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Congestion and Emission Impacts of Switching from In-person to Online Grocery Delivery: A Seattle Case Study

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Problem Statement

The COVID-19 pandemic has caused unprecedented growth in the use of online grocery services, influencing mobility choices as well as a range of decisions (e.g., where, how, and how much to shop). Before the pandemic, only 20% of customers in the US had ever bought their groceries online. But in June 2020, three months into the pandemic, nearly 80% of shoppers had ordered groceries online (Morgan, 2020). The same source also reports a sixfold increase in the online grocery shopping market share- from $1.2 billion in August 2019 (before the pandemic) to $7.2 billion in June 2020 (during the pandemic). The reasons for this increase might be explained by customer's willingness to pay for online delivery services, and a desire to reduce exposure to risk of contracting COVID. Nevertheless, the COVID pandemic has been a catalyzer for online grocery, and this shift in demand for e-groceries is expected to continue to grow after the pandemic subsides (McKinsey & Company, 2022).

With an increase in the use of online grocery shopping services comes changes in mobility patterns. Instead of an individual driving to the store, a delivery vehicle may travel to several homes per tour to deliver groceries. In addition, delivery can sometimes displace, and other times add to in-person grocery shopping trips. The impacts of such trends on the mobility ecosystem are uncertain. On one hand, this trend could potentially reduce the number cars on the road when delivery routes serve multiple homes, improving congestion and reducing emissions. On the other hand, this trend could lead to system wide inefficiencies, exacerbating congestion and emissions within a region. This study quantifies the impacts grocery delivery has on emissions, energy and congestion, for a wide range of scenarios.

Case Study Area

The case study used in our analysis is the city of Seattle, Washington. The city has a population of approximately 737,000 people. The city is located between two masses of water on the east and west. Two major bridges connect Seattle with the eastern landmass lying at the other side of Lake Washington.

Figure 1 shows the transportation network of Seattle. The freeways are shown in thick green, and the urban arterials in thin blue. A single major interstate highway (I5) goes through the city. This is the rightmost thick green line, that crosses the entire city vertically. The interstate and the two bridges on the eastern coast of the city are the most prominent road infrastructure in the transportation network. The rest of the city's network consists of other highways (like State Route 99, which lies to the west of Interstate 5 and can be seen as a thick green line left of I5) and urban arterial roads. Collector roads (minor roads connecting houses and businesses to the arterials and highways) are not considered in this analysis.

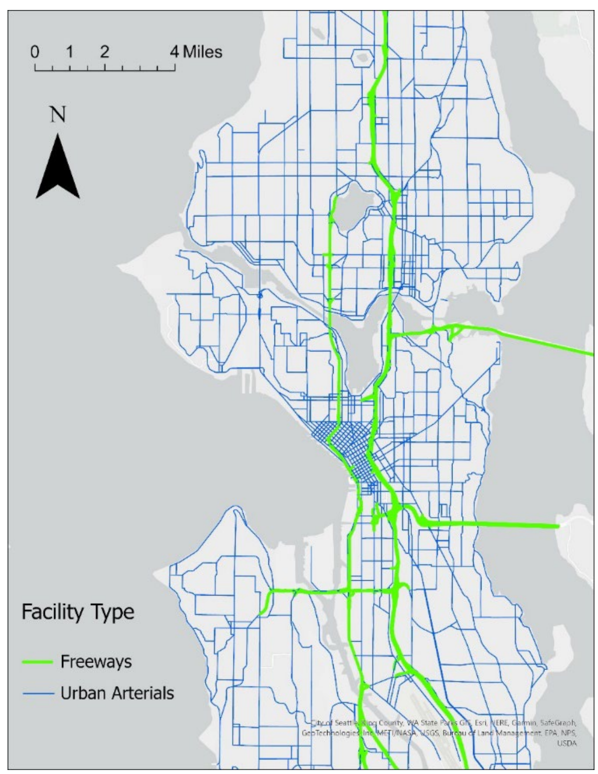


Figure 1. Transportation Network of Seattle.

Data

Data for Estimating Changes in Travel Patterns from Online Grocery Shopping

The primary data source used to understand grocery shopping travel patterns is the Puget Sound Regional Council (PSRC) 2014 Spring Household Travel Survey. The trip dataset contains about 47,918 entries, each of which represents a trip that was reported by one of the surveyed individuals. There are a total of 10,825 individuals, from 5,814 households that participated in the survey. Each entry contains information regarding the household ID, person ID, trip start time and end time, origin zip code, destination zip code, and trip purpose. Detailed information regarding trip or person-level data can be found in PSRC 2014 Household Survey Documents (Puget Sound Regional Council, 2014).

The location of the different grocery stores was determined manually using Google Earth. For the purposes of this analysis, we differentiate large grocery store chains such as Whole Foods, Safeway, Trader Joe's, QFC, from smaller community grocery shops because we assume that larger grocery stores will have the logistical and digital capacity to fulfill large orders of online delivery.

Data for Traffic Simulation Model

We leverage PSRC's regional planning model, which contains traffic analysis zones, a road network, and travel demand model containing information on origin-destination travel patterns across the Puget Sound Region. Traffic assignment zones (or TAZs) are a discrete representation of possible trip origins and destinations, and the TAZs used in this study were provided by the PSRC. The four-county Puget Sound region (King, Pierce, Snohomish, and Kitsap counties) is divided into 3,700 TAZs. Within Seattle, there are 859 TAZs.

To model traffic in the study region, we use a digital representation of the transportation network of Seattle. This was also provided by the PSRC and contains all highways and urban arterials. The network is composed of line segments called links representing roadways.

The transportation demand for the period of study (3-4 pm) is contained in an Origin Destination matrix (OD matrix). The baseline OD matrix used in this study was the same used in the study by (Fan and Harper, 2022) and was calibrated using observed traffic counts. This matrix contains a total of 116.6 thousand trips in the Seattle area during the 3 to 4 pm period. Trips that start in Seattle and end somewhere else or vice versa were counted as half a trip. This leads to a total VMT of 689 thousand, using the Manhattan distance approximation. As for trips related to grocery shopping, these account for 2.6 thousand and a total VMT of 12.3 thousand.

Methodology

The methodology consists of two main processes: a demand modification process and a traffic simulation process. In broad terms, the demand modification process aims to obtain a modified Origin-Destination (OD) matrix that reflects how travel demand would be in a city where online grocery shopping has been introduced. We modify the travel demand to reflect the changes introduced by grocery delivery. This modified OD matrix is then used as an input to the traffic simulation process. The traffic simulation process is used to determine changes in congestion of the transportation network.

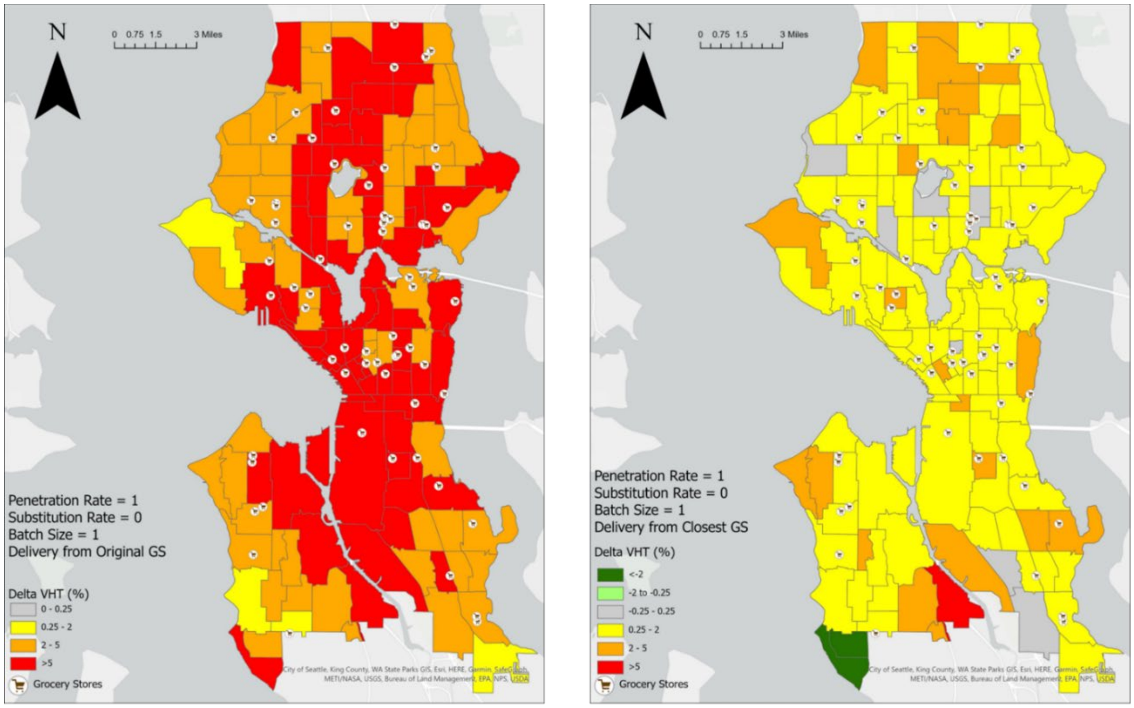
Results

To understand when variation in VMT becomes negative of positive, Table 1 depicts VMT values for all combinations of batch size and substitution rate tested, for a fixed penetration rate of 1. The color coding is green when there is a reduction in VMT, and red when there is an increase. Darker reds mean a higher increase and darker greens mean a greater reduction. We see that none of the deliveries from the original grocery store achieve VMT reductions, which means delivery distances are still too large to yield benefits even with high substitution and delivery optimization.   The reductions in VMT typically begin when over 20% of people start substituting their in-store trips for deliveries from the closest store, except in the case of a batch size of 1. Higher batch sizes also help reduce VMT, with most improvement happening when increasing the batch size from 1 to 3 parcels per tour. In the worst case (substitution rate =0, batch size = 1 grocery related VMT can increase more than fivefold, and in the best scenario (substitution rate =1, batch size = 10) VMT can be reduced by nearly 80%.

		Batch Size									
	Substitution Rate	1	2	3	4	5	6	7	8	9	10
ORIGINAL GROCERY STORE	0	2.22	1.71	1.53	1.43	1.37	1.32	1.29	1.27	1.28	1.26
	0.1	2.04	1.57	1.41	1.32	1.25	1.22	1.20	1.18	1.17	1.16
	0.2	1.84	1.42	1.27	1.20	1.15	1.11	1.09	1.07	1.07	1.06
	0.3	1.64	1.28	1.14	1.07	1.03	1.00	0.98	0.96	0.96	0.96
	0.4	1.47	1.14	1.02	0.95	0.91	0.89	0.87	0.86	0.86	0.85
	0.5	1.34	1.02	0.91	0.85	0.82	0.79	0.77	0.77	0.76	0.75
	0.6	1.22	0.92	0.82	0.76	0.73	0.71	0.69	0.68	0.67	0.67
	0.7	1.12	0.83	0.73	0.69	0.65	0.63	0.61	0.61	0.60	0.58
	0.8	0.99	0.73	0.63	0.59	0.55	0.53	0.52	0.51	0.50	0.49
	0.9	0.85	0.60	0.52	0.47	0.44	0.42	0.41	0.40	0.40	0.39
	1	0.64	0.46	0.39	0.35	0.34	0.32	0.32	0.31	0.30	0.30
CLOSEST GROCERY STORE	0	0.16	0.12	0.10	0.09	0.09	0.09	0.08	0.08	0.08	0.08
	0.1	0.11	0.07	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03
	0.2	0.05	0.01	0.00	-0.01	-0.01	-0.02	-0.02	-0.02	-0.03	-0.02
	0.3	0.00	-0.04	-0.05	-0.06	-0.07	-0.07	-0.07	-0.08	-0.08	-0.08
	0.4	-0.05	-0.09	-0.10	-0.11	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12
	0.5	-0.08	-0.13	-0.14	-0.15	-0.15	-0.15	-0.16	-0.16	-0.16	-0.16
	0.6	-0.12	-0.16	-0.18	-0.19	-0.19	-0.19	-0.19	-0.20	-0.19	-0.20
	0.7	-0.17	-0.20	-0.22	-0.23	-0.23	-0.23	-0.23	-0.24	-0.24	-0.24
	0.8	-0.21	-0.25	-0.27	-0.27	-0.27	-0.28	-0.28	-0.28	-0.29	-0.29
	0.9	-0.25	-0.29	-0.30	-0.31	-0.32	-0.32	-0.32	-0.33	-0.33	-0.33
	1	-0.24	-0.29	-0.30	-0.31	-0.32	-0.32	-0.32	-0.32	-0.32	-0.32

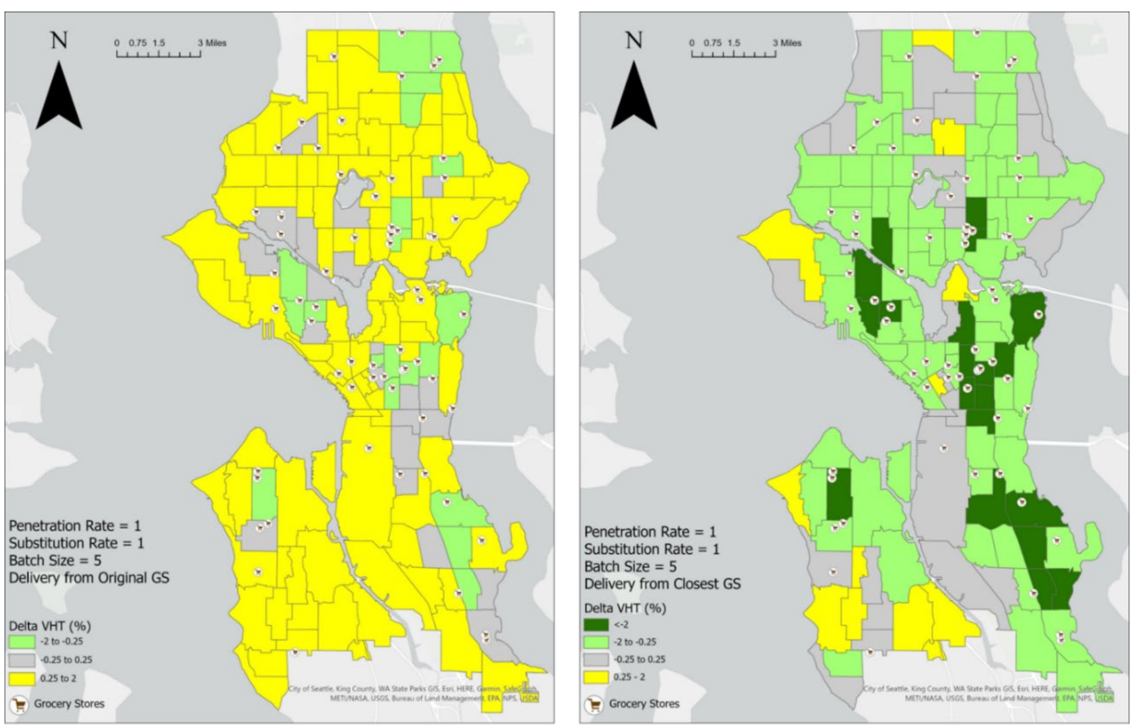
Table 1. Mean VMT variation (%) at penetration rate 0.5 for all values of batch size and substitution rate used, when delivering from original (top) and closest (bottom) grocery store

The worst case scenario for traffic impacts in terms of time traveled is shown in Figure 2.   This scenario corresponds to all customers using online delivery with no substitution of trips (essentially complementing their in-store shopping with online orders), and the most inefficient delivery case of one two-way trip per delivery. On the left, we see that if the delivery occurs from the original grocery store, increases of above 5% in VHT are common. On the right, if we switch to deliveries from the closest grocery store to the customer, we can dramatically decrease the impacts, with most of the areas experiencing only 0.25-2.5% increase in VHT. However, overall the city experiences a 1.5% increase in VHT.



(a) (b)

Figure 2. Map of variation of VHT in percent of the total VHT, for a penetration rate of 1, substitution rate of 0 and a batch size of 1. (a) Delivery from the original grocery store. (b) Delivery from the closest grocery store.



(a) (b)

Figure 3. Map of variation of VHT in percent of the total VHT, for a penetration rate of 1, substitution rate of 0 and a batch size of 1. Left: delivery from the original grocery store. Right: delivery from the closest grocery store.

The best-case scenario chosen corresponds to all customers using online delivery with full substitution of trips (essentially complementing their in-store shopping with online orders), and a batch size of 5. In Figure 3, part (a), we see that if the delivery occurs from the original grocery store, increases of 0.25-2% in VHT are common, although some areas experience a slight decrease of 0.25-2%. In Figure 3, part (b) if we switch to deliveries from the closest grocery store to the customer, we observe that most of the areas experience a 0.25-2% decrease in VHT. Citywide, this is equivalent to reducing the time spent driving by 107.5 hours.

Recommendations

From the results, we can see that substitution rate has a negative linear relationship with congestion and emissions- meaning increases in the substitution rate, results in reductions in congestion, energy, and emissions. It is important then for policymakers and grocery stores to implement policies and incentives to get grocery delivery customers to substitute their trips. One measure for this could be offering free delivery only for orders above a price or basket size threshold. Another measure could be to make delivery fees high enough to discourage small basket deliveries.

The start location of deliveries has the biggest impact on congestion and emissions, and our case study shows that it is only possible to achieve beneficial impacts (i.e., decreases in congestion and energy use) if groceries are delivered from the closest grocery store. This indicates that placing distribution centers in locations near high demand areas and the limits grocery stores set on how far they are willing to deliver, have huge impacts on the environmental sustainability of grocery delivery.

The results seem to indicate that grocery delivery is more likely to increase emissions, congestion, and energy consumption. The reason for this is that most of the replaced trips were not part of two-way trips, but trips optimized by the customers themselves by adding them to their tours as an extra trip. Two-way grocery trips (i.e. trips from home to the grocery store and back) represent only 36% of all grocery trips in Seattle. Focusing on this group of customers will have the most beneficial effect on the traffic network, emissions and energy consumption.

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