UNDERSTANDING LAST-MILE PACKAGE DELIVERY
IN URBAN AREAS AND THE INCLUSION
OF AUTONOMOUS TECHNOLOGY

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ABSTRACT

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The demand for same-day package delivery in the United States is growing and has fostered the development of new, technologically advanced delivery systems. Given the rate that humanity widely adopts new technologies it is important to explore these emerging delivery methods, including Sidewalk Autonomous Delivery Robots (SADRs) and App-Based Food Delivery (ABFD) systems, to gain an understanding of their potential impacts on urban transportation networks. By assessing consumer behaviors and characteristics in areas where these services currently operate, it is possible to predict where stress will be observed in other urban environments to aid planners in directing their efforts accordingly. This thesis explores this topic and highlights the importance of understanding how SADRs and ABFD services operate in multimodal environments and generates predictors of which populations are likely to use them.

Keywords: *Last-mile package delivery*, *Sidewalk autonomous delivery robot*, *App-based food delivery*, *Consumer behavior*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I: REVIEW OF LAST-MILE DELIVERY SERVICES

1.1 Introduction

Growing demand for same-day package delivery in the United States is developing beyond the capabilities of traditional delivery means. Accelerated by the Covid-19 pandemic, use of these services has spread to urban environments and continues to gain popularity for its convenience. While modern research has worked to assess some of the capabilities of alternative modes of package delivery, there is a gap between the implementation of technologies such as sidewalk autonomous delivery robots (SADRs) and app-based food delivery (ABFD) services and their potential impacts on transportation networks (Hirschberg 2021). Through the analysis of consumer behavior and opinion towards the use of these developing technologies, it is possible to determine the role that emerging delivery services can serve for same-day package delivery. This unique research topic has the capability to reveal themes on the human perception of developing modes of delivery. As time and scientific progress continues, the use of SADRs among other alternative food and grocery delivery methods will become increasingly effective and are more likely to be included in the urban environment. These strategies can be used to fill the growing need to deliver food and groceries on the same day of purchase if managed effectively and accepted by the public (Pani 2020). These services have the potential to reduce on-road miles traveled by conventional delivery vehicles which will positively impact roadway congestion and air quality in urban areas (Figliozzi 2019). However, it is important to understand how these services will integrate into the urban transportation network and the potential stress they may create in high demand areas.

1.2 Research Questions

To develop a wholistic answer to this research objective, the following questions are addressed in this thesis:

1. What last-mile package delivery (LMPD) services currently exist in real-world settings? What services are emerging? What LMPD services are on the horizon?
2. Where are emergent SADR services operating and what are the characteristics of consumers using these services? Are these early service adopters also more likely to use LMPDs in the future?
3. What neighborhood attributes are associated with areas of higher demand for current ABFD services and where can the adoption of these services be anticipated?

1.3 Literature Review

To develop a more wholistic understanding of LMPD services, it is important to begin by evaluating current research in autonomous delivery technology as well as other methods currently in use and services that are likely to emerge in the future. Modern LMPD methods include conventional delivery trucks and cargo bikes or trikes and are characterized by needing a driver or operator to physically deliver packages. There are a few emerging LMPD methods which use autonomous technologies to deliver food and groceries and others which allow for on-demand app-based ordering. An additional evolving autonomous delivery mode utilizes drones; however this method requires further development and is not likely to be utilized until the future.

1.3.1 Modern Last-Mile Delivery Methods

There are several options currently employed by delivery agencies which bring packages along to their last stage of transit where they are passed on to the consumer. One of the most widely utilized services is the conventional delivery truck (**Error! Reference source not found.** Smith

2020), with are operated by a driver and usually powered by a gasoline engine. While these delivery trucks are accompanied by numerous shortcomings including their contribution to traffic congestion and negative impacts on air quality in urban areas if powered by an internal combustion engine, research has been conducted to assess areas of improvement for this LMPD method. One such study tested conventional delivery trucks against a hybrid truck of similar specifications. Over an eighteen-month period, fuel economy data were gathered under intense and less intense kinetic driving conditions. Under less intense conditions, a 13-26% fuel economy advantage was observed from the hybrid vehicle and a 20-33% advantage was also observed for the hybrid truck under more intense kinetic conditions. Based on this research, noticeable fuel savings can be experienced when hybrid delivery trucks are utilized in place of conventional gasoline ones (Lammert 2012).

Figure 1: Example of a conventional delivery truck

It is also important to consider other last mile delivery options that are currently utilized to develop a well-rounded understanding of the current climate of package delivery, including cargo bikes (Figure 2 Benson 2015) and powered trikes. One study set out to compare the environmental performance of three LMPD options – conventional vehicles, using trucks as a mobile depot (storage areas for packages located near their destination) while making individual deliveries with motorized trikes, and using trucks as a mobile depot while making the final delivery with an electric trike. Data were collected from deliveries in Rio de Janeiro, Brazil and evaluated using a Monte Carlo simulation. Results showed that the multimodal options yielded substantial decreases in carbon dioxide emissions compared with CV delivery methods alone, and that multimodal delivery with e-trikes yielded the most substantial reductions in air pollutants and greenhouse gas emissions (Ferriera 2019).

Figure 2: Example of a cargo bike

Another popular area of research related to on-demand delivery technology evaluates the use of centralized package locations from which deliveries can originate known as depots. One such study placed three containers (depots) in the city center of Munich, Germany to evaluate the efficiency of centralized depot use with cargo bikes performing LMPD. This study provided important insights for cargo bike routing and showed that on-road mileage of diesel trucks could be dramatically reduced by utilizing an alternate form of last mile delivery (Niels 2018).

An additional study in Medellin, Columbia evaluated the application of cargo bikes as a LMPD method for developing cities, especially where topography may be of concern, to alleviate the pressures placed on the urban environment by conventional vehicle delivery alone. By conducting an analysis of serviceable areas by cargo bike based on topography of city streets, this study uncovered that despite the wide range in elevations observed across Medellin, a large percentage of the city was still accessible for delivery via cargo bike with greater efficiency than CVs alone (Gonzalez-Calderon 2022). A similar study compared the use of electric Light Commercial Vehicles (LCVs) for package delivery to using cargo bikes in Paris, France. Despite the LCVs being smaller than conventional vehicles and their fully electric nature, it was still shown that cargo bikes can be more efficient at servicing the densest regions of urban areas if micro-hubs for package storage are utilized (Robichet 2022). While cargo bikes have been shown to increase efficiency of deliveries in various urban environments, their use in the United States is not widespread.

1.3.2 Emerging Last-Mile Delivery Methods

The application of autonomous technology in last mile package delivery has received attention from researchers in recent years and has gained greater popularity because of the Covid-19 pandemic for its potential to eliminate person-to-person contact. Previous studies have evaluated public acceptance of autonomous delivery robots (ADRs) and uncovered six consumer shopping segments arising during the Covid-19 pandemic, namely direct shoppers, e-shopping skeptics, e-shopping lovers, COVID converts, omnichannel consumers, and indifferent consumers. This same research project discovered that over 60% of shoppers in a representative study were willing to pay extra to receive their package autonomously, especially those who were located a half-mile or further from the nearest shopping center (Pani 2020).

1.3.2.1 Delivery Modes and Autonomous Technology Regulations

In the existing literature, there are several different types of autonomous technologies that could be used for last mile package delivery. Among the most discussed are SADRs (Figure 3 Ackerman 2015), road autonomous delivery robots (RADRs), and drones. At present, the leading companies working with autonomous delivery robots are Starship, Nuro, and Kiwibot (Contreras 2022). Development of these upcoming technologies has created a need for new regulations across America, and several states and cities having inconsistent protocols to control ADR use. As of 2019, seven states and three cities had regulations in place regarding autonomous robots on sidewalks and streets. Among the most restrictive places for these technologies is San Francisco, implementing a 3mph speed limit and a competitive permit system. Other areas include a weight limit that varies from forty to ninety pounds and most include a speed limit of 10 miles per hour. Among the least restrictive states to implement regulations for autonomous technology is Arizona, which simply states that the vehicle must be powered by electricity, travel less than 10 miles per hour, be actively controlled, and yield to pedestrians traveling along the same paths – with no permits or warning lights specifically required (Jennings 2019).

Figure 3: Example of a sidewalk autonomous delivery robot

While there are achievable benefits that researchers have observed related to autonomous technologies, the equipment is presently hindered by notable complications. SADRs can deliver packages to a georeferenced location, however they require a customer on the receiving end to interact with the robot and offload the package. It also becomes clear that robot fleet size and proximity of a depot to their assigned delivery routes can hinder efficiency (Boysen 2018).

SADRs, while effective under certain conditions, have the potential to generate hazardous scenarios in an urban setting as they travel along pedestrian and cyclist lanes in proximity to pathway users (Gehrke 2022). This could suggest that RADRs may be a more acceptable form of autonomous delivery technology, considering that they share the road with vehicles and generally interact less with vulnerable roadway users (VRUs). However, research shows that RADRs are limited by a relatively short battery life and small storage capacity. It has also been noted that RADRs will generate more vehicle miles per delivery than traditional methods, potentially contributing to further traffic congestion in urban areas (Figliozzi 2020).

It is likely that regulations placed on these autonomous technologies will become a limiting factor as they gain popularity (Jennings 2019). However, these technologies continue to be improved regularly and are already used in some real-world applications. Starship Robots have been rolled out for autonomous food delivery on numerous university campuses in recent years, with many miles of self-driving operations recorded (Figliozzi 2020). Considering the ever-growing market for improved delivery methods, these new technologies may be at the forefront of the future of e-commerce.

1.3.2.2 Combined-Method Delivery and Depot Sites

Another key concept in the literature is a combined-methods approach to deliver packages by means of conventional and autonomous technologies. As pictured in Figure 4 (Figliozzi 2020), a frequently discussed delivery approach includes the use of a “mothership,” which is similar to a conventional vehicle and acts as a shuttle for SADRs to drop robots in an ideal location to run deliveries. Recent studies have explored the best methods to utilize the mothership approach, which can be improved using a “robot depot” eliminating the need to wait for the SADRs to return from their routes (Boysen 2018). Other articles discuss the use of a mothership in different contexts, making considerations to the size and emissions associated with using these vans in urbanized areas (Figliozzi 2019).

Figure 4: Example of a mothership and SADR combined delivery

1.3.2.3 Assessment of Autonomous Technology in Practice

As on-demand delivery gains popularity, the need for functional last-mile delivery strategies requires more attention from researchers. It is important that current on-demand delivery technologies are properly evaluated for their ability to reduce congestion in urbanized areas, limit on-road miles of food and grocery orders and deliver payloads in a timely and cost-efficient manner. Researchers have worked to assess the potential of various last-mile delivery methods for urban areas including SADRs, RADRs, and cargo bike delivery to address these credentials. To date, a portion of efficiency-related research is based on simulations that explore routing methods to improve delivery speed and time prediction accuracy. One such project focused on the development of an algorithm to route delivery robots in urbanized areas, revealing that considerable time savings could be achieved over traditional delivery methods when managing up to fifty customers at a time (Chen 2021). A similar study simulated numerous scenarios for a single day of grocery delivery service in a city via autonomous robot, managing up to thirty delivery units and 10,500 orders with a minimum delivery time of a single day (Kronmueller 2021). An additional study investigated the use of SADR depots to provide support to conventional truck-fleet delivery by coordinating delivery routes with a flow of empty robots returning to or departing from the centralized depot, which showed that significant time savings could be achieved when properly managed (Boysen 2018).

Among the most tangible solutions for the present issue of congestion generated by food delivery is the SADR which is already in use on numerous university campuses across the United States (Figliozzi 2020). Since this technology is already operating in multimodal settings, it is crucial that research is conducted to understand consumer behaviors and opinions of SADR implementation. A related study generated an online survey questionnaire to be answered by online shoppers in Iran. Analysis of 287 usable responses through partial least squares structural equation modeling revealed that the largest motives of respondents who favor SADR use were appreciation of innovativeness, optimism for the new technology and favor of potential environmental benefits (Edrisi 2021). Another study aimed to recount the current research on various aspects of SADR delivery systems and their associated operations by compiling a literature synthesis and dividing reviewed works into six major categories: routing, fleet and infrastructure, efficiency, acceptance, social intelligence, and others. Through this survey of current research results and extent, it was revealed that sensible pricing, analytics for improved performance, and intelligent fleet planning are among the most important areas of future research for SADR use to become a viable delivery option in the future (Srinivas 2022).

1.3.2.4 Other Emerging Trends

Innovative solutions for growing issues associated with congestion in urban areas must be explored to reduce negative impacts on public and environmental health. Ridehailing is an emerging mobility platform which must be assessed as it integrates into urban areas. One recent study seeks to assess whether autonomous vehicles are helpful or harmful to competing ridehailing platforms and their passengers. Utilizing a model which evaluates platform use price, wage for drivers, and fleet size, it was discovered that robust improvements could be enjoyed by platform users with the inclusion of autonomous vehicles if costs were managed in favor of the consumer (Siddiq 2022). A second study investigated the management of a mixed fleet of conventional vehicles and autonomous vehicles for a ridehailing service to assess how the area of service could be most efficiently operated. Using a fluid model to make optimal decisions about conventional vehicle and autonomous vehicle positioning, it was revealed that the inclusion of autonomous vehicles in the fleet could reduce neglect of low-demand areas while posing no negative effect to the wages of conventional vehicle drivers (Benjaafar 2021). These conclusions could indicate that autonomous technologies may be beneficial not only for the mobility of people but also for food and groceries.

In this same conversation about emerging transportation technologies, food and meal delivery adoption must also be considered. ABFD systems are growing in use and the increased stress on urban traffic systems provides reason for investigation. One study set out to explore the broader impacts of online food delivery (OFD) related to environmental sustainability through a synthesis on related modern research. It was concluded that the largest critiques of OFD are high commissions passed to the consumer, influence on public health and traffic, and environmental implications such as waste generation and high carbon footprints. Therefore, it is imperative that alternative methods are explored which can mitigate these sustainability issues (Li 2020).

An additional category of LMPD services is evolving but remains on the horizon of implementation into urban settings. The use of unmanned aerial vehicles (UAVs) to facilitate aerial deliveries (see Figure 5 (Alter 2018) for an example of a UAV delivery prototype) may introduce a rapid new mode to the LMPD conversation. However, at present and in the immediate future, there are particular environments which may be inaccessible or ineffective for safely navigating a drone (Chen 2021). While studies have been conducted to address this issue with drone technology to the point of delivering a package onto an apartment balcony, they have generally proven to be ineffective at this time due to an inability to transport a package and unreliable geospatial referencing (Brunner 2019). Other immediate concerns when considering drone usage in package delivery are battery life and swap time in conjunction with the immediate hurdle of only carrying a single parcel at a time (Figliozzi 2020). At present, a nascent evidence base on this topic points to the conclusion that drones are more suitable for delivery in rural environments and will generally struggle in the less-ideal urban realm (Sawadsitang2019). Current regulations regarding UAVs is limiting to drone usage in urban areas, and the technology involved is a long way off from being deemed reliable to fly so closely to humans and buildings (Sawadsitang 2019).

Figure 5: Example of a delivery drone prototype

1.4 Hypotheses Based on Reviewed Literature

Three research questions (RQs) were developed to guide this study. RQ1 prompts investigation of LMPD services that currently exist in real-world settings as well as which services are emerging and on the horizon. The hypothesis formulated for RQ1 is that current LMPD systems are limited to only a few modes that are generally effective and well-researched but unable to support same-day package delivery demand alone. Also, emerging methods are likely to come in a variety of technologically advanced modes but are faced with numerous hurdles that require ongoing research to address. The literature review above confirmed these predictions; however, it was also revealed that all types of services have their own unique positive impacts as well as limitations which should be understood by planners. RQ2 investigates where emergent SADR services are operating and what characteristics of consumers use their services and considers whether early service adopters are more likely to use autonomous LMPD services in the future. The anticipated outcome of this question is that SADR services are currently operating several university campuses across the United States due to their friendly pedestrian/cyclist infrastructure considerations and low motor vehicle speeds. It is likely that consumers of this service are younger, educated people that live within service range of the SADRs and that these people are likely to adopt the use of autonomous delivery in the future. To test these claims, statistical analysis of current SADR operation and adoption on a university campus informed by the administration of an original intercept survey instrument will be conducted.

The final RQ of this study is designed to determine what neighborhood attributes are associated with areas of higher demand for current ABFD services and where adoption of these services can be anticipated. It is probable that ABFD is most frequently used by people who have higher income levels to afford convenient services and most trips will occur closer to urbanized areas where restaurants operate. To assess this RQ, statistical analysis of ABFD service adoption in a major metropolitan region will occur and results will be tested on another urban environment through suitability analysis.

1.5 Methodological Framework

To investigate which consumer behavior related to emerging LMPD services, two empirical studies will be conducted:

1. Individual Preferences for Sidewalk Autonomous Delivery Robots
2. Predictors of App-Based Food Delivery Users in Phoenix, AZ

1.5.1 Individual preferences for sidewalk autonomous delivery robots

The first analysis will utilize survey data collected from the student population of Northern Arizona University during Spring 2022. The purpose of the original survey was to gather information on public perception of SADRs related to frequency of use of the service and the opinions of safety sharing pathways with the delivery robots. This intercept survey was administered at two student unions on NAU's campus, Monday through Friday for two weeks. Research team members approached prospective respondents and requested their voluntary participation, and if agreed they were passed a wireless tablet to take the Qualtrics-based survey. The survey instrument was divided into three sections – socioeconomic characteristics, perceptions and experiences with SADRs, and pre-recorded video clips to which respondents would indicate how safe they would feel during a pathway conflict with an SADR. Also included in the survey were two questions specifically designed for this analysis. One question asked respondents to report how frequently they currently use the Starship delivery service, on a Likert scale with seven choices ranging from Never to Always. The other question developed specifically for this analysis prompted respondents to indicate their level of agreement with the following statement: "I intend to use autonomous delivery vehicles as a food or grocery delivery option." Respondents indicated their response on a scale of 1 (Least agreement) to 5 (Most agreement). For more information on the survey instrument, please see Survey Instrument Design in chapter two.

Utilizing the socioeconomic data collected from section one of the survey instrument and the responses to the two questions recently discussed regarding current SADR adoption and intentions of future autonomous delivery use, two methods of analysis were performed. The first method will involve cross-tabulation of how demographic groups responded to the adoption questions to reveal trends in which groups are utilizing this technology. The second method will utilize ordered logistic regression modeling to determine which socioeconomic characteristics are the strongest predictors for both current SADR adoption and intentions of future autonomous delivery use. The information gained from these analyses, combined with review of relevant literature, will be able to help inform planning decisions regarding where autonomous technologies are likely to be effective and utilized by the population within range of their service.

1.5.2 Neighborhood indicators of on-demand food delivery systems

A second analysis utilizes census data acquired from the American Community Survey for comparison with a dataset of app-based food delivery route end points to gain an understanding of the sociodemographic characteristics of people utilizing this type of service. The study area is limited to the Phoenix, Arizona metropolitan region and utilized a dataset that contains food delivery app trip data from 2015 to 2019. After acquiring relevant sociodemographic data from ACS reported at census tracts (age, race, household income, vehicle ownership, etc.) and built-environment data, negative binomial regression models (NBRM) were estimated to determine which factors are significant predictors of ABFD service adoption. This information has the potential to be applied to other urban areas for determining where higher rates of food delivery may occur. Accordingly, using NBRM results, a suitability analysis was conducted for the City of Flagstaff to help identify which areas may be most likely to utilize ABFD services as the growth of same-day delivery continues.

CHAPTER 2: INDIVIDUAL PREFERENCES FOR SIDEWALK AUTONOMOUS DELIVERY ROBOT SERVICE ADOPTION

2.1 Introduction

There are already several locations in the United States where autonomous delivery is used regularly. In January 2019, Starship delivery robots, a specific brand of SADR, was introduced onto college campuses for meal delivery. The robots have been at Northern Arizona University (NAU) since their launch in 2019 and now span more than a dozen universities. Due to the user-friendly design of pathway infrastructure that accompanies university campuses, SADRs are generally successful at navigating these environments and making timely app-based meal deliveries. Use of the delivery service by students has become a standard occurrence in these environments, likely because the autonomous robots are already integrated into the multimodal transit network among pedestrians, cyclists, and vehicle users alike. However, the potential exists for SADR demand to expand from college campuses to urban settings as heightened pressures for same-day delivery and the growth of ABFD services increases. If this evolution comes to fruition, SADRs will transition from serving a predominately student population to various consumer groups and their operation will necessitate traversing more complex networks to ensure a successful integration into the urban environment.

To help gain a clearer understanding of public attitudes toward adopting SADRs in places where they are currently deployed, this first study analyzes the results of a survey administered to a student population at NAU. Study goals are attained by analyzing socioeconomic and transportation attributes collected from 522 survey respondents to identify characteristics associated with people's current SADR use patterns and their willingness to adopt these services in future off-campus settings. This chapter continues with a description of the survey data collection process and adopted analytic strategies of cross tabulation and ordered logistic regression modeling, followed by a results section which reports significant analytic findings and a discussion of how the findings of this study can be used to aid the decisions of transportation planners pertaining to SADR operations.

2.2 Data and Methods

2.2.1 Survey Instrument Design

This study utilizes data from a survey instrument administered to a population of respondents who are regularly exposed to SADRs on NAU's campus. The survey was designed in Qualtrics software with the purpose of gaining an understanding of individual experience and opinions of adopting this emerging delivery service which shares pedestrian and bicycle pathways. The original survey instrument was divided into three unique sections. The first section contained a set of questions regarding respondents' characteristics such as location of residency, education level, age, employment status, annual income, and other sociodemographic information. The second section contained questions regarding respondents' perceptions and experiences with SADRs, including their frequency of utilizing this delivery option, their experiences and comfort level as a pedestrian or cyclist sharing pathways with SADRs on campus, and their intent of using SADR delivery in off-campus applications for grocery or food delivery in the future. The final section presented prerecorded video clips of conflicts between campus pathway users and SADRs of varying severities and prompted the respondent to rate their comfort level with the observed interaction on a Likert scale of 1 (Very Uncomfortable) to 5 (Very Comfortable). This survey was designed with the intent of gaining an understanding of public perceptions of SADRs based on past individual experiences with the emerging technology from the perspective of a pedestrian or bicyclist and its future acceptance as a food delivery service. To view the original survey instrument, please see Appendix A. Using this information, it is possible to identify current consumer behaviors and speculate how survey respondents with greater exposure to emerging delivery technologies may utilize these services to fulfill their demand for future on-demand food and grocery deliveries.

2.2.2 Survey Administration

This intercept survey was conducted by research team members who invited students to take the five-minute tablet-based questionnaire on NAU's main campus. Tablets were connected to wireless internet and participants recorded their responses directly into the Qualtrics software. Surveys were administered in two locations on NAU campus where students were expected to possess adequate time to complete the survey without rushing or answering carelessly: the NAU University Union on north campus and the duBois Center Union on south campus. Administrators approached prospective respondents at these two data collection locations and briefly described the survey topic and purpose prior to giving them the tablet if they agreed to participate. Survey administration occurred over a two-week period in Spring 2022 and accrued a total of 522 usable survey responses.

2.2.3 Survey Results

Table 1 provides descriptive statistics related to the socioeconomic and transportation status of respondents who participated in the survey. Most participants were on-campus residents (74%) while the remainder were likely commuting students or NAU staff. The primary age group who participated in the study were people between ages 18-24 years old (96%) with an education level of a bachelor's degree or some college, indicating that the results will be most useful for reflecting the opinions of younger, educated individuals who are frequently exposed to SADR use and interactions. It is also important to note that 90% of respondents are categorized as making less than $15,000 a year, which is likely related to the fact that 75% of those surveyed reported their work status as a full-time student.

When evaluating the respondent opinion of SADR use, travel modes typically adopted by survey respondents should also be considered. According to survey results, 444 of 522 respondents indicated they primarily walk around campus while 81 (15%) indicated they bike. These modes of transportation place participants directly into the multimodal pathways shared with SADRs - leading to higher levels of exposure with the robots. This could have a relationship with increasing their likelihood of future use but could also lead to negative associations with the robots due to discomfort with their inclusion in the shared spaces on NAU's campus.

Table 1: Descriptive statistics of survey respondents

Variable	Count (n)	Share (%)
Residence: On-campus	391	74.9
Residence: Off-campus	131	25.1
Gender: Male	226	43.29
Gender: Female	272	52.11
Gender: Non-Binary or Self-Describe	24	4.6
Age: 18-24 years old	503	96.38
Age: 25-34 years old	16	3.04
Age: 35 years old or more	3	0.57
Education: High school or less	59	11.30
Education: Bachelor's or some college	460	88.12
Education: Masters of PhD	3	0.58
Race/Ethnicity: American Indian or Alaska Native	9	1.73
Race/Ethnicity: Asian	26	5.01
Race/Ethnicity: Black/African American	13	2.50
Race/Ethnicity: Hispanic/Latinx	65	12.52
Race/Ethnicity: Multiple races or ethnicities	47	9.06
Race/Ethnicity: Native Hawaiian or Pacific Islander	6	1.16
Race/Ethnicity: White, Non-Hispanic	353	68.02
Personal Income: Less than $15,000	435	90.06
Personal Income: $15,000-$34,999	42	8.70
Personal Income: $35,000-$49,999	2	0.41
Personal Income: $50,000 or more	4	0.83
Work status: Part-time student	13	2.58
Work status: Full-time student	388	75.19
Work status: Part-time employment	186	36.05
Work status: Full-time employment	18	3.49
Travel mode: To campus (car)	54	54.55

Travel mode: To campus (walk)	32	32.32
Travel mode: To campus (bike)	13	13.13
Travel mode: Around campus (car)	165	31.67
Travel mode: Around campus (walk)	444	85.22
Travel mode: Around campus (bike)	81	15.55

Table 2 describes the responses to question 12 (How often do you use Starship robot delivery services to order food and drinks) and question 16a (I intend to use autonomous delivery vehicles as a food or grocery delivery option) from the original survey instrument. Question 12, referring to frequency of current SADR use, demonstrates that while the largest percentage of respondents indicated that they never use the Starship robots, over 40% of people use them either rarely or occasionally. Furthermore, there is a significant number of people who use autonomous delivery services once a week or more (18%). This descriptive finding indicates that autonomous food delivery is already being adopted by students who are regularly exposed as pedestrians or cyclists to this service. Question 16a refers to respondents' expectations of utilizing autonomous delivery vehicles to order food and groceries in the future. Responses were indicative of a high level of interest in the future opportunity, with over 36% of respondents returning an answer of 4 or 5 (most agreement). Agreement level 3 reflects the most common response at 29%; a more neutral stance that may suggest people would use autonomous delivery options if shown to be effective and efficient in their area.

Table 2: Descriptive statistics of autonomous delivery opinions

Q. 12 – How often do you use Starship robot delivery services to order food and drinks?		
Variable	**Count(n)**	**Share(%)**
Never	126	24.14
Very rarely (one time per year or less)	87	16.67
Rarely (one time per month or less)	108	20.69
Occasionally (two or three times per month)	109	20.88
Frequently (one time per week)	51	9.77
Very frequently (two or three times per week)	30	5.74

Always (one or more times per day)	11	2.11
Q. 16a – I intend to use autonomous delivery vehicles as a food or grocery option.		
1 (Least agreement)	100	19.16
2	80	15.32
3	152	29.12
4	127	24.33
5 (Most agreement)	63	12.07

Additional insights on whether the regular exposure of on-campus residents to SADR services impacts their adoption decisions can be found by investigating SADR use of on-campus respondents versus that of off-campus respondents. Of the 393 on-campus respondents, more than 47% noted that they use the autonomous delivery option at least two to three times per month or more. Of the 133 respondents who live off-campus, only 13% indicated they use this delivery option two to three times per month or more. While it is necessary to mention that students who live on campus spend more time within SADR service range, it cannot be ignored that nearly half the on-campus respondent population is utilizing the delivery option. Another important distinction to make is how the on-campus population responded regarding a future use of autonomous delivery vehicles versus the off-campus populations' opinion. Of the 393 respondents who live on campus, 40% indicated either a 4 or a 5 (Most Agreement) when asked if they intended to use autonomous delivery vehicles as a food grocery delivery option. Compared to the 32% who fall into the same category from the off-campus respondents, it is possible that the added exposure to SADRs that comes from being an on-campus resident could play a role in the likelihood of future autonomous delivery use.

2.3 Analytic Approach

In this study, two methods were employed to understand how individuals' sociodemographic and transportation attributes informed a respondent's current SADR adoption patterns and intentions of future use. First, the cross tabulation of select attributes and outcomes of interest was conducted to determine how specific demographic groups generally responded to question 12 (current SADR adoption) and question 16a (intentions for future SADR adoption). This bivariate analytic method was pursued to help determine which respondent characteristics were indicative of current and future SADR adoption. The second analytic method included the estimation of two ordered logistic regression models to determine which independent variables had the strongest correlation to respondents' current SADR adoption and their intentions of future SADR use. Ordered logistic regression modeling was selected for latter analysis over other modeling approaches because it is commonly used in social science research to analyze variables with responses based on an ordered scale (Fullerton 2009). Previous research has also adopted ordered logistic regression model approaches for survey/scale-based data due to the ease of interpretation of its results (Abreu 2008).

Two final models will be presented: one which tests all socioeconomic and transportation characteristics against responses to current SADR adoption and another which tests all socioeconomic and transportation characteristics against responses to the intention of future autonomous delivery adoption. Each socioeconomic and transportation characteristic (independent variable) was first modeled individually to determine its significance based on the *p*-value produced. Independent variables with a *p*-value of 0.1 or less were noted and then added to a fully specified ordered logistic regression model. Next, employing a backwards elimination process, reduced models were estimated in an iterative process, where any independent variable producing a *p*-value > 0.1 was removed until all remaining independent modeled variables were significant. Finally, the independent variables eliminated in the previous step were individually tested with the final group of significant variables using a forward selection process to determine if their *p*-values changed to below the chosen threshold of significance. In the end, this multi-step model specification process produced a list of the strongest indicators for current SADR adoption and a list of the strongest indicators for future SADR adoption.

2.4 Results

2.4.1 Cross-Tabulation

Table 3 summarizes key sociodemographic variables collected from the survey and how these characteristics relate to respondents' answers to question 12 and question 16a. By investigating the relationship between these variables, one can determine a set of influential indicators of current Starship robot delivery services adoption and who is most likely to use this emergent technology as a future food or grocery delivery option. Based on Table 3 results, one of the most notable variables is location of residency. Of the 391 on-campus respondents, 22% claimed that they utilize Starship delivery at least one time per week or more, with 38% of respondents of on-campus respondents indicating agreement for using autonomous delivery vehicles as a food or grocery delivery option in the future. Compared with off-campus residents, of which 6% claimed to use SADRs once a week or more and 43% indicated disinterest in using autonomous delivery for future grocery delivery, it is reasonable to conclude that living on-campus (and its associated exposure to the technology) is a strong indicator of positive associations with autonomous delivery.

Table 3: Cross-tabulation of key variables and responses to q12 and q16a

	q12. How often do you use Starship robot delivery services to order food and drinks?							*q16a. I intend to use autonomous delivery vehicles as a food or grocery delivery option.*				
Variable	**N**	**VR**	**R**	**O**	**F**	**VF**	**A**	**1 (Least agreement)**	**2**	**3**	**4**	**5 (Most agreement)**
Residence: On-campus	59	59	89	100	47	29	8	64	60	119	98	50
Residence: Off-campus	67	28	19	9	4	1	3	36	20	33	29	13
Gender: Male	62	41	53	43	16	7	4	46	36	75	50	19
Gender: Female	58	42	51	62	31	21	7	47	42	74	66	43
Age: 18-24 years	115	82	109	106	51	30	10	98	75	149	120	61

Education: Bachelors or some college	108	76	98	100	45	25	8	85	69	133	120	53
Race/Ethnicity: White, Non-Hispanic	82	58	85	71	37	14	6	66	55	111	83	38
Personal Income: Less than $15,000	96	75	92	92	42	30	8	80	63	131	106	55
Work status: Full-time student	84	66	88	86	38	20	6	67	53	120	106	42
Work status: Part-time employment	50	30	41	37	13	10	5	36	28	48	53	21
Travel mode: Around campus (walk)	103	75	93	95	44	25	9	82	64	134	113	51
Travel mode: Around campus (car)	35	27	38	30	18	14	3	36	25	43	40	21
Travel mode: Around campus (bike)	24	18	16	10	10	2	1	25	13	22	15	6

Columns for q12: N = Never, VR = Very rarely, R = Rarely, O = Occasionally, F = Frequently, VF = Very frequently, A = Always

Three different modes were considered in this study: walking, driving (a car), or cycling. The cross-tabulation of results in Table 3 offer descriptive insights; of people who prefer to walk, 18% claimed to use SADRs frequently and 37% agree with intent to use autonomous delivery in the future. Of respondents who preferred to drive around campus, 21% claimed to use SADRs frequently and 37% indicated agreement for using autonomous delivery in the future. And of those who preferred to bike around campus, 17% used SADRs frequently and 27% agreed to have an intent of future use. Based on these results, it appears that people who walk or drive around campus have a better affinity for autonomous delivery use than those who bike. This could be a result of the danger SADRs pose to cyclists who share pathways with the delivery robots and travel at greater speeds than people who elect to walk. In conclusion, those who feel safer with autonomous delivery robots entering the multimodal travel environment may be more likely to use them currently and in the future.

2.4.2 Modeling Results of Current SADR Adoption

Table 4 outlines the results of ordered logistic regression modeling that occurred to determine which independent variables from the survey were significant indicators of current SADR adoption (question 12). For details on ordered logit model estimation, please see UCLA Statistical Consulting Group (2021). The variable of highest significance was being an on-campus resident. The link between being an on-campus resident and utilizing SADR delivery is understandable considering these respondents are regularly exposed to SADRs and live within their operational range. An additional significant predictor for this model comes from the question regarding preferred travel modes around NAU with the response “bike”. This negative relationship could arise from cyclists feeling unsafe sharing pathways with SADRs and therefore being opposed to their use or cyclists may be less inclined to use them since they can travel more efficiently than pedestrians around campus.

Table 4: Ordered logistic regression model estimates for current SADR adoption

Variable	β	SE	t-Value	p-Value
Residence: On-campus	1.821	0.205	8.901	<0.001
Gender: Male	-0.375	0.165	-2.275	0.023
Travel mode: Around campus (bike)	-0.494	0.229	-2.155	0.031
Intercepts				
Threshold 1	0.182	0.191	0.952	0.341
Threshold 2	0.723	0.196	3.680	<0.001
Threshold 3	1.691	0.207	8.175	<0.001
Threshold 4	2.863	0.224	12.797	<0.001
Summary Statistics				
Log Likelihood: -761.459				
Akaike information criterion: 1536.919				

2.4.3 Model Results for Future SADR Use

Error! Reference source not found. outlines the results from ordered logistic regression modeling of the independent variables from the survey against survey respondents’ reported intention to use SADR delivery as a grocery delivery option in the future (question 16a). Of note, the reporting levels of the outcome variable were aggregated prior to modeling, with Likert responses of 1 and 2 representing less agreement and Likert responses of 4 and 5 representing more agreement. Also, this model included one additional independent variable – the respondents' current SADR use. According to the final model, the strongest indicator of future autonomous delivery use as a grocery option was in relation to question 12 with the responses, "frequently", "very frequently", or "always". This correlation is understandable because it indicates that people who regularly use SADR delivery would be likely to use it in the future for grocery delivery. Another significant independent variable related to future SADR use was found in multiple responses to question 16b, "autonomous delivery will work well if sharing pathways with only pedestrians and bicyclists". This statement, which directly invites respondents to share their opinion about the SADRs in their current multimodal travel environment, may be significant because it is believable that the robots will continue to operate as they currently do. A third significant variable revealed in this final model was derived from question 16c, "autonomous delivery vehicles will work well if sharing roadways with only motorists". These results are significant for those who do not think SADRs will work well under these conditions and indicate a negative association with future autonomous delivery use. This may be a result of observing Starship robots struggling to navigate in the presence of motor vehicles around campus. An additional predictor of significance was being a full-time student. The positive relationship between this variable and the outcome could be a result of the frequent exposure that full-time NAU students have to SADRs as they navigate campus. The final significant predictor of future SADR grocery delivery use was choosing biking as a mode of travel around campus. The negative association observed here could suggest that those who primarily bike may not feel safe with SADRs adding congestion to their transit environment or that cycling as a travel mode is more favorable on the NAU campus than other modes for accessing physical dining establishments.

Table 5: Ordered logistic regression model estimates for future SADR use

Variable	**β**	**SE**	**t-Value**	**p-Value**
Work status: Full-time student	0.581	0.21	2.759	0.005
Travel mode: Around campus (bike)	-0.512	0.246	-2.079	0.038
Current SADR use: very rarely	0.797	0.286	2.784	0.005
Current SADR use: rarely	1.042	0.270	3.856	<0.001
Current SADR use: occasionally	1.576	0.274	5.760	<0.001
Current SADR use: frequently, very frequently, or always	1.945	0.300	6.483	<0.001
SADR path sharing with Pedestrians/Cyclists: 1(least agreement)	-1.475	0.564	-2.617	0.009
SADR path sharing with Pedestrians/Cyclists: 2	-0.431	0.256	-1.684	0.092
SADR path sharing with Pedestrians/Cyclists: 4	0.410	0.225	1.822	0.068
SADR path sharing with Pedestrians/Cyclists: 5	0.874	0.305	2.868	0.041
SADRs on roadways: 1(least agreement)	-0.889	0.249	-3.575	<0.001
SADRs on roadways: 2	-0.554	0.231	-2.401	0.016
Thresholds				
Threshold 1	0.252	0.295	0.855	0.393
Threshold 2	1.770	0.305	5.804	<0.001
Model Summary				
Log Likelihood: -489.205				
Akaike information criterion – 1010.410				

2.5 Discussion

To appropriately address the growing demand for same-day delivery of food and groceries in a sustainable manner, it is crucial to evaluate developing delivery strategies at hand. According to literature review, the largest critiques of ABFD are the high costs passed onto the consumer, a negative influence on public health and congestion of urban areas, and high carbon footprints (Li 2020). Therefore, it is important to conduct research such as this evaluation of survey data from NAU's campus population in Spring 2022. By assessing the respondents' opinions of their current SADR adoption and willingness to use them for grocery delivery in the future and comparing their responses with their relative sociodemographic information, proper planning strategies can be developed to utilize SADRs in areas where they will have the most effective impacts. These small, fully electric delivery robots have the potential to dramatically reduce on-road miles of conventional delivery vehicles (Chen 2021), therefore limiting traffic congestion and reducing carbon footprints.

Past studies have also shown that the use of centralized depot sites can dramatically improve the effectiveness of alternative delivery methods. Having depots allows for a flow of SADRs to depart from and return to a place where they can be recharged and loaded in a way that can exist on its own or in combination with alternate delivery methods (Niels 2018). NAU's SADR delivery fleet is an example of how this system operates, as it utilizes multiple staging areas for the robots across campus close to the restaurants that are likely to load them for delivery. If demand is manageable by the size of the SADR fleet, then the consumer generally experienced acceptable delivery times (Boysen 2018).

While places like NAU provide an environment to study SADRs operating on their own, it is important to recognize that literature suggests combinations of alternative delivery methods are an effective method of delivering to real-world urban areas (Samouh 2020). This calls for special attention to planning delivery routes specifically tailored to each area of service. It must also be noted that research such as this assessment of public opinions of current and future intentions of autonomous delivery use is imperative for the effective development of alternative delivery methods. Literature suggests that considerations to socioeconomic conditions of populations, sensible pricing, and analytics of performance are among the most important areas of future research for SADR use to become a viable delivery option in urban settings (Srinivas 2022). Therefore, the work completed in this empirical study may prove valuable for planners when considering which socioeconomic conditions will yield the highest demand of autonomous delivery use.

2.6 Conclusions

It is evident that the demand for same-day delivery options is growing, especially following the Covid-19 pandemic and associated widespread shifts toward online ordering. The purpose of this study was to perform an assessment of survey data from NAU's campus population to gain further understanding of public attitude towards SADR adoption. It also concludes that there is a sizeable portion of people who are willing to adopt alternate delivery methods if they have experienced previous exposure to their use. This work will be useful for determining areas where planners should anticipate high consumer demand and stress placed on the transport network by emerging delivery systems.

Among the most important findings resulting from survey data analysis was that previous SADR use is a significant indicator of future SADR use as a grocery or food delivery option. While this is logical, it provides sound reasoning to direct alternative delivery methods towards populations that have seen these methods function effectively. It also was revealed that being a full-time student is a significant indication of future SADR use. From this, it could be deduced that urban areas with dense populations of educated individuals could be more likely to utilize these services. It is important that planners make considerations to offer equitable solutions so more people have access to emerging technologies. Since these SADRs rely on pedestrian infrastructure and network connectivity, practitioners could aim to improve facilities in areas where they are less than sufficient. It could also be of use to conduct community outreach for education on these new systems prior to their implementation.

The findings of this research can contribute to the advisement of planning and policy strategies at many levels for municipalities that are considering the implementation of alternative delivery methods. This work reveals that through evaluation of population characteristics, delivery efforts can be directed towards areas of cities that are more likely to pay for and utilize SADRs and other alternate delivery methods. Planners can also push to utilize alternate delivery forms in areas that endure traffic congestion and public health issues due to conventional delivery methods.

It must be recognized that several limitations were encountered during this research process. Primarily, the population of survey respondents consisted almost entirely of young, undergraduate individuals who have connections to SADR use on their campus. While this convenient sampling strategy produces sound results for how this specific demographic group feels towards SADRs, future work could include a more representative general population. Future work could also expand beyond the boundaries of a university campus and into the urban areas where SADRs have been or could be implemented. Since campuses are generally accessible and bicycle/pedestrian friendly with limited motor vehicle traffic, they are environments conducive to successful SADR deployment. This is not always experienced in urban environments, so getting opinions from people outside the university boundaries could provide valuable results.

CHAPTER 3: NEIGHBORHOOD DETERMINANTS OF APP-BASED-FOOD DELIVERY SERVICE ADOPTION

3.1 Introduction

Among the most rapidly changing markets related to transportation research today is same-day food delivery directly to the home of consumers. In recent years, nationwide growth in the business of meal delivery has led to the development of a fleet of online platforms each competing for customers (Hirschberg 2016). Since 2015, these “new delivery” companies allow consumers to view, compare, and order food items from groups of restaurants on one centralized online interface. This innovation has caused the nature of food delivery to transform, as now higher end restaurants and grocery items can be accessed and transported directly to the customer. While the expansion of these ABFD services is experiencing high investments and values, little knowledge of consumer behavior or potential growth currently exists (Hirschberg 2016). To determine the future impacts that these services will have on urban areas and their transportation networks, it is important to investigate not only where these delivery trips are taking place, but the various factors which characterize the people utilizing these ABFD services.

3.1.1 Pre Covid–19 ABFD Research

While the volume of past investigations into ABFD projected growth and consumer behavior is low, past assessments on the impacts of these services to the public have been conducted. One such study synthesizes available literature to reveal the implications of OFD for public health in Australia. This study found that OFD revenue in Australia had grown by 72% over the previous five years and was expected to continue to grow, earning most of its support from working adults with higher levels of disposable income (Bates 2020). This study also noted that OFD platforms have the potential to negatively impact public health through physical and environmental means – issues that could only be remedied through innovative policies such as high associated usage fees or limit of use. (Bates 2020).

Additional research has addressed the relationship between OFD and sustainability through a comprehensive review of literature. Results of the analysis show conflicts with sustainability, including issues related to high commissions and questionable working conditions, negative influence on public health and traffic systems, and significant generation of waste (Li 2020). While limited in breadth, it is imperative from this review that stakeholders preemptively work to promote positive impacts of OFD to ensure it has a sustainable role in urban areas.

3.1.2 Post Covid–19 ABFD Research

It is important to address the role the Covid-19 pandemic played in how ABFD integrated into urban areas. While the window of research is still small for this idea considering how little time has passed since the pandemic's onset, some researchers have worked to gain an understanding of how these services have evolved since March 2020. One such study combined results from a synthesis of literature and survey administered to Bangladesh residents to determine the factors that affect consumer behavior for ABFD services. Out of 552 respondents, 359 claimed to use ABFD with confidence that Covid-19 protocol was being followed at all stages of delivery. Fifty-four of these respondents indicated they were certain they would not use ABFD services, largely related to health concerns regarding disease transmission (Akter 2021). The results produced from this survey possess the potential to aid ABFD companies in their marketing plans and provide insights into how consumers will react if faced with comparable conditions in the future. Additional work aimed to assess consumers' willingness to utilize ABFD services throughout the pandemic through evaluation of service adoption experience. Combined results of literature review and a survey administered to citizens in Spain revealed that innovative solutions provided by ABFD services can have a positive relationship to consumer use, however fear induced by the pandemic invokes a negative impact on experiential value (Gavilan 2021).

3.1.3 Analysis of ABFD Consumers

While recent research reveals trends related to consumer behavior of ABFD services, limited research exists which specifically utilizes spatial delivery trip data and socioeconomic variables to identify likely customer markets. This second study seeks to address this identified literature gap and is presented as follows. First, an assessment of food delivery trip destinations in the Phoenix, AZ metropolitan region is conducted. Neighborhood food delivery frequencies are compared with a robust set of socioeconomic and built-environment characteristics of these locations via the estimation of negative binomial regression models. This analytic approach is intended to reveal which neighborhood characteristics are significant predictors for ABFD service use. These results are then applied to the neighborhood characteristics of the Flagstaff, AZ metropolitan region through a suitability analysis to determine where ABFD services are most likely to be used in this alternative setting. The findings produced by this work will be useful for aiding planners in directing their efforts to effectively manage the implications of these services in areas where high demands on the transportation network are anticipated.

3.2 Data and Methods

3.2.1 Data Acquisition: Independent Variables

For this study, data regarding socioeconomic characteristics of the Phoenix metropolitan region population were collected. These characteristics, which are to be evaluated in relation to observed ABFD delivery locations, include gender, age, race, education level, number of household vehicles, housing tenure, household income, housing type, jobs per household, and population and employment density. Figure 6 represents the Phoenix metropolitan region extent that this research investigates and the observed locations of ABFD service adoption, discussed more in Section 3.2.2.

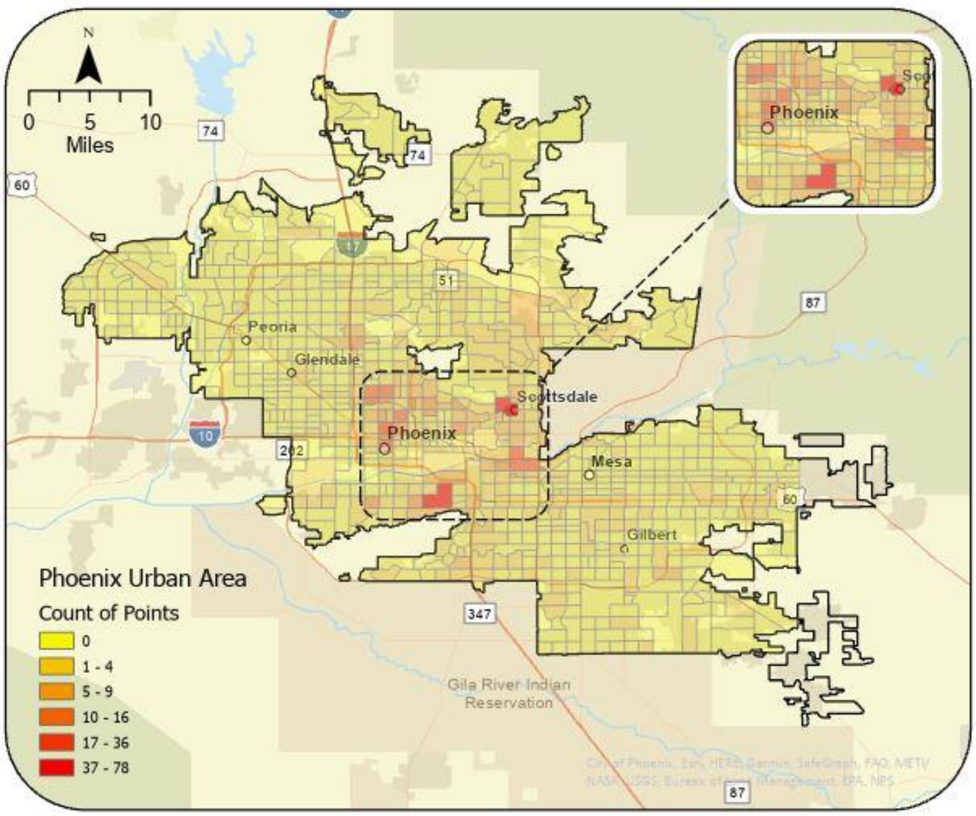

Figure 6: Study area of Phoenix, AZ metro region with census tracts and relative trip end totals

The primary source for socioeconomic data used in this study was the 2015-2019 American Community Survey (ACS) courtesy of the U.S. Census Bureau. Datasets DP02, DP03, DP04, and DP05 were filtered to yield socioeconomic data for Maricopa County, AZ by census tract. In total, 916 census tracts were part of the original dataset to represent the entirety of Maricopa County. Population information regarding gender, age, race, education, household vehicle access, income level, and housing characteristics were extracted from these datasets. The same datasets were compiled for the population of Coconino County, AZ which consists of 28 census tracts that encompassed the study area for the suitability analysis following the primary analysis of ABFD adoption in the Phoenix metropolitan area.

In complement, built environment information provided by the EPA Smart Location Database was accessed for other contextual factors such as jobs per household, population density, employment density, and jobs per person. Akin to collection of data provided by the ACS, the same built environment data were gathered for the Coconino census tracts. These census tract data were spatially joined in GIS software using shapefiles from the TIGER/Line 2019 that designated census tract boundaries in the two unique study areas (Phoenix metropolitan region and City of Flagstaff).

To maintain a study consistent with the Phoenix metropolitan area, it is necessary to eliminate areas that belong to Maricopa County but are not within the urbanized zone. To accomplish this, geoprocessing techniques that used a shapefile from TIGER/Line 2020 courtesy of the U.S. Census Bureau were performed to define census tracts in the Phoenix region's urbanized area as well as those in the City of Flagstaff, which were used for the suitability analysis following the primary analysis of pre-Covid-19 ABFD service demand in the Phoenix metropolitan region.

3.2.2 Data Acquisition: Dependent Variables

This study aims to investigate the relationship between socioeconomic characteristics of the Phoenix metropolitan area residents and ABFD usage throughout the region. To assess the latter, data was acquired from a third-party driver-assistance app called SherpaShare designed to help ridehailing and delivery drivers account for vehicle miles and escorting activities. The original dataset contains 87,124 GPS traces of ridehailing and food delivery trips in the month of October beginning in 2015 and ending in 2019. The month of October was selected due to data availability as well as lack of calendar limitations (no observed holidays) and anticipated normal travel conditions related to good weather. For this analysis, 1,068 ABFD trips were considered which occurred within the Phoenix metropolitan area (see Figure 6 above). ABFD companies such as Postmates, Uber Eats, Grub Hub, Instacart, and other delivery services were the source of these trips. Preparation of this dataset for analysis is outlined in the subsequent section.

3.2.3 Data Cleansing

With socioeconomic and built-environment data collected, a subsequent step was to standardize the data sources for statistical modeling that can be compared with food delivery trip end density. For the purposes of this study's two-part analysis, it is adequate to assess these populations at the level of census tracts in the Phoenix metropolitan region (ABFD demand analysis) and City of Flagstaff (ABFD suitability analysis).

3.2.3.1 ACS Data Preparation

Upon acquiring socioeconomic data from 2019 for Maricopa County from the ACS via the U.S. Census Bureau, 916 census tracts were included in the initial DP02, DP03, DP04, and DP05 datasets. These ACS data were converted into percentages against the total population per characteristic, producing the following set of potential predictors of ABFD service adoption

- Gender – Male, Female (percent of the total population)
- Age – Less than 18, 18 to 34, 35 to 44, 45 to 64, 65 and up (percent of the total population)
- Race – White, Latino, Black or African American, American Indian or Alaska Native, Asian, Native Hawaiian/Pacific Islander, and 2 or more races (percent of total population)
- Education level – Highschool or less, Bachelor's degree or some college, Master's degree or more (percent of 25 years or older adults)

- Income level – Less than $35,000, $35,000 to $74,999, $75,000 to $149,999, $150,000 or more (percent of total households)
- Household Vehicle Access – No vehicles available, One vehicle available, Two vehicles available, Three or more vehicles available (percent of total households)
- Tenure – Owner occupied residence, Renter occupied residence (percent of occupied households)
- Housing Design: Single-family detached unit, Other (percent of total housing units)

Comparable data for all census tracts in Coconino County were also collected for the suitability analysis.

3.2.3.2 EPA Smart Location Database Data Preparation

Built environment data at the census block level were acquired in a geodatabase provided by the EPA Smart Location Database for all of the United States and filtered to the 916 census tracts for Maricopa County, consistent with the ACS data set's spatial extent, using geoprocessing techniques. The final set of built environment characteristics were generated and later investigated as potential predictors of ABFD service adoption:

- Jobs per Household
- Population Density (calculated by dividing the total population by total unprotected land acres)
- Employment Density (calculated by dividing the total employment by total unprotected land acres)
- Jobs per Person (calculated by dividing total employment by total population)

After calculating these built environment measures for the Phoenix metropolitan region, comparable Coconino County data from this source were also compiled.

3.2.3.3 Cleansing SherpaShare Data

For this analysis, the SherpaShare ABFD data required modification prior to modeling. Since all trips were recorded as a line feature from a start location to an end location, the first step was to generate end points for all trips. After loading the SherpaShare trips into an ArcGIS Pro map, the delivery trips layer was inputted into the ‘Generate Points Along a Line’ tool with settings selected to create only a start and end point for each trip. The completion of this step produced a new layer with only start and end points of all food delivery trips from 2015 to 2019.

Since this study is concerned with where this food is being delivered, the next step was to remove start points of the delivery routes. Using the ‘Select By’ tool, all food delivery end points were selected and exported into a new layer. The product of this process provides a location within the Phoenix metropolitan region boundary where food or grocery items were delivered to.

The final step in making this SherpaShare delivery data useful for this study was to determine how many trip ends existed within each census tract. To determine this, the Delivery Trip endpoints layer and Maricopa County Census Tracts layer were inputted to the ‘Summarize Within’ tool which counts the number of trip ends within each polygon of the census tracts layer and adds the value as a field to the Maricopa County Census Tracts layer. Upon completion, an accurate count of how many delivery trip ends per census tract is available for analysis.

3.2.4 Suitability Analysis of the City of Flagstaff

To gain an understanding of how these predictors can be applied to other urban populations to determine where app-based food delivery trips are likely or unlikely to occur, it was decided to apply the predictors to the City of Flagstaff, AZ. Standardized coefficients from the negative binomial regression model results were calculated using the ‘QuantPsyc’ package in the R statistical computing software (Fletcher 2022). The lm.beta function from this package is used to generate standardized coefficients based on negative binomial regression model results, so the final model was inputted to this function and standardized coefficients were produced for all the significant predictors of food delivery service use. The standardized coefficients were then used as weights for the suitability analysis by multiplying the generated coefficient with respective data from Flagstaff census tracts to reveal areas that are likely to show higher demand of ABFD services.

4.3 Results

In addition to the socioeconomic and bult environment measures, the number of grocery or restaurant food delivery trip ends derived from the SherpaShare data were also calculated for the 828 census tracts in the Phoenix metropolitan region. Summary statistics for these data are found in Table 6.

Table 6: Descriptive statistics for Phoenix, AZ metro region census tracts

Variable	Mean	SD	Min	Max
Socioeconomic context				
Sex: Male	0.50	0.05	0.01	1
Sex: Female	0.50	0.05	0	0.64
Age: Less than 18 years	0.23	0.09	0	0.46
Age: 18 – 34 years	0.24	0.11	0	0.89
Age: 35 – 44 years	0.13	0.04	0	0.31
Age: 45 – 64 years	0.25	0.06	<0.01	0.47
Age: 65 years or more	0.17	0.16	0	0.91
Race/ethnicity: White, Non-Hispanic	0.58	0.25	0	0.99
Race/ethnicity: Hispanic/Latinx	0.28	0.23	<0.01	0.95
Race/ethnicity: Black/African American	0.05	0.05	0	0.36
Race/ethnicity: American Indian/Alaska Native	0.02	0.03	0	0.64
Race/ethnicity: Asian	0.04	0.05	0	0.80
Race/ethnicity: Native Hawaiian/Pacific Islander	<0.01	<0.01	0	0.06
Race/ethnicity: Two or more races	0.02	0.02	0	0.14
Education: High school or less	0.35	0.19	0.01	1.00
Education: Bachelors or some college	0.53	0.13	0	0.74
Education: Masters or PhD	0.12	0.08	0	0.40
Household Income: Less than $35,000	0.26	0.15	0.01	0.78
Household Income: $35,000 - $74,999	0.31	0.10	0.01	0.65
Household Income: $75,000 - $149,999	0.28	0.11	0	0.58
Household Income: $150,000 or more	0.14	0.14	0	0.66
Car ownership: 0	0.06	0.07	0	0.46
Car ownership: 1	0.35	0.14	0.01	0.81

Car ownership: 2	0.38	0.11	0.01	0.64
Car ownership: 3 or more	0.20	0.11	0	0.58
Tenure: Homeowners	0.61	0.24	0	1.00
Tenure: Renters	0.38	0.24	0	1.00
Housing design: Single family, detached	0.65	0.28	<0.01	1.00
Built environment				
Population density	8.15	5.38	0	45.41
Employment density	3.56	8.66	0.01	154.27
Jobs per person	1.53	22.06	<0.01	627.00
Jobs per household	5.08	18.26	0	372.92
App-based food delivery activity				
Trip end count	1.29	4.68	0	78.00

A general understanding of the socioeconomic context of the study area can be gleaned from Table 8. First, the largest age cohorts are 18 – 34 years and 45 – 64 years, which comprise 24% and 25% of the population, respectively. It should also be noted that 58% of the population is White, non-Hispanic, with 28% of the population identifying as Latino and lower shares of the population identifying as Black African American, American Indian or Alaska Native, Native Hawaiian or Pacific Islander, or two or more races.

Regarding education, the highest share of the adult population attained a Bachelor's degree or some level of college experience at 53%. For this reason, this group was chosen as the reference group for modeling. When considering household income, the largest share of the population made between $35,000 and $74,999 per year at 31%. This category was relatively well distributed, with 57% of the population making less than $75,000 a year and 43% making $75,000 a year or more. Concerning vehicle ownership, the largest share of the population claims to have access to two vehicles (38%). 41% of Phoenix metropolitan region households claim to have access to one vehicle or less. Regarding housing tenure, there is a 61% to 38% split between homeowner-occupied housing and renter-occupied housing, respectively. Since there is a clear majority, the homeowner occupied group is used as the reference group for modeling.

Among the most important takeaways from the built environment characteristics described in Table 6 is the variation among each category between census tracts. Regarding population density, the mean was 8.15 but the maximum value was 45.41. Employment density has a mean of 3.56 but a maximum value of 154.27. Jobs per household possess a mean of 5.08 but also has 372.92 jobs per household in its maximum census tract. Regarding delivery trip end count, an average of 1.29 trip ends per census tract was calculated but the highest count in any tract was 78. It becomes clear that there is variability in all these categories experienced across the 828 census tracts included in the Phoenix metropolitan region study area.

4.3.4 Determinants of App – Based Food Delivery Service Use

Based on the final negative binomial regression model results, 11 variables were found to be significant for predicting ABFD service use in the Phoenix metropolitan region. **Error! Reference source not found.** provides a summary of the negative binomial regression model results. The first significant variable was share of the tract population that is female, which has a positive correlation with utilizing these delivery services. Two variables related to age both showed a negative correlation with service adoption: people 65 years or more and people less than 18 years old. These results were expected since residents who are 65 years or older may be less likely to adopt the newer technology for food delivery and those less than 18 years old may not possess enough income to pay for ABFD services or are dependents of adult household members who make most decisions regarding meal preparations. The only variable which maintained significance through the final model related to race/ethnicity was White, Non-Hispanic, which exhibits a slightly negative association with ABFD use.

Table 6: Modeled predictors of app-based food delivery in the Phoenix, AZ metro region

Variable	β	SE	p-value	Standardized Coefficient

Sex: Female	3.353	1.578	0.034	0.037
Age: Less than 18 years	-9.233	1.611	<0.001	-0.178
Age: 65 years or more	-3.735	1.021	<0.001	-0.129
Race/ethnicity: White, Non-Hispanic	-4.630	0.663	<0.001	-0.243
Education: Masters or PhD	4.463	1.773	0.012	0.082
Household Income: $75,000 - $149,999	2.883	1.122	0.010	0.068
Household income: $150,000 or more	4.883	1.336	<0.001	0.142
Car ownership: 3 or more	-5.233	1.403	<0.001	-0.119
Housing design: Single family, detached	-1.375	0.508	0.007	-0.083
Employment density	0.039	0.009	<0.001	0.073
Jobs per household	0.008	0.004	0.033	0.031
Summary Statistics				
Theta: 0.365 (SE: 0.037)				
Log Likelihood: -919.264				

The only statistically significant variable related to education was attaining a Master's degree or PhD. This level of education has a positive relationship with using ABFD services, which is understandable considering individuals with a higher educational attainment may be more inclined to accept and have familiarity with developing forms of delivery methods. Regarding household income, two variables show a positive significance with ABFD use: $75,000 to $149,999 (standard coefficient of 0.068) and $150,000 or more (standard coefficient of 0.142). These results are in line with expectations, considering that they are the two highest earning groups considered in the household income category and therefore would be the most likely to pay for the convenient delivery service. The only variable to remain significant related to vehicle ownership was the group with access to three or more cars, which displayed a negative association with ABFD use. This finding is likely due to the fact that with consistent access to vehicles, these residents may be more likely to drive to get their food than pay for its delivery.

Single-family detached housing also shows a significant negative relationship with ABFD, possibly because it is common for larger households to occupy these residences who may also be more likely to avoid high meal costs by preparing their own meals. Employment density, however, exhibited a positive relationship with the use of ABFD services. This is perhaps a result of places with high activity having populations of residents younger, technologically savvy residents who support these services. The final significant modeled predictor was jobs per household, which has a positive association with use of delivery services – likely for similar reasons as employment density.

4.3.4 Suitability Analysis of ABFD Adoption in Flagstaff, AZ

In subsequent analyses, the negative binomial regression model results for the Phoenix metropolitan region can be applied to other populations to determine which areas have a higher likelihood of ABFD service use than others. To demonstrate this, all the same ACS and EPA data categories from the original Maricopa County analysis were also compiled for Coconino County with the motivation of applying the results to the City of Flagstaff. When summarized, values were produced to indicate how likely a census tract in the City of Flagstaff may be to utilize ABFD services (Figure 7).

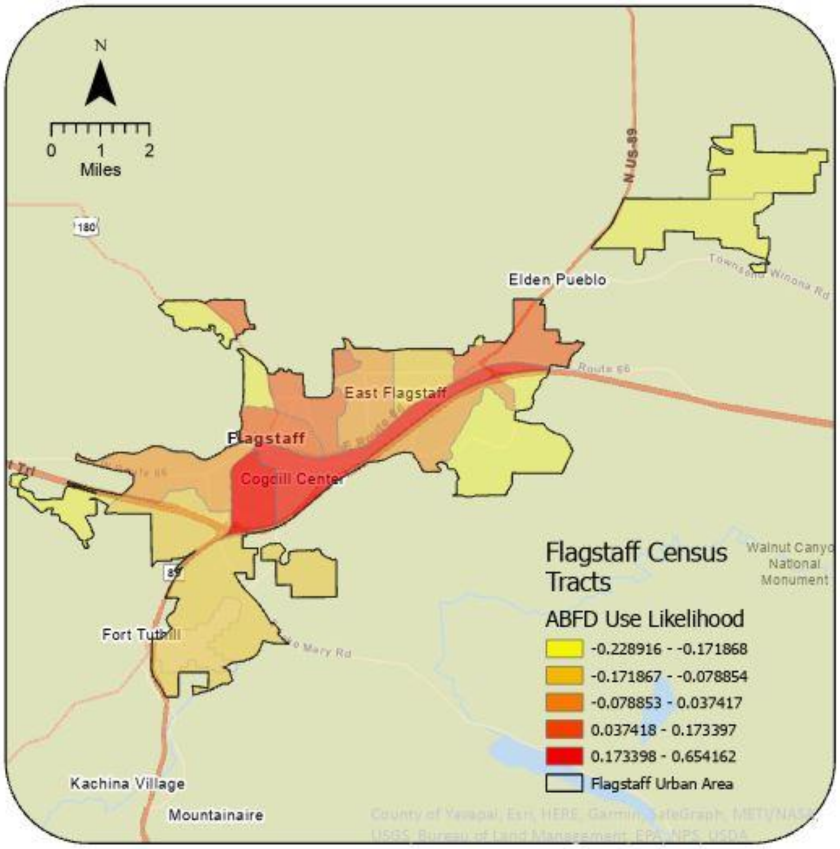

Figure 7: Suitability analysis of Flagstaff, AZ metro region

Based on the suitability analysis map of the Flagstaff census tracts, it becomes clear that areas located near the downtown region and along major roadways display the highest likelihood to utilize ABFD. Residents of the city nearest the NAU campus, which is largely characteristic of predictor assumptions, are most likely to adopt ABFD services. Residents near the campus, who may be characteristics of a college student population, also may be less likely to have vehicle access, another positive association for utilizing ABFD services based on the modeling results. Employment density and jobs per household are both going to be higher in these census tracts, which includes downtown Flagstaff, as additional indicators of food delivery service usage.

This suitability analysis also demonstrates that the further away from the Flagstaff metropolitan region people live, the less likely it is that delivery trips would be observed. Areas within the Flagstaff metropolitan region boundary but away from the downtown and NAU campus tend to be more suburban in nature, with higher shares of single family detached houses – a predictor which exhibits a negative association with ABFD. Residents in these tracts also are more likely to have access to vehicles, another indication of not utilizing delivery services. It should be noted that there are many differences between the metropolitan regions of Phoenix and Flagstaff. The City of Phoenix is characterized by milder weather, has a noticeably larger population and much larger area than what is observed in Flagstaff. While Phoenix does have influence on Flagstaff due to proximity and tourism, it may be worth applying the significant predictors produced from the Phoenix metropolitan region to cities with similar characteristics such as Tucson, AZ or Los Angeles, CA. Overall, what is observed when the significant predictors are applied to Flagstaff census tracts aligns with expectations based on the negative binomial regression model results.

4.3 Conclusions

In the scope of all work related to ABFD, it must be noted that the data utilized in this analysis was gathered prior to the Covid-19 pandemic. This research indicates how these sorts of services developed from 2015 onward without Covid-related impacts. As a result of technological advancement, convenience, and time savings, ABFD experienced modest-but-growing use throughout the pre-pandemic era. During the pandemic and in years since, these services have gained even more popularity resulting from the potential for contactless delivery and foregoing the need to enter public spaces. It is important to continue investigating how ABFD continues to grow and change, especially as post-pandemic data becomes available.

By combining delivery trip data and socioeconomic/built environment characteristics of residents in urban areas, it is possible to generate predictors of where delivery trips are likely to occur. This information can be useful for planning agencies to anticipate higher levels of roadway traffic. To make the final predictions even more useful, researchers could incorporate the time of day that these trips are occurring to anticipate peak period traffic flows. Since mealtimes are in line with peak travel periods in the mornings and early evenings, congestion to traffic networks could be experienced due to delivery drivers competing for space with commuters. This could exacerbate areas of high-volume transit and contribute to greater delays for commuters and delivery services alike. These impacts must be considered by planners and innovative solutions will be necessary, such as imposing higher delivery service fees during peak travel times to discourage service users from contributing to traffic issues.

The model results in this study reveal a positive relationship between employment density and ABFD service use. From this, it can be concluded that increasing amounts of motor vehicles performing deliveries are navigating these areas where walkability and biking are likely high. It is important for planners to consider the implications of this, especially during parts of the day when transportation activity increases. Infrastructure that is mindful of protecting vulnerable roadway users from motor vehicle traffic is important for separating different modes in these areas.

CHAPTER 4: CONNECTION OF STUDIES AND RESULTS

The capabilities of conventional LMPD systems may be unable to address the growing demand for same-day package delivery and the potential of emerging technologies to fill this gap must be reviewed. This thesis has reviewed literature of LMPD methods and conducted two empirical studies to assess consumer behavior for the adoption of developing delivery services. The research outlines which methods are currently in use as well as systems which have developed in recent years such as SADR and ABFD services.

4.1 Discussion of Conventional Delivery Methods

Modern demands for package delivery are predominantly fulfilled by a conventional vehicle with a delivery driver. While there are several shortcomings associated with this method including added congestion to urban areas and negative impacts on public health, research has shown that these issues can be improved upon. Replacing gasoline conventional vehicles with hybrid versions can improve fuel economy considerably and smaller, lighter versions of conventional vehicles have a less significant impact on urban area traffic congestion. However, it is important to note that smaller vehicles are less capable of transporting large numbers of packages and therefore may increase road-miles traveled.

Research also shows that employing cargo bikes or cargo trikes for LMPD in urban areas can lead to reductions in road-miles traveled by conventional vehicles. This method generally is powered by the driver or an electric motor and is characterized by a much smaller size than conventional vehicles which both reduces impacts on traffic congestion and is more favorable when considering public health. It is also shown that using a centralized depot point for package storage can improve efficiency for cargo bike delivery if all systems are managed properly. It is important to continue making improvements to these conventional LMPD methods as they are deeply integrated into urban areas. However, newer emerging technologies may possess the potential to increase efficiency and meet demands for same-day package delivery.

4.2 Discussion of Emerging and Future Delivery Methods

Among the most developed of newly implemented LMPD services is autonomous delivery via robot. SADRs are already in use on dozens of university campuses across the United States and are recording many miles of automated delivery each day. It must be noted that university campuses lend themselves well to SADR delivery due to considerate multimodal facility designs and low roadway speeds, however it is likely that these robots will begin running deliveries in urban areas in the future. Therefore, it is important to develop a clearer understanding of which consumer segments are likely to use these services.

This work has revealed several considerations regarding consumer ADR usage. Firstly, it has been shown that location of residency is an important factor related to ADR use. People who live where these services are regularly utilized are more likely to receive food or groceries by ADR than those who are exposed to the robots less or live outside of their service range. Those who live near where SADRs currently operate are generally more willing to consider using them in the future as well. This work has also shown that there is a positive correlation between SADR use and people who prefer to walk over other modes of transportation. Cross tabulation and OLRM analyses both revealed that people who walk show a higher likelihood of SADR service use than those who bike or drive primarily. This finding could result from the risk that SADRs pose to cyclists or motor vehicles when sharing pathways with them.

Another significant predictor of SADR use produced by the OLRM was related to education level. Having a status of “full-time student” showed a higher association with SADR use than other options from the PAR-D survey. A reason for this could be that the full-time students on NAU's campus are more frequently exposed to SADR use and likely to live inside their serviceable range. This association could also result from the busy lifestyle of full-time students, who are willing to pay service fees for the convenience of SADR delivery. It should also be noted that a strong relationship was shown between people who indicated they currently use SADR delivery and the future intention to use them for grocery delivery in off-campus applications. This is understandable, as those who currently enjoy the benefits of SADR use would be a likely group to continue using their services in the future.

This work also uncovers useful information for predicting neighborhood characteristics of people who use ABFD systems. ABFD has evolved over the last decade to provide its users not only with food from restaurants but also grocery items on the same day the order is placed. An association between age and ABFD is revealed based on empirical evidence of this work. It is shown through negative binomial regression modeling that people aged 18 years or younger as well as people aged 65 years or older are less likely to use this sort of delivery service. This could be caused by the younger demographic not having limited access to app-based platforms or eating at home instead and the older having less exposure to online ordering. This same study also revealed a link between those who attain an education higher than a bachelor's degree with a positive association of ABFD use. This could result from this demographic attaining a higher level of income or greater acceptance of developing technologies. Related to the former outcome, the two highest income groups included in the model ($75,000-$149,999 and $150,000 or more) both have positive associations with using ABFD. This is likely because households with higher income can afford extra fees for the convenience of this service.

Another important consideration revealed by NBRM in this work shows a negative association between households with three vehicles or more and ABFD use. This relationship is the same for single-family detached houses, and both are likely a result of suburban areas experiencing less deliveries than urban ones. It is possible that households with high vehicle access are more likely to drive themselves for food and grocery needs and service fees increase outside of urban environments where the trips originate.

It has been shown through previous research that there are pitfalls associated with ABFD and its impact on the public. These services can contribute to increased traffic on roadway networks especially in urban areas, with increased vehicle traffic leading to higher levels of emissions and a negative impact on public health. ABFD has also been linked to significant generation of waste and other environmental impacts. Since this mode of delivery is continuing to grow, it has never been more important to investigate consumer habits to advise planning decisions related to ABFD services.

This work also discusses drones, a delivery mode that is not likely to enter urban environments in the immediate future. While drones act as an effective method for reducing stress on roadway networks since they travel through the air, they are not currently at the level of effectiveness required for safe and efficient delivery. Beyond the tight regulations surrounding drone usage in urban areas, they also are currently unable to carry and release packages in a safe manner. They also are limited to small payloads and, like, ADRs, are limited in their ability to operate autonomously. However, drones could prove to be an impactful method for reducing congestion in multimodal transportation environments in the future following more research and development.

4.3 Planning Considerations and Conclusions

The results of this work possess the potential to help city planners and delivery companies make decisions about where to direct their efforts address areas of high delivery demand and contact the most likely market segments to use their services. Based on existing literature and results drawn from a primary data collection effort and subsequent statistical analysis of Phoenix metropolitan region residents, some guidance on the effective planning of these "new delivery" systems can be offered. A primary conclusion of this work is that planners should anticipate these services to develop networks in areas where people may already have familiarity with them. This could be adjacent to a university campus where they are already used or in an area where higher levels of educational attainment are popular. Based on the results of this study, people who are educated and have exposure to ADRs are some of the most likely to use their services. Delivery service zones should be developed in these areas and extended outwards from them, as it is probable that more people will begin to adopt their services as they are exposed to the robots operating around them.

Another consideration drawn from this research is related to decision making for routing ADRs through urban environments. Based on survey results, it is revealed that people who believe SADRs operate well when sharing pathways with pedestrians and cyclists have a higher correlation to using the service. It is also shown that people who walk use SADR delivery more frequently than those who prefer to bike or drive. Based on this information, it may be in the best interest of planners to route SADRs along paths that support walking more than cyclists or motor vehicles. Those who walk travel at slower speeds and exhibit more control around SADRs than people who ride bikes, so routing robots through these areas may generate the most pleasant human-robot interactions and allow for positive integration of the new delivery service into the multimodal environment.

An additional consideration for practitioners concerned with ABFD planning includes the prioritization of urban areas over suburban ones. Based on evidence from both studies conducted in this work, it is shown that people use these services to a higher degree inside urbanized areas. Modeling revealed that employment density and limited vehicle access are positive predictors of ABFD use and the suitability analysis of Flagstaff census tracts indicated that areas within the metro region may experience high demand compared to surrounding suburban areas. This could be beneficial for planners who must account for “new delivery services” impacting their environments to consider.

The integration of these “new delivery services” provides a fleet of new challenges for city planners which have not been experienced previously. Added stress on transportation networks which result from ABFD services and autonomous delivery modes require intelligent understanding of how these services impact the community and transportation networks in urbanized areas. Regarding ADRs, current transport facilities must be evaluated before routing robots along them. While this work has shown that sharing pathways with pedestrians may be the most acceptable method of integration, areas with high volumes of pedestrian traffic flows may hinder delivery efficiency of SADRs and generate hazardous environments. Routing SADRs along bike lanes may generate additional negative associations with use of the service since they pose a threat to cyclists traveling at greater speeds than pedestrians. In some cases, RADRs may be the most suitable option for urban area package delivery, however, careful consideration is imperative if these services are to integrate well and be accepted by the community. Regarding ABFD, it should be understood that these services will impact urban areas with the highest intensity and special considerations from practitioners need to be made. This could come in the form of new facility design in areas where delivery trips frequently originate to accommodate these services, perhaps through designated vehicle standing areas adjacent to restaurants or grocery stores which benefit from these services.

While this work reveals numerous developments that can aid planners in managing "new delivery" services, further research is needed to properly address this emerging wave of technology. Gathering consumer opinions of ADR integration into communities from wider groups could provide valuable insights into who would adopt these services or advise how to route them. Additionally, accessing a greater quantity of ABFD trip data from other urban areas could provide more detail about which consumer segments are using these services. Trip data in this study was recorded prior to the Covid-19 pandemic and accessing data from 2020 and later could be valuable for examining how ABFD use was affected by the event. It could also be of interest to planners if the day of the week and time of delivery trips were taken into consideration for determining when these sorts of trips peak throughout the day, week, and year.

Emerging services designed to cater to the convenience of their users are constantly evolving and attractive to consumers. ABFD services and ADRs possess the potential to fill the growing demand for same-day package delivery while providing customers with a service that is fast, contactless, and favorable compared with conventional methods of acquiring food or groceries. However, it is vital to understand how these services will impact traffic networks and public health before they are introduced on a wide scale. This thesis has sought to contribute to a nascent evidence base examining these impacts, but further research into consumer behavior and urban integration of these services is necessary to provide planners with robust information to address sustainability concerns with this new wave of technology.

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APPENDIX A: PAR-D SURVEY INSTRUMENT

Section I: Survey Participant Information

Please answer the following set of questions regarding your sociodemographic and economic background and general travel behaviors to the best of your abilities and as accurately as possible.

1. Which of the following best describes your current living accommodations in relation to NAU?

• On-campus housing

• Off-campus housing

2. What ZIP code do you currently live in?

Note: Display only if “Off-campus housing” is selected for Question 1.

3. What is your age?

• 18-24 years

• 25-34 years

• 35-44 years

• 45-64 years

• 65+ years

4. What is your gender?

• Female

• Male

• Self-describe (please specify)

• Prefer not to answer

5. Which racial/ethnic background do you identify with? Check all that apply.

• White/Caucasian

• Latino/Hispanic

• Black/African American

• Asian

• American Indian or Alaska Native

• Native Hawaiian or other Pacific Islander

• Self-describe (please specify)

• Prefer not to answer

6. What was your personal income during the past 12 months?

• Below $15,000

• $15,000 - $34,999

• $35,000 - $49,999

• $50,000 - $74,999

• $75,000 - $99,999

• $100,000 or above

• Prefer not to answer

7. What is your current employment status? Check all that apply.

• Full-time work (35 or more hours per week)

• Part-time work (1-34 hours per week)

• Full-time student

• Part-time student

• Retired

• Unemployed and looking for work

• Unemployed and NOT looking for work

• Other (please specify)

8. Which best describes your educational status?

Note: Display only if “Full-time student” or “Part-time student” is selected for Question 9.

• Freshman

• Sophomore

• Junior

• Senior

• Master’s student

• Doctoral student

9. Which best describes your educational status?

Note: Display only if “Full-time student” or “Part-time student” is not selected for Question 9.

• High school degree or equivalent

• Associate degree or some college

• Bachelor’s degree

• Graduate degree (Masters, PhD)

10. Which ONE of the following ways do you mostly travel TO NAU?

Note: Display only if “Off-campus housing” is selected for Question 1.

• Car

• Bus

• Bicycle

• Walk

• Other (please specify)

11. What are all the ways you travel AROUND NAU?

• Car

• Bus

• Bicycle

• Walk

• Other (please specify)

<u>Section II: Autonomous Delivery Vehicles</u>

Please answer the following set of questions regarding your experiences with and present perceptions of sidewalk automated delivery robots to the best of your abilities and as accurately as possible.

12. How often do you use Starship robot delivery services to order food or drinks?

• Never

• Very rarely (one time per year or less)

• Rarely (one time per month or less)

• Occasionally (two or three times per month)

• Frequently (one time per week)

• Very frequently (two or more times per week)

• Always (one or more times per day)

13. As a PEDESTRIAN or a BICYCLIST, have you altered your intended path because of an interaction with an autonomous Starship robot delivery service?

• Yes

• No

• Don't know

14. As a PEDESTRIAN, what is your comfort in sharing pathways with autonomous robot delivery services?

• Very uncomfortable

• Uncomfortable

• Neutral

• Comfortable

• Very Comfortable

• Don't know

15. As a BICYCLIST, what is your comfort in sharing pathways with autonomous robot delivery services?

• Very uncomfortable

• Uncomfortable

• Neutral

• Comfortable

• Very Comfortable

• Don’t know or don’t ride a bicycle

16. For the following questions, imagine that in five years the use of autonomous robot delivery services is more common in public places. Please answer the following questions based on your opinion and judgment, with a score of 1 indicating least agreement and a score of 5 indicating most agreement.

a. I intend to use autonomous delivery vehicles as a food or grocery delivery option.

• 1 (Least agreement)

• 2

• 3

• 4

• 5 (Most agreement)

b. Autonomous delivery vehicles will work well if sharing pathways with only pedestrians and bicyclists.

• 1 (Least agreement)

• 2

• 3

• 4

• 5 (Most agreement)

c. Autonomous delivery vehicles will work well if sharing roadways with only motorists.

• 1 (Least agreement)

• 2

• 3

• 4

• 5 (Most agreement)

<u>Section III. Choice Experiment</u>

Please review the following videos imagining that you are the pedestrian or bicyclist who is encountering the autonomous delivery vehicle. Please answer the following set of questions to the best of your abilities and as accurately as possible.

17. [Video: Pedestrian and Starship robot with post encroachment time (PET) = 1-3 seconds]

As a PEDESTRIAN, what is your comfort in sharing this pathway with the autonomous delivery vehicle?

• Very uncomfortable

• Uncomfortable

• Neutral

• Comfortable

• Very Comfortable

18. [Video: Pedestrian and Starship robot with PET = 0-1 seconds]

As a PEDESTRIAN, what is your comfort in sharing this pathway with the autonomous delivery vehicle?

• Very uncomfortable

• Uncomfortable

• Neutral

• Comfortable

• Very Comfortable

19. [Video: Bicyclist and Starship robot with PET = 1-3 seconds]

As a BICYCLIST, what is your comfort in sharing this pathway with the autonomous delivery vehicle?

• Very uncomfortable

• Uncomfortable

• Neutral

• Comfortable

• Very Comfortable

20. [Video: Bicyclist and Starship robot with PET = 0-1 seconds]

As a BICYCLIST, what is your comfort in sharing this pathway with the autonomous delivery vehicle?

• Very uncomfortable

• Uncomfortable

• Neutral

• Comfortable

• Very Comfortable