THE UNIVERSITY OF TEXAS AT AUSTIN
CENTER FOR TRANSPORTATION RESEARCH

TECHNICAL REPORT 0-7165-1
TxDOT PROJECT NUMBER 0-7165

Evaluate Logistics Sprawl's Impacts on E-commerce Travel Patterns

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February 2024

Published October 2024

https://library.ctr.utexas.edu/ctr-publications/0-7165-1.pdf

Technical Report Documentation Page

1. Report No. FHWA/TX-24/0-7165-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluate Logistics Sprawl's Impacts on E-commerce Travel Patterns		5. Report Date Submitted: February 2024 6. Performing Organization Code
7. Author(s) Katherine Asmussen, Samantha Anderson, Ali Kothawala, Lisa Macias, Stephen Boyles, Yu Li, Caitlan Zilligen, Brandy Savarese, Natalia Ruiz Juri, Kenneth Perrine, Shobhit Saxena, Chandra Bhat, https://orcid.org/0000-0002-0715-8121		8. Performing Organization Report No. 0-7165-1
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 3925 W. Braker Lane, 4th Floor Austin, TX 78759		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 0-7165
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Division 125 E. 11th Street Austin, TX 78701		13. Type of Report and Period Covered Technical Report September 2022 – February 2024 14. Sponsoring Agency Code

15. Supplementary Notes
Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

16. Abstract

E-commerce services and facilities have the benefits of bringing new employment opportunities to communities and meeting consumer needs, but they also attract heavy traffic, which results in congestion and negative environmental and economic repercussions. This project offers a new lens for studying future e-commerce facility siting, considering current and projected consumer demands that will drive facility siting from the perspective of e-commerce companies. It also considers the industry and workplace standards and the tax and zoning policies of governing bodies, including the Receiving Agency's own land-use regulation and standards, that can affect, and be proactively employed to influence, facility siting from the perspective of the Receiving Agency. This project shall provide a predictive mechanism that is not simply reactive to an e-commerce company's facility siting preferences, but can be proactively leveraged by the Receiving Agency, who can use land-use regulations and standards to influence the siting of e-commerce facilities in ways that bring home the positives of e-commerce to Texans, while tempering negative repercussions for the transportation network.

17. Key Words	18. Distribution Statement
Transportation, E-commerce, Urban Sprawl, Logistic Facility, Location Forecast	No restrictions. This document is available to the public through the National Technical Information Service, Alexandria, Virginia 22312; www.ntis.gov.

19. Security Classif. (of report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	66	

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CTR Technical Report:	0-7165-1
Report Date:	Submitted: February 2024
Project:	0-7165
Project Title:	Logistics Sprawl Impacts on E-commerce Travel Patterns
Sponsoring Agency:	Texas Department of Transportation
Performing Agency:	Center for Transportation Research at The University of Texas at Austin

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Acknowledgments

The authors gratefully acknowledge the financial support provided for this project by the Texas Department of Transportation (TxDOT). The authors would like to thank Darrin Jensen, Wade Odell, Geena Maskey, Loretta Brown, Steve Linhart, Marty Boyd, and Paul Truban of TxDOT for their support and constructive advice throughout this project.

Products

P1—Finalized Excel workbook tabulating: 1) top e-commerce logistic companies and general information on their facilities, and 2) current and future Texas zoning and tax policies and industry and workplace standards related to e-commerce facilities

P2—Finalized Excel workbook tabulating: data on company presence and geographic/spatial characteristics of the case study region, San Antonio

P3—ArcGIS database of each of the facilities enumerated in P2 in San Antonio

P4—Finalized Excel workbook compiling macro travel trends by at least four region types, as well as for the case study region, San Antonio

P5—Finalized Excel workbook and forecasting model and spreadsheet tool

P6—Prototype ArcGIS databased of forecasted facility locations in the case study region, San Antonio

P7—Workshop materials

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Chapter 1. Project Introduction

1.1. Introduction

"Doorstep delivery" is booming as e-commerce continues to skyrocket. In the US, e-commerce sales were nearly $880 billion in 2021, and that same year the share of e-commerce as a fraction of total retail sales reached 19.2%, up from 5.1% in 2007 (Young, 2022). This growth is expected to continue, as US retail e-commerce sales are projected to cross $1 trillion in 2022, after exceeding $760 billion in 2020 (19.1% share of total retail) and $578 billion in 2019 (15.5% share of total retail), implying a compound annual growth rate of about 9%. Globally, e-commerce sales have risen even more than in the US, from $1.336 trillion (USD) in 2014 to $4.938 trillion in 2021—an 18% compound annual growth rate—and they are projected to rise to $7.391 trillion by 2025 (Statista, 2022). The beginning of the COVID-19 pandemic in early 2020 caused concerns about shopping in-person, prompting a boom in e-commerce sales that led to a higher annual growth rate than had been projected. This boom has lasted and indicates this shift to online purchasing may outlast the pandemic, as individuals and families discovered new ways of acquiring goods. Online shopping continues to serve, as a zero-/low-contact option while also providing convenience to consumers.

These projected online shopping trends impact vehicle miles traveled (VMT), congestion levels, and other regional and environmental issues, due to the transportation effects from both the supply and demand sides of the market. Hence, this project explores the difference in classification and magnitude of effects that both sides of the market have on the transportation network and environment, as well as how local and regional governments can monitor these effects. Uniquely, the perspective of the logistic companies will be taken with regards to e-commerce, rather than exploring the changes in consumers' online presence. It is important to evaluate how the presence of an e-commerce company and the placement of its facility in any given region will disrupt the travel patterns and the environment of the area.

The remainder of this chapter proceeds as follows. Initially, a concise introduction to the e-commerce sector will be presented, followed by an exploration of the growth and transformations within the logistics sector over the past few years. Subsequently, we will propose an overview of logistic companies' facility placement strategies, seamlessly paving the way for the discussions in Chapter 2. Before concluding the present chapter, an exploration into the traffic congestion and related environmental externalities due to the escalated proliferation of logistics facilities will be undertaken. Additionally, recommendations will be provided on ways governments can effectively mitigate negative environmental externalities.

1.2. The E-Commerce Sector

E-commerce has already and will continue to change on both the demand side (due to the anticipated increase in e-commerce related purchases of consumers) and the supply side (as the logistics sector adapts to consumers' evolving preferences). On the demand side, eMarketer (2019) is forecasting that in 2025, e-commerce will make up 23.6% of total retail sales in the US. The upsurge in e-commerce demand already has a significant impact on the number of delivery, shipping, freight, and other logistic vehicles on the road.

1.3. An Overview of the Logistic Sector

As e-commerce booms, several companies have emerged as front-runners in the industry and have cultivated their online presence and network across the world, the country, and the state of Texas. In order to further analyze the growth of e-commerce, we will split the e-commerce industry into categories—shipping companies (such as UPS and FedEx), retail companies (specifically those with a significant online presence, such as Target and Walmart), and companies that do both (such as Amazon). Each category and company is rather dependent on the other. Retail companies such as Target still employ shipping companies such as FedEx to deliver products. Amazon Logistics delivers most of the items sold on the Amazon online platform, though Amazon also relies on shipping companies such as FedEx to deliver a portion of their goods.

In 2021, UPS saw a 13% gain in their overall revenue per package, offsetting their annual average 2% drop from the past decade (Black, 2021a). Even more impressively, FedEx's annual revenue has tripled over the past decade, and, since the pandemic began, their volume of small (mostly e-commerce) packages for final delivery has jumped 23%, hitting 3.1 billion packages in 2020 (Black, 2021b). USPS, DHL, and other smaller shipping companies are seeing similar revenue and package volume growth. However, for any of these companies to successfully complete their deliveries and retain and grow their customer base (especially as the expectation for faster, cheaper, and reliable shipping grows), they must invest in strategically located facilities, near marine ports, airports, cities, or densely populated residential areas. Their goal is to collect a package from the e-commerce retailer, transport it to the receiving area, and then get it to the consumer or business's home or office in the quickest, cheapest, and most reliable fashion.

Whether a distribution center, fulfillment center, or warehouse, logistic facilities are popping up all over the country in order to optimize the delivery process.

In Texas alone, UPS and FedEx have several warehouse facilities, as well as over 10,000 total stores and drop-off locations (FedEx, 2022; HIFLD, 2022). In 2018, UPS built a $200 million shipping center in Arlington employing over 1,400 individuals (Brown, 2017). Then, in 2019, UPS began construction on a 260,000-square-foot distribution center and created 575 new jobs in northwest Houston, in order to meet the growing demand for local package deliveries (Pulsinelli, 2019). Both new facilities were geographically placed on the fringe of nearby cities, the first equidistant between Dallas and Fort Worth, the second a convenient distance from the suburbs and intercity of Houston.

Additionally, over the pandemic, retail companies such as Target and Walmart have more than doubled their revenue from their digital platforms over the past year (Davis, 2020; Perez, 2020). Due to both store closures during the pandemic and their already convenient and accessible locations, most Target and Walmart brick-and-mortar stores now partially act as suburban or intercity fulfillment and distribution centers (ThomasNet.com, 2020). This became a smart business move for the retail companies, given that around 90% of the US population is within 10 miles of one of Walmart's 4,700 stores, allowing them to complete quick deliveries much easier than bigger shipping companies who may only have one facility in any region (Ross, 2020). This micro-warehouse model has inspired other retail and shipping companies to begin investing in smaller warehouses located in dense cityscapes in order to meet consumers' quick-turnaround expectations (ThomasNet.com, 2020).

Some companies, such as Amazon, are unique cases, as they fall into both shipping and retail categories. In 2020 alone, Amazon shipped and delivered 4.2 billion parcel shipments, up 2.3 billion from 2019. It now makes up, by volume, 21% of US parcel shipments, behind the USPS (38%) and UPS (24%) but ahead of FedEx (16%) (Waters, 2021). Amazon has 32 warehouses in Texas, spread across the entire state, and is projected to open two more in 2022. Amazon also has over 200 smaller facilities, like fulfilment or distribution centers, in Texas. In North Texas alone, Amazon owns over 30 facilities and employs over 37,000 workers.

Each type of company is projected to grow in unique ways, and their physical presence (as opposed to an online presence) in an area, in the form of warehouses, fulfillment centers, and distribution facilities, must be evaluated, as retail and shipping companies cultivate their presence in Texas. Based on market trends, it is projected that an additional 1.5 billion square feet of warehouse space is going to be needed by 2025, and real estate for these shipping and retail companies is going to be a hot commodity (Leonard, 2021). From 2003 to 2008, logistic facilities all across the US were moving further away from urban areas, due to cost and land restrictions. However, this national trend towards sprawl has halted since the economic recession in 2008 (Kang, 2020). Logistic facilities began popping up closer to suburban regions and on the outskirts of urban ones. In 2016, the average warehouse was about 24 miles from the nearest associated logistic sector (such as an airport or port) and 27 miles from a dense population concentration (Kang, 2020). E-commerce demand and supply have shifted the trend since then. Today most warehouses are located less than 20 miles away from the nearest residential, employment, or transportation hub, while most fulfillment or distribution centers are located less than 10 miles from the closest hub (Baglio et al., 2022). There is less spatial sprawl, due to facilities' placement closer to highly populated areas, but there is more sprawl across regions, due to an overall increase in logistic facilities. Logistic companies are being forced to think strategically about how and where to invest their time and money in order to meet the adjusted delivery expectations of consumers.

1.4. Facility Placement Strategies

Logistical processes and infrastructure are continually changing and adjusting to market factors with new innovations. For example, urban centers are generally not as well connected to the multi-modal freight network that connects global economies. However, consumers are demanding faster and more reliable delivery of their purchases. On one hand, as a part of logistics sprawl, a common tendency has been that logistical hubs are moving away from urban centers and towards highways, railroad networks, and intermodal terminals, which are located in more rural or fringe parts of a region. The cost of shifting a facility further away from the consumer is mitigated by the increased efficiency of avoiding collecting and distributing freight in dense, congested central business districts. Overall, when moved to a fringe location, logistics costs are reduced and, ultimately, the cost to the consumer decreases (Kang, 2020). On the other hand, and as discussed in the previous section, a conflicting tendency has been observed, logistic facilities are moving closer to dense population, employment and transportation hubs to keep pace with the rising delivery demands from consumers. The cost of disappointing a consumer because an item is not delivered in time due to a lengthy delivery distance, will lower their loyalty to the company and may indirectly create a huge financial burden for the logistic company. To balance both tendencies, logistic companies must be tactical in their placement of new facilities and methodically weigh the pros and cons of either moving away from hubs or moving closer. These shifts and the need for methodical placement-decision strategies have been amplified as shipping companies try to navigate the twists and turns of the COVID-19 pandemic and beyond.

In order to keep up with the changes in e-commerce demand and supply, logistic companies must invest in new facilities in ideally placed locations across the state of Texas. For example, Amazon's customer base is more urban than rural, so they place most of their facilities on the fringe of urban areas. On the other hand, UPS and FedEx stretch to more rural areas and have more warehouses located in geographically remote areas. While expanding, Amazon will likely avoid placing their facilities in rural areas: only 11% of their shipping is rural compared to 25% of UPS and FedEx deliveries (Cosgrove, 2019). Amazon's strategy benefits UPS and FedEx, because they are able to control the market in rural areas; Amazon actually uses FedEx for many of its deliveries to rural customers. Some other strategies behind a company's warehouse location choice include:

- Distance from airports, railway stations, and ports
- Cost of land
- Existing infrastructure (such as roads and facilities)
- New build vs. retrofitting an existing building
- Utility costs
- Roads, highways, traffic flow
- Workforce availability
- Markets and local environment factors
- Storage needs and packing area requirements
- Proximity to employment or residential hubs (strong customer bases)
- Where other logistic facilities are located (their own or competitors')

While the geographic placement of facilities is important, so is the number of new facilities each logistic company will require to meet consumer expectations. The number of facilities needed by logistic companies is driven both by customer demand and delivery expectations.

1.5. Congestion and Environmental Impacts

The popularity of online shopping and consumer demands for increased shipping speeds have forced companies to change their logistical processes. The optimization of truck routes becomes more difficult, and delivery fleets must have more trucks, even with the strategic placement of new facilities. As transportation engineers, what we want to know is: what are e-commerce's net environmental and traffic impacts?

Put simply, an increase in e-commerce means an increase in VMT, resulting in negative impacts on the environment due to increased emissions. This VMT is also spread across more delivery vehicles, which will increase the level of congestion on common roadways. Even if an increase in online shopping decreases consumers in-person shopping trips (which has been more recently contested in current literature and network studies), there will still be a net increase in heavy duty, logistic vehicles on the roads. Travel times will likely therefore increase, which may actually slow down delivery times and lead to even more delivery vehicles. Estimates suggest that by 2030, drivers in most metropolitan areas will experience commute times that are roughly 21% (11 minutes) longer, due in large part to the estimated 36% increase in the number of delivery vehicles on the road (World Economic Forum, 2020; Tokar et al., 2021). As this traffic moves out of the city, it decreases some congestion on urban roads but increases traffic flow in previously low-congestion areas, triggering the need for investment in better infrastructure, such as traffic signals and new roads, in those areas.

Traffic congestion also leads to increased emissions. By 2030, carbon dioxide emissions are expected to increase by 6% million tons, a 36% increase, since 2019 (Toussaint, 2020) due to increased e-commerce traffic. Other estimates project emissions will increase by 32% due to congestion (Tokar et al., 2021). And this increase in emissions isn't limited to vehicles—logistic companies also rely on expanding fleets of airplanes, which are even heavier consumers of fossil fuel (Tokar et al., 2021). Today, about 50% of packages are delivered in three days or less (Panko, 2020), and if consumer demand drives this to 90%, requiring ever more delivery trucks, emissions are expected to rise by over 15% (Muñoz-Villamizar et al., 2021), in addition to previously discussed rise. Clearly, e-commerce activity has the potential to cause a range of negative transportation impacts, making infrastructure change necessary to mitigate these problems and facilitate growth.

1.5.1. How Governments Can Mitigate the Negative Impacts

Concentrated emissions and heightened congestion levels generally decrease the quality of life in a region. Therefore, local and regional governments must negotiate the placement of logistic facilities and otherwise control and mitigate the negative effects that the facilities and the logistic industry can have on the region. Political leaders and policymakers must implement new regulations and standards to address the potential consequences accompanying an increase in e-commerce. Some areas in which to consider government regulation include energy restrictions, limits on driver hours, transportation limitations, land-use regulations, and more.

Land-use regulation, such as stricter zoning laws, may disincentivize logistic companies to move to an area, because the restrictions, increased costs, and other construction and development factors they must work around are too burdensome. A warehouse typically must be built in an industrial zone. In the Austin area, only 6.6% of land is zoned for industrial use, and of that, only 38% is actually being used for industrial purposes (including logistic facilities) (Walters and Engstrom, 2020). Austin, like most cities, is also rezoning significant portions of this small area to no longer be industrial. This could be done preemptively in some already high-trafficked, outer edges of cities or suburbs or an area predetermined as a "strategic facility location" by a logistic company or a regional government. Laws in New York and California are combating emissions and traffic issues by mandating certain types of environmentally friendly packaging materials, off-peak delivery hours, electric delivery vehicles or delivery drones, and various other requirements. These may deter a logistic company from building in specific regions across the state, and will decrease the negative impacts if it does move into an area (Mohan, 2019; Tabuchi, 2020; Tokar et al., 2021). Similar restrictions could be implemented in metropolitan areas across Texas.

1.6. Summary

The growth of e-commerce and the sprawl of logistic facilities are shifting travel trends and increasing emissions. The increased demand for online goods and faster deliveries alongside shifts in facility placements have loaded more vehicles into the system, which has already compounded congestion in urban and suburban areas. As e-commerce continues to rise, logistic companies will build facilities in closer proximity to already crowded and congested areas, which will only increase the negative impacts on traffic and the environment. Logistic companies are strategic about picking the optimal location for the investment of building a facility. It is now up to local and regional governments to try to monitor and shape logistic companies' decisions to maintain the quality of life for their community.

In-depth reviews of each subsection within this chapter are meticulously conducted in connection with the respective products associated with this project. Consequently, in this project report, we reference out details on logistic or e-commerce company market trends (found in Product 1), Texas policies and standards potentially influencing facility placement (found in Product 1), e-commerce company data specific to the case study region (Products 2 and 3), and macro travel trends triggered by the growth of e-commerce (Product 4). For more comprehensive information on these subjects, kindly refer to the associated products. Notably, this report provides a comprehensive overview of the development of facility placement criteria (Chapter 2), along with guidelines for utilizing the forecasting tool (Product 5) and the geographic prototype (Product 6).

Chapter 2. Determine Optimal Placement Strategies and Criteria

2.1. Introduction

Logistical processes and infrastructure are continually changing and adjusting to market factors. For example, urban centers are generally not as well connected to the multi-modal freight network that connects global economies. However, consumers are demanding faster and more reliable delivery of their purchases. On one side, as a part of logistics sprawl, logistical hubs are moving away from urban centers and towards highways, railroad networks, and intermodal terminals, which are located in more rural or fringe parts of a region. The cost of shifting a facility further away from the consumer is mitigated by the increased efficiency of avoiding the collection and distribution of freight in dense, congested central business districts. Overall, when moved to fringe locations, logistics costs are reduced, and, ultimately, the cost to the consumer decreases (Kang, 2020). On the other side, logistic facilities are moving closer to dense population, employment, and transportation hubs to keep pace with the rising delivery demands from consumers. Disappointing a customer because an item is not delivered in time due to a lengthy delivery distance will lower their loyalty to the company and may indirectly create a huge financial burden for the logistic company. To balance both strategies, logistic companies must be tactical in their placement of new facilities and methodically weigh the pros and cons of either moving away from population hubs or moving closer. These shifts and the need for methodical placement-decision strategies have been amplified as companies navigate the twists and turns from the e-commerce boom during the COVID-19 pandemic and beyond.

As e-commerce booms, several companies have emerged as front-runners in the industry and have cultivated their online identities and networks across the world, the country, and the state of Texas. In order to further analyze its growth, we will split the e-commerce industry into categories—shipping companies (such as UPS and FedEx), retail companies (specifically those with a significant online presence such as Target and Walmart), and companies that do both (such as Amazon). Each category and company are dependent on the other. Retail companies such as Target utilize shipping companies such as FedEx to deliver products. Amazon Logistics delivers most of the items sold on its online platform, but the company also relies on shipping companies such as FedEx to deliver some of its goods.

In this task, and for the remainder of the project, e-commerce companies will be categorized into the following:

- **Shipping companies:** In Texas, UPS and FedEx have several warehouse centers, as well as more than 10,000 stores and drop-off locations.

- **Brick-and-mortar (BM) retail stores:** Some retail stores, such as Target and Walmart, now partially act as suburban or intercity fulfillment and distribution centers.

- **Unique cases:** Amazon has thirty-two warehouses across Texas, with two more projected to open in 2024. It also has more than 200 smaller fulfilment or distribution centers. In North Texas alone, Amazon employs more than 37,000 workers.

In coming years, each company type is projected to grow in unique ways, and their physical presences (as opposed to an online presence) in a geographic area (warehouses, fulfillment centers, and distribution [WaFuD] facilities) must be evaluated. Based on market trends, it is projected that an additional 1.5 billion square feet of warehouse space will be required by 2025, and real estate for shipping and retail companies will be in high demand (Leonard, 2021). From 2003 to 2008, logistics facilities across the US moved further away from urban areas due to cost and land restrictions. However, the national trend of suburban sprawl has declined since the economic recession in 2008 (Kang, 2020), as developers began to site logistics facilities on the outskirts of urban areas at urban-suburban boundary points as opposed to external fringes of existing suburban areas bordering rural areas. In 2016, the average warehouse was about twenty-four miles from the nearest associated logistics hub (such as an airport or port) and twenty-seven miles from a dense population concentration (Kang, 2020). E-commerce demand and supply have shifted the trend such that most warehouses now are located fewer than twenty miles from the nearest residential, employment, or transportation hub, while most fulfillment or distribution centers are located fewer than ten miles from the closest hub (Baglio et al., 2021). Although there is less spatial sprawl, due to facilities' placement closer to highly populated areas, there is more sprawl across regions due to an overall increase in the development of logistics facilities. Logistic companies are being forced to think strategically about how and where to invest their time and to meet the adjusted delivery expectations of consumers, especially as e-commerce continues to strengthen its hold on consumer purchase behavior.

In order to keep up with the changes in e-commerce demand and supply, logistics companies must invest in new facilities in ideally placed locations across the state of Texas. For example, Amazon's customer base is more urban than rural, so it must place most of its facilities on the urban fringe. On the other hand, UPS and FedEx serve relatively more rural areas and thus have more warehouses located in geographically remote areas. While expanding, Amazon will likely avoid placing its facilities in rural areas: only 11 percent of its shipping is rural compared to 25 percent of UPS and FedEx deliveries (Supply Chain Dive, 2019). Amazon's strategy benefits UPS and FedEx by allowing them to control the market in rural areas; Amazon, in fact, uses FedEx for many of its rural deliveries. This chapter will focus on strategies (or criteria) driving a company's warehouse location choice, to include several key decision-components, such as proximity to existing infrastructure and communities, as well as costs and investments for facility construction.

Based on the logistics companies' approaches for selecting facility locations from Task 2 (P1, P2, P3), and the evaluation and database developed in Task 3 (P4), a framework of the main criteria and strategies used by e-commerce companies in locating a new facility is developed. The resulting forecasting framework to has been customized to account for variances within three unique region types: urban, suburban, and rural (we have combined 'large urban region' with 'mid-to-small urban region,' as findings from the previous tasks reveal little variation in facility presence in either urban category). Such customization is needed because strategies may differ from region to region due to differing land-use zoning, regulations, standards, physical space, e-commerce demand, and costs.

In addition to the placement criteria, the forecasting framework also employs an optimization-based approach to predict whether or not a company would choose to develop a facility in a region in the first place. We suggest that facility placement is not only to satisfy demand, as our original placement criteria indicated, but is also related to maximizing profit for a company.

Ultimately, the forecasting framework provides qualitative guidelines for the facility location prediction tool developed in Task 5 (P5).

2.2. Criteria for Facility Placement

There are five major factors that have an influence on the placement of logistics facilities: (1) geographic, (2) spatial, (3) temporal, (4) demographic, and (5) market. Geographic factors focus on determining where the region is located relative to macro-location considerations (i.e., proximity to large population centers of the state). Spatial factors focus on determining how well the region is connected to the larger transportation network of the state and to consumer residences in its immediate vicinity. This includes micro-location considerations associated with the nature and quality of the region's transportation infrastructure, the region's facilities, and regional multi-modal hubs. Temporal factors determine how travel patterns vary over the course of the days, weeks, months, and years in the region. Demographic factors determine the demographic composition of the population in the region (age, employment patterns, lifecycle patterns, and consumer expenditure patterns). Finally, market factors determine the current state of the economy in a region and revenue trends of e-commerce companies from current operations.

The research team developed the following twelve strategies based on the five major facility location factors just discussed.

1. Current Presence in Relevant Region
    - Reflection of the current status of the company's existence and market presence in that region type. This includes the location of existing warehouses, as well as the promise of quick delivery services, such as two day or next day shipping.
2. Proximity to Highway
    - Determination of whether the company prioritizes the placement of facilities in close proximity to highways.
3. Proximity to Airport
    - Determination of whether the company prioritizes the placement of facilities in close proximity to airports.
4. Proximity to Port
    - Determination of whether the company prioritizes the placement of facilities in close proximity to ports.
5. Proximity to Rail
    - Determination of whether the company prioritizes the placement of facilities in close proximity to railways.
6. Proximity to Existing Facility (of any company type)
    - Determination of whether the company prioritizes the placement of facilities in close proximity to the company's existing facilities.
7. Proximity to (or placement within) Population/Employment Hubs
    - Determination of whether the company prioritizes the placement of facilities near or within densely populated regions (which is categorized by either high in population or high in number of companies/jobs).
8. Minimize Construction and Land Costs

- Determination of whether the company prioritizes the minimization of construction and land costs.

9. Desire for New Build
   - Evaluation of whether, when investing in a new facility, the company builds the facility from scratch rather than retrofitting an existing building and site.
10. Desire to Own Facility
    - Assessment of whether a company is purchasing the land and related facility infrastructure, as opposed to leasing the space for a set period of time.
11. Maximize Facility Size
    - Estimation of facility size.
12. Effect of Traffic Flow
    - To what extent does the existing traffic and congestion around the site effect placement decisions.

Within the framework, each of the three-e-commerce company types (shipping companies, BM retail stores, and unique cases), have been positioned on each of the twelve criteria listed above and with regard to the three region-types (urban, suburban and rural). We will quantify each criterion on a three-point scale (low, medium, and high priority). Evaluation of each area is based on previous literature that has been cited in the discussion of each category below. The qualitative scales for each criterion are described in Table 1.1, 1.2, and 1.3.

Table 2.1 Defining the Scales for the Placement Criteria

Scale	Current Presence in Relevant Region	Proximity to Highway	Proximity to Airport	Proximity to Port	Proximity to Rail
Low	Company does not prioritize facility presence in this region, and rarely are existing facilities found here	On average, facilities are placed more than 5 miles from the nearest highway	On average, facilities are placed more than 40 miles from the nearest airport	On average, facilities are placed more than 40 miles from the nearest port	On average, facilities are placed more than 40 miles from the nearest rail line or station
Medium	Company facility presence in this region exists but it is not the main market for the company	On average, facilities are placed between 2 and 5 miles from the nearest highway	On average, facilities are placed between 20 and 40 miles from the nearest airport	On average, facilities are placed between 20 and 40 miles from the nearest port	On average, facilities are placed between 20 and 40 miles from the nearest rail line or station
High	Company highly prioritizes its facility presence in this region	On average, facilities are placed under 2 miles from the nearest highway	On average, facilities are placed under 20 miles from the nearest airport	On average, facilities are placed under 20 miles from the nearest port	On average, facilities are placed under 20 miles from the nearest rail line or station

Table 2.2 Defining the Scales for the Placement Criteria

Scale	Proximity to Existing Facility	Proximity to Population / Employment Hubs	Minimization of Construction and Land Costs	Desire for New Build	Desire to Own Facility
Low	On average, facilities are placed more than 15 miles from existing facility	On average, facilities are placed more than 15 miles from the nearest hub	These companies do not prioritize the minimization of construction and land costs (money matters less)	The majority of facilities are developed in existing or retrofitted infrastructure	These companies lease the majority of their facilities
Medium	On average, facilities are placed between 5 and 15 miles from existing facility	On average, facilities are placed between 5 to 15 miles from the nearest hub	These companies somewhat prioritize the minimization of construction and land costs (money matters somewhat)	There is a fairly even split between new build and retrofitted facilities	There is a fairly even split between owned and leased facilities
High	On average, facilities are placed fewer than 5 miles from existing facility	On average, facilities are placed fewer than 5 miles from the nearest hub	These companies highly prioritize the minimization of construction and land costs (money matters more)	Most, if not all, of these companies' facilities are built from scratch	These companies own the majority of their facilities

Table 2.3 Defining the Scales for the Placement Criteria

Scale	Maximize Facility Size	Effect of Traffic Flow
Low	Company facility size is on the smaller side (less than ~300,000 sq. ft).	Existing traffic flow is of little consideration on facility placement.
Medium	Company facility size is between 300,000 and 600,000 sq. ft.	Existing traffic flow is of some consideration, though the impact on congestion would be minimal if the facility is introduced.
High	Company builds the largest facilities (more than ~600,000 sq. ft).	Existing traffic flow is highly considered when placing facility due to the new facility's significant impact on traffic in the region and the concerns raised by the community and local government.

2.3. Framework Review

Based on the findings from Tasks 2 (P1, P2, P3) and 3 (P4) regarding current facility locations, we have developed a framework that establishes a ranking of the importance of fourteen unique facility placement strategies for the three e-commerce company categorizations, as well as by region-type. Tables 1.4, 1.5, and 1.6 provide an overview of each rank assignment, separated by region-type; subsequent subsections review the methodology and theory behind each rank assignment. Subsections are organized such that we review one criterion at a time, further segmenting it into region type, and then even further on a company-type-specific basis (in terms of the three company types). Many of the criterion reviews are based on spatial analysis of current warehouse, fulfillment centers, and distribution centers (WaFuD) placement across Texas. This analysis, combined with the findings from Tasks 2 (P1, P2, P3) and 3 (P4) (existing market reports and company initiatives), help us form a justification for each rank assignment. Refer to P1 of this project for the original data sources and citations for each rank.

2.3.1. Current Presence in Relevant Region

- Urban
  - Shipping and Retail: **Medium**
    - WaFuDs are typically located on the outskirts of urban regions, but rarely within the actual region.
  - Shipping: **Medium**
    - WaFuDs are typically located on the outskirts of urban regions, but rarely within the actual region.
  - Retail: **Low**
    - Rarely are these WaFuDs located within urban regions.
- Suburban
  - Shipping and Retail: **High**
    - About 80 percent of Amazon's WaFuDs are located in the suburbs.
  - Shipping: **High**
    - WaFuDs are generally located in suburban regions, in order to have delivery access to both the suburban and urban populations.
  - Retail: **Medium**
    - While many of their storefronts are located in suburban regions, the majority of retail WaFuDs are found in more remote and isolated areas, between multiple urban/suburban areas.

- Rural
    - Shipping and Retail: **Low**
        - Roughly a third of all Americans live within twenty miles of an Amazon distribution center, though this number is much smaller for rural areas.
    - Shipping: **Low**
        - Only some shipping companies deliver to post office boxes (commonly found in rural areas), and many shipping companies rely on USPS to deliver their items.
    - Retail: **Medium**
        - Although not very prevalent, WaFuDs may be located in these areas if the rural region is within a 30-mile radius of an urban area. The one exception is Walmart, which focuses on serving rural regions, along with non-rural regions.

2.3.2. Proximity to Highway

- Urban (using San Antonio as the urban center)
    - Shipping and Retail: **High**
        - Google Earth was utilized to determine that these WaFuDs are typically located near highway interchanges.
    - Shipping: **Medium**
        - Google Earth was utilized to determine that these WaFuDs are typically located near a highway interchange, but further from the highway than the shipping and retail WaFuDs.
    - Retail: **High**
        - Google Earth was utilized to determine that these WaFuDs are typically located near a highway interchange.
- Suburban (using Lago Vista as the suburban area)
    - Shipping and Retail: **High**
        - Google Earth was utilized to determine that these WaFuDs are typically located near a highway interchange.
    - Shipping: **High**
        - Google Earth was utilized to determine that these WaFuDs are typically located near a highway interchange.
    - Retail: **High**
        - Google Earth was utilized to determine that these WaFuDs are typically located near a highway interchange.

- Rural (using Hutto as the rural area)
  - Shipping and Retail: **High**
    - Google Earth was utilized to determine that these WaFuDs are typically located near a highway interchange.
  - Shipping: **High**
    - Google Earth was utilized to determine that these WaFuDs are typically located near a highway interchange.
  - Retail: **High**
    - Google Earth was utilized to determine that these WaFuDs are typically located near a highway interchange.

2.3.3. Proximity to Airport

- Urban (using San Antonio as the urban center)
  - Shipping and Retail: **High**
    - Google Earth was utilized to determine that these WaFuDs are typically located within proximity to an airport.
  - Shipping: **Low**
    - Google Earth was utilized to determine that these WaFuDs are not typically located within proximity to an airport.
  - Retail: **Medium/High**
    - Google Earth was utilized to determine that these WaFuDs are typically located within proximity to an airport.
- Suburban (using Lago Vista as the suburban area)
  - Shipping and Retail: **Low**
    - Google Earth was utilized to determine that these WaFuDs are not typically located within proximity to an airport.
  - Shipping: **High**
    - Google Earth was utilized to determine that these WaFuDs are typically located within proximity to an airport.
  - Retail: **Low**
    - Google Earth was utilized to determine that these WaFuDs are not typically located within proximity to an airport.
- Rural (using Hutto as the rural area)
  - Shipping and Retail: **High**
    - Google Earth was utilized to determine that these WaFuDs are typically located within proximity to an airport.

- Shipping: **High**
  - Google Earth was utilized to determine that these WaFuDs are typically located within proximity to an airport.
- Retail: **High**
  - Google Earth was utilized to determine that these WaFuDs are typically located within proximity to an airport.

2.3.4. Proximity to Port

- Urban (using Lake Jackson as the urban center)
  - Shipping and Retail: **Low**
    - Google Earth was utilized to determine that these WaFuDs are not typically located within proximity to a port.
  - Shipping: **Medium**
    - Google Earth was utilized to determine that these WaFuDs are somewhat located within proximity to a port.
  - Retail: **Low**
    - Google Earth was utilized to determine that these WaFuDs are not typically located within proximity to a port.
- Suburban (using Freeport as the suburban area)
  - Shipping and Retail: **Low**
    - Google Earth was utilized to determine that these WaFuDs are not typically located within proximity to a port.
  - Shipping: **Medium**
    - Google Earth was utilized to determine that these WaFuDs are somewhat located within proximity to a port.
  - Retail: **Low**
    - Google Earth was utilized to determine that these WaFuDs are not typically located within proximity to a port.
- Rural (using Brazoria as the rural area)
  - Shipping and Retail: **Low**
    - Google Earth was utilized to determine that these WaFuDs are not typically located within proximity to a port.
  - Shipping: **Low**
    - Google Earth was utilized to determine that these WaFuDs are not typically located within proximity to a port.

- Retail: **Low**
  - Google Earth was utilized to determine that these WaFuDs are not typically located within proximity to a port.

2.3.5. Proximity to Rail

- Urban (using Houston as the urban center)
  - Shipping and Retail: **Low/Medium**
    - Google Earth was utilized to determine that these WaFuDs are somewhat located within proximity to a railway.
  - Shipping: **Low/Medium**
    - Google Earth was utilized to determine that these WaFuDs are somewhat located within proximity to a railway.
  - Retail: **Medium**
    - Google Earth was utilized to determine that these WaFuDs are somewhat located within proximity to a railway.
- Suburban (using Freeport as the suburban area)
  - Shipping and Retail: **Medium**
    - Google Earth was utilized to determine that these WaFuDs are somewhat located within proximity to a railway.
  - Shipping: **Low**
    - Google Earth (using Freeport as the suburban area) was utilized to determine that these WaFuDs are not typically located within proximity to a railway.
  - Retail: **Low**
    - Google Earth (using Freeport as the suburban area) was utilized to determine that these WaFuDs are not typically located within proximity to a railway.
- Rural (using Brazoria as the rural area)
  - Shipping and Retail: **Low**
    - Google Earth was utilized to determine that these WaFuDs are not typically located within proximity to a railway.
  - Shipping: **Medium**
    - Google Earth was utilized to determine that these WaFuDs are somewhat located within proximity to a railway.
  - Retail: **Medium**

        - Google Earth was utilized to determine that these WaFuDs are somewhat located within proximity to a railway.

2.3.6. Proximity to Existing Facility (of any company type)

- Urban
    - Shipping and Retail: **High**
        - There are nine Amazon facilities located within a twenty-mile radius of Austin.
    - Shipping: **High**
        - The highest number of FedEx facilities in the U.S. are located in Houston, Dallas, Austin, and San Antonio.
    - Retail: **High**
        - Walmart has twenty-nine stores in San Antonio.
- Suburban (using Cinco Ranch as the suburban area)
    - Shipping and Retail: **High**
        - Google earth was utilized to determine that there were ten Amazon facilities located within a five-mile radius of the city.
    - Shipping: **Low**
        - The average distance between UPS stores is about fifteen miles in suburban areas. Additionally, Google Earth was utilized to determine that there are very few shipping companies located near each other in Cinco Ranch.
    - Retail: **Medium**
        - Google Earth was utilized to determine there are one Target facility, eight Walmart facilities, and seven H-E-B facilities within a five-mile radius of the suburb.
- Rural (using Brazoria as the rural area)
    - Shipping and Retail: **Low**
        - Although roughly a third of all Americans live within twenty miles of an Amazon distribution center, though this number is closer to 0 percent for rural areas.
    - Shipping: **Low**
        - Google Earth was utilized to determine that there is one UPS center in the area.
    - Retail: **Low**
        - Google Earth was utilized to determine that there are no Target or Walmart locations in the area.

2.3.7. Proximity to (or placement within) Population/Employment Hubs

- Urban
  - Shipping and Retail: **Medium**
    - Typically, companies focus their larger WaFuD developments on the outskirts of big cities. While near dense areas, these companies do not focus on being directly next to the densely populated and job-dense areas within the urban region (in the range of 5–15 miles from the denser areas). Additionally, companies are building mini-warehouses within the cities to serve the dense areas. The mini-warehouses, however, may not generate the same traffic (and therefore concern) as a full-sized WaFuD.
  - Shipping: **Medium**
    - A sixty-mile radius of a dense presence of shipping companies' WaFuDs are maintained around urban areas extending into the suburbs. Typically though, the largest warehouses for any shipping company are built on the outskirts of urban regions. So, the presence near the dense population and employment hubs is high, but these facilities are usually at least 10–15 miles away from an urban center and commonly on the outskirts of a city (and in the suburbs).
  - Retail: **Low**
    - Generally, there is a low presence of distribution centers for retail companies near dense population and employment hubs. However, many retail companies have converted storefronts into "dark stores" to serve denser areas.
- Suburban
  - Shipping and Retail: **High**
    - Amazon has an objective to build 1,000 more warehouses in suburban neighborhoods across the U.S.
  - Shipping: **Medium**
    - The average distance between a shipping company's facility and a dense suburban area is between 10 and 15 miles.
  - Retail: **Medium**
    - While there is a high presence for both retail storefronts and solely e-commerce fulfillment centers near densely populated areas within suburban regions, there is a lower presence of their warehouses and larger fulfillment centers.
- Rural
  - Shipping and Retail: **Low**

        - Does not focus its facilities in rural areas. Delivers to these areas solely through shipping companies, such as USPS.
    - Shipping: **Low**
        - In rural areas, facilities are located more than fifteen miles from the nearest dense area.
    - Retail: **Medium**
        - Due to cheaper land, many retail companies are focusing the placement of future WaFuDs in rural areas, and some retail companies aim to focus on the rural market. For example, Walmart's objective is to ensure fulfillment of online orders at "exceptional speeds" for at least 90 percent of the US population.

2.3.8. Minimization of Construction and Land Costs

There is no difference for each company type's ranking for this criterion based on region-type.

- Shipping and Retail: **Low**
    - Amazon prioritizes buying land and buildings for the investment of all future facilities. Amazon is willing to heavily invest into new facilities and places low importance on the construction of cheaper facilities. Money matters less to Amazon.
- Shipping: **Medium**
    - Shipping companies prefer cheaper real-estate costs.
- Retail: **High**
    - Retail companies prioritize cheaper construction and real-estate costs.

2.3.9. Desire for New Build

There is no difference for each company type's ranking for this criterion based on region-type.

- Shipping and Retail: **High**
    - Rather than retrofit a department store, Amazon prefers to demolish a vacated building or buy an empty lot and construct its WaFuDs from the ground up.
- Shipping: **Low**
    - Shipping companies commonly retrofit old warehouses to be cost efficient.
- Retail: **Medium**

- There is no trend toward new builds nor retrofitting WaFuDs for retail companies.

2.3.10. Desire to Own the Facility

There is no difference for each company type's ranking for this criterion based on region-type.

- Shipping and Retail: **High**
  - Amazon typically owns all of its facilities.
- Shipping: **Medium**
  - The majority of shipping companies trend toward owning their facilities, with some exceptions.
- Retail: **High**
  - Most retail companies will buy their own land for their centers, instead of leasing.

2.3.11. Maximize Facility Size

There is no difference for each company type's ranking for this criterion based on region-type.

- Shipping and Retail: **High**
  - The average Amazon WaFuD is about 800,000 sq. ft.
- Shipping: **Low**
  - The average shipping company's WaFuD is between 150,000 to 350,000 sq. ft.
- Retail: **High**
  - The average retail company's WaFuD is 800,000 sq. ft.

2.3.12. Effect of Traffic Flow

There is no difference between urban and suburban regions for each company type's ranking for this criterion.

- Urban and Suburban
  - Shipping and Retail: **High**
    - As the areas are already so dense, companies must consider their own impact on the current traffic flow due to delivery traffic and WaFuD worker traffic. As these facilities are usually huge, they will generate a high volume of traffic.
  - Shipping: **High**

        - As the areas are already so dense, companies must consider their own impact on the current traffic flow due to delivery traffic and WaFuD worker traffic. As these facilities are fairly large, they will generate a high volume of traffic.
    - Retail: **Medium**
        - Though these facilities are large, there are not as many delivery trips being made in and out of strictly retail facilities. They will, therefore, not disturb the traffic flow as much as a purely delivery-based facility. Because of this, the company may not need to consider the current traffic patterns and volumes before placing their facility.
- Rural:
    - Shipping and Retail: **Low**
        - Company will unlikely be affected by the traffic in low density areas.
    - Shipping: **Low**
        - Company will unlikely be affected by the traffic in low density areas.
    - Retail: **Low**
        - Company will unlikely be affected by the traffic in low density areas.

Table 2.4 Location Decision Criteria Rankings for Urban Placement

Company Type	Current Presence in Relevant Region	Proximity to Highway	Proximity to Airport	Proximity to Port	Proximity to Rail	Proximity to existing facility	Close proximity to Population/Employment Hubs	Minimize Construction and Land Costs	Desire for New Build	Desire to Own Facility	Maximize Facility Size	Effect of Traffic Flow
Shipping and Retail	Medium	High	High	Low	Medium	High	Medium	Low	High	High	High	High
Shipping	Medium	Medium	Low	Medium	Low	High	Medium	Medium	Low	Medium	Low	High
Retail	Low	High	High	Low	Medium	High	Low	High	Medium	High	High	Medium

Table 2.5 Location Decision Criteria Rankings for Suburban Placement

Company Type	Current Presence in Relevant Region	Proximity to Highway	Proximity to Airport	Proximity to Port	Proximity to Rail	Proximity to existing facility	Close proximity to Population/Employment Hubs	Minimize Construction and Land Costs	Desire for New Build	Desire to Own Facility	Maximize Facility Size	Effect of Traffic Flow
Shipping and Retail	High	High	Low	Low	Medium	High	High	Low	High	High	High	High
Shipping	High	High	High	Medium	Low	Low	High	Medium	Low	Medium	Low	High
Retail	Medium	High	Low	Low	Low	Medium	Medium	High	Medium	High	High	Medium

Table 2.6 Location Decision Criteria Rankings for Rural Placement

Company Type	Current Presence in Relevant Region	Proximity to Highway	Proximity to Airport	Proximity to Port	Proximity to Rail	Proximity to existing facility	Close proximity to Population/Employment Hubs	Minimize Construction and Land Costs	Desire for New Build	Desire to Own Facility	Maximize Facility Size	Effect of Traffic Flow
Shipping and Retail	Low	High	High	Low	Low	Low	Low	Low	High	High	High	Low
Shipping	Low	High	High	Low	Medium	Low	Low	Medium	Low	Medium	Low	Low
Retail	Medium	High	High	Low	Medium	Low	Medium	High	Medium	High	High	Low

2.4. Optimization-Based Forecasting

The previous sections of the report discussed how facility placement can be correlated to geographic, spatial, temporal, demographic, and market factors, and how this correlation varies for different logistics company types. These factors can be used to forecast where new facilities might be built, assuming that these observed correlations continue in the future. A complementary approach is to directly consider the problems faced by each logistics company. From a business perspective, at what point does it make sense to construct additional facilities? And where should such facilities be located to maximize profit? Combined with forecasts of demand growth and land use, models can be used to estimate the rate at which new facilities will be constructed, and where specifically in a region.

The optimization literature considers a range of logistics problems under the umbrella label of "facility location problems." Facility location problems typically consider the perspective of a single firm that must decide where to locate facilities (e.g., warehouses or distribution centers) in order to minimize a cost function. This cost represents transportation costs between the facilities and the ultimate destination for products—in this case, the delivery cost between a distribution center and e-commerce consumers—considering that warehouse location affects delivery cost substantially. Costs are also associated with opening facilities at particular locations, reflecting the difference in real estate costs over a region. The key tradeoff these models seek to capture is the tension between locating distribution centers close to demand (which minimizes transportation cost) and constructing them where land is cheaper (which is typically far from the demand).

There are two broad approaches to solving facility location problems. The first uses the language of discrete optimization, formulating the facility location problem as a mixed-integer program on a mathematical network, with nodes representing locations of customers and potential facilities. Daskin (1995), Drezner & Hamacher (2002), and Laporte et al. (2019) provide reviews of discrete optimization formulations and solution methods applied to the facility location problem. The advantage of discrete optimization approaches is that they identify specific locations for facilities using a detailed model for the transportation costs; it is straightforward to incorporate vehicle routing optimization problems into the facility location problem. However, the facility location is difficult to solve computationally (NP-hard), especially as the number of facilities grows.

An alternative approach is continuum approximation, which eschews the fine-grained detail of discrete optimization for an aggregate representation of the underlying geography (demand and facility location costs). The resulting models are much easier to solve and are more stable in the face of uncertain data. The latter is especially important, as accurate e-commerce demand forecasts are difficult to obtain. Some precision is lost by moving to a continuum model, but the hope is that the advantages in tractability and stability outweigh this loss of accuracy, in much the same way that continuous probability distributions often provide acceptable (and much simpler) descriptions of an underlying discrete process. Langevin et al. (1996) and Daganzo (1999) have reviews of continuum approximation techniques. One common technique is to find good facility locations by finding a mechanical equilibrium, assuming that each facility is acted on by fictitious forces (demand is an attractive force, while other facilities and the boundary of the region are repulsive forces); see Ouyang & Daganzo (2006) for more on this solution method. Peng et al. (2014) describe how discrete geographic data can be converted to distributions needed for continuum approximation.

Continuum approximation approaches are most suitable for the goals of this research project. Facility location decisions are based on private, proprietary data and forecasts that e-commerce companies will be hesitant to share. Furthermore, demand must be forecasted into the future, meaning there is additional uncertainty in the inputs to the model. The stability of continuum approximation fits this environment well. An additional advantage of continuum approximation is that closed-form expressions are often available expressing the total cost in terms of the number of facilities, demand distributions, locations of competitors, and so forth.

As some specific examples, continuum approximation models can accommodate the possibility of supply-chain disruptions: whether independent (Cui et al., 2010) or correlated (Li & Ouyang, 2010); competitive markets where multiple firms are locating facilities (Wang & Ouyang, 2013); imperfect information in transportation costs (Yun et al., 2019); emerging delivery technologies such as drones (Li et al., 2020) or crowdshipping (Stokkink & Geroliminis, 2023); and so forth. In all of these applications, continuum approximation reflects complexities in a far simpler way than discrete optimization, creating additional reasons to recommend their use for forecasting where e-commerce firms are likely to locate facilities in the future.

These formulas are complex but straightforward to compute (Campbell, 1993). To illustrate how they may be used to forecast when and where additional facilities are located, assume a cost function of the form $D(f,N,t)$, where f is the demand distribution (a two-dimensional continuous probability density), N is the number of facilities, and t indexes time (the demand distribution and facility costs may be functions of t). The optimal number of facilities to locate at any point in time is

$$N^*(t) = \arg\min_N \{D(f,N,t)\}.$$

This function will be piecewise-constant, with jumps at the time points when the optimal number of facilities changes. In particular, the times t corresponding to an increase $N^*(t)$ represent the times when the additional profit gained from opening an additional facility (more capacity, lower transportation costs) outweighs the associated land acquisition and construction costs. By substituting demand forecasts for f, we can forecast when additional warehouses are likely to be opened. The continuum approximation method can then be used to forecast a likely location for this warehouse, considering where the new demand is, where the existing facilities are, and what the transportation costs are.

This approach is complementary to the methods described in the previous two sections of this chapter. The earlier methods can be used for each firm to estimate parameters which affect their costs and customer locations without relying on proprietary data (using an "inverse optimization" technique). Continuum approximation may either be used on its own (as described in this section), or in conjunction with the methods described earlier as a sanity check that directly considers firm profitability.

2.5. Conclusion

As e-commerce continues to rise, logistic companies must build more and more facilities in order to keep pace with consumer demand in the growth of purchases and consumer expectations for a timely delivery. To meet consumer expectations, logistics companies will build larger facilities in closer proximity to already crowded and congested areas, which will increase the negative impacts on traffic and the environment. Logistics companies are strategic about picking the optimal location for the investment of building a facility.

In this chapter, we first established twelve facility placement criteria and strategies. Next, we determined how each categorization of logistic company emphasizes (or rates) these strategies while choosing a site and location for a new facility (which has been further specified based on in what region-type the facility will be built). The resulting rating system becomes the project's quantitative framework, which will be used as a baseline for the development of the tool/model used to predict and model the locations of future logistic centers. Finally, we complement the facility placement criteria with an optimization-based forecasting method, which establishes, from a business perspective, whether a company would choose to develop a facility in that region in the first place. The qualitative facility placement strategies and criteria established here will be implemented and translated into a decision-based algorithm to forecast future locations.

Chapter 3. Methodology for P5: The Facility Placement Tool

3.1. Introduction

This Chapter outlines the methodology for utilizing the Facility Placement Forecasting Tool in Excel (P5).

3.2. The “Input” Tab

1. Use the dropdown menu to select the Company Type from the following options:
    a. Shipping
    b. Retail
    c. Shipping and Retail
2. Use the dropdown menu to select the Facility Type from the following options:
    a. Warehouse
    b. Fulfillment Center
    c. Distribution Center
3. Use the dropdown menu to select the Region Type from the following options:
    a. Urban
    b. Suburban
    c. Rural

3.3. The “COP Algo” Tab

- **Do not make changes to this tab.**
- This tab contains the Location Decision Criteria (LDC) rankings established in Task 4, meticulously encoded into a location-forecasting algorithm tailored to the specific LDC of each e-commerce company.

3.4. The “POP Algo” Tab

- **Do not make changes to this tab.**
- This tab contains the Facility-based Macro-level Vehicle Miles Travelled (VMT) generation due to e-commerce. These numbers and calculations are based on findings from P1 and from information from the “Travel Pattern Database” table from P4. This is the population-oriented algorithm for the forecasting tool.

3.5. The "Output" Tab

Under the heading "Placement Outputs"

- **Output Overview:** Provides a comprehensive overview of the most crucial location criteria applicable to the respective facility.
- The remainder of the table predicts the location of the future facility based on the:
    - Approximate number of existing facilities of that type in the given region
    - Proximity to a highway
    - Proximity to an airport
    - Proximity to a port
    - Proximity to a rail line
    - Proximity to an existing e-commerce related facility
    - Proximity to a population or employment hub
    - Company's focus on minimizing construction costs
    - Company's emphasis on retrofitting existing facility or new construction
    - Facility's likely size
- Each of these outputs come with a quantitative and qualitative predictive description of the facility's future location.

Under the heading "Travel Generation Outputs"

- **Facility Review:** Provides an overview of the facility type and size.
- Left-most table:
    - The top half of this table predicts the average hourly VMT generated across the entire region based on four different vehicle types due to the size and type of facility that is built.
    - The bottom half of the table predicts the total VMT generated across the entire region, which has been split into different periods of the day.
- Middle text/table:
    - This table allows users to manually input ordinance descriptions and assess their impact on facility placement. By utilizing the traffic generation figures presented in the table above, one can align these values with the permissible thresholds specified in different zoning ordinances. These regulations serve to manage and constrain facility placement in specific areas, given the limitations they impose on VMT generation. Conducting a manual comparison between the VMT numbers in the leftmost table under the same header and the ordinance restrictions is essential for this evaluation.
- Right-most text:
    - This text delineates the existing state of ordinances in Texas (currently none) and provides recommendations for prospective

policies and standards that could influence facility placement and be inserted into the middle table.

Chapter 4. User's Manual for P6: Geographic Prototype in ArcGIS

4.1. Introduction

These guidelines outline the methodology for utilizing the Facility Placement Forecasting Tool in ArcGIS. This document serves as a complementary resource to the recorded live prototype demo conducted during the workshop.

There are two ways in which the prototype can be used:

1. In identifying the location of **one Warehouse, Fulfillment Center, or Distribution Center (WaFuD)** of interest:
   - Comprises the most straightforward use of the Forecasting Tool outputs within the geographic prototype.
2. In locating the projected positions of **all WaFuDs** within a specific timeframe:
   - Requires forecasting the number of facilities in a region over a defined number of years, as informed by E-commerce revenue growth.
   - While not initially part of the project scope, it serves as an illustrative example in the Live Demo.

In this user manual, we review how to administer the second use. When predicting a single WaFuD (or for the first use case), users should follow steps A through D as outlined, and then only perform step E for a single facility.

For the remainder of the user manual, we exemplify the process by geographically situating the forecasted WaFuDs in the San Antonio Region for the year 2028. However, the following steps also offer instructions for customizing the prototype to adapt it for use in different regions. Following the instructions, we offer insights on leveraging the forecasting tool and prototype outputs as crucial inputs for TxDOT's travel demand models, as well as limitations of the prototype.

4.2. Instructions

GIS operations can be performed in many ways to achieve the same outcomes. Below, we illustrate a typical process of creating new layers for each forecast year (2028 and 2033) under each combination (1 and 2). We create new labels, or fields as is often referred to in GIS terminology, for each criterion from Chapter 1. These labels are located in the zoning data layer, making it easy to track the task flow.

A. Prepare initial zoning layer.

   i. Collect zoning data for the cities in study area. The zoning data must contain land-use type and area of land parcels.

   ii. For each city jurisdiction in the study area, identify the land-use codes of any land parcels where existing WaFuDs are placed. Create a new label, say INDUSTRIAL, and set it to 1 in order to label (the rows of) industrial land parcels.

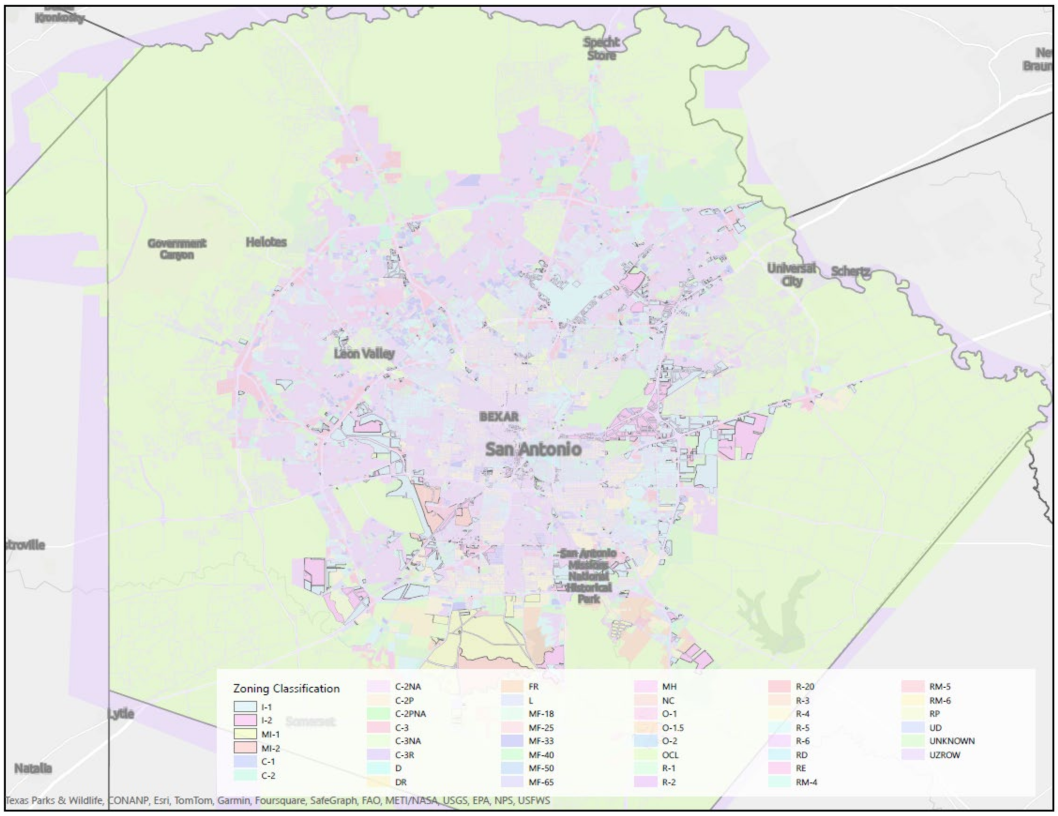

Figure 4.1 All land use zoning codes in City of San Antonio zoning map (industrial zones with boundary)

   iii. Tag eligible land parcels. Assume companies will shortlist land parcels that can accommodate a WaFuD entirely on one land parcel in order to reduce the transaction complexity of buying/leasing multiple adjacent parcels. Label each parcel as Small, Medium, or Large based on the criteria below:

      1. Small: 60,000 square feet (sqft) to 300,000 sqft
      2. Medium: 300,000 sqft to 600,000 sqft
      3. Large: 600,000 sqft to 1,800,000 sqft

Table 4.1 Snapshot of Zoning Layer Attribute Table After Step (A)

OBJECT ID	Zoning	Base Description	Area SQFT	Small	Medium	Large	Cluster
562846	I-1	General Industrial District (Sec. 35-310.13)	481997	0	1	0	Far Northeast
16695	I-2	Heavy Industrial District (Sec. 35-310.14)	1002731	0	0	1	East
597534	I-1	General Industrial District (Sec. 35-310.13)	1550555	0	0	1	West
141413	I-1	General Industrial District (Sec. 35-310.13)	2035390	0	0	1	Periphery

B. Prepare other important layers.

i. Existing WaFuDs: Map the existing facilities in the area, by company type.

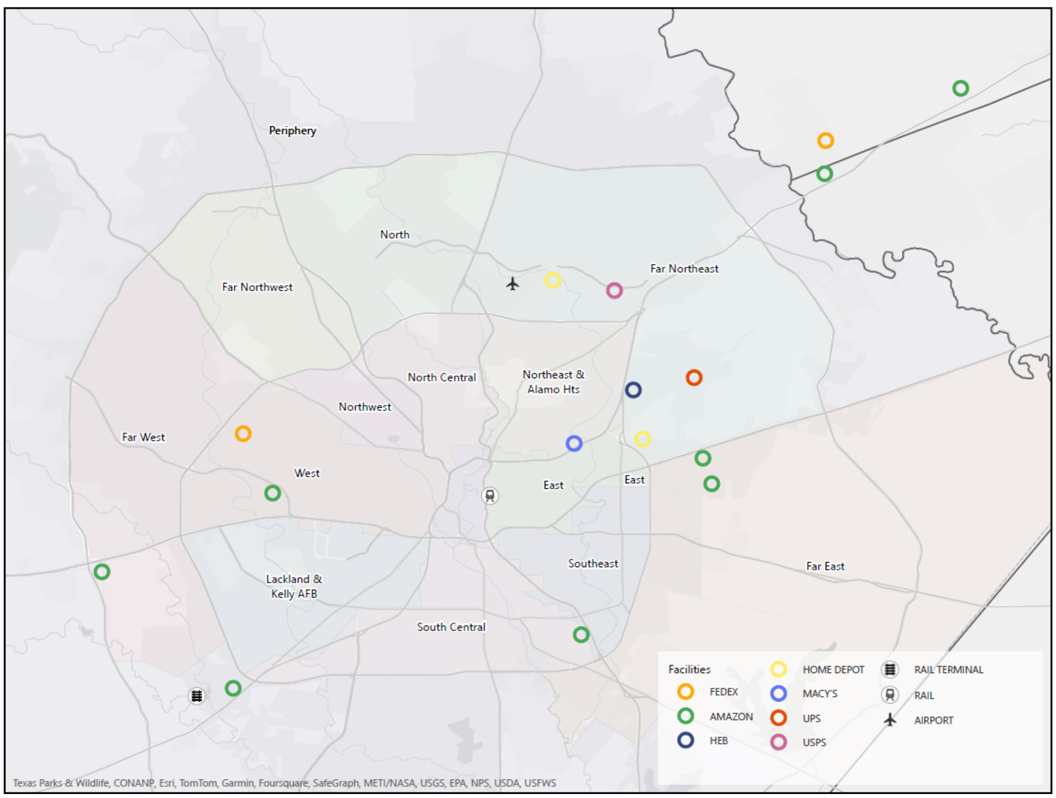

Figure 4.2 Facilities

ii. Map the population and employment hubs. For ease of spatial analysis, convert these hubs into point features.

iii. Create a city polygon layer for each city in the study area. If commonly known neighborhood divisions of cities exist, break each city layer into its respective divisions. This will help aggregate and summarize the sited facilities later.

iv. Create a roadway layer, preferably as a line file with the entire roadway network appearing as a single object. TIGER line shapefiles for Roads are commonly used for this purpose.

C. Prepare buffers to check which land parcels meet the qualifying criteria from Task 4. Dissolved buffers are preferred. These buffers include:

i. Highway buffer

ii. Airport buffer(s)

iii. Port buffer(s)

iv. Existing facility buffer

v. Population and employment hub buffers

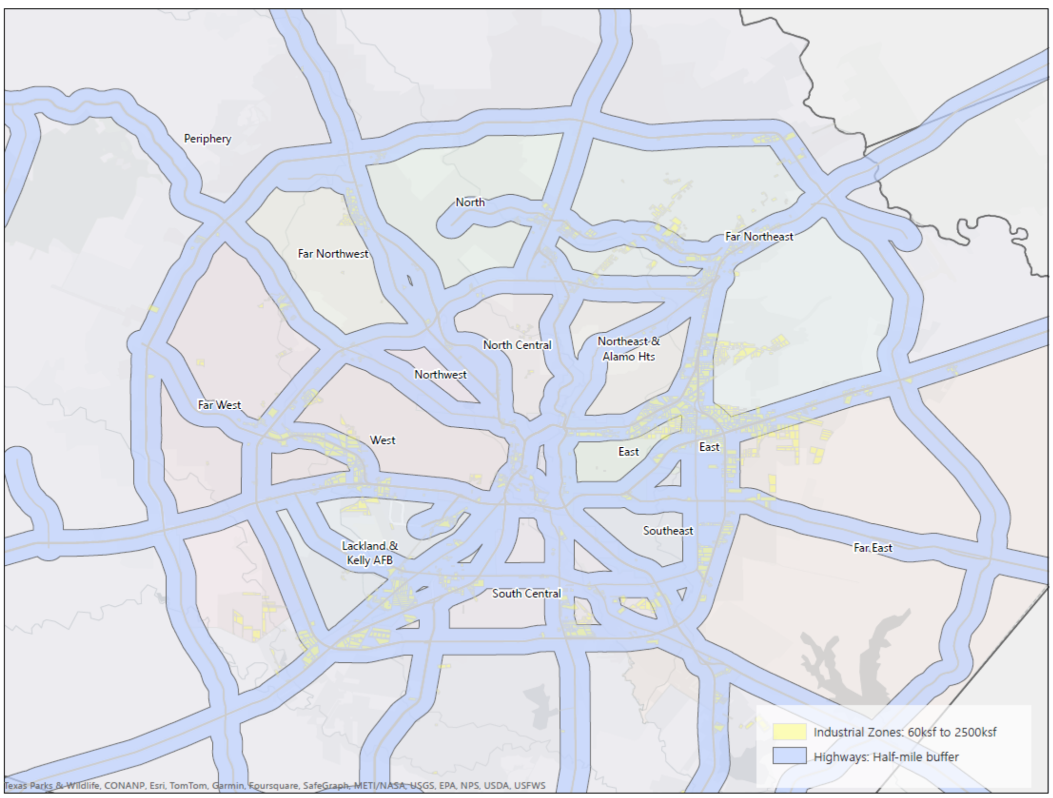

Figure 4.3 Buffer example: Half-mile along the highways

D. Label each parcel as either overlapping with each of the buffers from (C), or not. This can be done in several ways. For example, use the zoning layer as *Input Features* in the *select by location* tool, and then said buffer layer as

Selecting Features. Create a new label identifying the *selected* parcels as 1, and the rest as 0. Repeat the procedure for each buffer. The final layer would have as many new columns as the buffers you identified as overlapping.

E. Determine parcel suitability for each company type: Shipping (S), Retail (R), and Shipping + Retail (SR).

  a. Create three new labels in the zoning layer. For example: S, R, and SR.

  b. Using the selection criteria established in Task 4 for each desired new WaFuD, classify each parcel as eligible for one or more of these company types. For example, a retail company will overlap with highway buffer of 2 or less miles, an airport buffer of under 20 miles, a railway buffer of 20 to 40 miles, and an existing facility buffer of under 5 miles.

  c. The qualifying criteria does not vary by facility types (warehouse, fulfilment center, and distribution center). Therefore, no additional labels are needed.

Table 4.2 Snapshot showing sample fields in the parcel data attribute table (after steps (D) and (E))

OBJECT ID	Zoning	OL B Facilities 5mi	OL B Airport 20mi	OL B Roads 2mi	OL B POPEMP 5mi Dissolve	Shipping (S)	Retail (R)	Shipping and Retail (SR)	SR Small	SR Medium	SR Large
562846	I-1	1	1	1	1	1	1	1	0	1	0
16695	I-2	1	1	1	1	1	<Null>	<Null>	0	0	0
597534	I-1	1	1	1	1	1	<Null>	<Null>	0	0	0
141413	I-1	1	1	1	1	1	1	1	0	0	1
		1	1	1	1	1	<Null>	<Null>	0	0	0

F. For each forecast year (F), create additional labels as needed. In certain applications of the geographical prototype, a single-year forecast may be sufficient. Alternatively, users may choose to project WaFuDs for 5 or 10 years in a given area in other scenarios. Multiple year forecasts will allow for a temporal and spatial element to be added to the location forecasts of a region.

  a. Generate new labels for each unique F and company type.

  b. For example, the analysis for the Combo 1 2028 scenario forecasts one large retail distribution center, one large shipping + retail warehouse, one large shipping + retail fulfilment center, and one medium retail distribution center. This would necessitate four labels.

G. Lastly, subset forecast x combination pairs to create multiple (in this case four) maps. Note: only perform this step if developing multi-year, multi scenario forecasts. Here a “combination” means the total array of size, type, and company of the forecasted WaFuDs based on e-commerce and regional growth calculations.

a. A total of four layers/maps can be generated (2 forecast years x 2 combinations (C)). Maps will be based on the forecast and combination labels created in F.

b. If there are too many locations that qualify for each F, C, and company type, shortlist a few (or just one) per category. Companies will commonly prioritize highway proximity and access over another criterion. Therefore, parcels closest to major highways/interchanges take priority.

c. Prioritization can be applied using buffers or other geographic tools. A rank based on proximity, or just the most proximate to highways of all F x C x company locations, can be identified on the map.

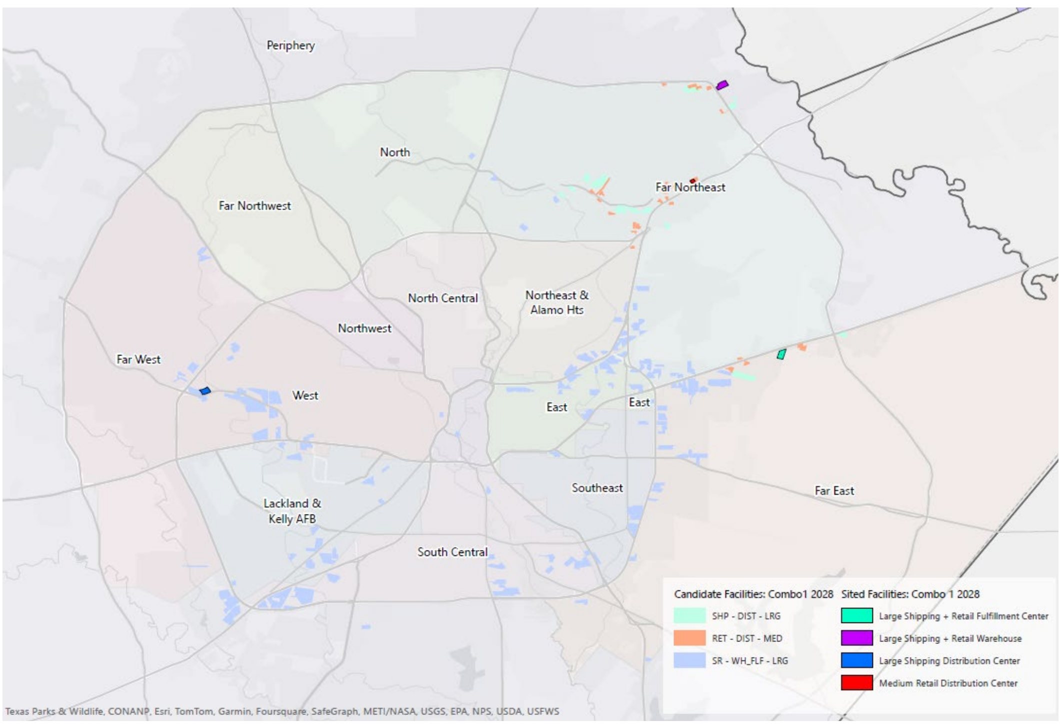

Figure 4.4 Forecast for 2028 combination 1 (final outcome).

4.3. Conclusion

What is excluded from this spatial analysis?

Factors that cannot be spatially measured, or need additional market insights, but would appear as constraints in an optimization search:

1. Construction and land costs.
2. Desire for new build and/or ownership: This is determined by the market's vacancy and availability rates, macroeconomic factors (like availability of capital and existing discount rates), and the company's operating model – leasing vs. ownership of facilities.

Besides these factors, we do not account for the effect of traffic flow and the local transportation planning requirements. In many states, local agencies have been known to charge a transportation impact fee for developments that cause 'significant impact' on the infrastructure and/or the environment.

What if you have multiple candidate locations in steps E and F that meet the criteria?

This is likely to be the case. When it happens, apply stricter criteria to winnow down the locations. The biggest priority for most WaFuDs is easy access to highways and other transportation infrastructure (Gingerich and Maoh, 2019). Therefore, narrowing down search criteria to under a mile or less from major freeways is recommended. Proximity to residential hubs is also very beneficial to WaFuDs. Average proximity to population centers can be used as a secondary criterion to narrow down possible sites.

Ultimately, it is not worth discriminating between proximate candidate parcels; picking any parcel at random should suffice. Because, if several parcels fall in the same transportation analysis zone or an aggregate geography (typically the size of a block group) used in transportation analysis, their precise location does not matter as much.

Why not use Google maps to determine vacancy when siting facilities?

While establishing if a parcel is empty is easy, determining vacancy is not. It is therefore not advisable to rely on Google maps. More information about land occupancy is needed to determine precise site locations with accuracy.

How can this analysis be customized for a new location?

We have outlined a generic workflow for identifying locations where e-commerce companies could locate in the future. The workflow can be easily replicated for locations whose spatial data is available.

How can these results be used in travel demand models?

The results from this geographic analysis can be compared against land use data used in travel models. Travel demand models use transportation analysis zones (TAZs) as the geographic unit of analysis. Cities and metropolitan regions encode these TAZs with land use information (for example, population, employment by industry type, etc.). This information is used to directly estimate how many trips will be generated/attracted by TAZs. The results from our geographic analysis (i.e., the location, sizes, and the number of jobs these facilities will generate) can inform or correct the data encoded in TAZ files.

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Appendix A: Forecast Maps for P6

San Antonio Forecasted E-commerce Facility Location Maps

There are two combinations of forecasted facilities included in this appendix:

1) **Large Facility Focused:** The majority of the facilities are anticipated to have a footprint of 600,000 square feet (sqft) or more (which is considered a "large" facility"). This strategic approach emphasizes a concentration on a smaller number of larger facilities, aimed at efficiently and effectively managing the surge in e-commerce sales growth within the region.

- Combo 1 2028 Map
- Combo 1 2033 Map

2) **Small/Medium Facility Focused**: The majority of the facilities are anticipated to have a footprint of under 300,000 sqft (which is considered a "small" facility) or a footprint between 300,000 to 600,000 sqft (which is considered a "medium" facility). This strategic approach underscores a focus on a greater number of smaller facilities. It addresses the need to regulate traffic generation around each facility by virtue of their more compact sizes.

- Combo 2 2028 Map
- Combo 2 2033 Map

Note: The terms "Warehouse," "Fulfillment Center," and "Distribution Center" are generally interchangeable on these forecast sheets. However, Fulfillment Centers are typically larger than Distribution Centers. Furthermore, it's worth noting that "Shipping and Retail" companies are usually the sole company that operate a Fulfillment Center.

Combo 1 2028 Map

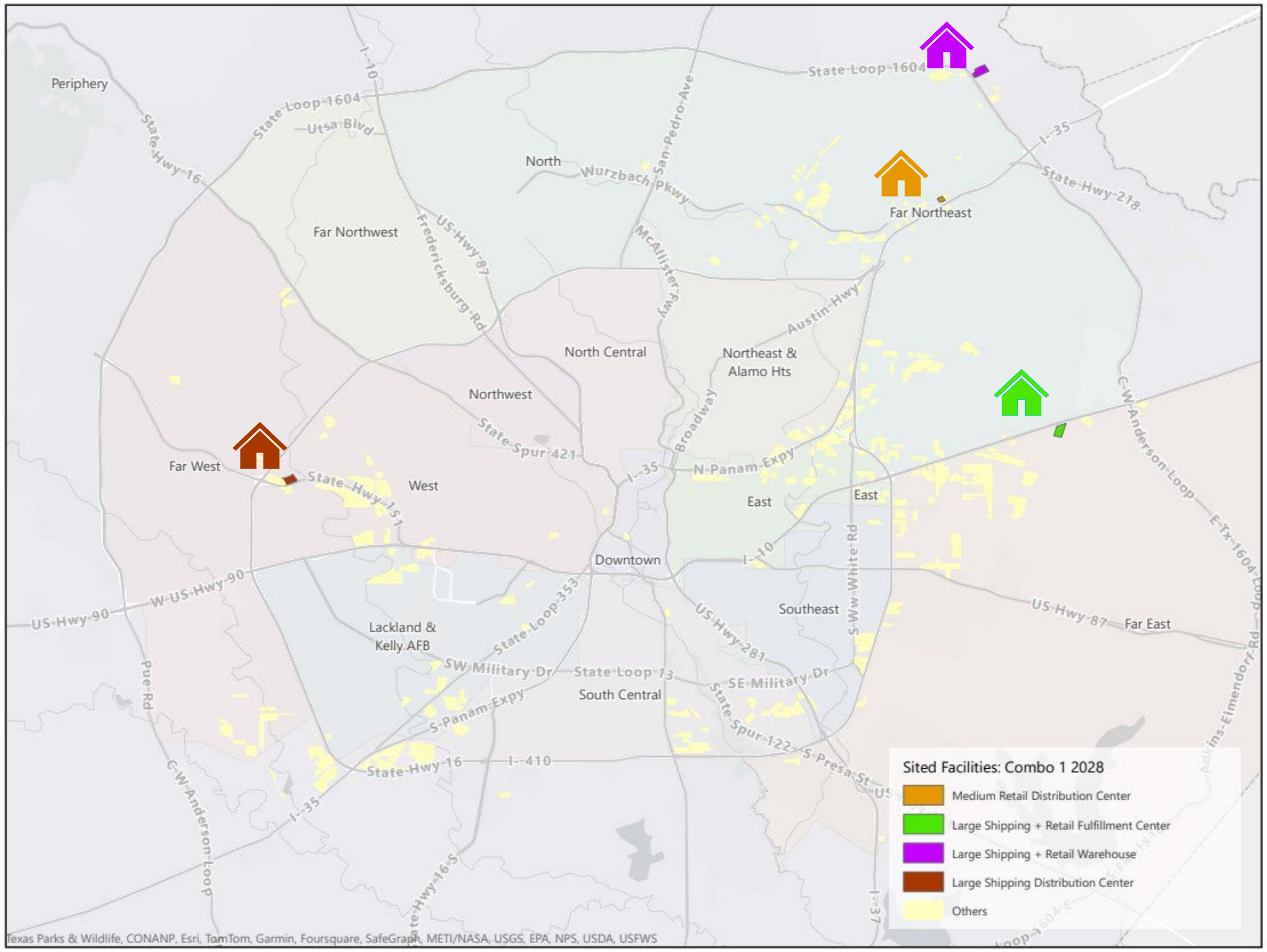
San Antonio Forecasted Facility Locations in 2028 Combo 1

Large Shipping and Retail Fulfillment Center

Large Shipping Warehouse

Large Shipping Distribution Center

Medium Retail Distribution Center



<u>Combo 1 2033 Map</u>

San Antonio Forecasted Facility Locations in 2033 Combo 1*

Small Shipping and Retail Distribution Center (1)

Small Shipping and Retail Distribution Center (2)

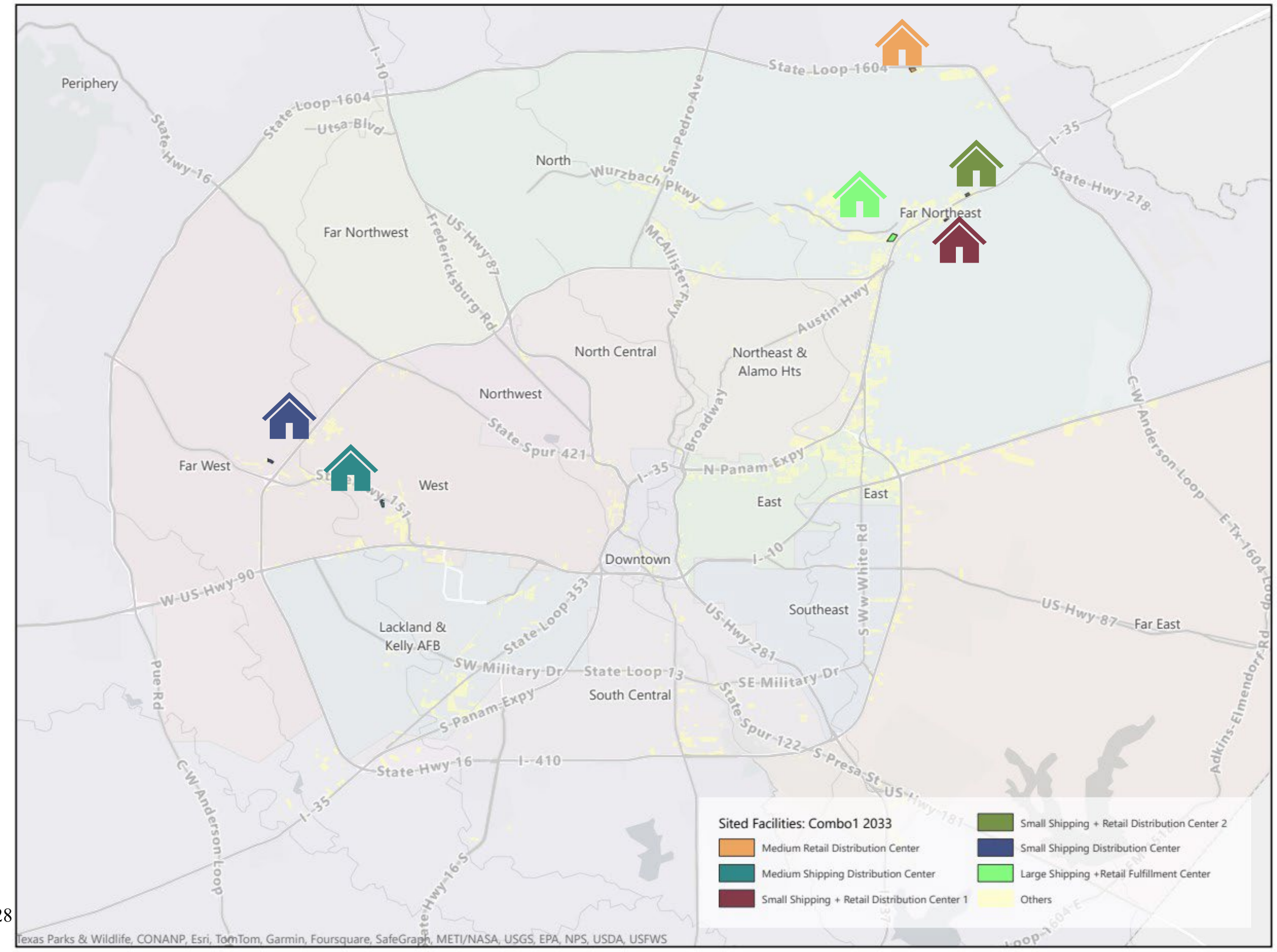
Large Shipping and Retail Fulfillment Center

Medium Shipping Distribution Center

Small Shipping Distribution Center

Medium Retail Distribution Center

*These facilities will be strategically positioned alongside those already outlined in the "Combo 1 2028 Map"



Combo 2 2028 Map

San Antonio Forecasted Facility Locations in 2028 Combo 2

Medium Shipping and Retail Fulfillment Center (1)

Medium Shipping and Retail Fulfillment Center (2)

Medium Shipping and Retail Fulfillment Center (3)

Small Shipping and Retail Distribution Center (1)

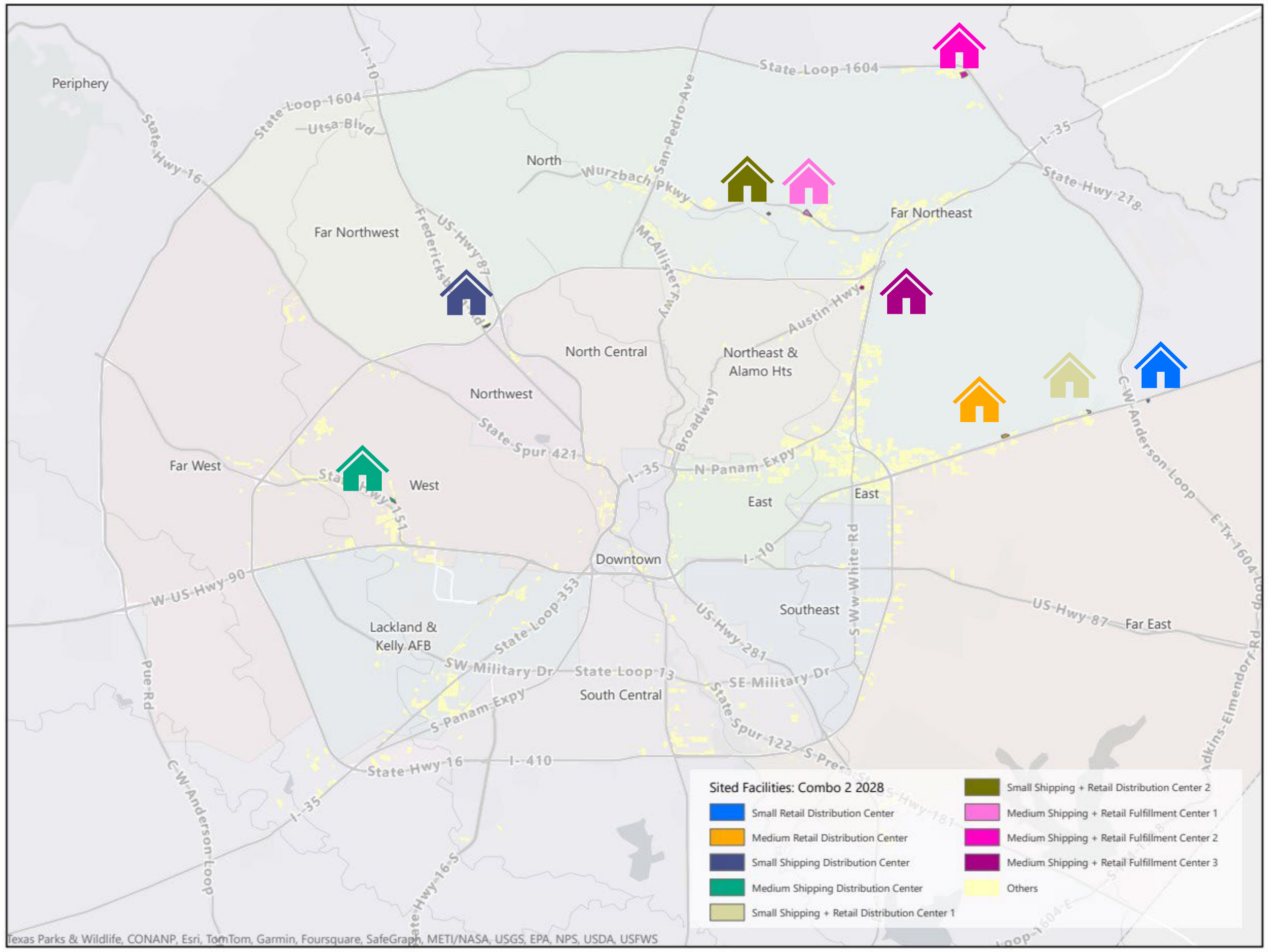
Small Shipping and Retail Distribution Center (2)

Small Shipping Distribution Center

Medium Shipping Distribution Center

Medium Retail Distribution Center

Small Retail Distribution Center



Combo 2 2033 Map

San Antonio Forecasted Facility Locations in 2033 Combo 2

Small Shipping and Retail Distribution Center

Small Shipping and Retail Warehouse

Medium Shipping and Retail Fulfillment Center

Large Shipping and Retail Fulfillment Center

Small Shipping Distribution Center (1)

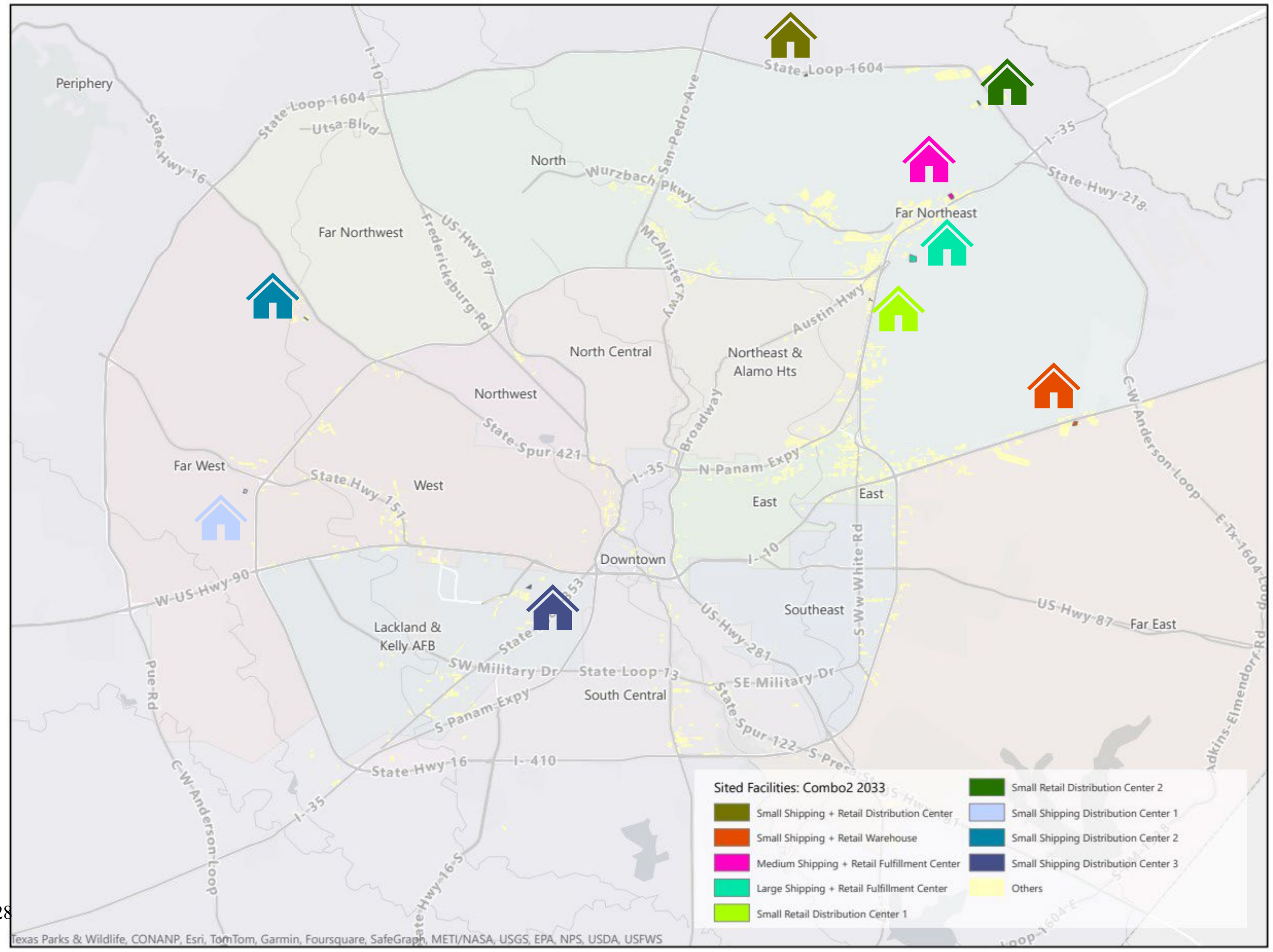
Small Shipping Distribution Center (2)

Small Shipping Distribution Center (3)

Small Retail Distribution Center (1)

Small Retail Distribution Center (2)

*These facilities will be strategically positioned alongside those already outlined in the "Combo 2 2028 Map"



Location Guide for Forecasted Facilities

Combo	Forecast	Site	Address (or lat/long)	ZoneKey	ObjectID
		Medium Retail Distribution Center	29.548859, -98.36885	632151	562846
		Large Shipping Distribution Center	29.600759, -98.351802	551598	597534
		Large Shipping + Retail Warehouse	29.435066, -98.63564	269093	141413
1	2028	Large Shipping + Retail Fulfillment Center	29.457605, -98.318065	130118	157795
		Small Shipping Distribution Center	3420-3452 Pin Oak Dr, San Antonio, Texas, 78229	759550	334843
		Small Shipping + Retail Distribution Center 2	29.542483, -98.440665	245906	294659
		Small Shipping + Retail Distribution Center 1	9025-9081 I-10 E, Converse, Texas, 78109	180092	208646
		Small Retail Distribution Center	10194-10194 I-10 E, Converse, Texas, 78109	195900	118351
		Medium Shipping Distribution Center	501-535 S Acme Rd, San Antonio, Texas, 78237	851775	652747
		Medium Shipping + Retail Fulfillment Center 3	8150 Crosscreek, San Antonio, Texas,78218	659601	619382
		Medium Shipping + Retail Fulfillment Center 2	6558 N Loop 1604 E, San Antonio, Texas, 78247	682636	597870
		Medium Shipping + Retail Fulfillment Center 1	PA-1502 W, San Antonio, Texas, 78217	248419	268991
2	2028	Medium Retail Distribution Center	7280-7318 Sandy Bay, Converse, Texas, 78109	604738	572624
		Small Shipping Distribution Center	237-263 Richland Hills Dr, San Antonio, Texas, 78245	631950	561934
1	2033	Small Shipping + Retail Distribution Center 2	6230 Charlottesville St, San Antonio, Texas, 78233	203301	235199

Combo	Forecast	Site	Address (or lat/long)	ZoneKey	ObjectID
		Small Shipping + Retail Distribution Center 1	6001 Randolph Blvd, San Antonio, Texas, 78233	173621	191983
		Medium Shipping Distribution Center	1261-1293 S Callaghan Rd, San Antonio, Texas, 78227	552687	619602
		Medium Retail Distribution Center	5210 N Loop 1604 E, San Antonio, Texas, 78247	233295	128399
		Large Shipping +Retail Fulfillment Center	29.5336909810697, -98.3924612425935	615648	601289
		Small Shipping Distribution Center 3	2000-2004 Frio City Rd, San Antonio, Texas, 78226	654258	611091
		Small Shipping Distribution Center 2	7492 Reindeer Trl, San Antonio, Texas, 78238	507822	485442
		Small Shipping Distribution Center 1	1560 Cable Ranch Rd, San Antonio, Texas, 78245	359020	190734
		Small Shipping + Retail Warehouse	8700 Interstate 10 E, Converse, Texas, 78109	654489	608654
		Small Shipping + Retail Distribution Center	17245 Jones Maltsberger Rd, San Antonio, Texas, 78247	216665	117439
		Small Retail Distribution Center 2	16210 Nacogdoches Rd, San Antonio, Texas, 78247	200620	115636
		Small Retail Distribution Center 1	7902 Webbles Dr, San Antonio, Texas, 78218	120217	78721
		Medium Shipping + Retail Fulfillment Center	12125 Crownpoint, San Antonio, Texas,78233	203234	235074
2	2033	Large Shipping + Retail Fulfillment Center	5431 Crestway Rd, San Antonio, Texas, 78239	160385	189364

Appendix B: Value of Research (VoR)

Introduction

An analysis of the forecasted economic benefits of the TxDOT Research Project 0-7165 is explained in this appendix. With e-commerce companies expanding their facilities across urban, suburban, and rural regions, a significant surge in vehicular traffic is anticipated. This uptick will be driven by the influx of new delivery drivers and facility workers in these diverse areas. The tool and prototype created in this project are poised to assist TxDOT in forecasting future facility placements, enabling proactive planning for the expected surge in traffic and congestion within their travel demand models. This enhanced forecasting capability will empower TxDOT to make informed decisions and allocate resources effectively for infrastructure investments. Even a slight enhancement in forecasting and policy analysis can yield significant advantages. For instance, the construction of each mile of roadway or bridge comes with a hefty price tag ranging from 3 to 20 million dollars. In comparison to such substantial investments, the cost of implementing new models crucial for decision-making in transportation investment is negligible. Notably, research in transportation constitutes only about 1% of the sector's GDP output, a stark contrast to other sectors like IT, where the figure stands at approximately 10%. Considering that the findings from this project influence land-use, transportation, air quality, greenhouse gas emissions, and energy sectors, the anticipated benefit-to-cost ratio for the project is expected to be substantial.

Overall, the findings of this study offer valuable insights for predicting future land use patterns and traffic expansion attributed to the escalating prevalence of e-commerce. As the world, especially Texas, hurtles towards a rapidly evolving digital future, employing the developed tool and prototype across various Texas regions will serve as a valuable guide for Metropolitan Planning Organizations (MPOs). This guidance is crucial for anticipating traffic growth and devising strategies to regulate and manage the placement of facilities effectively. Such outcomes will prove instrumental for TxDOT in evaluating shifts in travel behavior amid the accelerating rise of e-commerce, intricate transportation and land use policies, and large-scale infrastructure initiatives.

The project's economic advantages are extensive and possess the capacity to impact nearly every facet of the transportation planning process, encompassing:

- Safety
- Equity
- Mobility

- Investment in infrastructure
- Sustainability
- Cost reduction
- Investment cost reduction
- Air quality
- Climate adaption

Yet, due to the inherent challenge in quantifying the monetary economic impact of each qualitative benefit, this VoR will concentrate on the cost reduction associated with road system investments, particularly in the domains of new construction and maintenance on roadways.

Cost Savings on New Construction and Maintenance of Roadways

Facility placement insights from both the forecasting tool and geographic prototype will lead to network and travel demand insights that can help prevent unnecessary new roadway construction, as well as minimize road infrastructure maintenance. This will save a substantial amount of money for TxDOT. To illustrate this potential, consider a scenario where an agricultural zone on the outskirts of a city is rezoned for an industrial park. TxDOT, anticipating increased warehouse construction, upgrades connecting roads to highways and the city. However, this area, over 40 miles from the regional airport and lacking proximity to existing facilities or dense populations, attracts no companies. The roads built by TxDOT become redundant. Employing the forecasting methodology tool and geographic prototype could have revealed that the rezoned area was not strategically viable for e-commerce companies. This oversight results in wasted time, money, and resources on roads unlikely to see a significant traffic increase. Inaccurate traffic flow forecasts can lead to multi-million-dollar misinvestments, which might have been preventable had TxDOT utilized the developed tool and prototype. Instead, a targeted approach could have identified roads needing maintenance, a more cost-effective solution than constructing new ones.

To provide a sense of the value of the research undertaken in the context of road investment costs, the following assumptions will be made, and the following estimation process will be followed.

1. The researchers assume that the insights from this study will impact Texas's entire transportation roadway network, which amounts to about **200,000 miles** (according to the 2020 Texas Roadway Inventory Annual Report).

2. However, it can also be assumed that this study's insights will only impact a minor portion of roadway infrastructure investments, perhaps **1% of roadway construction and maintenance** costs.
3. Determine the percentage of roads impacted each year:
    - **12%** of the 200,000 road miles have <u>maintenance</u> performed on them each year (~24,000 miles) (According to TxDOT's 4-Year Pavement Management Plan (FY2019-FY2022))
    - **0.2%** more road miles are <u>newly constructed</u> each year (~400 miles) (according to calculations using the same 4-Year Pavement Management Plan (FY2019-FY2022))
4. Evaluate cost per mile for[1]:
    - <u>Maintenance</u>: **$8,333 per road-mile** (according to calculations using the same 4-Year Pavement Management Plan (FY2019-FY2022))
    - <u>New construction</u>: **$3.3 million per road-mile** (according to calculations using the same 2019-2022 four-year plan)
5. Calculate the total cost per year spent on the entire road network in Texas:
    - <u>Maintenance</u>: $8,333 × 12% × 200,000 miles = **$199,992,000 a year** ($200 million, which is the number that aligns with the costs from Texas's most current, 2022 four-year plan ($0.2 billion for maintenance))
    - <u>New construction</u>: $3.3 million × 0.2% × 200,000 miles = **$1,320,000,000 a year** ($1,320 million, which is the number that aligns with the costs from Texas's 2022 four-year plan ($1.3 billion for new construction))
    - Total: $1,520,000,000 ($1.5 billion) for the entire Texas road network per year
6. Appraise the money saved from the effect of the project's insight:
    - 5% × $1,520,000,000 = $76,000,000 a year (in 2023)
    - 2% × $1,520,000,000 = $30,400,000 a year (in 2023)
    - 1% × $1,520,000,000 = **$15,200,000 a year** (in 2023)
        - Even with just a 1% impact, the projects' insights will save **<u>$1.52 million in road system investments a year</u>**.

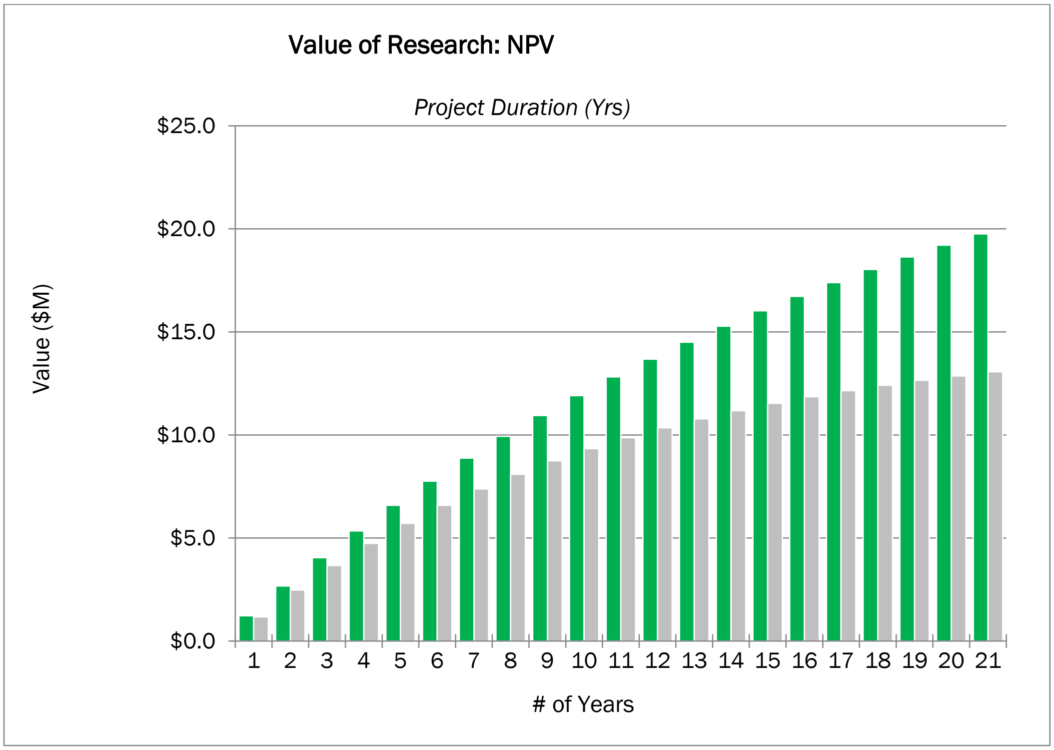
Final Benefit-Cost Ratio

The total project cost was $293,389.

[1] These costs only account for only the money spent on road and related infrastructure, and exclude overhead or other costs.

To calculate the benefit-cost ratio on just the study's impact on new construction and maintenance of roadway described in the analysis above, the yearly value of saving of $1.52 million is input into the VoR calculation system.

In evaluating this across a period of 20 years with a 5% discount rate, the benefit-cost ratio totals to 45:1, with the net present values (NPV) of over $13 million and total savings of more than $19 million. This roughly models a similar impact of the newfound ability to forecast where future e-commerce WaFuDs will be placed, each year for over 20 years, as is ensured by this study.



The benefit-cost ratio is a modest 1% impact of this research on the new construction and maintenance of roadways and associated infrastructure throughout Texas. It is crucial to emphasize that further scrutiny of the extensive list of economic benefits outlined earlier can be conducted, potentially resulting in an even greater VoR for TxDOT spanning the next 20 years and beyond.