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The Value of Data: Analyzing Transportation Network Company Trips for Transit Planning

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The Value of Data: Analyzing Transportation Network Company Trips for Transit Planning

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Dedicated to my grandfather, Wendell F. Grant, for his sense of humor and for teaching me how to persevere in the face of adversity.

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The Value of Data: Analyzing Transportation Network Company Trips for Transit Planning

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Private transit in the US has evolved over the last decade to include car-sharing services like car2go and Zipcar to Transportation Network Companies (TNCs) such as Uber, Lyft, and RideAustin. As these services become more convenient and cost-effective for users, they continue to increase in popularity. However, despite some initial studies, there is not yet consensus on why people choose to use TNCs or what their effects on existing transit systems or society at large will be. RideAustin, a non-profit ride-hailing company that began in May 2016, emerged to fill a gap left when Uber and Lyft stopped operations in Austin. Can TNC trip profiles and rider profiles be developed based on the RideAustin dataset to determine when and where people choose to use TNCs, and what the characteristics of such people are? Where are transit and TNCs competitive, and where are they complimentary? This study aims to answer the questions raised by the emergence of TNCs by analyzing trips in the RideAustin dataset along with land use and Census data to develop

trip and rider profiles. Downtown trips are shorter than the average trip, concentrated on Friday and Saturday nights, and primarily internal to the downtown area. Airport trips are much longer than the average trip, spread out during the week, and to a mix of low-density residential areas and hotspots like downtown. Downtown presents a good market for a transit circulator or TNC pickup zone. Airport trips to hotspots may be served well by transit if hours are extended, but trips to low-density residential areas are better served by TNCs.

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Chapter 1

Introduction

Transportation Network Companies (TNCs) have been shaking up the world of transportation planning since Uber launched in 2011. Born in Silicon Valley, with a "move fast and break things" mentality, Uber, Lyft, and a variety of smaller companies, had to be comfortable operating in a legal grey area until city and state regulations could catch up. While Uber and Lyft claim that this strategy was necessary for their success, it was also an adversarial way to begin operations. This negative beginning has hampered relationships between TNCs and cities, and only a few cities have been able to work past that point to date. Adding to the complexity, there are other stakeholders in the picture with different goals. Taxi companies have been particularly critical of TNC operations, seeing the new service as nearly identical from the customer perspective but with fewer regulations.

There are a host of companies and services contained within this "new mobility" paradigm, and some confusion is inevitable. Early car-sharing programs, such as Zipcar and City CarShare, operated on a station-based model where a user pays by the hour and picks up and drops off the car in the same location [19]. Later models, such as car2go, allow a user to pick up and drop off a vehicle in any location within a geofenced area [13]. TNCs, some of the most recent entrants to this space, pick up riders at their origin and drop them off at their destination. Riders pay for the time and distance that they are in-vehicle, as with other models, but do not have to find a vehicle or park it when their trip is over [19]. While similar to taxis, TNCs differentiate themselves by arranging rides for independent contractor drivers via a smartphone app, whereas Taxi service is typically hailed from the curb [36]. In some places, like New York City, this distinction is enforced by law, and TNCs are not allowed to pick up passengers outside of the app interface [33]. Any service that has disrupted transportation as thoroughly as car-sharing and TNCs have is bound to be controversial as cities struggle to adapt to the changes. However, in spite of the controversial beginnings, some cities have had success working with TNCs on programs that enhance peoples' lives.

These relationships between cities and TNCs are complex and highly dependent on the local conditions, including cities' needs and staff attitudes. Several areas have tried to cooperate, only to have agreements fall through. Others have tried to force TNCs' hands by requiring trip data or imposing other restrictions, only to have the TNCs leave the area, or to be preempted by state law. But cities are getting used to the idea that TNCs are here to stay, and TNCs are getting less possessive of their data. As the two learn to work together, they will open up a world of new mobility options for more and more people.

1.1 Problem Statement

Ride-hailing is becoming an increasingly popular mode of transportation, yet little is known about why people choose TNCs or how TNCs will coexist with traditional transit service. Can TNC trip profiles and rider profiles be developed based on the RideAustin dataset to determine when and where people choose to use TNCs, and what the characteristics of such people are? Where are transit and TNCs competitive, and where are they complimentary?

1.2 Research Goal & Objectives

This thesis attempts to analyze TNC data in order to provide information for transportation planners to develop new partnerships with TNCs to better serve consumers. Basic information about RideAustin trips is examined, then specific trips are analyzed to develop trip and rider profiles. Certain trip profiles are highlighted for being well-suited to transit, while others are ideally suited to TNCs service.

1.3 Organization of This Document

This chapter has introduced TNCs and how they fit into the transportation planning landscape. Chapter 2 presents an in-depth literature review of the transportation planning process with a focus on public transit and data requirements, ending with examples of transit agencies that stand out for their innovative work with TNCs. Chapter 3 discusses the methodology used to analyze trip records of a local TNC in order to obtain useful insights for transportation planners. Chapter 4 conveys basic information about the trips made, then develops trip and rider profiles based on land use characteristics and Census data. Chapter 5 draws conclusions regarding opportunities for co-operation and competitive advantages of each service, followed by discussion of the limitations of the study and suggestions for future work.

Chapter 2

Literature Review

2.1 Traditional Public Transit Planning

Traditionally, transit planning has followed a four-step process to set routes, timetables, and schedules for vehicles and staff. First, route planning is done, typically on an approximately ten-year cycle [92]. This process consists of the network design problem, modeling trips and setting the physical location of routes based on demand. Once routes have been established, service planning is performed to adjust frequency and timetables based on performance and desired headways [9]. This step is done more frequently as it is subject to seasonal and annual fluctuations in demand, making it much more sensitive to increases in population or changes in signal timing. Finally, scheduling of vehicles and staff is performed based on service needs and labor considerations. Software packages such as TRAPEZE and ROUTEMATCH focus on assisting planners with these two steps, as driver wages are often the largest expense for a transit agency, and these are the easiest to change [9].

Two types of service standards are commonly used when planning transit: route-design characteristics and service design characteristics. Route-design characteristics include route structure, short-turn techniques, and measures of directness; while service-design includes number of standees, maximum headway, and schedule adherence [9]. Similarly, service performance may be evaluated with passenger- or cost-based methods, such as passengers per hour or cost-recovery ratio [9]. In order to measure these performance metrics, certain data must be collected and analyzed. Manual, automated, and Automatic Vehicle Location (AVL) methods are used to collect peak loads, arrival and departure times, passenger loads along an entire route, deadhead times, and passenger surveys regarding origins and destinations [9]. AVL and Automated Passenger Count (APC) devices are differentiated due to their higher accuracy and more comprehensive coverage—when installed in a vehicle, they collect information on every trip that vehicle makes, not just peak load or high-demand routes.

In recent years, Automatic Vehicle Location devices have been utilized to make schedule adjustments. The devices collect data about time-dependent vehicle location and compare that to the schedule. This data can then be used to evaluate measures of service reliability, such as on-time performance, run time variation, headway variation, and excess waiting time. [74] In addition, techniques are being developed to set optimal stop locations and headways based on AVL data combined with APC devices. For "frequent" routes, (based on headway, often of 10 minutes or less, instead of time points) techniques are being proposed to automatically determine the appropriate control strategy in case of service deviation. [74] Increased data collection of route performance and ridership is helping them plan for increased reliability and optimal operations. This can help transit agencies provide an attractive service in the face of increased competition and diminishing ridership.

Origin-Destination information is some of the most valuable for a transit agency, as it provides direct knowledge about an entire trip. However, it is also some of the most difficult to get, as it requires in-person or computer-based surveys of passengers. For example, AVL and APC data provide highly accurate information about passenger load and schedule adherence, but they do not connect a passenger across transfers, or let the agency know anything about the first and last mile of the trip. Only by surveying passengers and potential passengers can an agency determine if the demand exists for new service to an uncovered area.

The introduction of TNCs affects transit agencies by changing how they must approach the first stage of transit planning. From the customer's perspective, TNCs provide a competitive service, typically with faster travel time or smaller travel time variance. Frequency and reliability of transit service are among the most effective means of increasing or maintaining ridership, but transit agencies sometimes choose to focus on attracting "choice" riders while neglecting "captive" ones [9] [101]. TNCs therefore have the potential to alter demand (people's choices) by filling a niche that did not exist before. As transit agencies plan their networks for the next ten years of service, they need to be aware of how current trends in mobility will change. Network design is a difficult process, performed infrequently, and it has a strong impact not only on the other parts of the planning process, but also on ridership and quality of service as well. If transit agencies are unable to plan for increased use of TNCs in the future or predict where TNCs will have a strong market presence, they are likely to fail due to losing ridership to a more cost-effective mode.

Paratransit in particular is a service provided by traditional transit agencies that could benefit greatly from operational changes. Definitions of paratransit vary, but in general the term refers to a demand-responsive service for people who meet certain eligibility requirements, such as age or disability [55]. It also typically operates in a more limited area, such as within $\frac{3}{4}$ mile of fixed-route transit [100]. Current paratransit operation involves a staff of dispatchers taking calls from eligible customers, confirming eligibility, and scheduling door-to-door service with an appropriate vehicle. Approximately 60% of operating costs for paratransit providers in Central Texas are driver salaries and benefits. Additionally, calls from dispatchers to drivers regarding cancellations occupy about 75% of dispatcher time [55]. Early versions of paratransit planning software did not include information about fixed-route service, resulting in door-to-door trips when first or last mile connections may have been an appropriate choice. And given how cash-strapped many agencies are, they may still be using outdated software for trip planning that does not incorporate these advancements.

In light of the above, Thole and Harvey [100] recommend accounting for access to fixed routes, accurate population statistics, agency size, cost to and income level of user, and convenience factor when estimating demand for paratransit services. These recommendations have merit, but what is most clear is that something needs to change. The current methods for scheduling and delivering paratransit rides are expensive to operate, inconvenient to use, and inefficient. Paratransit providers need to find a way to increase operational efficiency and ease of use in order to remain a viable mode for vulnerable populations.

2.2 Disruptions to the Norm

In more recent years, the introduction of ride-sharing services (such as car2go) and ride-hailing services (such as Uber and Lyft) have disrupted the typical planning process and caused uncertainty among transit planners. Starting with the introduction of City CarShare in San Francisco, studies have focused on how new services will affect how people choose to get around. Early studies of that program indicated slight reductions in Vehicle Miles Traveled (VMT) and reductions in the number of cars owned by participating households [13]. The success of these programs have only grown as services like car2go (introduced in 2008) and Zipcar become more prevalent. Importantly, despite initial indications that it was creating new vehicle trips, car2go appears to have resulted in a net reduction of household vehicles among users [10] [13].

In a survey conducted in 2014 and 2016, Clewlow and Mishra [19] find that ride-hailing services result in a 3% reduction in bus usage and a 6% reduction in light rail usage after their introduction. Additionally, 91% of ride-hailing users did not change the number of vehicles they owned. However, they also find a 3% increase in commuter rail usage in cities where it is available. This suggests (and aligns with traditional transit planning knowledge) that people use commuter rail differently from light rail or bus service. It also suggests that the effects on traditional transit services will be different depending on this underlying motivation. For example, ride-hailing appears to be a good first- or last-mile connection for longer commuter rail trips. This is confirmed by Lownes and Machemehl [63], who discuss the traditional importance of Park-and-Ride systems at the home end of commute trips. They show that typical commuter-rail patterns are heavily reliant on first-mile connections, which can be served by Park-and-Rides or ride-hailing services. This new research from Clewlow and Mishra indicates that ride-hailing may be a more cost-effective or convenient method for commuters than owning a car and leaving it at a Park-and-Ride all day.

The situation is more grim for light rail and bus services. When asked why they would prefer to take ride-hailing over light rail or bus service, the most important reason among respondents was that transit is too slow [63]. Regardless of the actual speed of transit and ride-hailing services, public impression is important here. Public transit has a reputation for being slow and unreliable, which discount it as a viable option for many people. Transit agencies face an uphill battle compared to the apparent efficiency of tech-savvy ride-hailing companies.

2.2.1 Current State of Transit

Nationally, transit agencies have lamented falling ridership and have had to make tough decisions about levels of service and reduced budgets. While bus ridership fell 16% between 2000 and 2017, an APTA study of agency reports found that rail ridership was up 43% for the same period [38]. They find a number of reasons for these changes, including reduced cost of auto loans, low gas prices, increased teleworking making monthly transit passes less cost-competitive, service cuts, and free parking in downtown areas. As such, they recommend improving time competitiveness of existing services and ensuring that service matches demand. Time competitiveness is probably why rail has done so well: an analysis by TransitCenter in New York found that service frequency and travel times were the most important aspects of transit service [101]. These two factors more than any others were what determines if people are willing to take transit versus driving or another mode. In places with robust rail networks, trains come frequently and have good travel times that are unaffected by vehicle congestion. Buses, on the other hand, are subject to the same traffic conditions as regular traffic, and even BRT may have a hard time matching the frequency and travel time of a grade-separated rail during peak periods.

Another important factor in the success of rail (and decline of bus ridership) is matching service to demand. During the recession of 2008, many agencies were forced to cut bus service and have not replaced it [38]. Due to the nature of transit planning for bus networks, once a route is eliminated it can be very difficult to re-instate service to that area again. Rail service, on the other hand, is easier to replace once economic conditions allow. Typically, service cuts for rail only involve reduced frequency, but even if a line is eliminated, the infrastructure remains. Agencies may also be less willing to cut rail service due to the higher investment cost: more money was spent developing the service, so it is seen as more permanent. What this means for riders is that service was cut during the recession and now a bus route that they may have used no longer goes where they need it. This reduces the number of "all-purpose" riders—people who take transit for most of their trips [101]. All-purpose transit riders are more common in places where walking to or from the stop is possible, service is frequent, and there are many accessible destinations. In other words, when transit agencies cut service to reduce costs, they were making it impossible to take transit on a regular basis by removing access to a variety of destinations. In order to recover those riders, agencies need to design frequent, fast service to places with high demand.

2.3 Opportunities for Cooperation

Transit and TNCs are often portrayed as natural competitors, and the rise of TNCs may be a factor in decreased transit ridership in certain circumstances.[8] [19] This, however, is an oversimplification, and ignores other effects behind the rise of TNCs and decline of transit ridership. It also ignores applications where TNCs and public transit could be complimentary, such as data collection for planning purposes; first- and last-mile solutions; VMT and congestion reduction; and equity, paratransit, and disaster response assistance.

2.3.1 Transit Service Planning

Origin-Destination information is incredibly valuable for any kind of transportation planning. For public transit in particular, where passengers' exact origin and destination are not known to the agency, this information is valuable and difficult to obtain. It can be used to simplify existing routes and make them more reliable, or to add service in a high-demand area, reducing traffic congestion for all. If TNCs shared their pickup information with public agencies, that data could be used to assist transportation planning. Transit planning in particular would benefit from knowing where people are trying to go. Programs such as SharedStreets simplify and standardize data collection for industry partners and cities, while protecting customers' privacy and industry's trade secrets [25]. They also enable other beneficial applications for cities, such as vision zero outcomes and smart curb management techniques. Some cities are moving to require data reporting from TNCs, but current state law in Texas prohibits such measures at the local level. Fortunately, many companies in Texas understand the public need and are willing to work with cities to deliver this information.

2.3.2 Congestion & VMT Reduction

At a service level, TNCs can be used to reduce congestion and VMT within the city. Options like UberPool and LyftLine get multiple people in the same vehicle and the companies' efficient routing algorithms automatically choose the best path between each rider's origin and destination. While discussion of results of passenger surveys focuses on an increase in VMT due to TNCs, the reality is more complex. When asked which other mode they would have taken if Uber and Lyft were not available, around 60% of survey respondents in San Francisco would have chosen active or shared modes, but another 21% would have driven alone [19]. The reduction in drive-alone trips does not overcome the VMT from other modes, but it does show that there is a segment of the population that is willing to forgo driving themselves. These people may be willing to reduce household vehicle ownership, as was seen with City CarShare in San Francisco during its first four years of service [13]. In addition, Clewlow and Mishra find that ride-hailing services are complimentary for commuter rail services, increasing net usage by 3% [19]. Furthermore, Lownes and Machemehl state that some mature commuter rail services have outgrown their initial park-and-ride services, and require new first-mile strategies to attract or maintain ridership [63]. In some cases, shared-ride TNC services could fill that role by partnering with cities to provide access to the existing infrastructure.

2.3.3 Paratransit and Disaster Response

Cities could also partner with TNCs to provide paratransit services or increase mobility during a disaster event. During an evacuation, people could coordinate evacuations via the existing app interface, which would increase the capacity of roadways during a critical time and provide people who may not be able to drive with a safe option. In addition, the Massachusetts Bay Transportation Authority (MBTA) and The Ride (MBTA's existing paratransit partner) have teamed up with Uber and Lyft to provide paratransit-eligible customers with a new degree of mobility. This program is discussed in more detail below, but a similar program could be implemented to help people without vehicles during an evacuation scenario. Interacting with a familiar app, with drivers that have been vetted by the TNC, may be more convenient for people than other means, and is certainly safer than remaining in place when ordered to evacuate.

2.4 Data Collection

Data is critical for transportation planners to make important decisions about how to improve infrastructure. Without information on how many people are making trips via ride-hailing services and where and why they are traveling, cities cannot plan for future infrastructure needs. To that end, several cities have initiated data-sharing or reporting mechanisms with TNCs in their area, with varying degrees of cooperation and success.

2.4.1 Shared Data

For example, New York City's Taxi and Limousine Commission (TLC) passed regulations in February 2017 requiring TNCs to report origins and destinations, including time and a driver ID, for each trip [33]. The city is also collecting whether or not a trip was shared among multiple customers. However, Uber and New York's Public Advocate have opposed the ruling, citing privacy concerns for passengers [75]. New York City's TLC are primarily using this information to calculate hours-of-service for TNC drivers, in order to increase safety by monitoring driver exhaustion. However, the city also plans to use the data for transportation planning, vision zero initiatives, and equity analyses. An analysis by the blog FiveThirtyEight on an earlier dataset which did not include destination or shared ride information concluded that Uber was probably serving the outer boroughs of New York better than traditional yellow cabs were [4]. However, they also conclude that TNC traffic within Manhattan was probably contributing to congestion—63% of all Uber rides started in Manhattan, south of 59th street. Ultimately, passage of this rule shows that TNCs can share data with cities, even if there are privacy concerns involved. Furthermore, the corresponding analysis shows the value of this data for transportation planners.

The National Association of City Transportation Officials (NACTO) and the Open Transport Partnership have developed a standard mechanism for sharing transportation data, known as SharedStreets [25]. The standard is an abstract representation of intersections built on OpenStreetMap, and can be used with a combination of proprietary and open data. [91] The abstraction enables different entities to compare and combine their datasets without manually aligning each point or revealing proprietary basemaps. While still in its infancy, the program promises to simplify transportation planning, and has the backing of the World Bank and Uber. Current example applications on their website include basemap-independent sharing of traffic conditions, detailed curb inventory, and real-time incident and road closure reporting.

A paper by Cambridge Systematics [53] highlights the benefits of making TNC trip data publicly available. They examine the RideAustin dataset, developing insights that would not have been possible without the detailed information provided by RideAustin. In particular, they are able to link drive trips to compute deadheading distances and develop a customer usage profile based on length of active membership, number of trips per rider, and primary and secondary locations for riders. They also perform a detailed analysis of South by Southwest (SXSW) and Austin City Limits (ACL) festivals, which bring a lot of tourists to the city and increase demand for transportation services.

The advantages of the RideAustin dataset are clear, especially when compared to what other cities have been able to determine based on data that TNCs provide them. The unique, consistent rider and driver ID's unlock the ability to analyze deadheading and develop rider profiles. As seen in San Francisco, it is possible to estimate deadheading by scraping public API's. The advantage of the RideAustin dataset is that driver ID's are guaranteed to be consistent from day to day, whereas other TNCs may change the vehicle ID periodically. Additionally, RideAustin provides access to information about riders, which is unavailable to most other cities. As discussed by Komanduri, et. al. [53], it may be possible to determine traditional trip types (such as home-based work) based on the primary and secondary location of a rider. However, what is lacking from this data are the characteristics of a typical TNC rider and more information about their trips. This paper attempts to determine more about the typical TNC user using RideAustin's data combined with land use and Census data. Learning more about these riders' habits help transportation planners accommodate for the changes in demand introduced by TNCs.

2.4.2 Scraping Data

Faced with a drastic new paradigm and unable to reach an agreement with existing TNCs, the San Francisco County Transportation Authority (SFCTA) devised a method to scrape data from the public-facing API's of Uber and Lyft. By tracking when and where vehicles appear or disappear from the API, the authors were able to construct a partial picture of trips in the San Francisco area. They discovered that TNCs generate 569,700 VMT over 170,400 trips on a typical weekday with an average in-service trip length of 2.6 miles [8]. This was similar trip length to taxis, but the out-of-service trip length was much larger for taxis (2.0 miles vs. 0.7), reflecting the more efficient routing algorithms used by the TNCs. They also conclude that the southeastern neighborhoods may be under-served by TNCs, based on the number of TNC pickups per taxi pickup and TNC pickups per population/employment. However, they do not hypothesize a cause for this phenomenon. Even without the cooperation of TNCs, it is possible to get some information about their effects on the transportation system. However, Uber and Lyft have questioned the accuracy of the SFCTA study, and open datasets provide more information than can be gleaned from the methods they used.

2.5 Leading Transit Agencies

Some cities have had more success than others in adapting to recent market pressures on transit systems. In particular, Houston was able to revitalize its entire system and come back from a years-long decline in ridership by focusing on frequency and reliability in dense areas. New York City was able to pass regulations requiring data sharing from TNCs at a time when the companies were more than willing to leave other cities. Los Angeles, Boston, and Washington, DC also have innovative TNC partnerships.

2.5.1 Houston METRO

Starting in 2009, Houston passed an ordinance to encourage Transit-Oriented Development (TOD). TOD's are a planning tool for cities to encourage livable, pedestrian-friendly communities by increasing convenience of non-driving modes and internal trip-making [56]. The ordinance in Houston encourages pedestrian traffic, light rail use, and attempts to shape growth near critical corridors. Allowing smaller frontages for buildings in TOD zones and relocating parking and driveways to be more convenient for pedestrians increases the walkability and "curb appeal" of buildings, making pedestrian traffic more likely [40]. Pedestrian-friendly environments, coupled with frequent transit service, is one way to increase ridership for near the development. There is always a tradeoff between high-frequency over a small geographic area and less frequent service over a larger area, but the "coverage" model is less useful for riders [101]. Unfortunately, as of 2014, only three developers had opted in to the TOD ordinance, utilizing a mix of the recommended elements, so the initiative was not as successful as it could have been [40].

However, the TOD ordinance was followed by an overhaul of the transit network in 2014. Revitalizing the transit network may see increased interest from developers as the two pieces, frequent transit and dense, walkable communities, come together. Already, the average weekday ridership across the entire network has grown about 5% since 2013, an amazing turnaround compared to the 39% drop from 1999 to 2013 [67] [101]. Overall, effects of changes have been slower than supporters would like, but there is evidence that the TOD ordinance and transit system overhaul will be successful in the long run.

2.5.2 New York City

New York City is already the densest city in the US, and arguably the one with the best public transit. Where they have had success is in regulating TNCs in order to get valuable data for transportation planning. When other cities have tried similar regulations, TNCs have simply packed up and left until the rules are repealed or superseded. The City of Mountain View attempted to reach an agreement for voluntary data sharing, but it appears to have fallen through due to concerns about privacy and trade secrets [78]. However, New

York represents too large of a market for this tactic to work, and while Uber and Lyft have complained about the regulations, they remain active in the city. The result is a huge database of valuable data that transportation planners can use to monitor the effects of TNCs in the city. Unfortunately, NYC's open records laws do not exempt TNC data, so the current set of laws does not protect consumer privacy as much as it could. The rules were adopted in February 2017, so there is not yet a critical analysis of this data, but analysis of earlier datasets from New York indicate that this will be incredibly useful for determining transportation demand within the city [75] [4]. Hopefully, New York paves the way for more open, transparent data sharing from TNCs so that other cities can benefit from the same kind of insights that this data can provide.

2.5.3 Los Angeles

Findings from Los Angeles show that Lyft is serving areas of the city where taxis have a weak presence. Anne E. Brown, at UCLA, discovered that while most Lyft users were wealthy, car ownership was actually a better indicator of usage than income [5]. And, at least in L.A., Lyft drivers are more likely than taxi drivers to make pickups in neighborhoods that are predominantly non-white. She concludes that Lyft appears to be providing mobility for people who do not have vehicles, and is therefore increasing equity in spite of the high costs. However, this type of research is likely highly dependent on the city and may not apply generally. Regardless, it shows that TNCs can provide valuable options for some people in the right circumstances.

2.5.4 Boston

The transit agency in the Boston area, MBTA, partnered with Uber and Lyft to provide on-demand service to anyone who is qualified for paratransit service. During five months between 2016 and 2017, the two TNCs provided 10,000 rides for customers, saving about $40,000 for the MBTA [2]. The Ride is still an option for people who want or need the service, but the addition of the TNCs allows for more spontaneous and diverse trip-making for those who can take advantage of the partnership. In addition to being cheaper for the MBTA, the program was wildly popular among users, who suddenly did not have to make plans 24 hours in advance. Instead of calling the day before, they can either use a complimentary smartphone from Uber or call in for a Lyft ride when they are ready to make a trip, and the TNC will accommodate their mobility needs [2]. This service is a great example of how TNCs can partner with public agencies to increase mobility for a specific group of people. However, the federal rules for paratransit service are extremely strict and complex, and any city looking to supplement ADA service with a TNC partnership must be careful to stay within these rules.

2.5.5 Washington, DC

The District Department of Transportation (DDOT) has made a different agreement with Uber and Lyft that is sure to have interesting results.

Both companies shared anonymized ride data with DDOT so they could pilot a new program, removing 60 parking spaces in downtown districts at night to make room for TNC drop-off zones [88]. DDOT used the data to pinpoint hotspots of TNC pickup activity, and closed the parking spaces accordingly. Though the pilot is still in early stages, the premise is sound and the results seem promising. It has the potential to reduce drunk driving incidents as more people feel comfortable taking ride-hailng services, and increases the amount of people that can be picked up in the hour following bar closures. This innovative partnership in DC shows how cities and TNCs can partner together to improve outcomes for both stakeholders.

2.6 Summary

Traditional transit planning needs accurate data on when and where people travel in order to set routes and timing of vehicles. This data has typically been collected by in-vehicle surveys (either manual or automatic) and area-wide surveys such as the National Household Travel Survey. However, new mobility options such as car-sharing and TNCs are changing the ways people get around, possibly reducing the need for individual vehicle ownership. These new modes, and TNCs in particular, may be causing issues such as increased VMT due to deadheading, reduced transit ridership, and increased overall tripmaking. They can also complement traditional public transit by providing first and last mile connectors, reducing VMT, acting as a source of data for planners, and providing new, innovative services.

Some cities are leading the way with TNC cooperation on innovative programs. Houston managed to redesign their entire network to increase ridership. New York City has successfully regulated TNCs to require data, which can be used for planning but also has been criticized for potential privacy violations. Data from Los Angeles show that TNCs are more equitable than taxis in the city, while Boston has used TNCs to increase flexibility of paratransit rides. Both cities show that TNCs can increase mobility for vulnerable populations. And Washington, DC has partnered with TNCs on pickup zones to increase safety and efficiency during peak times. Each of these cities is trying to be proactive about a new service to help their citizens get around. With luck, other cities will follow their lead to get access to planning data, increase safety, and reduce congestion.

Chapter 3

Methodology

The literature review has shown that TNCs have disrupted the pubilc transit planning process by providing mobility that is perceived as more convenient, faster, or safer than existing options. Transit agencies have had mixed success working with TNCs to optimize operations and share data, but comprehensive data-sharing agreements such as NACTO's Shared Streets program are gaining ground, and the tide is beginning to turn. One of the key insights that can be leveraged from TNC data is trip and rider profiles. Learning more about what kinds of trips people make with TNCs, and who these people are, can help transit agencies navigate this uncertain space.

In order to develop rider and trip profiles, the Ride Austin trip records have been complemented with the City of Austin Land Use Dataset from 2016 and ACS Census data from the same year. The methodology will cover the basic elements of each of the three datasets that were used. Relevant and interesting information is pulled from each dataset, then the three are combined to glean additional information. The City of Austin Land Use Inventory shows parcel-level detail on how all of the land in the city, and much of the Extra-Judicial Territory, is used. Age, income, race, and car ownership information were used from the ACS 2016 5-year estimates. And the RideAustin dataset is a comprehensive database of 1.5 million trips made in 2016 and 2017.

3.1 City of Austin Land Use Inventory

The City of Austin provides a GIS file at the parcel level for land uses. This extremely detailed inventory is based on zoning and is updated annually with information from building permits, satellite imagery, and citizen complaints. It includes land from the City of Austin, as well as limited purpose and extra-territorial jurisdiction. While the accuracy of such a large dataset may be questioned, we group each use into broad categories, defined in Table 3.1, for two reasons: First, we believe any coding errors are likely to be contained by the groups as we have defined them. Second, these more general groups will be more useful for our analysis.

As seen in Table 3.2, much of the land covered in this inventory is Undeveloped, Low-Density Residential, and Public. The inventory is at the parcel level, which results in low coverage of Mixed-Use properties, since such a classification would require retail and apartments on the same lot. With this dataset, and the assumption that people traveling from Downtown and the Airport to Low-Density Residential parcels are going home, we are able to determine socio-economic characteristics of RideAustin users. This assumption will obviously not be true all the time, but we believe it is valid for these trips due to other characteristics of the trips, such as distance and time of day.

City of Austin Definition	Land Use Group
Single-Family	Low-Density Residential
Mobile Homes	Low-Density Residential
Large-lot Single Family	Low-Density Residential
Apartment/Condo	High-Density Residential
Commercial	Commercial
Mixed-Use	Mixed-Use
Office	Office
Industrial	Industrial
Resource Extraction	Industrial
Civic	Civic
Parks / Open Space	Public
Transportation	Public
Right-of-Way	Public
Utilites	Public
Water	Public
Undeveloped	Undeveloped

Table 3.1: Aggregated City of Austin Land Use Codes

Land Use Group	Square Miles	Percentage
Low-Density Residential	180.5	27.9
High-Density Residential	21.4	3.3
Commercial	20.4	3.2
Mixed-Use	0.5	0.1
Office	14.4	2.2
Industrial	39.4	6.1
Civic	21.6	3.3
Public	155.6	24.0
Undeveloped	193.8	29.9

Table 3.2: Size and Proportions of Land Use within Austin

	CAMPO Counties	City of Austin	RideAustin Trips	Downtown Destination	Airport Destination
min ($)	5,156	5,156	5,156	5,156	5,156
median ($)	64,821	62,220.5	65,193	67,018	67,041
mean ($)	70,612.5	69,912.4	71,783.3	73,124	73,013.4
max ($)	232,039	232,039	232,039	232,039	232,039
n	975	552	914	800	811

Table 3.3: Median Income Statistics

3.2 Census Information

The American Community Survey (ACS) dataset for the five-year period ending in 2016 was used to aggregate ride information and for household demographics. Census data and maps were collected for the six-county area comprising CAMPO, made up of Bastrop, Burnet, Caldwell, Hays, Travis, and Williamson counties. There are 994 block groups in the study area, 841 of which contained trip origins and 928 of which contained trip destinations. In order to develop rider profiles, the information from ACS about household demographics and income was analyzed for block groups that served as destinations of trips starting Downtown and at the Airport. The data for the destinations was then compared to overall data for the region in order to determine how RideAustin users differ from the local population. We are particularly interested in income level, age, and car ownership as the primary demographic determinants of trip-making. Analysis was done at the block group level, which provided the desired balance of detail and aggregation across the large area.

RideAustin trips have endpoints in almost all of the 994 block groups within the study area, so statistics for the whole set are very similar to the

	CAMPO Counties	City of Austin	RideAustin Trips	Downtown Destination	Airport Destination
min	16.4	16.4	16.4	16.4	16.4
median	35.4	35.24	35.0	34.8	34.9
mean	36.73	34.3	36.29	35.77	35.90
max	75.7	65.1	75.7	75.7	75.7
n	993	566	930	815	827

Table 3.4: Median Age Statistics

Race	CAMPO Counties	City of Austin	RideAustin Trips	Downtown Destination	Airport Destination
White	80.42	77.87	80.12	79.32	82.43
Black	6.60	7.05	6.70	6.94	6.88
American Indian	0.42	0.46	0.41	0.43	0.42
Asian	4.46	5.83	4.73	5.28	5.21
Hawaiian	0.06	0.08	0.06	0.06	0.06
Other Alone	4.88	5.31	4.73	4.63	4.61
Two or More	3.06	3.22	3.13	3.21	3.15

Table 3.5: Racial Statistics for Study Area

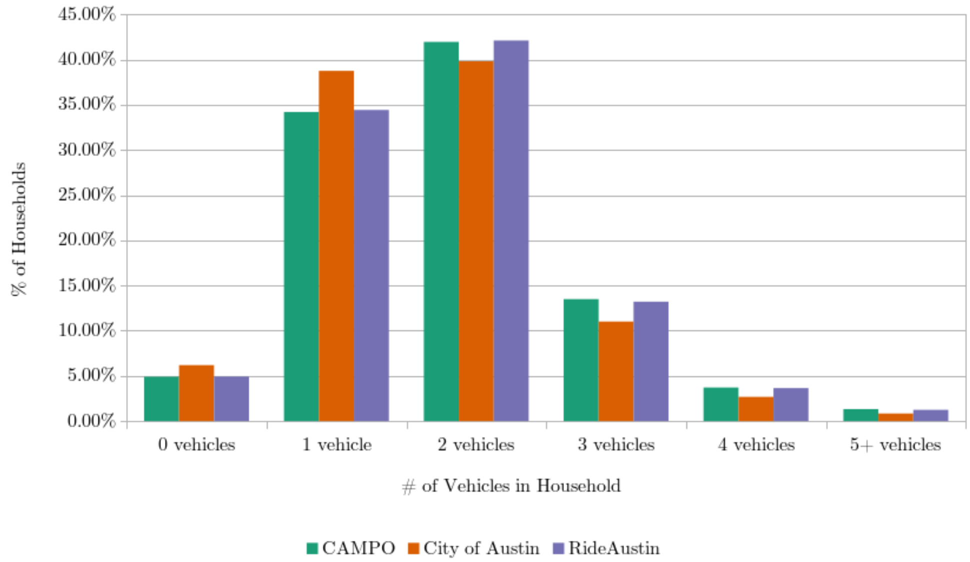


Figure 3.1: Car Ownership in the Study Area

study area as a whole. Later, individual block groups will be analyzed separately. For block groups with trip ends, the median income was $65,193, slightly higher than the City of Austin. Median age for block groups with trip ends was 36.29, also slightly higher than the City of Austin. Racial makeup of block groups with trip ends is slightly more white than city of Austin. Overall, more households had 3-5+ cars than in Austin, which makes sense as rural populations are more car-dependent than urban ones. Full statistics can be seen in Tables 3.3, 3.4, and 3.2, as well as Figure 3.1.

3.3 RideAustin Dataset

RideAustin, a local, non-profit ride-hailing company, made trip records from June 6, 2016 to April 13, 2017 available online. The dataset contains records of 1.5 million trips, made by 260,959 riders and 4,976 drivers. Uber and Lyft were not present in Austin at this time, and RideAustin was one of several smaller ride-hailing companies that appeared to fill the gap after they left [47]. This time period spans two local festivals, Austin City Limits and South by Southwest, as well as times when UT Austin was in and out of session. It is therefore possible to analyze differences in demand when festivals are in town and when school is in session. This dataset provides persistent rider and driver IDs, and includes start and end times and locations, fare information, and where and when the driver accepted the ride. All locations are rounded to three decimal places longitude and latitude, which corresponds to about 360 feet. This intentional inaccuracy protects the privacy of users while still allowing for detailed analysis of these points. While 360 feet is not accurate enough to match directly to a parcel of land, land use determination will be more accurate in areas with homogeneous land use patterns that can be observed in much of Austin. Residential uses, and specifically low-density residential, cover a large portion of the city and are fairly homogeneous; therefore the accuracy of land use determination will be higher. Mixed-use, which only covers 0.5 square miles, will probably have much lower accuracy due to rounding of the latitude and longitude. The huge number of trips and rich information make it possible to perform a variety of analyses on TNC use, as explored by Cambridge Systematics [53], SUMC [29], and San Francisco County Transportation Authority [8]; among others.

3.4 Combining Datasets

In order to develop ridership and trip profiles, information from each dataset was utilized. From the Land Use Inventory, primary focus is on residential and commercial areas, since this is where most trips ended. From the ACS, income, car ownership, race, and age were all used to describe the block groups where trips began and ended. In this way, we were able to describe aspects of RideAustin users and determine who may have been making these trips. In order to draw conclusions about rider demographics, we assume that people taking trips to low-density residential areas at specific times of day are going home. We are also able to draw conclusions about the trips themselves based on time, length, and characteristics of the endpoints.

Chapter 4

Results

This section presents findings from the analysis described in the previous section and attemts to construct profiles for trips and riders. Trip profiles are developed for the set as a whole, and then interesting sub-sets of trips are analyzed. Similarly, ridership profiles are developed for all users, then for riders who made different numbers of trips.

4.1 Basic Trip and Rider Information

Descriptive statistics, located in Table 4.1, reveal that the average trip was 13 minutes over a distance of about 5.5 miles, cost $14, and that the rider waited 1 minute 20 seconds for a driver to arrive. The Surge Factor, a multiplier to the base fare to increase supply and reduce demand during peak times, averaged at 1.71 for rides when it was in effect. The total fare calculation, seen in Equation 4.1, was given by RideAustin [87]. The 1.01 multiplier is a 1% fee that went to the city.

Data were cleaned as follows based on trip distance, trip time, trip cost, and wait time: Trips longer shorter than 360 feet (the precision of the anonymized data) were removed, while trips longer than 50 miles were capped at 50 miles. 2,930 trips longer than two hours were capped at two hours, and 1,688 trips costing over $100 were capped at $100. Trips with wait times longer than two hours were assumed to be collection errors and removed from the set for a total of 1,481,556 valid trips. In general, long trips bear more study to discern collection errors from actual long trips and study the long trips in more detail.

$$\text{Total Fare} = ((\text{Base Fare} + \text{Distance Fare} + \text{Time Fare}) * \text{Surge Factor}) + \text{Booking Fee}) * 1.01 \tag{4.1}$$

Trip counts per week of operation are seen in Figure 4.1. The service appears to ramp up from its introduction in May of 2016 to September of 2016, then remains fairly constant at 5,000 rides/week until ACL Live in March, where it peaks at 11,000 rides per week. The last week in April was a partial week, which explains the below average number of trips.

Examining trip start times by hour and day of the week, seen in Figures 4.2 and 4.3, reveals that most usage occurs Friday and Saturday nights between 10PM and midnight. Note that the graphic is shifted so that midnight-4AM are shown with the previous day in order to break at the low point for each day and more clearly show the overnight trends. There is a steady base of around 6,000 trips who use the service from 8AM through 11PM on weekdays, but service peaks at 11PM on Friday with 31,104 trips.

Next, we examined how many rides each rider took and how long they

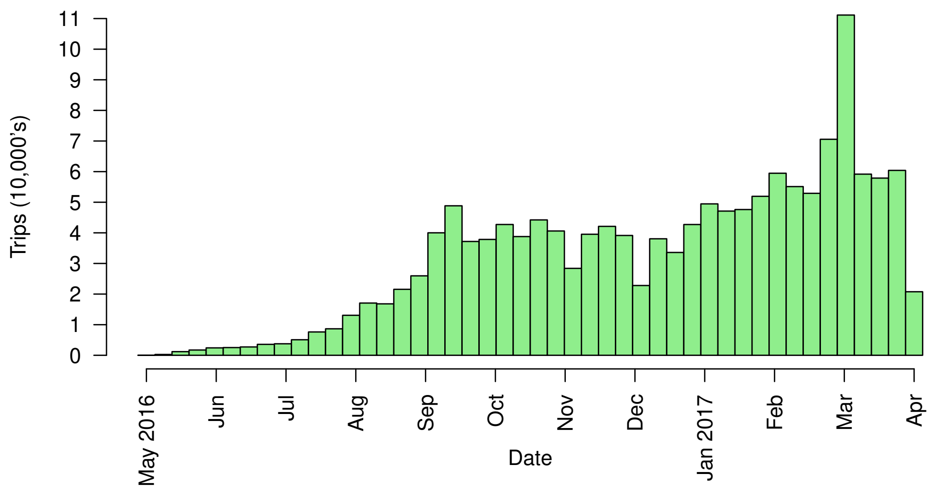
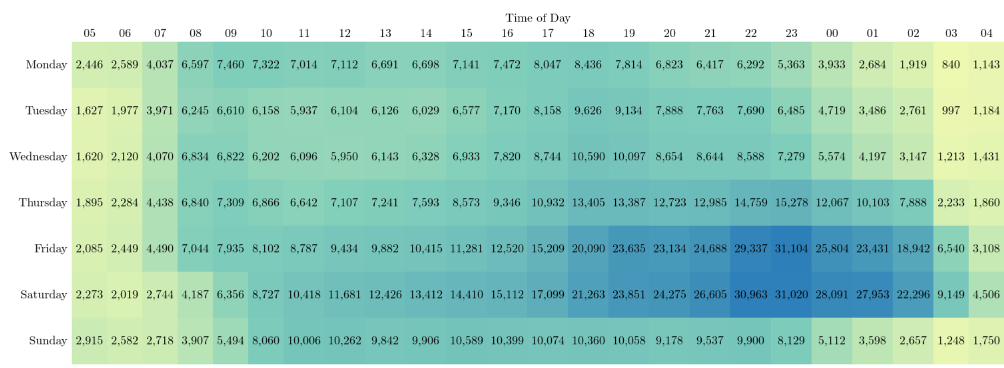


Figure 4.1: Trips per Week



Time of Day

	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00	01	02	03	04
Monday	2,446	2,589	4,037	6,597	7,460	7,322	7,014	7,112	6,691	6,698	7,141	7,472	8,047	8,436	7,814	6,823	6,417	6,292	5,363	3,933	2,684	1,919	840	1,143
Tuesday	1,627	1,977	3,971	6,245	6,610	6,158	5,937	6,104	6,126	6,029	6,577	7,170	8,158	9,626	9,134	7,888	7,763	7,690	6,485	4,719	3,486	2,761	997	1,184
Wednesday	1,620	2,120	4,070	6,834	6,822	6,202	6,096	5,950	6,143	6,328	6,933	7,820	8,744	10,590	10,097	8,654	8,644	8,588	7,279	5,574	4,197	3,147	1,213	1,431
Thursday	1,895	2,284	4,438	6,840	7,309	6,866	6,642	7,107	7,241	7,593	8,573	9,346	10,932	13,405	13,387	12,723	12,985	14,759	15,278	12,067	10,103	7,888	2,233	1,860
Friday	2,085	2,449	4,490	7,044	7,935	8,102	8,787	9,434	9,882	10,415	11,281	12,520	15,209	20,090	23,635	23,134	24,688	29,337	31,104	25,804	23,431	18,942	6,540	3,108
Saturday	2,273	2,019	2,744	4,187	6,356	8,727	10,418	11,681	12,426	13,412	14,410	15,112	17,099	21,263	23,851	24,275	26,605	30,963	31,020	28,091	27,953	22,296	9,149	4,506
Sunday	2,915	2,582	2,718	3,907	5,494	8,060	10,006	10,262	9,842	9,906	10,589	10,399	10,074	10,360	10,058	9,178	9,537	9,900	8,129	5,112	3,598	2,657	1,248	1,750

Figure 4.2: Heatmap of Trip Activity in Time

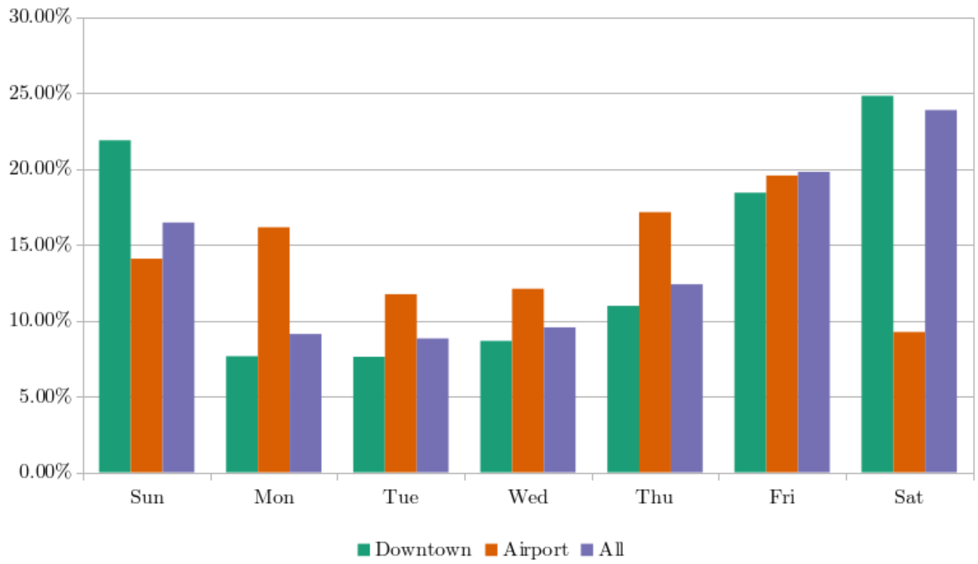


Figure 4.3: Trips by Day of Week

	min	median	mean	max
Trip Time	00:00:01	00:11:17	00:13:05	2:00:00
Trip Dist. (mi)	0.0683	3.658	5.41	50.0
Wait Time	00:00:01	00:00:38	00:01:19	1:59:34
Total Fare	$0.00	$11.14	$13.95	$100.00
Surge Factor	0	1	1.097	6
SF >1	1.25	1.5	1.71	6

Table 4.1: Descriptive Statistics of RideAustin Dataset

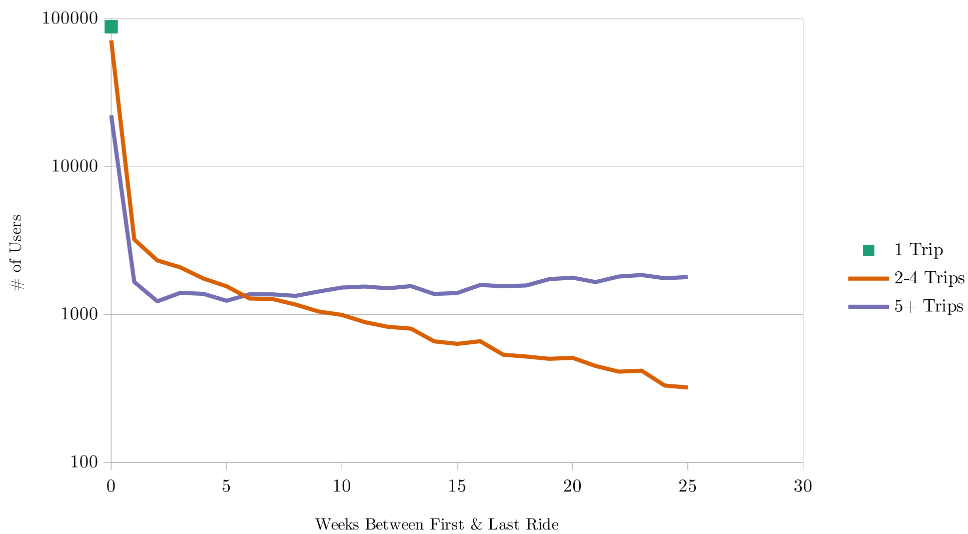


Figure 4.4: Membership Duration and Number of Trips

were active members. As seen in Figure 4.4, over 88,000 people used the service only once during the 45-week period, a group that makes up about a third of riders. Most users were active for less than a week—34% of riders only made one trip, and users who were active for 1-3 days make up 30% of riders. There is also a group of intense users who made five or more trips in only 1-2 weeks. Overall, trip-making for the group of people who made five or more trips is more uniformly distributed in time than for people who make fewer trips. As discussed in Cambridge Systematics, the methods used here may be overcounting the number of unique riders due to cell phone replacement, but that number is assumed to be small [53].

Given that about a third of RideAustin members made only one trip, and there seems to be a difference in behavior for people who make 2-4 trips and 5 or more trips, we next compared origins and destinations of these groups, seen in Tables 4.3, 4.4, and 4.5. All three population segments have essentially the same endpoints, but their order differs somewhat. People who made fewer than five trips all have the same top three endpoints, in the same order. The most trips by far took place in the "East Downtown" block group, which is a large area bounded by I-35 on the West, Waller Creek on the East, Town Lake on the South, and 11th Street on the North. Many of Austin's downtown attractions are within this area, including the 6th street bar district and tourist destinations along Congress Ave., as well as many of the city's high rises, containing employment and residential centers. The airport and Rainey St., another popular bar district, take the next two spots in the top five for people making fewer than five trips.

For people who made only one trip, the Capitol grounds and the Domain round out the top five. The Capitol is not a surprising entry to the list, as a tourist destination that is also nearby some of the downtown nightlife options mentioned earlier. The Domain is a mixed-use residential and shopping center whose block group also encompasses several breweries and Top Golf, so it is also not a surprising entry to the list. For people who made 2-4 trips, the Capitol also makes an appearance, as the 5th most popular destination. However, the Southwest downtown area is the 5th most popular origin for this group of people. This area stretches from Waller Creek west to MoPac, and is bordered by Town Lake and 11th Street on the South and North. The Clarksville neighborhood appears to be excluded from this block group.

Endpoint	# Trip Ends (%)
East Downtown	583,252 (19.5)
Airport	150,193 (5.0)
Rainey St.	123,653 (4.1)
SW Downtown	70,850 (2.4)
East 6th	65,678 (2.2)
Capitol Area	55,069 (1.8)
UT Main Campus	54,583 (1.8)
S. Lamar / Zilker N'hood	51,261 (1.7)
The Domain	47,548 (1.6)
Auditorium Shores	45,158 (1.5)

Table 4.2: Top Ten Trip Endpoints

Endpoint	# Origins (%)	# Dest. (%)
East Downtown	17,005 (19.2)	16,435 (18.6)
Airport	8,219 (9.3)	13,764 (15.6)
Rainey St.	3,478 (3.9)	3,781 (4.3)
The Domain	1,727 (2)	1,511 (1.7)
Capitol Area	1,664 (1.9)	1,559 (1.8)

Table 4.3: Top Five Endpoints for Users who Made One Trip

For people who made more than five trips, the endpoints are all the same as the other segment, just in a different order. Given the prevalence of bars and possible festival locations in the final destination list, it is clear that people are using TNCs primarily to go out and drink. The presence of the airport on the list suggests that this usage pattern may be extensible to "times when a personal vehicle would be inconvenient." We next examined effects of time-of-day to determine when people were using the service.

Time of Day was also analyzed using the CAMPO time periods, except that the overnight period (6:30 PM - 6:00 AM) was divided into two groups

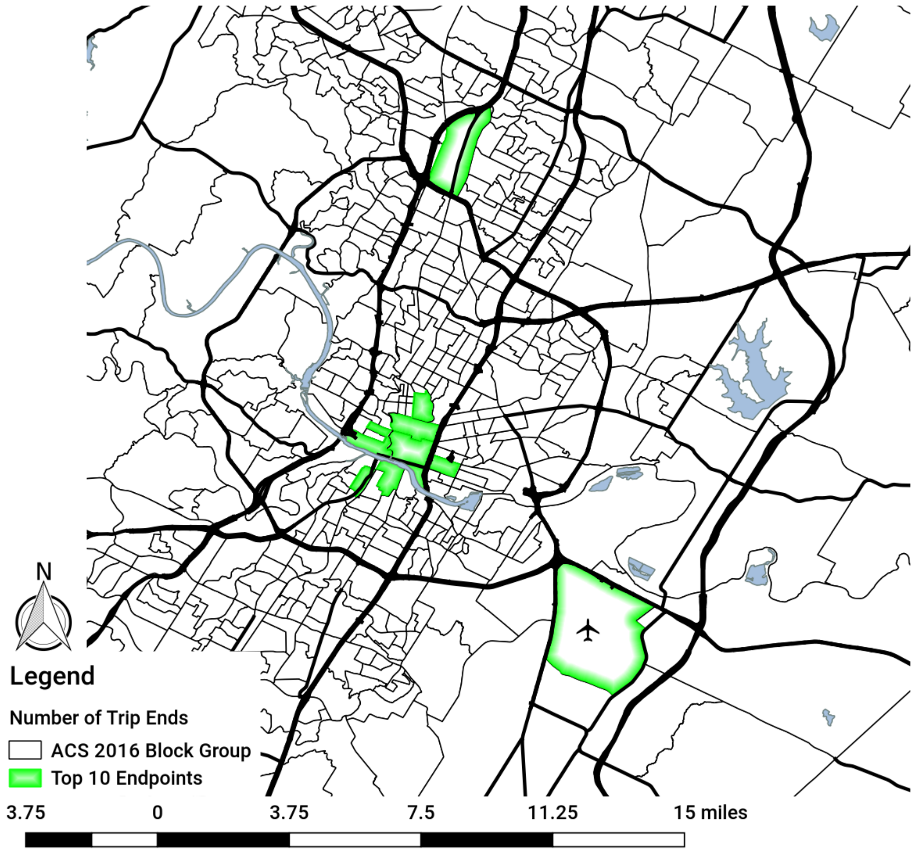


Figure 4.5: Top Ten Trip Ends

Endpoint	# Origins (%)	# Dest. (%)
East Downtown	57,047 (57.9)	56,928 (53.6)
Airport	17,515 (17.8)	25,095 (23.6)
Rainey St.	12,680 (12.9)	13,948 (13.1)
East 6th	5,716 (5.8)	5,007 (4.7)
SW Downtown	5,523 (5.6)	- (-)
Capitol Area	- (-)	5,239 (4.9)

Table 4.4: Top Five Endpoints for Users Who Made 2-4 Trips

Endpoint	# Origins (%)	# Dest. (%)
East Downtown	210,375 (60.8)	225,462 (60.1)
Rainey St.	42,168 (12.2)	47,598 (13.3)
Airport	35,568 (10.3)	50,032 (12.7)
SW Downtown	31,112 (9.0)	26,737 (7.1)
East 6th	26,752 (7.7)	25,456 (6.8)

Table 4.5: Top Five Endpoints for Users Who Made 5 or More Trips

# Rides	Zone Name
33,002	East DT
17,468	Airport
11,595	Rainey St.
6,927	SW Downtown
5,906	S. Lamar / Zilker Nhood
5,820	Capitol Area
5,320	East 6th
5,273	Auditorium Shores / Bouldin Nhood
4,825	West Campus
4,413	S. 1st – S. Congress, N of Oltorf

Table 4.6: Destinations of Trips Starting Downtown

# Rides	Zone Name
10,317	East DT
2,223	Rainey St.
1,470	SW Downtown
1,302	Auditorium Shores / Bouldin Nhood
1,204	The Domain
936	UT Main Campus
900	Capitol Area
788	East 6th
783	S. Lamar / Zilker Nhood
701	Airport

Table 4.7: Destinations of Trips Starting at the Airport

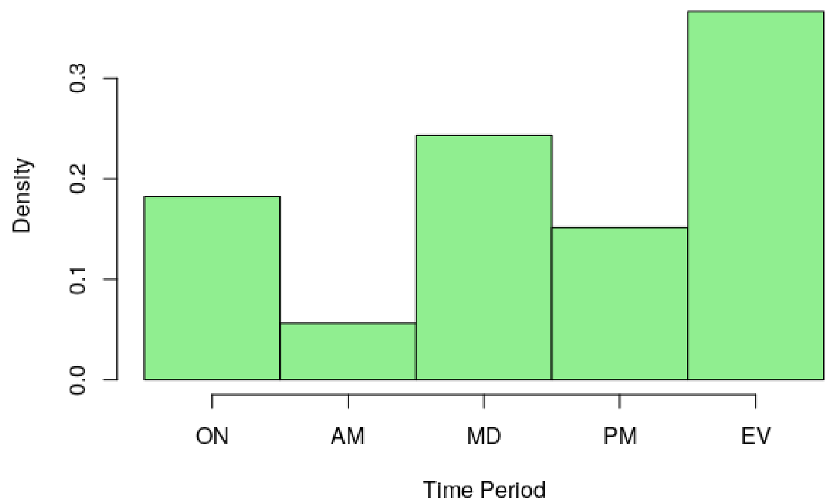


Figure 4.6: Time Period Distribution for All Trips

at Midnight due to the high number of trips taking place in this time period. These distributions can be seen in Figures 4.6, 4.7, and 4.8. Trips beginning in the East Downtown block group are disproportionately concentrated in the Midnight - 6:00 AM period, which indicates people using the service to go bar-hopping or as a safe ride home afterwards. Trips beginning at the airport are highest from the mid-day period (starting at 9:00 AM) through the Evening (ending at midnight), which lines up with most flights. These trips from the airport should be served well by transit, but other factors (such as distance) likely contribute to the use of RideAustin instead.

Trip length distribution was calculated for all trips, trips beginning downtown, and trips beginning at the airport. Average trip distance is 5.41

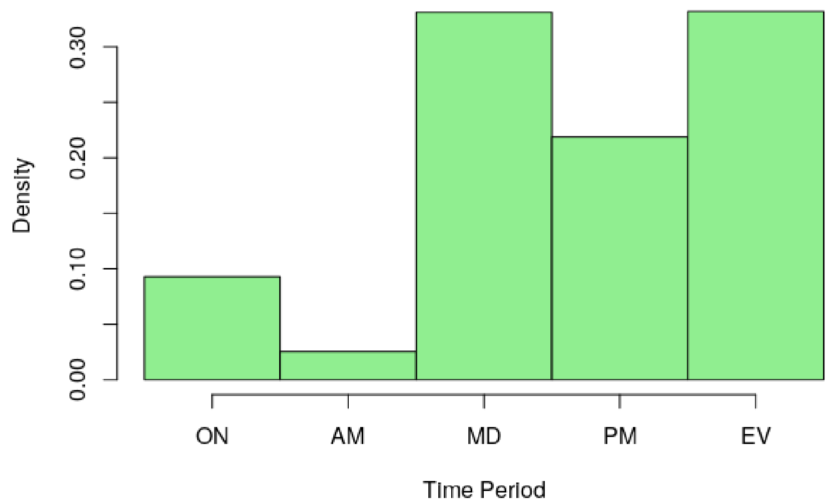


Figure 4.7: Time Period Distribution for Airport Trips

miles for all trips, 4.35 miles for trips beginning downtown, and 12.51 miles for trips beginning at the airport. All segments of trips have some very long trips; about 5% of trips overall were 15 miles or more. The CDF of the trip length distribution for each group of trips can be seen in Figure 4.9.

Finally, before trip and rider profiles are developed, we examine land use at some of the hotspot areas. Half of the top ten trip ends are downtown and can be seen in Figure 4.10. The hotspots highlighted in the map are all bar districts, along 6th and 4th streets, as well as Rainey Street to the South. The high concentration of trip origins in these specific locations indicates how hyper-local TNC trip-making can be, and suggests that a downtown circulator or TNC pickup zone may be appropriate. The airport was not analyzed in this

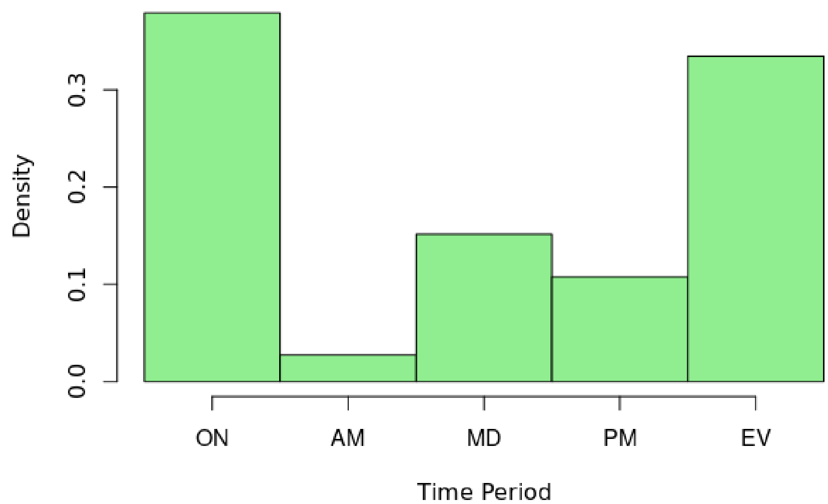


Figure 4.8: Time Period Distribution for Downtown Trips

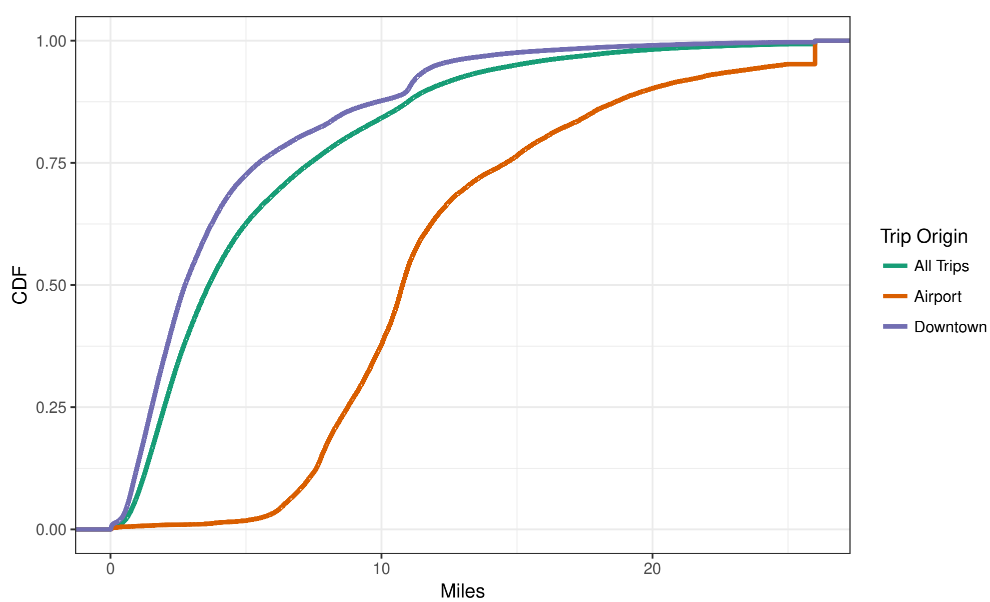


Figure 4.9: Trip Length Distribution

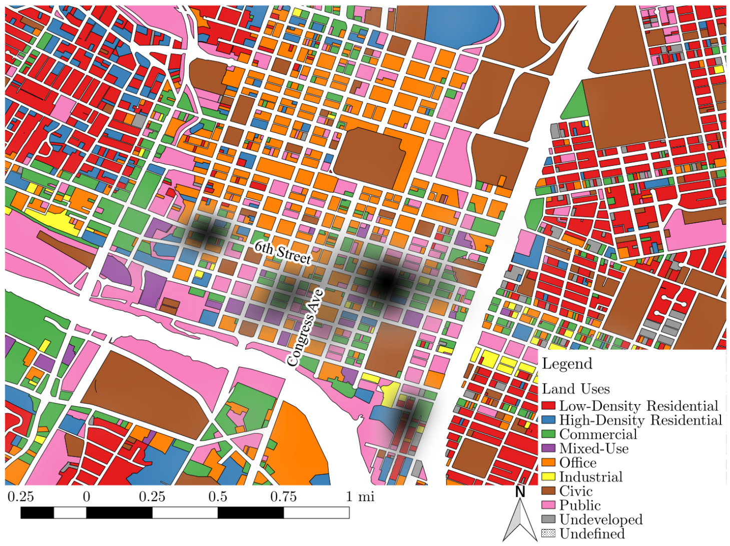


Figure 4.10: Land Use Downtown with a Heatmap of Trip Origins

manner because its land use is homogeneous and virtually all trip origins were concentrated at the pickup zone. The Domain, seen in Figure 4.11, is discussed further in the next section but is notable because of the presence of mixed-use developments, uncommon within the city.

4.2 Trip Profiles

Next, trip profiles are developed for the entire dataset of 1.5 million trips. Origins, destinations, trip length, time-of-day, day-of-week, and land use are used to describe the trips as a whole. Next, specific trip origins are analyzed separately. Trips beginning in the Eastern downtown area are by far the most numerous, and are therefore the first group analyzed. Next, trips beginning at the airport are analyzed because they are the second most

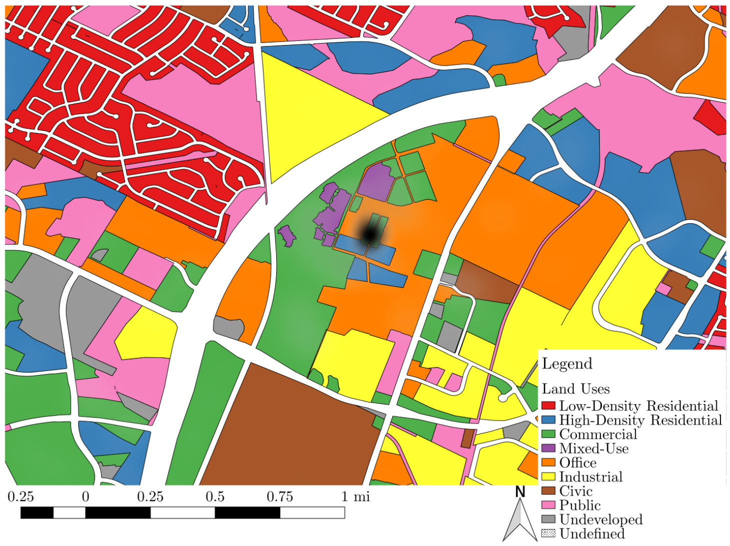


Figure 4.11: Land Use at the Domain with a Heatmap of Trip Origins

numerous and more difficult to serve well with transit.

4.2.1 All Trips

A typical RideAustin trip was 5.4 miles, took about 13 minutes, and cost the rider $14. The average speed of such a trip would be about 25MPH, and the rider waited about 1:20 to be picked up. They were probably leaving a bar downtown late on the weekend to go home. If there were a surge factor in effect, it probably would have been 1.5x the base fare.

Regardless of how many trips people made, there are a series of common endpoints that make up top trip origins and destinations. These are concentrated in the downtown area, as well as the airport and The Domain, and can be seen in Figure 4.5 and Table 4.2. Areas covered in "Downtown" include several bar districts (East 6th Street, Rainey Street) and tourist destinations (the State Capitol, Auditorium Shores, South First Street).

The Domain is a mixed-use development consisting of high-density apartment units and an open-air mall. For our analysis, the City of Austin Land Use Inventory breaks the area into a mix of uses, from Commercial to Mixed-Use. However, most of the trips in this area (see Figure 4.11) are concentrated on Rock Rose Ave and Esperanza Crossing, an area with apartments and nightlife attractions.

Downtown Austin predictably has a wide variety of land uses, but most trips are concentrated on Commercial parcels, which encompasses bars and nightlife but not office space. The East Downtown block group had the most trip ends by far, followed by the airport and Rainey street. We choose to focus on East Downtown, with roughly 20% of the trip ends, and the airport, which had only 5% of trip ends but is also interesting because far-flung airports are traditionally difficult to serve by transit.

4.2.2 Downtown Origin Trips

Trips that start downtown are a little shorter than average, coming in at 4.35 miles vs. 5.41 miles overall. These trips are predominantly on Thursday, Friday, and Saturday nights in the evening and overnight periods, indicating nightlife activities. Land uses of the destinations of these trips are more residential and commercial than the overall trips are; and less Industrial, Office, and Civic. Eleven percent of these trips are internal to the East DT

	min	median	mean	max
Trip Time	00:00:01	00:09:49	00:11:31	02:00:00
Trip Distance, miles	0.0683	2.781	4.351	50
Wait Time	00:00:01	00:00:37	00:01:16	01:45:56
Trip Cost	$0.00	$10.35	$13.83	$100.00
Surge Factor	0	1	1.215	6
SF >1	1.25	1.5	1.859	6

Table 4.8: Descriptive Statistics for Trips Beginning Downtown

block group, and 22% are in block groups within the downtown area. Other common endpoints for these trips are tourist areas South of the river and the UT Campus/West Campus.

These usage patterns are overwhelmingly consistent with people who use RideAustin to go to bars, bar-hop, and then get a ride home. They also indicate usage to visit some tourist destinations, such as the Capitol or Auditorium Shores. A slightly lower average cost of $13.83 reflects the lower average distance of these trips, and a wait time of just 1:16 is even better than the overall average. (As with all trips, trips with wait times longer than 2 hours were not included in the average.) These trips could be more profitable for drivers if they are able to make significantly more of them per hour, but a higher surge factor might help more in this regard.

4.2.3 Airport Origin Trips

Airport trips, on the other hand, are much longer than average, at about 12.5 miles. These trips are concentrated during the day, from 9:00 AM - Midnight, corresponding with flight arrivals. Land use of destination and the

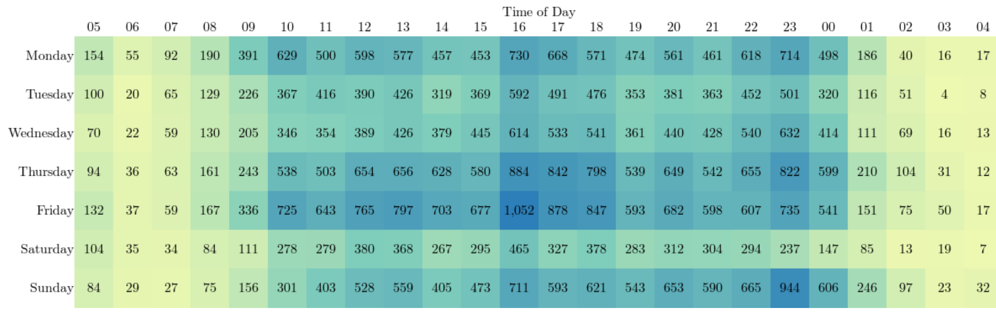


Figure 4.12: Trip Activity from the Airport by Hour and Weekday

top destinations tell different stories, however. There is a high concentration of residential destinations, especially Low-Density. There are also fewer trips to Public uses, such as parks and transportation uses, and Office spaces. However, looking at the block group destination of airport trips, several of the same common points re-surface, seen in Table 4.7. The 701 internal trips are likely trips to the Airport Hilton, which is within the block group. The number of trips begins to get small because there are a limited number of trips from each origin. In addition, the Land Use Inventory shapefile only codes parcels of land, not city or state right-of-way, so there are plenty of holes even within the coverage area. Combined with the 110m accuracy of the RideAustin trip data, and the fact that not all trips will end within the coverage area, and a reduction in the number of points available for analysis is inevitable. However, given that we are using these for illustrative purposes only, the reduced sample size is not a concern.

These trips have an average cost of $22.75, much higher than the overall dataset. Despite the high cost, the average surge factor is less than one,

	min	median	mean	max
Trip Time	00:00:01	00:20:07	00:21:50	02:00:00
Trip Distance, miles	0.069	10.785	12.512	50
Wait Time	00:00:01	00:00:36	00:01:05	01:59:34
Trip Cost	$3.14	$19.66	$22.75	$100.00
Surge Factor	0	1	0.9814	2
SF >1	1.25	1.5	1.526	2

Table 4.9: Descriptive Statistics for Trips Beginning at the Airport

meaning it was not in effect. Looking at the time of these trips, in Figure 4.12, most of them are midday, not during overall peak hours, so the surge was not active. Wait times are shorter than even the Downtown trips, at 1:05. The short wait times are probably due to the higher average cost of these trips attracting more drivers, who can wait nearby in the cell phone lot during peak times. In addition, there are bands of peak times at 5AM, 10AM, 4PM, and 11PM, seen in Figure 4.12, that are consistent across weekdays. Drivers were likely aware of these peak pickup times, and therefore waiting nearby to secure a good fare quickly. The lack of Saturday night trips may reflect a combination of lack of demand (nobody flying in on a Saturday) and a lack of supply (drivers focused on the downtown area). The higher cost for airport trips is probably due to the longer distance of these trips, and overall the airport trips seem to be a good use of drivers' time.

Given the higher cost and distance of these airport trips, and the fact that significantly more of the land use of destinations is residential (see Table 3.1), it seems likely that there is a group of people who take ride-hail service from the airport directly to their homes. These people are probably wealthier and therefore more willing to pay for the convenience of having a direct ride home after traveling. In any case, their homes are spread out across West Austin, and therefore difficult to serve well with transit. Contrast this with the other group of people making trips from the airport, who took RideAustin downtown. These people were probably either staying in hotels downtown or connecting to another mode once they were more centrally located. Given that there were over 10,000 trips just to the East Downtown block group, these people would probably be served well by a frequent, all-hours transit option between the airport and downtown. These are two distinct groups of people with different travel needs: One is well-suited to a door-to-door, more expensive option while the other could be served well by a light rail or BRT connection between two hotspots. This is just one example of an area that ride-hailing and public transit can compliment one another. Now that we know what kinds of trips people are making, we will attempt to discern who is using these services, where they live, what their income level is, and how many cars they own.

4.3 Rider Profiles

Now that the typical trip characteristics have been analyzed, we will next examine some ridership characteristics using census data. The analysis in this section relies on the assumption that people's destinations are their homes; this will obviously not always be the case. However, for certain types of trip, such as trips to residential land uses, it is more likely that people will

Land Use	All Destinations # Trips	%	Downtown to LU # Trips	%	Airport to LU # Trips	able to wait %
Low-Density Residential	184,252	17.09	45,371	21.41	12,409	28.05
High-Density Residential	193,317	17.93	50,187	23.68	9,878	22.33
Commercial	274,833	25.49	44,951	21.21	9,135	20.65
Mixed-Use	46,333	4.3	9,461	4.46	2,576	5.82
Office	108,800	10.09	15,749	7.43	3,752	8.48
Industrial	23,814	2.21	3,196	1.51	557	1.26
Civic	66,925	6.21	10,088	4.76	1,858	4.2
Public	160,981	14.93	29,247	13.8	3,226	7.29
Undeveloped	18,830	1.75	3,655	1.72	846	1.91
n	1,078,085	100	211,905	99.98	44,237	99.99

Table 4.10: Land Use of Trip Destinations

be traveling home. Even if these representations do not correspond directly to the people making the trips, the still tell us about the areas where these trips end. Some insights might be taken from the conclusions even under these circumstances.

4.3.1 All Riders

The typical person taking a RideAustin home was a 35-year old white person who made around $66,000 / year and had two vehicles in the household. These characteristics match strongly with the general demographic profile of the area. While destinations are a bit more spread out than origins, RideAustin users are still more concentrated to the middle of the study area, where income and car ownership are higher. Therefore, on average, income and car ownership for RideAusitn users are a little higher than the rest of the study area.

4.3.2 Riders Making Trips from Downtown

There is a lot of overlap between overall top trip destinations and downtown destinations, so here we will focus on block groups that were top ten destinations for trips from downtown, but not top ten overall. This group reflects a high number of trips while still revealing some interesting differences in tripmaking patterns.

The first block group in this category is West Campus, with 29,694 trips overall and 4,825 trips from downtown. This block group serves as housing for much of the undergraduate population of UT, which is reflected in these results. Median income is only $11,065, and the median age is 21.1. The area is much more diverse than other parts of Austin, with only 69% white, while are 21% Asian, and 6% are two or more races. It also has higher household car ownership than Austin as a whole, with 23% having 3 vehicles in the household, probably due to the larger household sizes associated with apartment living. However, 16% of households in this area have no vehicles, much higher than the city as a whole. This seems to show a dichotomy: Large households with either no vehicles, or many vehicles. This is somewhat different to the next and only other block group in the category, which covers South First St. to Oltorf.

This block group contained 40,630 trip ends, with 4,413 destinations from the downtown block group. Income is much closer to the city's median at $51,941, but median age is higher at 43.1. This area is one of the least diverse in Austin, at 95% white, 3% black, and all other races at just 2%.

Household vehicle distribution is much more uniform than West Campus and the city as a whole, with 13% of households having no vehicles, 50% having one, and 25% having two. While there are some apartment complexes in the southern portion of this block group, the usage patterns primarily align with tourist activity and the connection between RideAustin users and residents seems weak.

4.3.3 Riders Making Trips from Airport

Trips from the airport have the same destinations, in the same order, as overall trips, so we instead choose to focus on the land use and time aspects of these trips. Airport trips tend to be much more residential in destinations, and more low-density residential, mixed-use, and public in origins. (See Table 4.11 for land use of trip origins.) Residential destinations would imply that people are taking trips from the airport directly to their homes or AirBnBs. We do not have a good method for determining which trips were to homes vs. temporary vacations, we assumed that people were going home. Since these are all the same as the overall destinations, we conclude that these are typical Austinites taking RideAustin home from the airport.

We break up trips to the airport into three categories, based on land use of the origin. The first is from low-density residential land use, and is people who are not willing to take transit or pay for parking for the duration of their stay. RideAustin could be cheaper than paying for parking, and they could prefer the convenience of a door-to-door option that transit does

	All Origins		LU to Downtown		LU to Airport	
Land Use	# Trips	%	# Trips	%	# Trips	%
Low-Density Residential	201,400	18.3	49,436	21.8	16,739	25.3
High-Density Residential	229,877	20.9	57,865	25.6	13,202	20.0
Commercial	289,483	26.3	50,451	22.3	15,569	23.5
Mixed-Use	54,105	4.9	12,174	5.4	4,702	7.1
Office	97,912	8.9	16,047	7.1	6,074	9.2
Industrial	19,142	1.7	3,155	1.4	992	1.5
Civic	60,416	5.5	10,384	4.6	3,353	5.1
Public	125,977	11.4	21,878	9.7	4,277	6.5
Undeveloped	23,461	2.1	5,073	2.2	1,231	1.9
n	1,101,773	100.0	226,463	100.0	66,139	100.0

Table 4.11: Land Use of Trip Origins

not provide. Transit may also not fit the time of day requirements for these people. The second group is from mixed-use developments, who have lower incidence of car ownership and may not have another way to get to the airport. If this is the case, the City should focus on more mixed-use housing with good access to transit. The third group is from Public land use, and is more difficult to analyze. From Table 3.1, Public incorporates parks, transportation, and right-of-way (but not streets, which are excluded from the land use inventory). Without additional analysis, it is difficult to say anything about these people. They could be connecting to RideAustin from buses, or there could be something else at play. Due to the small sample size of this group, we were unable to investigate further.

Chapter 5

Discussion and Conclusions

The RideAustin dataset provides a robust snapshot of ride-hailing activity in Austin. However, there is a larger opportunity to share data among all cities and ride-hailing companies in Texas that is being missed. This data can be invaluable for planners, revealing hotspots in demand and supplementing traditional data-gathering techniques. The benefits to society as a whole are also potentially immense, as data sharing is a necessary prerequisite for cooperative operation that can reduce VMT and increase mobility for vulnerable citizens. Private industry stands to benefit, as well, by accessing untapped markets.

But to date, large-scale data sharing agreements to achieve these goals do not exist. Industry is concerned about giving up trade secrets used in their driver routing algorithms, and privacy concerns related to Freedom of Information Act (FOIA) laws put public agencies at risk. Even RideAustin, which continues to operate even after the return of Uber and Lyft, have not released more data. Data-sharing agreements that do exist have to be negotiated individually between each city and ride-hailing company, wasting time for both city officials and industry executives. Initiatives like NACTO's SharedStreets exist to serve as a common spatial reference and data-collection standard, but do not address the legal and privacy issues that stakeholders face when resolving these agreements. By highlighting the opportunities for cooperation and chances to unlock a competitive edge, we hope to inspire both cities and industry to adopt a general data-sharing attitude that can be applied broadly, without being renegotiated in every city and state.

5.1 Opportunities for Cooperation

The strategies outlined in this section have the largest impacts for transit or public agencies, which are inherently concerned with the public good. However, private companies that are concerned with their image may also benefit from the strategies outlined in this section.

5.1.1 First and Last Mile

First- and Last-Mile connections have already been identified as a potential point of cooperation. In particular, shared ride-hailing complements commuter rail service. It can reduce single-occupancy vehicles driving to the rail station, freeing up space on the street and in the parking lot. Furthermore, a commuter who also chooses to drive for a TNC could make money by carpooling with the TNC app. In particular, Palo Alto has partnered with Waze Carpool to provide trips to and from the downtown area [93]. This service could be expanded or shifted to the end of a commuter rail to unlock additional benefits.

At the last-mile end of the trip, TNC drivers could circulate between a commuter rail station and downtown destinations. This would expand the effective service area of existing commuter rail lines, which are not always aligned with demand. Implementing this strategy in a shared fashion would minimize the extra impact of additional vehicles on the street and may be more cost effective than a downtown circulator. It also provides commuters with the convenience of door-to-door service that people value in traditional TNC use.

5.1.2 Reduce Congestion and VMT

As seen with the Downtown trips (Figure 4.10), TNC trips can be highly clustered on a specific location. This time and spatial clustering of rides further exacerbates congestion. While encouraging shared rides is one obvious way to reduce congestion caused by TNCs, intelligently grouping people who are comfortable sharing a car is significant challenge. However, successfully solving this problem will result in reduced congestion, cheaper rides, and more income for TNCs and drivers.

The solution also will probably require reducing driver deadheading, which may entail some more controversial measures by cities. Drivers are currently incentivized to make as many trips as possible, and certain classes of trips (such as from the Airport) are more profitable than others. As a result, a driver may drive a long distance between rides to get to the airport in order to make more money. To combat this, cities may need to impose some sort of deadheading fee to counteract the effects of driving far between rides in order to get a more profitable fare. This is bound to be controversial among drivers and TNC companies, however, and should only be done when the data collected indicate that deadheading is a problem. Furthermore, in San Francisco, TNCs represent an improvement on deadheading distance compared to taxi service, so an effective solution will require changing taxicab regulations as well. [8].

Another possibility to reduce congestion, especially for the downtown area, would be a TNC “Pickup Zone” similar to the one being piloted in Washington, DC. Eliminating parking spaces, while controversial, may reduce drunk driving if people find it more difficult to use their vehicles. Increased efficiency in this area will provide a better experience for drivers and passengers, increase safety due to less drunk driving and pedestrian conflicts, and help reduce emergency response times.

In addition, an inherent benefit of having ride-hailing services available is that they may encourage people to reduce car ownership. Similar studies done on car2go, a car-sharing service, indicate that people may reduce car ownership when alternatives are available. Having ride-hailing services available in a city may provide that alternative for certain groups of people, such as the students in West Campus in Austin. The large percentage of people with no cars in West Campus may have done so in part because services like RideAustin are readily available.

5.1.3 Paratransit

TNCs can also be a boon to those who cannot reliably get around on their own. For an example, look at what the Massachusetts Bay Transit Authority (MBTA) have accomplished with The Ride (their Paratransit provider), Uber, and Lyft. They initially began a pilot program where anyone who qualified for paratransit service could instead contact Uber or Lyft for an on-demand ride. Program participants remained eligible for regular paratransit service while participating, and gained the flexibility of being able to make same-day or even same-hour decisions about their mobility. Obviously not all paratransit recipients could take advantage of the program, but those who did loved the additional flexibility. In addition, the MBTA saved roughly $40,000 in costs [2]. As a result the program has moved from a pilot to a full-fledged service. Other cities should partner with TNCs to provide similar services for their citizens in order to increase mobility and save money.

5.1.4 Fund Transit

While this option is not specific to data-sharing, there are benefits to being able to charge a per-ride fee and direct that revenue towards transit. This strategy could be paired with a congestion-mitigation strategy as discussed above, charging more for longer deadhead distances. Current state law in Texas prohibits cities from charging a per-ride fee on TNC rides, but the state could allow a fee of up to a dollar (leaving future increases on this cap for another time) to be implemented by cities. This puts a cap on the fees, keeping things fair for consumers, while also allowing cities that need the extra cash to take advantage of a new revenue stream. Under this framework, larger cities like Houston and San Antonio can determine their needs individually and set the fee accordingly. Or, cities like Arlington can use the money for new public transit systems altogether. Different cities within Texas have different needs, so allowing each city to determine the correct fee is a great way to enable innovative projects. As seen in Chicago, even a modest fee of $0.15 can bring in millions of dollars in new revenue. (In 2017, Chicago raised its per-ride TNC fee from $0.52 to $0.67, and directed all of that new money to an Accessibility Fund. They predict an additional $15 million in revenue from the fee in 2018 [64].) Given the political atmosphere around toll roads in Texas right now, this fee could be a much-needed new source of revenue. Because this is a new funding stream, it could potentially save TxDOT money—cities will have the option to fund projects with this source instead of asking the state for money.

Based on the reactions to a similar fee being raised in Chicago, this is likely to be a fairly uncontroversial proposal. Transit funding is typically done through property taxes, which are extremely difficult to raise and generate fallout virtually every time. There are some key differences here, though. Firstly, a TNC User Fee benefits people who are being charged. Improvements to non-driving modes, funded by this fee, may ultimately mean that the people using TNCs will have another option to get where they are going. Contrast this with property taxes: the majority of complaints come from people who don't take transit and are upset that their money is being used to fund something they don't use. Secondly, Austin is an event city. A large portion of TNC users are here for SXSW or ACL, then leave. While they might complain at the time, they have little long-term political capital here and are unlikely to be able to enact long-term policy change. Other cities in Texas may not be quite as festival-focused as Austin, but they still have large events like football games which draw an out-of-town crowd. And even locals will have a hard time arguing against a fee that is supposed to fund transportation improvements.

5.2 Unlocking Competitive Advantages

Competitive advantages for public agencies can mean moving more people with less money and fewer of the negative side effects that are typically associated with single-occupancy vehicle travel. For industry, it means access to new markets, and increased customer loyalty, as well as less risk. Both sides stand to benefit, whether they are adding ridership to serve newly discovered demand or cutting service to areas better served by another method.

5.2.1 Transit-Advantaged Trips

Certain trip profiles lend themselves to transit much better than TNC service. For example, take the group of trips from the airport to common destinations such as Downtown and UT Campus. This amounts to around 16,000 trips over ten months, from just one ride-hailing company. Other ride-hailing companies, taxis, buses, and private autos presumably also made that trip. A large number of trips from a single origin to a concentrated set of destinations is a transit planner's dream. In addition, the downtown area provides excellent connectivity to other transit services, and a frequent, reliable connector from the airport to downtown is sure to bring in plenty of business. During the time this data was collected, the route 100 ran from the Airport to many of the top destinations, but only every 30 minutes. In addition, the bus was frequently caught in traffic and often delayed, especially at peak times for airport trips. Route 20, which now runs to the airport, is likely to be plagued by many of the same issues. A better option, to connect people where there is clearly demand, would be to run a light rail or BRT option that could bypass the typical traffic seen on this route. Rail has been unpopular of late in Austin, but the DOT is working on adding tolled lanes from the airport along 183. Allowing a BRT line to run for free in the tolled lanes will provide a more reliable connection for people and may serve them better than RideAustin did.

Another area that is a good choice for new transit service is a downtown circulator. 33,000 trips that started downtown were internal to the block group. These are the kinds of short trips that transit planners have nightmares about: they cause undue amounts of congestion as drivers circle, looking for fares or stop in traffic to drop off passengers. A circulator loop that ran to all four hotspots seen in Figure 4.10, at the times highlighted in Figure 4.2, would take cars off the road and connect people to a series of destinations that are very close together. Late night service is not popular in Austin, with most routes ending service around midnight. Austin has not had a downtown circulator since the removal of the “Dillo” Shuttle in 2009, and even that service never operated overnight [43]. The data from RideAustin clearly show demand for this type of service, and drivers stand to make more money by not being stuck in traffic as much.

Transit clearly has an advantage for situations like downtown circulators and certain airport trips. But not all trip profiles lend themselves to transit service. There are areas where transit should not attempt to serve, or could even cut service and “yield” that market to the private sector.

5.2.2 Ride-Hail-Advantaged Trips

For example, not all airport trips are a good match for transit service. Many people took RideAustin from the airport directly to their homes, which are spread out over a large area of the city. These people tend to be wealthier and are willing to pay for the convenience of door-to-door travel. They are unlikely to want to take transit, and it is difficult to have door-to-door service for such a dispersed set of destinations. These trips are a bad match for transit service, but great business for TNCs. In fact, the most expensive, longer trips, that are poorly suited to replacement by transit, are best suited for TNCs. This fact should put drivers at ease who may be nervous about losing a reliably profitable trip.

Other areas with similar trip patterns could be a great opportunity for transit agencies to sit back and let TNCs capture market share. Rather than trying to entice so-called “choice” riders with expensive amenities and circuitous routes, transit agencies should focus on their strengths: moving large numbers of people between common points. TNCs can serve the other trips, and having access to a ride without needing to own a vehicle may reduce VMT overall.

5.3 Future Work

While this thesis begins to analyze TNC data in an attempt to aid transportation planners, data are difficult to acquire and there is much work to be done. In particular, the following areas are particularly promising areas for future work.

5.3.1 Limitations of Data

While the RideAustin dataset is extremely robust and can reveal much about users travel patterns, it has been anonymized somewhat to protect users' privacy. This resulted in some inaccuracy when comparing trip ends to the Land Use Inventory. It is also only one TNC that was operating at the time, so there could be sampling bias with respect to the entire market. Due to a lack of additional customer information, it is difficult to tell which users are local Austinites and which were visiting for a festival or other reason. While RideAustin has this information, in the form of billing address, it would be irresponsible to share that in a public form. In order to gain the most insight from TNC data, cities should request or require exact trip ends from these companies. However, cities also need to make sure that the raw planning data is not subject to Open Records Requests or shared with law enforcement so that individuals' privacy and rights remain intact. This is a difficult goal to achieve, but the accuracy of planning tools depends on access to this information.

5.3.2 Trip Analysis

Additional analysis should be done on trips, beginning with segmentation by person. By analyzing trips at the individual level and combining frequent endpoints with the Land Use Inventory, it may be possible to begin to determine a person's home and work locations with more certainty. Then, it should be possible to recreate trip tours or traditional planning trip types. Finally, these trips could be compared to existing transit networks for an analysis of transit service and deserts. This information would be invaluable for transportation planners.

5.3.3 Demographics

In addition, once more is known about which users are local residents and which are visitors, more exact demographic information can be determined. Some information is already available about who uses TNCs in other cities, but having a clearer picture of these people in Austin could help TNCs and the City of Austin when making transportation decisions. In particular, gender, household size, and family composition all have known effects on trip making and should be studied more.

5.3.4 Paratransit

While we have discussed paratransit, no data was available for analysis. If such data on paratransit trips were procured, it may be possible to determine how cost effective TNCs would be as a paratransit supplement in the Austin area. This service already exists in the Boston area, and Austin should see if a similar program is viable.

5.4 Conclusion

In short, it is an exciting time for transportation planners. TNCs have given people more options to get around and revealed gaps in the transportation system that existed. And while some people fear that TNCs will mean increased congestion, VMT, and pollution, nothing is certain yet. With the right policy levers, public agencies can work together with TNCs to share data and encourage responsible travel for individuals. The vast amount of data unlocked by TNCs can tell transportation planners about unknown demand, reveal potential equity issues, and support increased funding for transit. Cooperation with TNCs can help transit agencies provide access for disadvantaged populations and reduce dependence on privately owned vehicles. Transit service and TNCs each have their strengths and weaknesses, and both can work together as part of a cohesive whole to improve mobility for everyone.

Bibliography

[1] Aldrete-Sanchez, Rafael et al. *Integrating the Transportation System with a University Transportation Master Plan: Best Practices and Lessons Learned*. May 2010. URL: https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6608-3.pdf (visited on 03/21/2018).

[2] Bankson, Amy MacMillan. "Uber and Lyft Partner with Boston Transit Agency to Provide On-Demand Rides to Disabled Residents". In: *MIT Management Sloan School* (Mar. 14, 2017). URL: http://mitsloan.mit.edu/newsroom/articles/uber-and-lyft-partner-with-boston-transit-agency-to-provide-on-demand-rides-to-disabled-residents/ (visited on 06/19/2018).

[3] Bhat, Chandra. *Measuring Access to Public Transportation*. 2006. URL: https://library.ctr.utexas.edu/hostedpdfs/txdot/psr/5178.pdf (visited on 03/21/2018).

[4] Bialik, Carl et al. *Uber Is Serving New York's Outer Boroughs More Than Taxis Are*. Aug. 10, 2015. URL: https://fivethirtyeight.com/features/uber-is-serving-new-yorks-outer-boroughs-more-than-taxis-are/ (visited on 06/19/2018).

[5] Brown, Anne E. *Ridehail Revolution: Ridehail Travel and Equity in Los Angeles*. Jan. 1, 2018. URL: https://escholarship.org/uc/item/4r22m57k (visited on 07/16/2018).

[6] Bullard, Diane L. *Texas Public Transit Reference Manual*. Nov. 1985. URL: https://static.tti.tamu.edu/tti.tamu.edu/documents/1082-1F.pdf (visited on 03/16/2018).

[7] Cartmell, Sarah et al. *Rise of the Real-Time Traveler*. 2015. URL: g3ict.org/download/p/fileId_1029/productId_338 (visited on 03/16/2018).

[8] Castiglione, Joe et al. *TNCs Today: A Profile of San Francisco Transportation Network Company Activity*. San Francisco: San Francisco County Transportation Authority, 2017. URL: http://www.sfcta.org/sites/default/files/content/Planning/TNCs/TNCs_Today_112917.pdf.

[9] Ceder, Avishai. *Public Transit Planning and Operation: Theory, Modelling, and Practice*. First. Butterworth-Heinemann, 2007. 626 pp. ISBN: 978-0-7506-6166-9.

[10] Cervero, Robert. "City CarShare: First-Year Travel Demand Impacts". In: *Transportation Research Record* 1839 (2003), pp. 159–166. URL: http://trrjournalonline.trb.org.ezproxy.lib.utexas.edu/doi/pdf/10.3141/1839-18.

[11] Cervero, Robert. *Transit-Supportive Development in the United States: Experiences and Prospects*. 1993. URL: https://rosap.ntl.bts.gov/pdfjs/web/viewer.html?file=https://rosap.ntl.bts.gov/view/dot/3141/dot_3141_DS1.pdf (visited on 03/16/2018).

[12] Cervero, Robert et al. "City CarShare in San Francisco, California: Second-Year Travel Demand and Car Ownership Impacts". In: *Transportation Research Record: Journal of the Transportation Research Board* 1887 (Jan. 2004), pp. 117–127. DOI: 10.3141/1887-14. URL: http://trrjournalonline.trb.org/doi/10.3141/1887-14.

[13] Cervero, Robert et al. "City CarShare: Longer-Term Travel Demand and Car Ownership Impacts". In: *Transportation Research Record: Journal of the Transportation Research Board* 1992 (Jan. 2007), pp. 70–80. ISSN: 0361-1981. DOI: 10.3141/1992-09. URL: http://trrjournalonline.trb.org/doi/10.3141/1992-09.

[14] Chowdhury, Subeh et al. "Assessing Connectivity Equity of a Regional Public Transport Network". In: (2017). URL: http://pubsindex.trb.org/view/2017/C/1438002.

[15] Circella, Giovanni et al. *What Affects U.S. Passenger Travel? Current Trends and Future Perspectives*. Feb. 2016. URL: http://www.dot.ca.gov/research/researchreports/reports/2016/CA16-2825_FinalReport.pdf (visited on 03/16/2018).

[16] City of Austin Planning and Zoning Department. *Land Use Inventory Detailed*. 2016. URL: https://data.austintexas.gov/Locations-and-Maps/Land-Use-Inventory-Detailed/fj9m-h5qy (visited on 04/17/2018).

[17] Clark, Hugh M et al. *Who Rides Public Transportation*. 2017. URL: http://www.apta.com/resources/reportsandpublications/Documents/APTA-Who-Rides-Public-Transportation-2017.pdf.

[18] Clewlow, Regina R. "Carsharing and Sustainable Travel Behavior: Results from the San Francisco Bay Area". In: *Transport Policy* 51 (Oct. 2016), pp. 158–164. DOI: 10.1016/J.TRANPOL.2016.01.013. URL: http://www.sciencedirect.com.ezproxy.lib.utexas.edu/science/article/pii/S0967070X16000056?via%3Dihub.

[19] Clewlow, Regina R. et al. *Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States*. Institute of Transportation Studies, University of California, Davis, 2017. URL: https://itspubs.ucdavis.edu/index.php/research/publications/publication-detail/?pub_id=2752.

[20] Clower, Terry L. et al. *Evaluating the Impact of Transit-Oriented Development*. Oct. 2010. URL: https://digital.library.unt.edu/ark:/67531/metadc32970/ (visited on 03/19/2018).

[21] Council, State Independent Living. *Transportation Works: The Blueprint for Connectivity: Enhancing Accessible Transportation in Rural & Small Urban Texas for Individuals with Disabilities and Seniors*. 2015. URL: https://www.regionalserviceplanning.org/coordination/documents/transportation-works-report-silc.pdf (visited on 03/21/2018).

[22] "Buffalo CarShare: Two Years in Review: A Look at the Organization's Growth, Membership, and Impacts". In: (Nov. 2011). Ed. by Randall Creighton. In collab. with Adam Blair et al., p. 34. URL: https://www.dot.ny.gov/divisions/engineering/technical-services/trans-r-and-d-repository/Buffalo%20CarShare%202yr%20report%20-%20print.pdf (visited on 03/16/2018).

[23] Daniel, Janice et al. *Assess Impacts and Benefits of Traffic Signal Priority for Busses*. Jan. 2005. URL: http://www.state.nj.us/transportation/refdata/research/reports/FHWA-NJ-2004-013.pdf (visited on 03/16/2018).

[24] Economics Research Associates. *Station Area Market Analysis Update: MLK, Jr., Plaza Saltillo, and Crestview Stations*. May 12, 2008. URL: https://www.capmetro.org/uploadedFiles/Capmetroorg/Future_Plans/Transit-Oriented_Development/station-area-market-analysis-2007update.pdf (visited on 03/19/2018).

[25] Engel, Alexander. *National Association of City Transportation Officials and the Open Transport Partnership Launch Transportation Data Standard and Platform, Building Foundation for Public-Private Partnerships in the Digital Age*. Feb. 22, 2018. URL: http://sharedstreets.io/public/SharedStreets_Release.pdf (visited on 06/18/2018).

[26] European Conference of Ministers of Transport. "Transport Benchmarking, Methodologies, Applications, & Data Needs". In: 1 (2000), p. 208. URL: http://lnweb90.worldbank.org/eca/transport.nsf/

ECADocByUnid/B5D08FB665636F9585256B09007BD3E4?Opendocument (visited on 03/16/2018).

[27] Fagant, Daniel J. et al. *The Future of Fully Automated Vehicles: Opportunities for Vehicle- and Ride-Sharing, with Cost and Emissions Savings*. Aug. 2014. URL: https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/600451-00081-1.pdf (visited on 03/16/2018).

[28] Fan, Wei et al. *Optimal Transit Route Network Design Problem: Algorithms, Implementations, and Numerical Results*. May 2004. URL: https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/167244-1.pdf (visited on 03/16/2018).

[29] Feigon, Sharon et al. "Who's Riding TNCs and What Does It Mean for Public Agencies?" May 15, 2018. URL: http://onlinepubs.trb.org/onlinepubs/webinars/180515.pdf (visited on 05/21/2018).

[30] Ferreira-Pinto, João Batista et al. *Dialysis Patient Transportation in Far West Texas*. June 10, 2013.

[31] Firnkorn, Jörg et al. "Selling Mobility Instead of Cars: New Business Strategies of Automakers and the Impact on Private Vehicle Holding". In: *Business Strategy and the Environment* 21.4 (May 2012), pp. 264–280. DOI: 10.1002/bse.738. URL: http://doi.wiley.com/10.1002/bse.738.

[32] Flamm, Bradley et al. "Changes in Access to Public Transportation for Cycle-Transit Users in Response to Service Reductions". In: *Transport Policy* 35 (2014), pp. 154–161. DOI: https://doi.org/10.1016/j.tranpol.2014.05.013. URL: http://pubsindex.trb.org/view/2013/C/1242404.

[33] *For-Hire Base Owners*. Feb. 2017. URL: http://www.nyc.gov/html/tlc/downloads/pdf/proposed_rule_rev_driver_fatigue_2_2_17.pdf (visited on 06/19/2018).

[34] Geiselbrecht, Tina et al. *Dynamic Ride-Share, Car-Share, Bike-Share, and Statewide Mobility*. 2016. URL: https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6818-S.pdf (visited on 03/16/2018).

[35] Godazi, Khosro et al. *Proposing Transportation Designs and Concepts to Make Houston METRO's Southeast Line at the Palm Center Area More Walkable, Bikeable, and Livable*. Dec. 2015. URL: https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/600451-00048-1.pdf (visited on 03/19/2018).

[36] Goodin, Ginger et al. "Transportation Network Companies: Testimony of Ginger Goodin and Maarit Moran to the Texas Senate Committee on Business and Commerce, March 14, 2017". Mar. 14, 2017. URL: `https://policy.tti.tamu.edu/wp-content/uploads/2017/03/TTI-PRC-TNCs-SBC-031417.pdf` (visited on 03/16/2018).

[37] Griffin, Greg Phillip et al. "Equity Analysis of Transit Service in Large Auto-Oriented Cities in the United States". In: 2015. URL: `http://pubsindex.trb.org/view/2015/C/1336579`.

[38] Grisby, Darnell et al. *Understanding Recent Ridership Changes: Trends and Adaptations*. American Public Transportation Association, Apr. 2018. URL: `https://www.apta.com/resources/reportsandpublications/Documents/APTA-Understanding-Recent-Ridership-Changes.pdf` (visited on 05/29/2018).

[39] Hamilton, Timothy et al. "Bicycle Infrastructure and Traffic Congestion: Evidence from DC's Capital Bikeshare". In: *SSRN Electronic Journal* (2015). ISSN: 1556-5068. DOI: `10.2139/ssrn.2649978`. URL: `http://www.ssrn.com/abstract=2649978` (visited on 03/21/2018).

[40] Hassell, Walter et al. *The Effect of the City of Houston Transit Corridor Ordinance on Development along METRO's Light Rail Corridors*. Southwest Region University Transportation Center (SWUTC), Oct. 2014. URL: `https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/600451-00047-1.pdf` (visited on 03/19/2018).

[41] Henao, Alejandro. "Impacts of Ridesourcing - Lyft and Uber - on Transportation Including VMT, Mode Replacement, Parking, and Travel Behavior". Doctor of Philosophy. University of Colorado, 2017. URL: `https://search.proquest.com/docview/1899208739?pq-origsite=summon&accountid=7118`.

[42] Hendricks, Sara J. *Impact of Transit Oriented Development on Public Transportation Ridership*. Aug. 2005. URL: `http://www.nctr.usf.edu/pdf/576-10.pdf` (visited on 03/19/2018).

[43] Henry, Terrence. "Austin's 'Dillo Shuttle Returns — Sort Of". In: *KUT* (June 24, 2015). URL: `http://kut.org/post/austins-dillo-shuttle-returns-sort` (visited on 07/13/2018).

[44] Hickman, Mark D. et al. *An Investigation of Integrated Transit Service*. Aug. 2001. URL: `https://static.tti.tamu.edu/swutc.tamu.edu/`

publications/technicalreports/472840-00023-1.pdf (visited on 03/16/2018).

[45] Higgins, Laura et al. *Transit-Operated Vanpools in the United States: Selected Case Studies*. Mar. 2002. URL: https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/167122-1.pdf (visited on 03/21/2018).

[46] Holguín-Veras, José et al. *New York City Park and Ride Study: Final Report*. Jan. 13, 2012. URL: https://www.dot.ny.gov/divisions/engineering/technical-services/trans-r-and-d-repository/C-07-66_Final%20Report%20NYC%20PR%20Study.pdf (visited on 03/16/2018).

[47] *How Many Ridesharing Apps Operate in Austin? Here's the List*. URL: https://www.bizjournals.com/austin/news/2016/06/07/the-complete-field-guide-to-austins-ridesharing.html (visited on 07/12/2018).

[48] Institute, Texas A&M Transportation. *2013 Texas Public Transportation Resource Inventory. Technical Memorandum*. Dec. 2013. URL: https://www.regionalserviceplanning.org/coordination/presentations/09-23-2015/2013-Texas-Public-Transportation-Inventory-Dec2013-techmemo.pdf (visited on 03/21/2018).

[49] Kavage, Sarah et al. *Implementing Transportation-Efficient Development: A Local Overview Phase 1 of Integrating Land Use and Transportation Investment Decision-Making*. June 2002. URL: http://www.wsdot.wa.gov/research/reports/fullreports/549.1.pdf (visited on 03/19/2018).

[50] Khan, Mubassira et al. "The Impact of Land-Use Variables on Free-Floating Carsharing Vehicle Rental Choice and Parking Duration". In: *Seeing Cities Through Big Data*. Springer, Cham, 2017, pp. 331–347. ISBN: 978-3-319-40902-3. DOI: 10.1007/978-3-319-40902-3_19. URL: http://link.springer.com/10.1007/978-3-319-40902-3_19.

[51] Khasnabis, Snehamay et al. *Transit-Oriented Development on Detroit Rail Transit System*. Oct. 2010. URL: http://www.michigan.gov/documents/mdot/MDOT_Research__Report_RC-1545L_364114_7.pdf (visited on 03/19/2018).

[52] Kockelman, Kara et al. *Best Practices for Modifying Transportation Design, Planning, and Project Evaluation in Texas*. Mar. 2017. URL:

`https://library.ctr.utexas.edu/ctr-publications/0-6847-P1.pdf` (visited on 03/16/2018).

[53] Komanduri, Anurag et al. "Assessing the Impact of App-Based Ride Share Systems in an Urban Context: Findings from Austin". In: *Transportation Research Record: Journal of the Transportation Research Board* (Nov. 14, 2017).

[54] Kuhr, James et al. "Travel Modeling in an Era of Connected and Automated Transportation Systems: An Investigation in the Dallas-Fort Worth Area (122)". In: Technical Report (D-STOP) (Feb. 2017), p. 61.

[55] Lasdon, Leon S. et al. *Transit Scheduling Data Integration: Paratransit Operations Review and Analysis*. May 2000. URL: `http://ctr.utexas.edu/wp-content/uploads/pubs/1884_1.pdf` (visited on 03/21/2018).

[56] Lastrape, Krystal M. et al. *An Evaluation of the Effects of Transit Oriented Development in a Suburban Environment*. Oct. 2010. URL: `https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/476660-00048-1.pdf` (visited on 03/19/2018).

[57] Lede, Naomi W. *Suburban Employment Growth and Public Transit Accessibility: A Comparative Analysis*. Apr. 1993. URL: `https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/60026-1.pdf` (visited on 03/21/2018).

[58] Lewis, Carol A. *An Examination of the Smart Growth Initiative in US DOT's Region VI*. Jan. 2001. URL: `https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/473700-00042-1.pdf` (visited on 03/19/2018).

[59] Lewis, Carol Abel et al. *Regional Transit Coordination Guidebook*. Jan. 2009. URL: `https://static.tti.tamu.edu/tti.tamu.edu/documents/0-5345-P1.pdf` (visited on 03/21/2018).

[60] Lewis, Carol Abel et al. *Transit Agency Strategies That Encourage Mixed Use around Stations*. Aug. 2012. URL: `https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/476660-00054-1.pdf` (visited on 03/19/2018).

[61] Li, Bin et al. "Performance Evaluation of Arrival Time Prediction Models". In: (2014), p. 7.

[62] Litman, Todd. *Autonomous Vehicle Implementation Predictions: Implications for Transport Planning*. Feb. 9, 2018. URL: `http://www.vtpi.org/avip.pdf` (visited on 03/16/2018).

[63] Lownes, Nicholas E. et al. *The Commuter Rail Circulator Network Design Problem: Formulation, Solution Methods, and Applications*. Aug. 2007. URL: https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/473700-00077-1.pdf (visited on 03/19/2018).

[64] Lutenegger, Brian. *Chicago to Use TNC Fees to Improve 'L' Service*. Feb. 26, 2018. URL: https://www.ssti.us/2018/02/chicago-to-use-tnc-fees-to-improve-l-service/ (visited on 05/09/2018).

[65] Martin, Elliot W. et al. "Greenhouse Gas Emission Impacts of Carsharing in North America". In: *IEEE Transactions on Intelligent Transportation Systems* 12.4 (Dec. 2011), pp. 1074–1086. DOI: 10.1109/TITS.2011.2158539. URL: http://ieeexplore.ieee.org/document/5951778/.

[66] Martin, June et al. *Examining Challenges, Opportunities and Best Practices for Addressing Rural Mobility and Economic Development under SAFETEA-LU's Coordinated Planning and Human Services Framework*. July 2011. URL: https://web.archive.org/web/20160610095738if_/http://utcm.tamu.edu/publications/final_reports/Martin_08-17-09.pdf (visited on 03/16/2018).

[67] METRO, Houston. *Ridership Report METRO*. URL: https://www.ridemetro.org/Pages/RidershipReport.aspx (visited on 06/19/2018).

[68] Miller, Kristi et al. *Dynamic Ride-Share, Car-Share, and Bike Share and State-Level Mobility: Research to Support Assessing, Attracting, and Managing Shared Mobility Programs: Final Report*. Feb. 2016. URL: https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6818-1.pdf (visited on 03/16/2018).

[69] Minifie, Jim. *Peer-to-Peer Pressure: Policy for the Sharing Economy*. Apr. 2016. URL: https://grattan.edu.au/report/peer-to-peer/ (visited on 03/16/2018).

[70] Moeng, Thabo et al. *An Assessment of Criteria Used for Transit Friendly Decision-Making*. Dec. 2005. URL: https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/167322-1.pdf (visited on 03/19/2018).

[71] Moran, Maarit. *Policy Implications of Transportation Network Companies*. July 2016. URL: https://static.tti.tamu.edu/tti.tamu.edu/documents/PRC-2016-1.pdf (visited on 03/16/2018).

[72] Moran, Maarit et al. *Assessment of Zipcar and Car Sharing Services on University Campuses*. Mar. 2017. URL: https://static.tti.tamu.edu/tti.tamu.edu/documents/165610-2.pdf (visited on 03/16/2018).

[73] Moran, Maarit et al. "Policy Implications of Transportation Network Companies: Final Report". In: (), p. 78. URL: https://static.tti.tamu.edu/tti.tamu.edu/documents/PRC-17-70-F.pdf (visited on 03/16/2018).

[74] Moreira-Matias, L. et al. "Improving Mass Transit Operations by Using AVL-Based Systems: A Survey". In: *IEEE Transactions on Intelligent Transportation Systems* 16.4 (Aug. 2015), pp. 1636–1653. ISSN: 1524-9050. DOI: 10.1109/TITS.2014.2376772.

[75] Morris, David Z. *New York City Says Uber Must Share Ride Data*. Feb. 5, 2017. URL: http://fortune.com/2017/02/05/uber-data-new-york-city/ (visited on 06/19/2018).

[76] Murphy, Colin et al. *Shared Mobility and the Transformation of Public Transit*. Washington, D.C.: Transportation Research Board, Sept. 15, 2016. DOI: 10.17226/23578. URL: https://www.nap.edu/catalog/23578 (visited on 03/16/2018).

[77] Neff, John. *A Profile of Public Transportation Passenger Demographics and Travel Characteristics Reported in On-Board Surveys*. Washington, D.C.: American Public Transportation Association, May 2007.

[78] Noack, Mark. "City's Partnership with Uber, Lyft Stalls". In: *Mountain View Voice* (Jan. 19, 2018). URL: https://www.mv-voice.com/news/2018/01/19/citys-partnership-with-uber-lyft-stalls (visited on 05/10/2018).

[79] *Open Data — City of Austin Texas*. URL: https://data.austintexas.gov/dataset/Land-Use-Inventory/fj9m-h5qy/about (visited on 06/04/2018).

[80] Overman, John H et al. *Regional Public Transportation Coordination in Texas*. Jan. 2008. URL: https://static.tti.tamu.edu/tti.tamu.edu/documents/0-5542-1.pdf (visited on 03/16/2018).

[81] Perkins, Judy et al. *Regional Public Transportation Solutions for Intercity Commute Traffic*. 2007. URL: https://library.ctr.utexas.edu/hostedpdfs/txdot/psr/5345.pdf (visited on 03/21/2018).

[82] Prepared by Public Financial Management. *City of San Antonio Car-Sharing Feasibility Study*. Jan. 10, 2011. URL: http://www.sanantonio.

gov/Portals/0/Files/Sustainability/Transportation/CarShare/CarShareFeasibilityStudy.pdf (visited on 03/16/2018).

[83] Prepared by. *Plans for Public Transportation in Texas*. 1988. URL: https://library.ctr.utexas.edu/digitized/texasarchive/phase3/tx_MS1710_1988.pdf (visited on 03/16/2018).

[84] Public Transportation Association, American. *Shared Mobility and the Transformation of Public Transit*. Prepared for American Public Transportation Association by the Shared-Use Mobility Center, 2016. URL: http://www.apta.com/resources/reportsandpublications/Documents/APTA-Shared-Mobility.pdf.

[85] Quadrifoglio, Luca et al. *Evaluating the Use of Transfers for Improving Demand Responsive Systems Adopting Zoning Strategies*. Aug. 2011. URL: https://web.archive.org/web/20160610095640if_/http://utcm.tamu.edu/publications/final_reports/Quadrifoglio_10-60-59.pdf (visited on 03/21/2018).

[86] Ramani, Tara L et al. *Conference on Performance Measures for Transportation and Livable Communities: Summary of Work Performed*. 2012. URL: https://web.archive.org/web/20160610094951if_/http://utcm.tamu.edu/publications/final_reports/Ramani_11-15-78.pdf (visited on 03/16/2018).

[87] Ride Austin. *Ride-Austin-june6-april13 [Data file and code book]*. 2017. URL: https://data.world/ride-austin/ride-austin-june-6-april-13.

[88] Schneider, Benjamin. "D.C. Gives Uber and Lyft a Better Spot in Nightlife". In: *CityLab.com* (Oct. 25, 2017). URL: https://www.citylab.com/transportation/2017/10/a-dc-neighborhood-rethinks-parking/543870/.

[89] Schreffler, Eric N. *Implementing a Statewide Rideshare and Vanpool Program in Arizona*. June 2008. URL: https://apps.azdot.gov/ADOTLibrary/publications/project_reports/PDF/AZ610.pdf (visited on 03/16/2018).

[90] Shaheen, Susan et al. *Shared Mobility: A Sustainability & Technologies Workshop: Definitions, Industry Developments, and Early Understanding*. Nov. 2015. URL: http://innovativemobility.org/wp-content/uploads/2015/11/SharedMobility_WhitePaper_FINAL.pdf (visited on 03/16/2018).

[91] *SharedStreets*. URL: http://sharedstreets.io/ (visited on 06/19/2018).

[92] Shen, Yindong et al. "Public Transit Planning and Scheduling Based on AVL Data in China". In: *International Transactions in Operational Research* 23.6 (Nov. 2016), pp. 1089–1111. DOI: 10.1111/itor.12164. URL: http://doi.wiley.com/10.1111/itor.12164.

[93] Sheyner, Gennady. "Palo Alto Commits Funds to Fight Solo-Driving". In: (Sept. 20, 2017). URL: https://www.paloaltoonline.com/news/2017/09/20/palo-alto-commits-funds-to-fight-solo-driving.

[94] Shih, Mao-Chang et al. *A Design Methodology for Bus Transit Networks with Coordinated Operations*. 1994. URL: https://library.ctr.utexas.edu/digitized/swutc/60016-1.pdf (visited on 03/16/2018).

[95] Simons, Vic. "LRT's Big Bang in the US Oil Capital". In: *Tramways & Urban Transit* (Jan. 2015). ISSN: 1460-8324. URL: https://trid.trb.org/View/1355125 (visited on 05/30/2018).

[96] "Sound Transit Settlement Will Subsidize Uber and Lyft Rides to Mercer Island Transit Center — The Seattle Times". In: *Seattle Times* (Mar. 29, 2018). URL: https://www.seattletimes.com/seattle-news/transportation/sound-transit-settlement-will-subsidize-uber-and-lyft-rides-to-mercer-island-transit-center/ (visited on 03/30/2018).

[97] Stillwater, Tai et al. "Carsharing and the Built Environment". In: *Transportation Research Record: Journal of the Transportation Research Board* 2110 (Dec. 2009), pp. 27–34. DOI: 10.3141/2110-04. URL: http://trrjournalonline.trb.org/doi/10.3141/2110-04.

[98] Stoeltje, Gretchen et al. *Policy Brief: The Legal Status of Low Speed, Electric, Automated Vehicles in Texas*. Jan. 2018. URL: https://static.tti.tamu.edu/tti.tamu.edu/documents/PRC-2018-1.pdf (visited on 03/16/2018).

[99] *Surface Transportation: Moving into the 21st Century*. 1999. URL: https://www.gao.gov/archive/1999/rc99176.pdf (visited on 03/16/2018).

[100] Thole, Cheryl et al. *Update Methodology for ADA Demand Estimates: Lessons Learned*. July 2005.

[101] TransitCenter. *Who's On Board 2016*. New York, NY: TransitCenter, 2016.

[102] *Transit-Oriented Development (TOD) Guidebook - Reconnecting America*. Apr. 2006. URL: http://www.reconnectingamerica.org/resource-center/browse-research/2006/transit-oriented-development-tod-guidebook/ (visited on 03/19/2018).

[103] United States Census Bureau / American FactFinder. “B01002: Median Age by Sex”. *2012-2016 American Community Survey*. U.S. Census Bureau’s American Community Survey Office, 2016. URL: http://factfinder2.census.gov (visited on 05/2018).
[104] United States Census Bureau / American FactFinder. “B02001: Race”. *2012-2016 American Community Survey*. U.S. Census Bureau’s American Community Survey Office, 2016. URL: http://factfinder2.census.gov (visited on 05/2018).
[105] United States Census Bureau / American FactFinder. “B19001: Household Income in the Past 12 Months”. *2012-2016 American Community Survey*. U.S. Census Bureau’s American Community Survey Office, 2016. URL: http://factfinder2.census.gov (visited on 05/2018).
[106] United States Census Bureau / American FactFinder. “B25044: Tenure by Vehicles Available”. *2012-2016 American Community Survey*. U.S. Census Bureau’s American Community Survey Office, 2016. URL: http://factfinder2.census.gov (visited on 05/2018).
[107] Van Lierop, Dea et al. “Enjoying Loyalty: The Relationship between Service Quality, Customer Satisfaction, and Behavioral Intentions in Public Transit”. In: *Research in Transportation Economics* 59 (Nov. 2016), pp. 50–59. ISSN: 07398859. DOI: 10.1016/j.retrec.2016.04.001. URL: http://linkinghub.elsevier.com/retrieve/pii/S0739885915300809 (visited on 05/11/2018).
[108] Wang, Xiasen et al. “Complement or Competitor? Comparing Car2go and Transit Travel Times, Prices, and Usage Patterns in Seattle”. In: *Transportation Research Record* (2017). URL: http://faculty.washington.edu/dwhm/wp-content/uploads/2017/02/Wang-MacKenzie-Cui-17-06234.pdf.
[109] *Wayback Machine*. June 10, 2016. URL: https://web.archive.org/web/20160610095640/http:/utcm.tamu.edu/publications/final_reports/Quadrifoglio_10-60-59.pdf (visited on 03/21/2018).
[110] Weiner, Edward. *Urban Transportation Planning in the United States: An Historical Review*. DOT-T-97-24. Washington, D.C.: US Department of Transportation, Sept. 1997, p. 295.
[111] West, Kelly. *Planning, Designing, and Operating Bus-Related Street Improvements and Services*. July 1993. URL: https://static.tti.tamu.edu/tti.tamu.edu/documents/1225-S.pdf (visited on 03/16/2018).

[112] Wisniewski, Mary. "Ride-Sharing Services like Uber Cutting into Public Transit Use in Chicago, Elsewhere: Study - Chicago Tribune". In: (Oct. 2017). URL: http://www.chicagotribune.com/news/local/breaking/ct-met-ride-hailing-survey-20171016-story.html.

[113] Zhang, Ming et al. *Getting the Parking Right for Transit-Oriented Development*. Mar. 2012. URL: https://static.tti.tamu.edu/swutc.tamu.edu/publications/technicalreports/161027-1.pdf (visited on 03/19/2018).

[114] Zhao, Jinhua et al. "Customer Loyalty Differences Between Captive and Choice Transit Riders". In: *Transportation Research Record: Journal of the Transportation Research Board* 2415 (Dec. 2014), pp. 80–88. ISSN: 0361-1981. DOI: 10.3141/2415-09. URL: http://trrjournalonline.trb.org/doi/10.3141/2415-09 (visited on 05/11/2018).

Vita

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