Navigation Apps Induce Cut-through Traffic Congestion: an Analysis of Real-life App Routing Suggestions

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Abstract

This research collects data from Waze and Google Maps, two navigation apps, during rush hour for travel times of alternative routes and local street segments of 7 different freeway segments in the San Francisco Bay Area. We isolate timeframes where the alternative route is faster than the freeway route (which thus causes drivers to reroute) and determine that travel times increase in these situations on the alternative route by 0.3 to 1.6 minutes for every 10 minutes that pass; compared to an average day, travel times are 0.28 to 0.95 minutes higher. We also match these timeframes to vehicle flows collected from inductive loops embedded in off-ramps and find an increase of 1.5 to 10.2 vehicles per 5 minutes compared to an average day. This research shows that navigation apps have a statistically significant impact on increasing local traffic and a modest impact on travel times on average. Finally, this study pinpoints instances where particularly high congestion on the freeway causes navigation apps to reroute drivers, increasing local streets' travel times by upwards of 260%. These results demonstrate that app-induced congestion is already prevalent and can have crippling impacts on local streets. This effect will only increase as usage of navigation apps increase; thus, this research should prompt cities and transportation planners to start understanding how they can fix this app-induced congestion, and provide insights about when, where, and how this phenomenon occurs.

Introduction and Background

GPS-enabled navigation apps have risen in popularity in the past few years. Besides giving directions, navigation apps like Waze are built upon using crowd-sourced data to "outsmart traffic and get everyone the best route" [1]. However, as a consequence, many local residents have complained that their streets are being congested with cut-through traffic—non-local drivers who have been redirected by Waze as a shortcut. For example, in Fremont, CA, Waze told drivers to route off a congested portion of the freeway and through residential streets [2]. In Leonia, NJ, local streets were clogged to the point where residents could no longer back out of their driveway in the mornings [3].

This problem has been made worse with the rise of ride-sharing apps like Uber and Lyft. Drivers are given the task of delivering their passenger from Point A to Point B as fast as possible in unfamiliar settings, so they use apps like Google Maps and Waze. Studies have shown these services increase congestion and increase the number of total miles driven [4].

To deal with this problem, cities have implemented low-tech, crude solutions. In Leonia, the city blocked off entire streets to non-residents during rush hour, fining violators $200. In Fremont, the city installed turn restrictions during peak times. However, these solutions are temporary at best. They add complexity to drivers' routes, and in the case of Leonia, hurt businesses and inconvenience residents too. Ultimately, such solutions are selfish—when one city refuses to allow traffic through it, cars will only find the next shortest alternative and drive through there.

Mahmassani and Jayakrishnan (1991) first predicted app-induced congestion using a route choice model for drivers with in-vehicle information systems [5]. Arnott, de Palma, and Lindsey (1991) demonstrated that imperfect information can cause drivers to choose different departure times and intensify congestion [6]. In an experimental behavioral study, Ben-Elia and Shiftan (2010) showed that providing drivers with information increases their knowledge of the environment and can increase their tendency to switch routes [7]. Using a cognitive cost model, Thai, Laurent-Brounty, and Bayen (2016) determined that navigation apps cause an increase of traffic on local streets with little to no change in congestion on freeways [8].

Cabannes et al. (2018) previously conducted research on travel times of an I-210 corridor and alternative routes with INRIX and PeMS (Caltrans Performance Measurement System) data [9]. They concluded that during rush hour, the alternative route travel times increased as well to reach equilibrium with the freeway. However, the study could only likely conclude that was due to navigation apps because it had no access to Waze/Google Maps data showing that those alternative routes were actually suggested. This paper aims to remedy that problem by directly collecting Google Maps and Waze suggested routes.

This paper attempts to empirically confirm this effect of app-induced congestion on local streets by analyzing data and quantifying the increase in travel times on local streets due to cut-through traffic. Seven congested freeway segments were selected throughout the Bay Area. Using Waze and Google Maps' API, these services were queried for directions every 3 minutes. The fastest route and all suggested alternatives are recorded. Additionally, we select an individual, local segment of a few alternative routes and query them on Waze and Google Maps for their travel times as well. From this, we can extract insights about when an alternative route is faster than the freeway route and how it affects local streets. These insights can be helpful to transportation planners or future research.

It is true that we have no evidence drivers will take an alternative route if suggested one—we would need user data from navigation apps that is not shared to the public. However, we can assume fairly certainly that drivers using these apps are looking for the fastest route possible and most drivers will take an alternative route. The increases in travel time and vehicle flow that this study demonstrates are still relevant no matter what percentage of drivers follow navigation suggestions.

Finally, it is important to consider that the penetration of navigation apps is still relatively low. For example, in the Los Angeles metro area, one of Waze's most popular regions, estimates show around 10% of drivers use Waze [10]. In the future, as usage of navigation apps increases, this effect will only be exacerbated.

Methodology

Selecting routes

Routes were chosen in locations where Waze suggested many alternative routes that would be shorter than the freeway during the afternoon rush hour. These locations tended to have extremely high traffic with easily accessible arterial roads. For example, Figure 1 shows the different routes Waze would suggest for the San Mateo segment. The pink route is the US-101 and CA-92 freeway route, while the other colored routes are alternatives. During rush hour, the fastest route is not the freeway, but local routes, highlighted in indigo, green, and yellow.

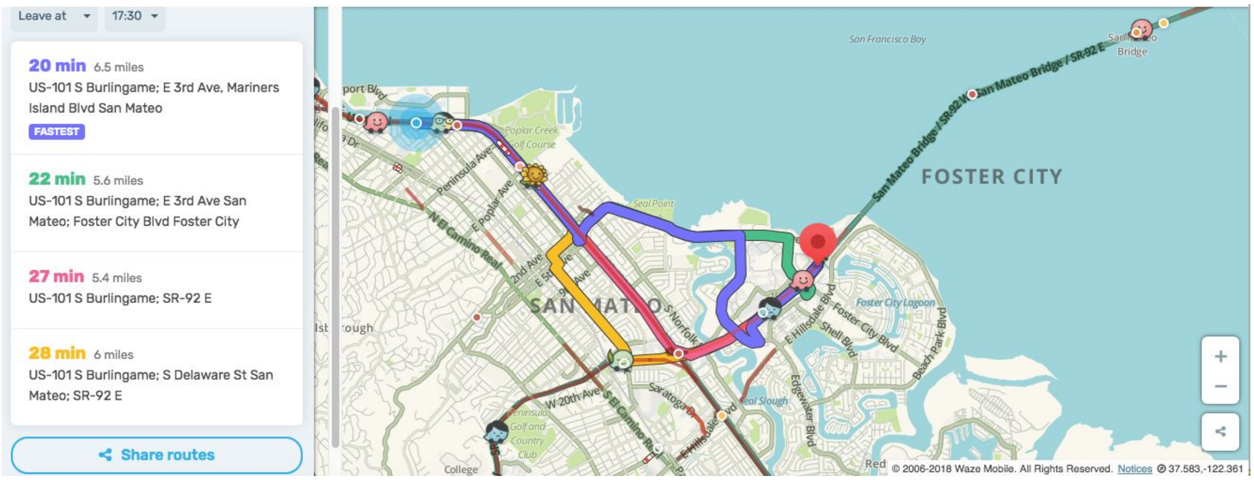
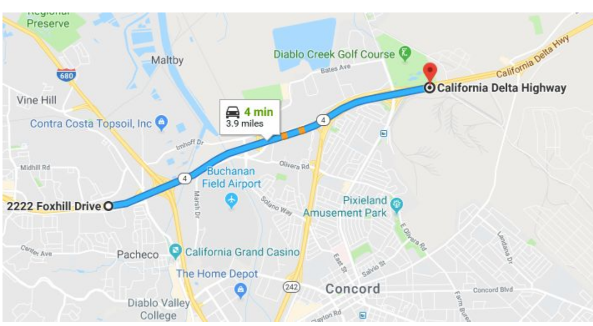


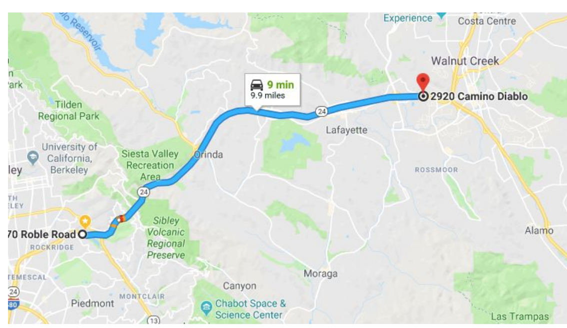
Figure 1: Waze suggests various routes in San Mateo at 5:30 pm on a weekday. The pink highlighted route is the main freeway route, while other highlights like yellow, indigo, and green depict alternative routes.

7 of these segments were tracked, shown in Figure 2. Data started being collected on each route at different times: Hwy 24, San Mateo[1], and Los Altos started on August 9, 2018. Belmont started on August 24, 2018. Morgan Hill and Concord started on September 17, 2018, and CA-237 started on October 8, 2018. Data up to November 9, 2018 was calculated as part of analysis in this paper.

Concord (a)

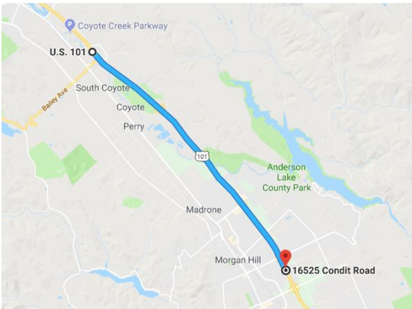


Highway 24 (b)

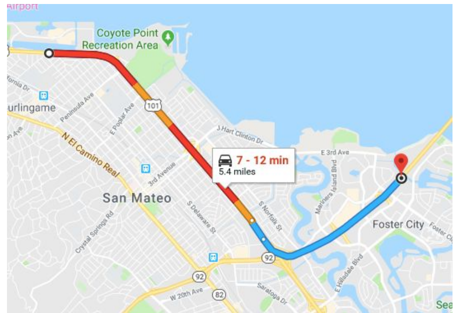


[1] Due to a coordinate error in Google Maps, the directions for the San Mateo segment were off; thus, data from San Mateo will not be used for Google Maps.

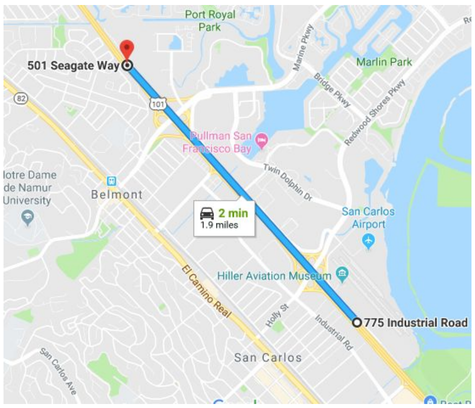
Morgan Hill (c)



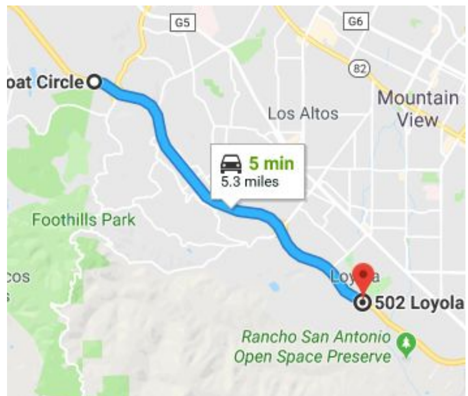
San Mateo (d)



Belmont (e)



Los Altos, I-280 (f)



Highway 237 (g)

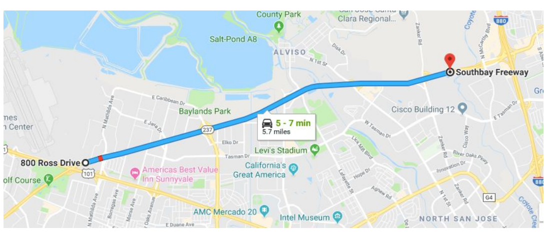


Figure 2 (a-g): The seven routes around the Bay Area picked to be measured.

In addition, from alternative routes, we selected a few local street segments of those routes to individually measure their travel times—"individual segments." Alternative routes have both freeway and local segments; by measuring the individual segment directly, we can isolate that local streets are getting congested and increasing travel times, not the freeway.

Gathering data

Data was gathered by a Python program run everyday from 3:30 pm to around 10 pm. The program used Google Maps Developers' Directions API and the Python module WazeRouteCalculator for the Waze API.

The program cycles around each of the 7 main routes and individual local street segments, querying both Waze and Google Maps. Each query records the main route and all suggested alternative routes. Travel times and directions are thus updated about every 3 minutes. Details including the alternative route name, distance, travel times, and component waypoints are recorded. Each data entry is assigned a batch number—representing the cycle at which the data was collected. This says two entries from the same batch essentially occurred at the same time. Moreover, each app-query combination is assigned a "service" variable. The service is 0.0 is for a freeway segment Waze query, 2.0 for a Waze individual segment query, 3.0 for a freeway segment Google Maps query, and 4.0 for a Google Maps individual segment query.

Analysis

A. Alternative routes

We analyze the data to identify *shortcut events* where the alternative route is faster than the freeway route. This means the alternative route is the first suggested route, causing drivers to reroute and take the alternative. Figure 3 shows a shortcut event.

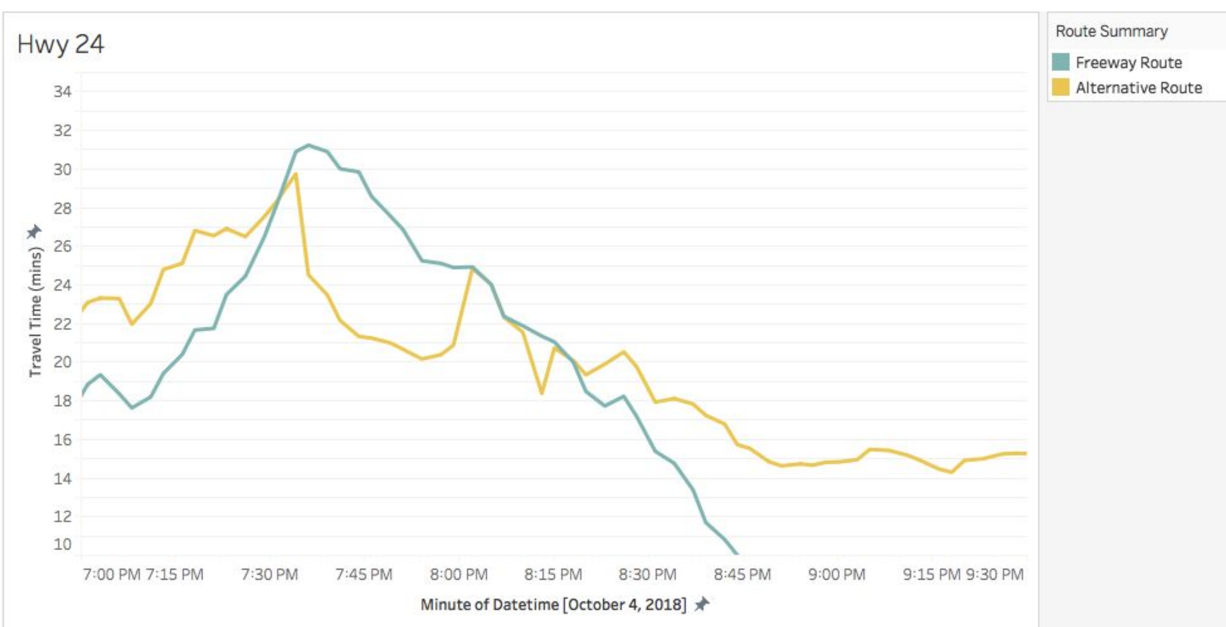


Figure 3: Graph of travel time vs. time of day on October 4, 2018 for Highway 24. The yellow route is the alternative route (through Mt. Diablo Blvd) while the turquoise route is the freeway route (Hwy 24). Between 7:35 and 8:05, the alternative route is faster than the freeway.

A Python program iterates through the data, checking for when an alternative route is faster than the freeway route and then permanently tracks that alternative route until one of two things happens:

1. The alternative route suddenly disappears and is no longer suggested by the navigation app. These *shortcut events* are called "vanishing."

It is not completely understood why some alternative routes suddenly appear or disappear. One theory is that these vanishing routes are more computationally intensive to calculate and thus only appear when traffic congestion is at its extreme; the moment congestion lightens, these routes are no longer calculated. However, this theory does not explain every case of these vanishing routes—it may be that navigation apps' suggestions are erratic with respect to time. Ultimately, vanishing routes can hurt the quality of data since one cannot see the trends in travel times across the entire period. Figure 4 demonstrates vanishing and non-vanishing routes.

2. The alternative route becomes slower than the freeway route and thus is no longer the first suggested route by the navigation app. These *shortcut events* are nonvanishing.

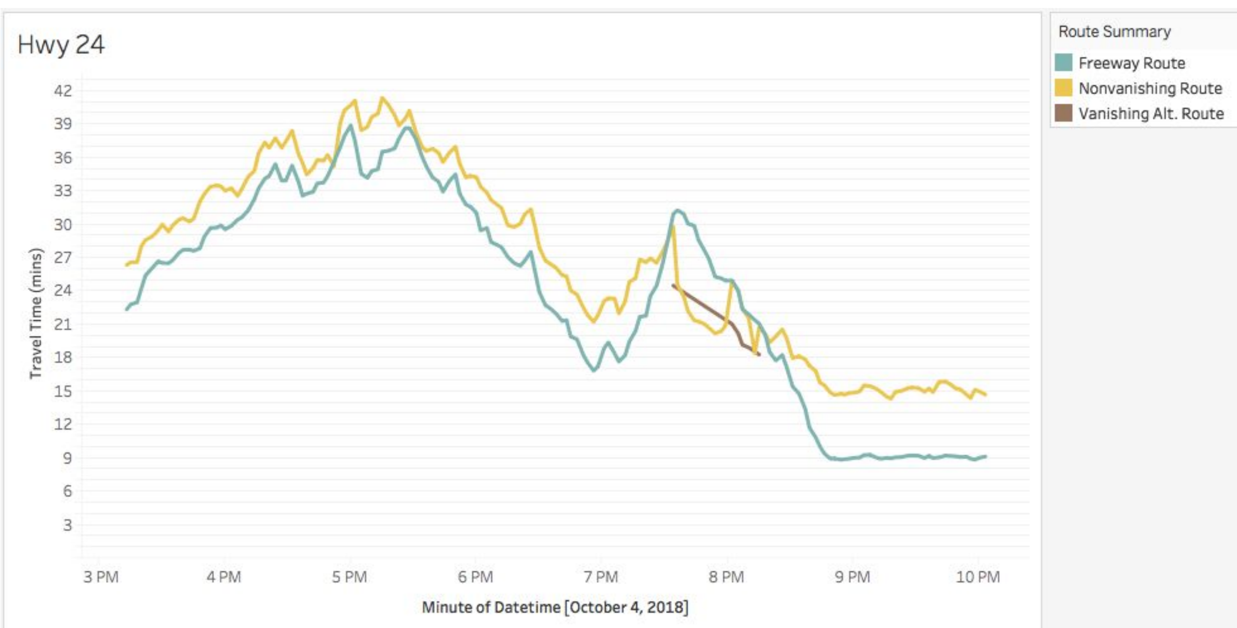


Figure 4: The graph compares different routes on Highway 24, plotting the travel time vs. the time of day passes. Note that between 7:30 PM and 8:00 PM the yellow alternative route briefly becomes faster than the turquoise freeway route, but eventually reaches equilibrium with the freeway route again. Thus, it is nonvanishing. The brown route is vanishing.

After running the program for Waze routes, there were 2833 occurrences of these *shortcut events*, where the alternative route was shorter than the freeway. Out of these, 1200 were nonvanishing, while 1633 were vanishing. The average duration of these events was 9.9 minutes. For Google Maps, there were 957 shortcut events, 877 of which were vanishing and 80 nonvanishing. The average duration was 9.3 minutes. The short duration of shortcut events illustrate that when these shortcuts appear, drivers quickly opt to take them, returning travel times to equilibrium. In this section, we examine these shortcut events' travel time rate of change, percent change, travel time increase, and correlation with the freeway route.

1. Alternative route travel time rate of change

A key metric to determine whether navigation apps are redirecting drivers onto side streets is to analyze the rate of change of the alternative route travel time during the shortcut event (when it is faster than the freeway and drivers are rerouting onto it). To compute this, we perform a linear regression with the x-axis as the time of day, and the y-axis as the travel time. The line's slope represents how much the travel time increases for every 1 minute that passes.

Including both vanishing and non-vanishing Waze routes, the average rate of change was 0.033; that is, for every minute that passes, the travel time increases by 0.033 minutes. Measuring just nonvanishing routes, the average rate of change was 0.090 (164% increase). For Google Maps, the overall rate of change was 0.067, and for just nonvanishing routes, it was 0.169 (152% increase).

This has several implications: first, the fact that the rates are positive shows that navigation apps suggesting alternative routes first do have a significant impact ($P<.001$) on *increasing* travel times of local streets. Second, due to the erratic nature of vanishing routes, if we exclude them from the calculation, the average rate of change more than doubles for both Waze and Google Maps. This rate of change is substantial—for every 10 minutes that an alternative route is the top-ranked suggestion, the travel time will increase by 0.9 to 1.6 minutes.

Additionally, the percent change in the alternative route travel times for these *shortcut events* confirms this effect.

$$\textit{percent change} = \frac{\textit{last recorded travel time} - \textit{first recorded travel time}}{\textit{first recorded travel time}} \times 100$$

For Waze, the average percent increase from the start of the shortcut event to the end of the shortcut was 1.55%, and using solely non-vanishing routes, there was a 3.78% increase. For

Google Maps, there was an overall 2.49% increase, and using only non-vanishing routes, there was a 13% increase.

Non-vanishing routes show a higher rate of change and percent increase than vanishing routes because vanishing routes disappear after the amount of time saved is not substantial anymore—i.e., their travel times have increased. If it was possible to continue tracking these vanishing routes after they disappear, their rate of change would likely increase too.

Additionally, Waze routes drivers more aggressively than Google Maps. Although there may be a faster alternative route, Google Maps will not suggest the route without a significant reduction in travel time; on the other hand, Waze will suggest any faster route. As a result, drivers are much more likely to opt for Google Maps alternative routes when they appear, substantially increasing the travel time on the route. On the other hand, Waze suggests alternative routes even when there is a miniscule time savings; a much lower percentage of drivers will take the alternative route in that case. Because of this, Waze data is diluted with minor shortcut events that cause very few drivers to reroute, while Google Maps consists of only major shortcut events that many drivers take, explaining the greater increases on Google.

2. Average travel time increase

For a given shortcut event with a start time and an end time, the period where travel times will be impacted is defined from the start time plus 6 minutes to the end time plus 21 minutes (the timeframe is as such because data is recorded in 3-minute cycles). Each travel time for the alternative route in this period is subtracted from the average travel time of the alternative route for that time of day over 3 months. Then, the median of the differences (to reduce the impact of outliers) is the overall travel time increase. Table 1 depicts the travel time increase for each freeway segment on each app for overall and just nonvanishing routes.

For example, if on October 6, say an alternative route, Mt. Diablo Blvd, is faster from 3:25 to 3:28. Then the period is defined from 3:31 to 3:49. The times for the period would be in 3-minute cycles: [3:31, 3:34, 3:37, 3:40, 3:43, 3:46, 3:49] and the corresponding travel times: [20, 21, 34, 23, 34, 23, 21]. Then, the average travel time for Mt. Diablo Blvd at 3:31 on any day would be calculated, and at 3:34, and so on, and then subtracted from the corresponding travel time on October 6. The final list could look like this: [4, 3, 2, 5, 4, 2, 3]. Finally, the median of the list is the overall travel time increase.

The average travel time increase for Waze routes was 0.76 minutes; only considering nonvanishing routes, it was 0.95 minutes. The average increase for Google Maps was 0.28

minutes; only considering nonvanishing routes, it was 0.89 minutes. All increases were statistically significant ($P<.001$). This supports the hypothesis that during a shortcut event, navigation apps cause the travel time on the alternative route to increase for a period of time, compared to that same period on any other regular day.

3. Correlation in travel times

The Pearson correlation coefficient measures the correlation in travel time between an alternative route and the freeway for each day. The overall correlation coefficients are calculated by averaging the correlation coefficients of each day. Table 1 illustrates the overall correlation coefficients for each city, on both Waze and Google Maps (service 0.0 and 2.0, respectively).

City/Freeway Segment	Waze	Google Maps
Concord	.942	.630
Highway 24	.974	.848
Highway 237	.734	.670
Belmont	.682	.526
San Mateo	.778	n/a
Morgan Hill	.547	.365
Los Altos	.767	.339
Average across all segments	.746	.557

Table 1: Pearson correlation coefficients for each freeway segment, for both Waze and Google Maps.

Nearly all freeway segments had strong levels of correlation on Waze; the overall Waze $r = .746$. Ultimately, across either app, the data shows that as the travel times of the freeway increase, so do the travel times of alternative routes, likely in part due to navigation apps. Indeed, the travel time of an alternative Waze route increases on average by 42% over rush hour.

B. Individual segment routes

Each individual segment was one portion of an alternative route, although not all alternative routes had individual segments being tracked. A Python program iterated through a data file of *shortcut events* (with information about the shortcut's duration, date and time, rate of change, percent change, and more) and attempted to match the timeframe of the *shortcut event* with the timeframe of its corresponding individual segment, if available.

The program calculates the Pearson correlation coefficient between the travel time data points of the Waze alternative route versus the individual segment in that given timeframe. Table 2 shows each alternative route, its corresponding individual segment, its corresponding city/freeway segment, and the correlation coefficient.

City/Freeway Route	Alternative Route	Individual Segment	Distance (km)	r	Individual Segment Service
Highway 24	SR-24 E Orinda; Mt Diablo Blvd Lafayette	Mt Diablo Blvd	2.068	.348	Google Maps
San Mateo	US-101 S Burlingame; E 3rd Ave San Mateo	J Hart Clinton Dr and E 3rd Ave	2.917	.339	Google Maps
Concord	SR-4 E Martinez; Concord Ave, SR-242 N Concord	Concord Ave	1.626	.211	Google Maps
San Mateo	US-101 S Burlingame; S Delaware St San Mateo; SR-92 E	S Delaware St	1.546	.100	Google Maps
CA-237	SR-237 E, Lawrence Expwy Sunnyvale; Tasman Dr Santa Clara	Tasman Dr	5.567	.565	Google Maps
Concord	SR-4 E Martinez; Concord Ave, SR-242 N Concord	Concord Ave	1.626	.337	Waze
San Mateo	US-101 S Burlingame; S Delaware St San Mateo; SR-92 E	Delaware Street	1.546	.146	Waze
San Mateo	US-101 S Burlingame; E 3rd Ave San Mateo	E 3rd Avenue	2.917	.337	Waze
Morgan Hill	US-101 S, Monterey Hwy San Jose	Monterey Rd	11.798	.533	Waze
Hwy 24	SR-24 E Orinda; Mt Diablo Blvd Lafayette	Mt. Diablo Blvd	2.068	.156	Waze
CA-237	SR-237 E Sunnyvale; Great America Pkwy, Tasman Dr Santa Clara	Tasman Dr	5.567	.300	Waze
Waze average:	.302	Google Maps average:	.295		

Table 2: Average Pearson correlation coefficient between individual segment and freeway route over 3 months.

The correlation is weak to moderate at best, which is surprising considering it was shown in part A that travel times increase on alternative routes; thus, they should increase on individual segments too. However, many of these individual segments were short; on average, they were 2.9 km, which can cause navigation apps to estimate travel times inaccurately. For example, on a 1.91 km stretch of Highway 24, Waze calculated the travel time as a flat 1.15 mins every single day throughout rush hour, which is clearly erroneous. Ultimately, the correlation shows there exists a relationship, albeit weak, between individual segments' travel times and the main alternative route. This is important because we isolate that within the alternative route, it is local streets, not the freeway portions, that are becoming congested.

C. PeMS Data

The Caltrans Performance Measurement System (PeMS) records traffic flows and travel times using inductive loops embedded in freeways. We examine three off-ramps that correspond to alternative routes—Bailey Road in Morgan Hill, E 3rd Street in San Mateo, and Holly St in Belmont—to see if traffic flow is higher than normal during a shortcut event. PeMS provides flow data every 5 minutes in vehicles per 5 minutes.

Similar to calculating average travel time increase in Part A-2, we define the timeframe for flow increases from the shortcut event start time to the end time plus 4 minutes. Each flow for the ramp in this timeframe is subtracted from the average flow of the ramp for that time of day over 3 months. Then, the median of the differences is the overall increase in traffic flow. Table 3 depicts the average increase in traffic flow for each off ramp on each app. Across all three cities, there was a substantial increase in cars taking the off-ramp onto local streets, which could contribute to increased traffic.

	Waze Flow Increase (veh/5 min)	Google Maps Flow Increase (veh/5 min)
Bailey Road in Morgan Hill	9.2	7.2
E 3rd Street in San Mateo	10.2	n/a
Holly Street in Belmont	4.67	1.5

Table 3: Average traffic flow increases on PeMS off ramps during shortcut events.

D. Severe Cases of App-induced Congestion

So far, the metrics we have used show a statistically significant yet modest increase in travel times and traffic flow due to navigation apps—however, nothing like the stories reported in the news of bumper-to-bumper streets and backed-up driveways. This can be expected because these metrics are an average over the entire dataset. In this section, we pinpoint a few shortcut events that had a severe impact on local road traffic.

In Concord on October 10, 2018, data suggests an accident occurred on eastbound Highway 4 from around 5:15 PM to 5:45 PM, causing highway times to spike up. Figure 5 illustrates how the freeway route, alternative route, and individual segment travel times change over the course of rush hour according to Waze.

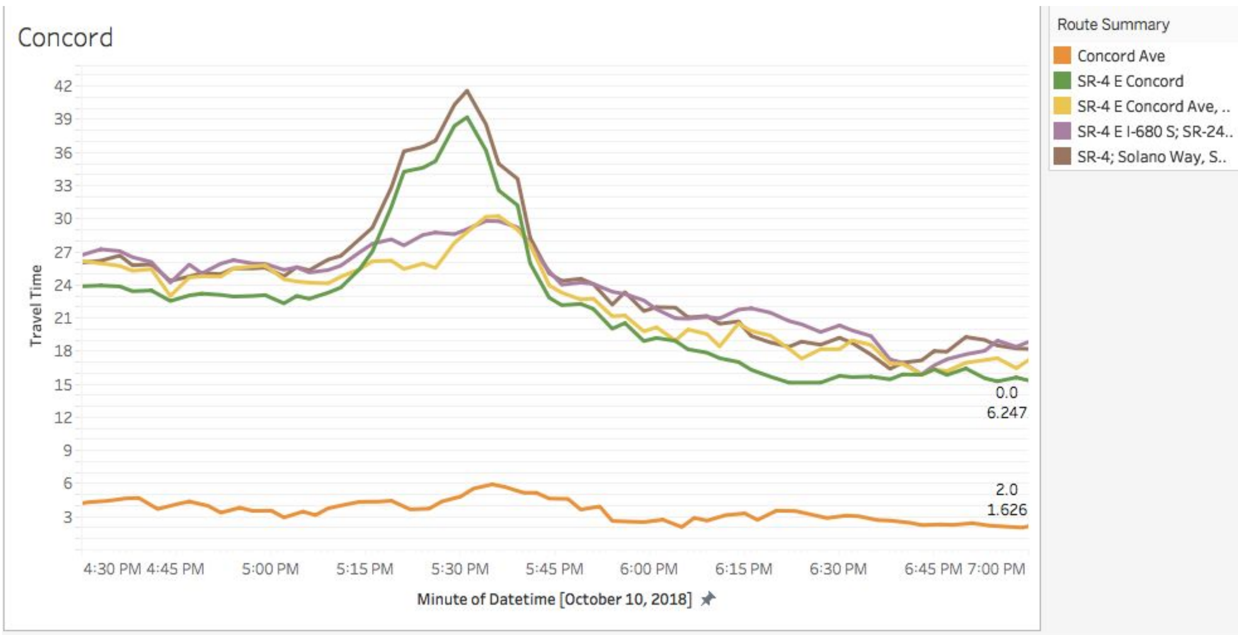


Figure 5: Graph of travel time vs. time of day for Highway 4 eastbound through Concord on October 10, 2018. The orange route (Concord Ave.) is the individual segment; the green route (SR-4 E Concord) is the freeway segment; all other routes are alternative routes.

Figure 6 illustrates the Concord Ave. individual segment and the SR-4 E Concord Ave. alternative route on the map. In this shortcut situation, the alternative route using Concord Ave. becomes much faster. As a result, drivers redirect onto that route, which increases travel times on Concord Avenue itself. A 1 mile stretch of Concord Avenue that took about 3 minutes before the accident, at 5:07 PM, takes about 6 minutes to drive through at 5:35 PM. This 100% increase in travel time signals severe congestion on the local street, which lasts for about 30 minutes. The overall SR-4 E Concord alternative route experienced a 20% increase in travel time from 25 minutes to 30 minutes. A different alternative route, SR-4 E I-680 S, experiences a similar increase in travel time.

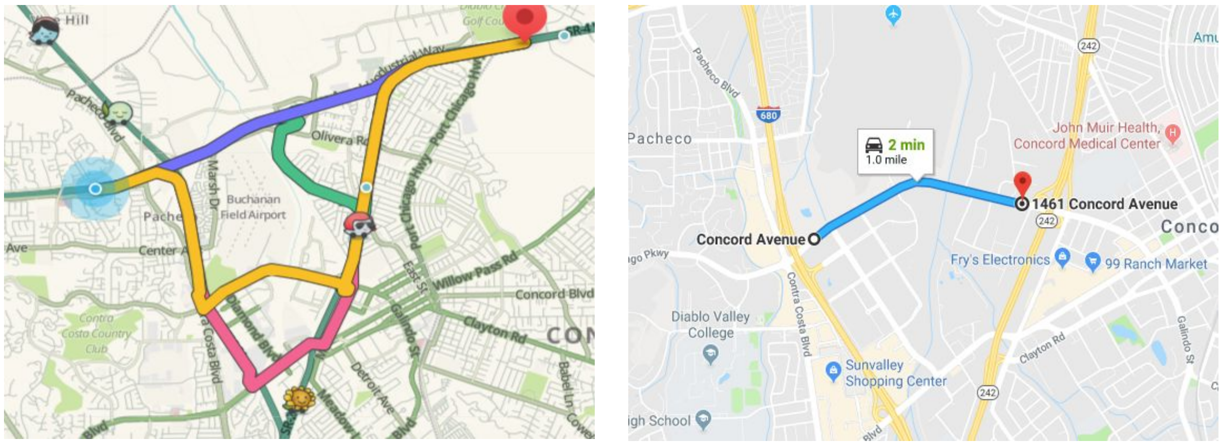
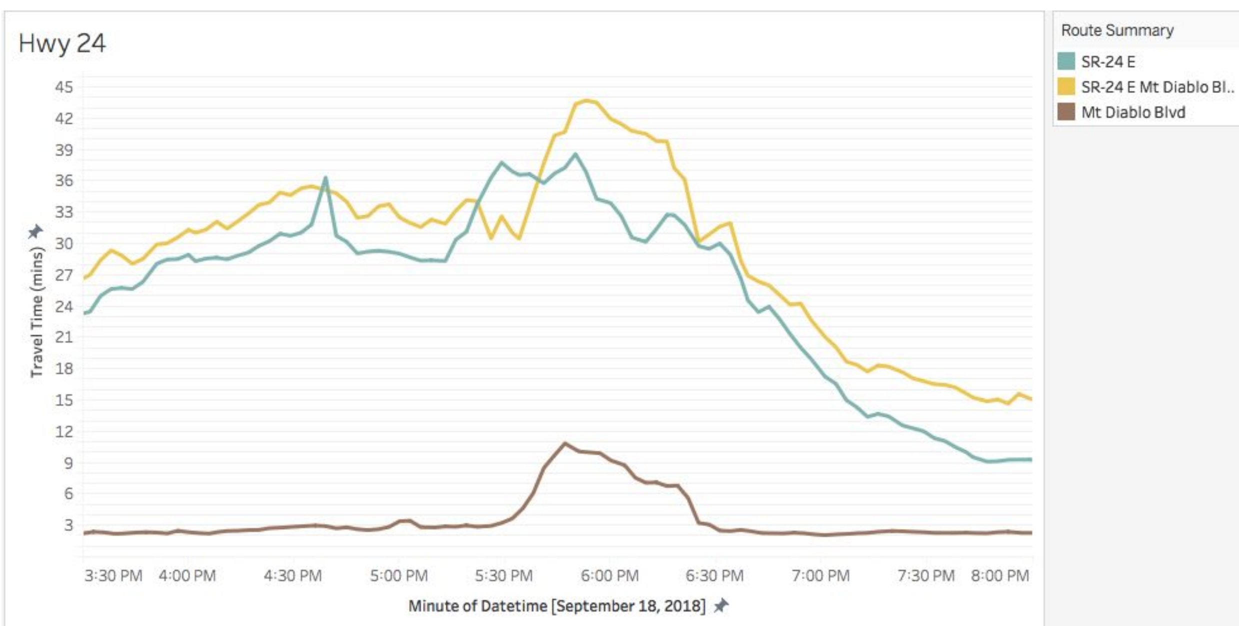
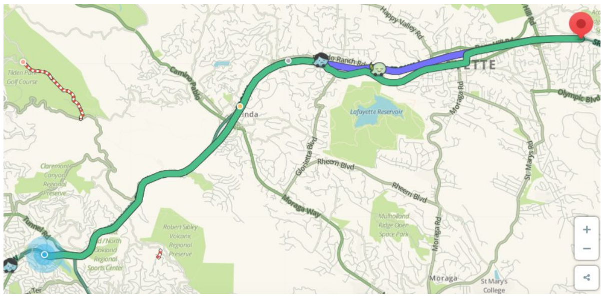


Figure 6: The left image depicts the alternative routes for Hwy 24 eastbound through Concord; the yellow route is SR-4 E Concord Ave. The right image depicts the individual segment of Concord Ave. that is measured.

Another example can be seen on Highway 24 eastbound towards Lafayette on September 18, 2018, when the freeway travel time suddenly increased at 5:16 PM while the Mt. Diablo alternative route stayed constant. This can be seen in Figure 7a, which depicts the travel times as they change over the course of rush hour. Figures 7b and 7c depict the alternative route (SR-24 E Mt. Diablo Blvd) and the individual segment (Mt. Diablo Blvd) on a map, respectively.



(a)



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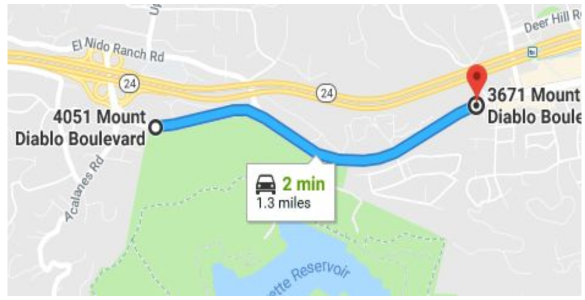
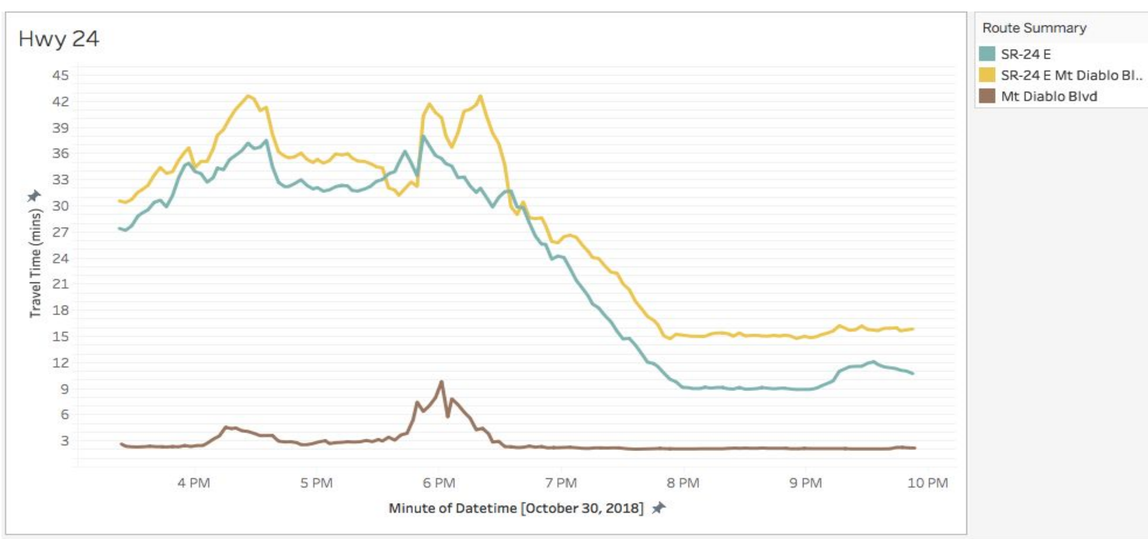


(c)

Figure 7a: Graph of travel time vs. time of day for Highway 24 eastbound on September 18, 2018. The brown route (Mt Diablo Blvd.) is the individual segment; the turquoise route (SR-24 E) is the freeway segment; the yellow route (SR-24 E Mt. Diablo Blvd) is the alternative route. **Figure 7b:** The alternative route is highlighted in green. **Figure 7c:** The individual segment of Mt. Diablo Blvd is pictured.

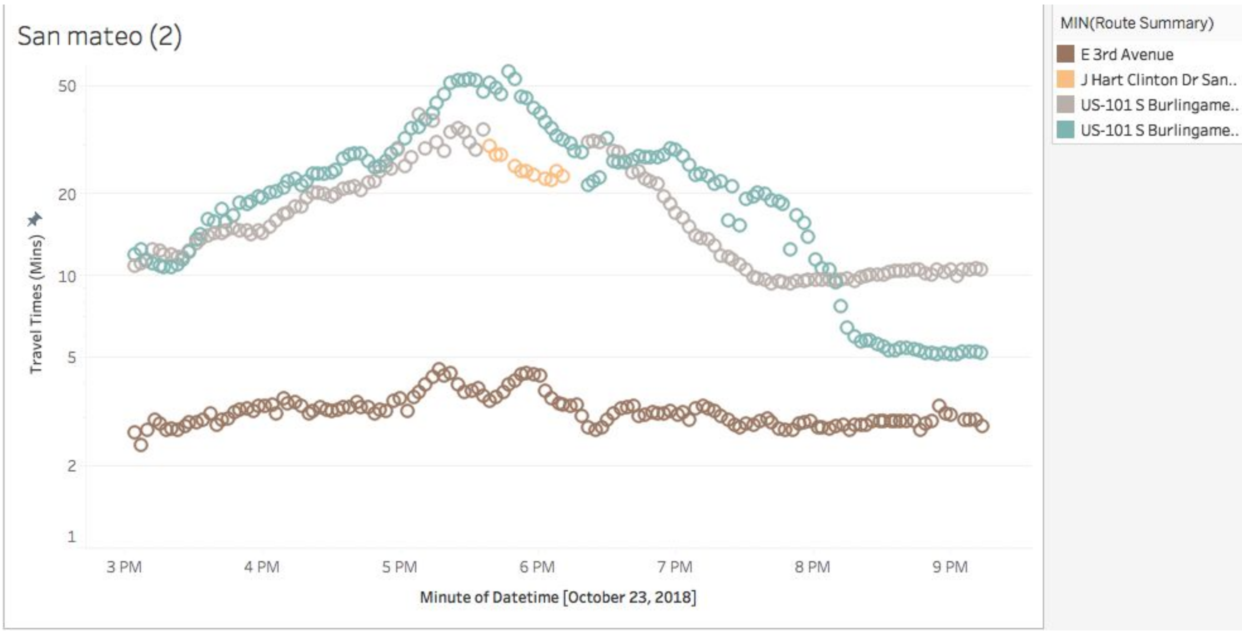
Due to the alternative route being faster, drivers reroute onto Mt. Diablo Blvd, thus increasing the overall alternative travel time and also the individual segment. Note the delayed impact: although Waze begins ranking the route first starting at 5:26 PM, the effects begin to materialize in the individual segment at around 5:30 PM. The travel time of the 1.3 mile segment of Mt. Diablo Blvd increases from 3 minutes to 10.8 minutes at its peak—a 260% increase. The local street congestion lasts for about 1 hour. Finally, compared to typical days, the travel time for the alternative route is 7.6 minutes longer.

Figure 8 depicts various other shortcut events and their effect on individual segment travel times using a travel time vs. time of day graph.[2]



(a)

[2] Graphs have been cleaned up to remove extraneous routes that do not have an individual segment.



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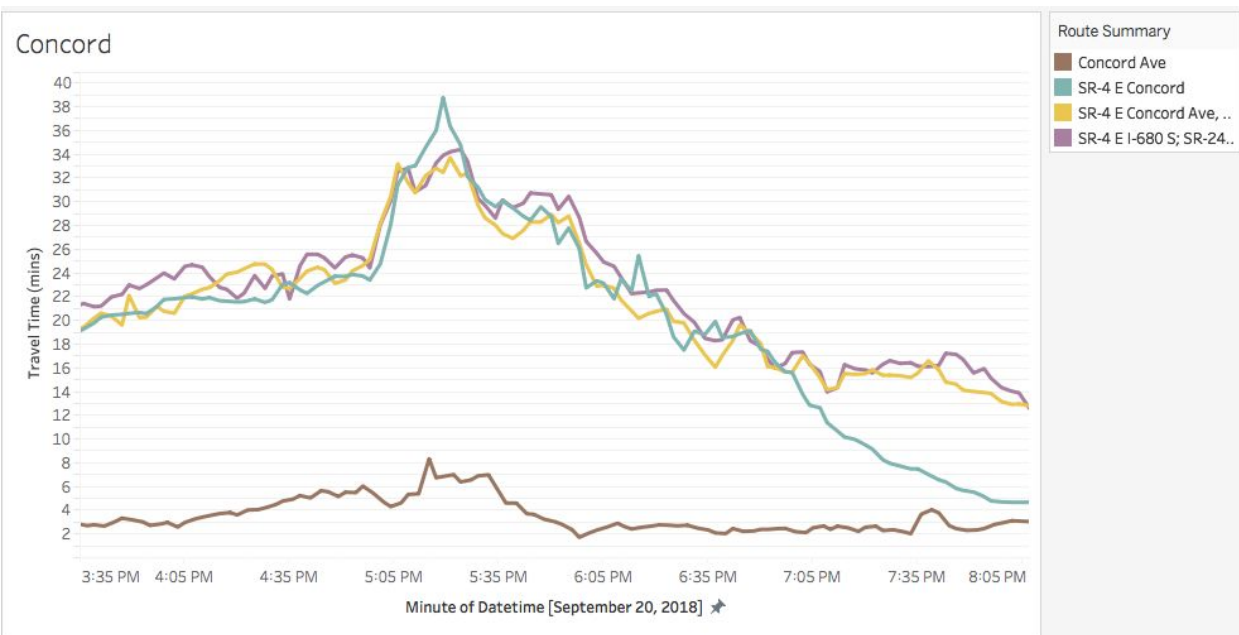

(c)

Figures 8a-8c: Graph of travel time vs. time of day. Individual segments are brown and freeway routes are turquoise. Other routes are alternative routes. Figure 8b uses a logarithmic y-axis to depict the change in the individual segment.

Conclusions

This project recorded the directions and travel times suggested by navigation apps like Google Maps and Waze over 3 months, as well as recording individual segments of local streets. Shortcut events were identified where an alternative route was faster than the freeway route, and thus drivers reroute onto it. In these events, the alternative route travel time on average increases by 0.3 to 1.6 minutes per 10 minutes that pass and travel times are higher than an average day by 0.28 to 0.95 minutes. Moreover, there was a strong correlation between freeway routes and alternative route travel times, suggesting that when travel times of freeways go up, navigation apps play a role in redirecting traffic onto alternative routes. This project also analyzed PeMS ramp data, finding a 1.5 to 10.2 vehicles per 5 minutes increase in traffic flow during a shortcut event. Finally, specific shortcut events that had severe impacts on local street traffic were analyzed.

Overall, this research proved empirically that navigation apps have a statistically significant impact on local streets—increasing travel times and vehicle flows. On balance, these shortcut events have a modest effect on local streets, but in the most severe cases, this study shows local streets can see travel times increase by several times, demonstrating that app-induced congestion is a widespread phenomenon. Our results can prompt cities and transportation planners to start understanding how they can fix this app-induced congestion, while also providing information about when, where, and how this phenomenon occurs.

Future work can involve collecting further data to analyze trends over months and years. Due to API quotas, this project was only able to collect data every 3 minutes; more granular detail would have improved precision. Some freeway segments performed better than others; to record the best freeway segments, researchers can track news stories for app-induced congestion incidents, because those segments are likely to have the greatest impact on local street traffic. Additionally, future routes should be chosen to coincide with off ramps that are tracked by PeMS. Vanishing routes could be tracked throughout the entire day by recording the coordinates that make up the route and inputting them as waypoints. Finally, researchers could build upon theoretical models of app-based routing like the work of Cabannes et al. (2018) [9] to evaluate the effectiveness of current methods of preventing cut-through traffic (e.g., blocking off roads or implementing turn restrictions) and develop new solutions to this growing problem. Of particular interest are routing algorithms for cars that can all communicate with each other and share real-time traffic information (Du, Chen, and Han 2015) [11].

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