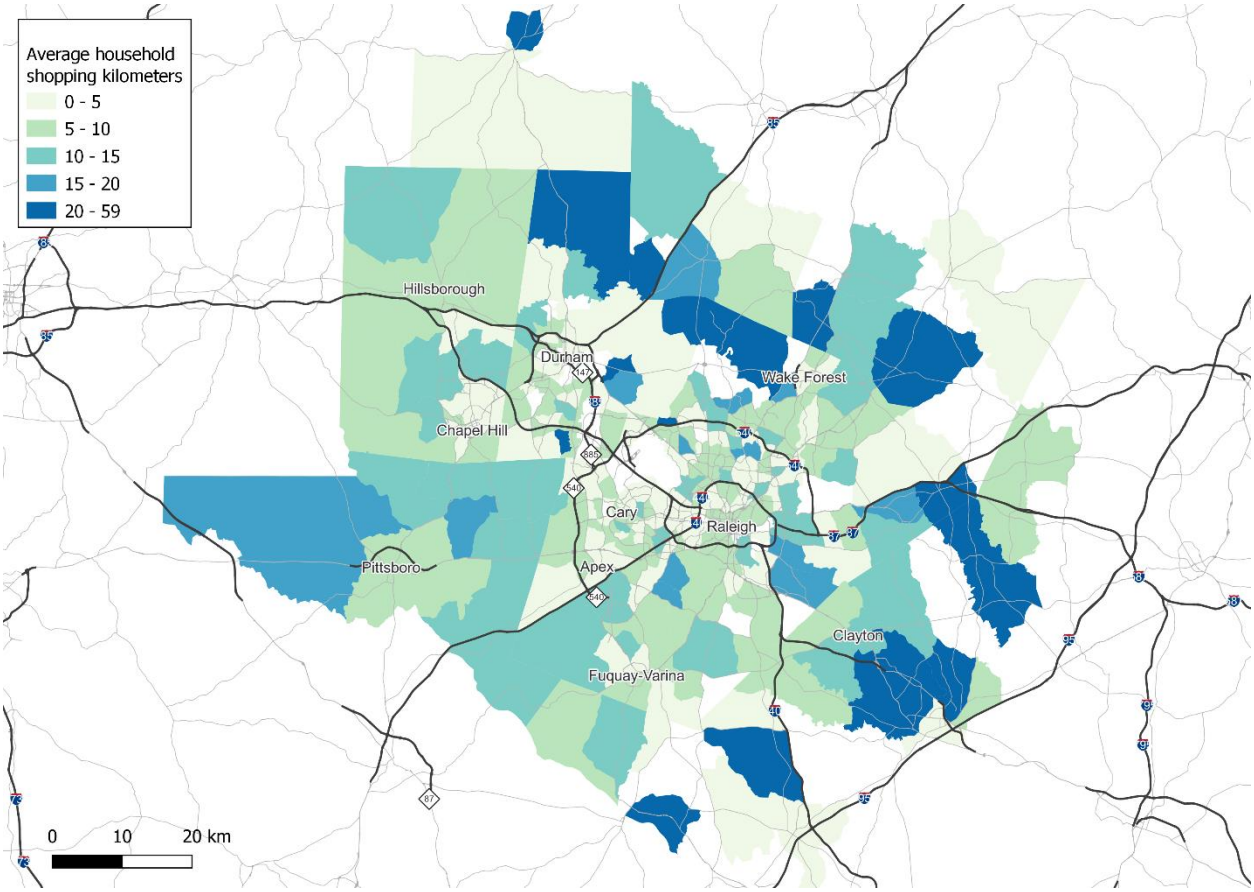

FIGURE 5: AVERAGE HOUSEHOLD DAILY SHOPPING TRAVEL, BY CENSUS TRACT (DATA © OPENSTREETMAP CONTRIBUTORS)

One significant difference between central and outlying areas is density. In central areas, homes are closer together, and less area is needed to provide a sufficient market for a store. Table 6 shows the marginal shopping travel distance by households living in different density areas. As expected, density is negatively correlated with shopping travel. Households in the densest areas drive less than half as far to shop as those in the least dense areas.

TABLE 6: MARGINAL SHOPPING TRAVEL, BY DENSITY

Density (housing units per square mile, home block group)	Household daily average marginal shopping travel distance (km)	Sample size
≤ 100	12.9	380
100-500	9.8	1099
500-1,000	6.8	833
1,000-2,000	7.5	1178
2,000-4,000	4.2	457
> 4,000	4.9	63

5.0 CONCLUSION

This project introduced a new, more accurate method of computing the marginal vehicle travel attributable to in-person shopping, and applied it to a case study in the Research Triangle region of North Carolina. We found that the marginal shopping travel is relatively closely estimated by the prevalent method of summing up travel distances by destination purpose. Though this is coincidental, it suggests that the significant work that has gone into research using this method has not been in vain.

Estimating shopping travel as the round-trip distance from home locations to stores, however, significantly overestimates the amount of travel attributable to shopping. This is especially concerning when these estimates are used as a baseline to compare e-shopping to. By overestimating the amount of travel that currently supports shopping, these analyses make e-shopping look relatively better in terms of transport and environmental outcomes. A valuable direction for future research would be to perform a simulation of e-shopping transport impacts in the Research Triangle region, and compare it against the baseline computed here.

Detailed travel survey data may not always be available to research teams that need to estimate baseline in-person shopping travel. In this case, research teams may want to adopt the approach taken by Brown and Guffrida (2014), who multiply round-trip travel estimates by a factor to account for trip chaining. They estimate this factor as 0.64, while we estimated a slightly lower 0.42, possibly due to differences in context or methodology. More research is needed to estimate this factor in different contexts.

The data used in this project were collected before the COVID-19 pandemic. During the pandemic, many workers transitioned to working from home, and many of them do not expect to return to the office full-time as pandemic restrictions are lifted (Salon et al., 2021, 2022). Since work was the destination most often chained with shopping in this prepandemic data, a reduction of work travel could affect shopping travel. People working from home may have to make separate trips to travel to the store, rather than chaining them with their work trips. This could lead to an increase in overall shopping travel. It may also lead to a “spreading” of rush hour, with peak-hour commute trips replaced by off-peak shopping and maintenance trips. This spreading has already been observed in the California freeway network (Bhagat-Conway & Zhang, 2023). That said, the results above showing that shopping travel does not vary much between household with different numbers of workers may limit the extent of changes to shopping travel caused by WFH.

Online shopping is already commonplace, with e-commerce representing 14.5% of all retail sales in the second quarter of 2022, and has grown rapidly since the start of the pandemic. Even when the Triangle Travel Survey data were collected, e-shopping represented 8% of retail (US Census Bureau, 2022). The results of this project, therefore, do not represent a 100% in person shopping scenario, and the numbers may already be affected by e-shopping. Respondents may have selectively switched trips to far-flung stores for e-shopping, which

would bring down the total in-person shopping travel more than proportionally with the level of e-commerce.

6.0 RECOMMENDATIONS

The overarching recommendation of this research is that it is important to accurately account for the travel distance of in-person shopping when comparing potential e-shopping transport impacts. Some current practices overestimate in-person shopping travel, making e-shopping look more attractive than it is.

The COVID-19 pandemic has significantly changed lifestyles for many Americans, in particular with regard to the work commute. Many people are working flexible schedules or working from home exclusively. The effects of this shift on shopping travel are unclear; re-doing this research with post-lockdown data would provide an interesting update. The 2022 National Household Travel Survey is currently underway, which may provide the necessary data for such an exercise.

This project focused on shopping travel by car. In part this is because this is the mode with the most environmental and congestion impacts, and the mode that is most comparable to e-delivery, which also uses large vehicles. Additionally, other travel options in the Research Triangle region are limited. Transit services are limited in spatial and temporal extent, and walking and cycling infrastructure is often not present. In the Triangle Travel Survey data, 92% of shopping trips were by car, the rest were mostly by walking. Through the Transportation Secure Data Center, we have access to data from locations with a less lopsided modal split, and an analysis based on this data for other modes may prove of interest.

There is likely heterogeneity in the amount of daily shopping travel per household, and in how much travel a particular shopping trip generates. Further research could further disaggregate the results presented here using a regression model to evaluate the correlates of shopping travel.

From a policy perspective, this work is likely to be most useful if incorporated into travel demand models. The Research Triangle region has a travel demand model based on this survey dataset. An avenue we plan to pursue in future research is comparing how shopping travel as forecasted by the model compares with the shopping travel estimated by the marginal-shopping-travel approach above. This may inform future model development, which will ultimately affect transportation and development planning in the region going forward. The methodology described in this document used only open-source software components, and thus could be replicated by any modeling team with appropriate travel survey data.

7.0 REFERENCE LIST

Brown, J. R., & Guiffrida, A. L. (2014). Carbon emissions comparison of last mile delivery versus customer pickup. *International Journal of Logistics Research and Applications*, *17*(6), 503–521. https://doi.org/10.1080/13675567.2014.907397

Couclelis, H. (2004). Pizza over the Internet: E-commerce, the fragmentation of activity and the tyranny of the region. *Entrepreneurship & Regional Development*, *16*(1), 41–54. https://doi.org/10.1080/0898562042000205027

Ellsworth-Krebs, K. (2020). Implications of declining household sizes and expectations of home comfort for domestic energy demand. *Nature Energy*, *5*(1), Article 1. https://doi.org/10.1038/s41560-019-0512-1

Gonder, J., Burton, E., & Murakami, E. (2015). Archiving Data from New Survey Technologies: Enabling Research with High-precision Data While Preserving Participant Privacy. *Transportation Research Procedia*, *11*, 85–97. https://doi.org/10.1016/j.trpro.2015.12.008

Jaller, M., & Pahwa, A. (2020). Evaluating the environmental impacts of online shopping: A behavioral and transportation approach. *Transportation Research Part D: Transport and Environment*, *80*, 102223. https://doi.org/10.1016/j.trd.2020.102223

King, D. A., Smart, M. J., & Manville, M. (2019). The Poverty of the Carless: Toward Universal Auto Access. *Journal of Planning Education and Research*, *7*(4), 0739456X1882325-18. https://doi.org/10.1177/0739456X18823252

Le, H. T. K., Carrel, A. L., & Shah, H. (2022). Impacts of online shopping on travel demand: A systematic review. *Transport Reviews*, *42*(3), 273–295. https://doi.org/10.1080/01441647.2021.1961917

Luxen, D., & Vetter, C. (2011). Real-time routing with OpenStreetMap data. *Proceedings of the 19th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems - GIS '11*, 513. https://doi.org/10.1145/2093973.2094062

McGuckin, N., & Fucci, A. (2018). *Summary of Travel Trends: 2017 National Household Travel Survey*. Federal Highway Administration. https://nhts.ornl.gov/assets/2017_nhts_summary_travel_trends.pdf

Salon, D., Conway, M. W., da Silva, D. C., Chauhan, R. S., Derrible, S., Mohammadian, K., Khoeini, S., Parker, N., Mirtich, L., Shamshiripour, A., Rahimi, E., & Pendyala, R. (2021). The potential stickiness of pandemic-induced behavior changes in the United States. *ArXiv:2104.14708 [Stat]*. http://arxiv.org/abs/2104.14708

Salon, D., Mirtich, L., Bhagat-Conway, M. W., Costello, A., Rahimi, E., Mohammadian, A. (Kouros), Chauhan, R. S., Derrible, S., da Silva Baker, D., & Pendyala, R. M. (2022). The COVID-19 pandemic and the future of telecommuting in the United States. *Transportation Research Part D: Transport and Environment*, *112*, 103473. https://doi.org/10.1016/j.trd.2022.103473

Suel, E., & Polak, J. W. (2018). Incorporating online shopping into travel demand modelling: Challenges, progress, and opportunities. *Transport Reviews*, *38*(5), 576–601. https://doi.org/10.1080/01441647.2017.1381864

US Census Bureau. (2022). *Quarterly retail e-commerce sales: 2nd quarter 2022*. https://www.census.gov/retail/mrts/www/data/pdf/ec_current.pdf

Wygonik, E., & Goodchild, A. V. (2018). Urban form and last-mile goods movement: Factors affecting vehicle miles travelled and emissions. *Transportation Research Part D: Transport and Environment*, *61*, 217–229. https://doi.org/10.1016/j.trd.2016.09.015