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A Comprehensive Study of Impacts of "Q" Bus Rapid Transit System on Blackstone Avenue

Yertai Tanai, PhD Kamil Ciftci, PhD

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Report 25-10

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May 2025

A publication of the
Mineta Transportation Institute
Created by Congress in 1991
College of Business
San José State University
San José, CA 95192-0219

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. 25-10	**2. Government Accession No.**	**3. Recipient's Catalog No.**	
4. Title and Subtitle A Comprehensive Study of Impacts of "Q" Bus Rapid Transit System on Blackstone Avenue		**5. Report Date** May 2025 **6. Performing Organization Code**	
7. Authors Yertai Tanai, PhD, ORCID: 0000-0002-0431-9137 Kamil Ciftci, PhD, ORCID: 0000-0002-2042-4260		**8. Performing Organization Report** CA-MTI-2450	
9. Performing Organization Name and Address Mineta Transportation Institute College of Business San José State University San José, CA 95192-0219		**10. Work Unit No.** **11. Contract or Grant No.** SB1-SJAUX_2023-26	
12. Sponsoring Agency Name and Address State of California SB1 2017/2018 Trustees of the California State University Sponsored Programs Administration 401 Golden Shore, 5th Floor Long Beach, CA 90802		**13. Type of Report and Period Covered** **14. Sponsoring Agency Code**	
15. Supplemental Notes 10.31979/mti.2025.2450			
16. Abstract This study examines the dual impact of the Fresno Area Express (FAX) Q Line, a 15.7-mile Bus Rapid Transit (BRT) system launched in 2018, on the Fresno housing market and passenger satisfaction. The Q Line, designed to modernize public transit, features eco-friendly compressed natural gas (CNG) vehicles, real-time passenger information, and improved service efficiency. Housing market analysis focused on residential properties sold between 2012 and 2024, utilizing Geographic Information System (GIS) mapping to segment properties into three regions: the Q Line corridor, an outer buffer zone, and the rest of Fresno. Results indicate no statistically significant increase in property values within the Q Line corridor, challenging assumptions that public transit improvements substantially influence housing prices. Passenger satisfaction was assessed using FAX survey data and advanced machine learning models to identify key predictors. Statistical independence tests revealed no significant differences in satisfaction based on age, gender, employment status, or education. However, larger households reported higher satisfaction, while lower-income passengers expressed dissatisfaction. Machine learning models highlighted eight key factors influencing satisfaction, including audio-visual quality, value, comfort, closeness to home, and driver helpfulness. The findings underscore the importance of inclusive, passenger-centered transit services to enhance satisfaction while addressing disparities among lower-income riders. Policy recommendations encourage continued investment in public transit improvements without expecting significant housing market impacts. By prioritizing the identified satisfaction drivers, FAX can further improve the Q Line's service quality and better meet the community's needs, ensuring its long-term success.			
17. Key Words Rapid transit, bus rapid transit, bus, public transit, transportation.	**18. Distribution Statement** No restrictions. This document is available to the public through The National Technical Information Service, Springfield, VA 22161.		
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 35	**22. Price**

Form DOT F 1700.7 (8-72)

DOI: 10.31979/mti.2025.2450

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ACKNOWLEDGMENTS

The authors express their heartfelt gratitude to the Fresno State Transportation Institute (FSTI) for their invaluable support and resources, which were essential in carrying out this research. Additionally, the authors also extend their thanks to the Fresno Area Express (FAX) authority for providing critical insights and valuable information that greatly contributed to the study. Special appreciation is also extended to Dr. Jacquelin Curry for providing real estate data and to the Gazarian Real Estate Center at the Craig School of Business for their support, which significantly enriched the scope and depth of the analysis.

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Executive Summary

In 2015, Fresno Area Express (FAX) embarked on a transformative initiative to address socioeconomic challenges by constructing a 15.7-mile Bus Rapid Transit (BRT) system, known as the Q Line. Spanning Blackstone Avenue from North Fresno to downtown and Ventura/Kings Canyon from downtown to Clovis Avenue, the Q Line replaced the existing local bus service, significantly enhancing transit efficiency with fewer stops and more frequent schedules. Equipped with advanced features such as transit signal priority; queue jump lanes; and low floor, compressed natural gas (CNG) vehicles, the Q Line provides a cleaner and more eco-friendly transit alternative. Additional passenger amenities include real-time information systems, fare machines, boarding platforms, and distinctive branding, elevating the service experience. Initially studied in 2008, construction commenced in 2016, and operations began in February 2018. To date, the Q Line has served over 12.2 million passengers, solidifying its position as a cornerstone of Fresno's public transit system.

This study aimed to analyze the Q Line's dual impacts on Fresno: its influence on the housing market and factors affecting passenger satisfaction. Housing market analysis focused on residential properties sold between 2012 and 2024, leveraging Geographic Information System (GIS) mapping to segment the market into three regions: the Q Line corridor, an outer buffer zone, and the rest of Fresno. Comparative metrics like property prices, sales trends, and appreciation rates are analyzed to determine whether the Q Line has influenced property values near its route.

Simultaneously, passenger satisfaction was assessed using FAX survey data, emphasizing Q Line users. Statistical independence tests evaluated relationships between satisfaction levels and demographic attributes such as age, income, and household size. Advanced machine learning models are developed to uncover complex patterns, focusing on factors including timeliness, comfort, cleanliness, and customer service.

The housing price analysis within the Q Line corridor showed minor increases, but these are not statistically significant. Contrary to common assumptions, the implementation of a transit line did not trigger noticeable property value changes, suggesting that improvements in public transportation alone may not directly impact housing markets in Fresno during the study period.

Passenger satisfaction analysis revealed notable trends. Demographics such as age, gender, work status, and education had no significant effect on satisfaction levels. However, larger households reported higher satisfaction, while smaller households expressed greater dissatisfaction. Income disparities are also evident: higher-income riders consistently reported greater satisfaction, while lower-income riders are more dissatisfied. These findings suggest varying service perceptions and highlight the need to address lower-income riders' concerns to improve overall satisfaction.

Advanced machine learning models identified eight influential factors driving passenger satisfaction: audio-visual quality, value, proximity to home, comfort, driver helpfulness, disability access, proximity to destination, and weekend hours. These factors underscore the importance of an inclusive and passenger-focused transit system to enhance the commuting experience.

Policymakers should advocate for sustained investment in public transit systems like the Q Line, even though housing price impacts may be limited. Instead, the focus should be on improving the overall transit experience, addressing concerns of underserved groups, particularly lower-income riders, and prioritizing factors critical to passenger satisfaction. By refining these areas, FAX can foster a more inclusive and efficient transit system that benefits the broader community.

1. Introduction

Fresno Area Express (FAX), a department of the City of Fresno governed by the Fresno City Council, operates the largest transit system in the region, including both its fixed-route transit system and the Handy Ride paratransit service. FAX is committed to providing reliable and clean transportation to essential destinations such as schools, workplaces, shopping centers, and more. Its mission is to offer exceptional customer service, ensuring passengers reach their destinations safely and on time. With a fleet of 120 buses, FAX handles almost 7 million annual boardings and operates on a budget of over $134 million.[1] The system consists of 18 fixed routes in the city of Fresno, with three major hubs: the Downtown Transit Center at Courthouse Park, the Manchester Transit Center at Blackstone and Shields Avenues north of downtown, and a transfer point at the River Park shopping center in north Fresno.[2]

Fresno, the fifth largest city in California and a vital economic center in the heart of the San Joaquin Valley, has faced numerous challenges that might seem out of place in a region known for its agricultural productivity. One such challenge lies on Blackstone Avenue, an over eight-mile-long commercial corridor connecting downtown Fresno to its expanding suburbs. This area has been characterized by crime, poverty, and vacant buildings, which are the result of failed land use policies and a lack of developmental ingenuity. These issues highlight the region's need for transformation.

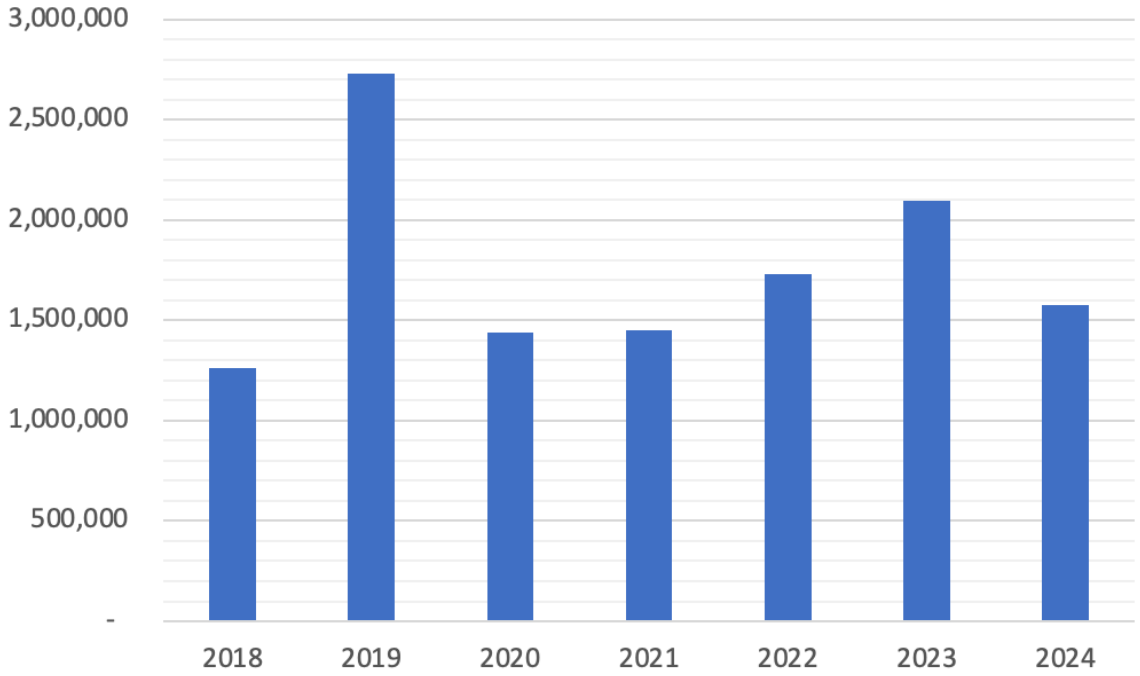
In 2015, Fresno Area Express (FAX) initiated a major step forward in addressing these challenges by launching the construction of the 15.7-mile Bus Rapid Transit (BRT) line, known as the Q Line. The Q Line, which serves as the flagship route for FAX, operates along Blackstone Avenue from North Fresno to downtown and along Ventura/Kings Canyon from downtown to Clovis Avenue. This new BRT system replaced the existing local bus service, improving efficiency by decreasing travel times through fewer stops and more frequent service. The project included a variety of innovative features, such as transit signal priority, queue jump lanes, and stations, as well as low floor, compressed natural gas (CNG) BRT vehicles that offer a cleaner, more eco-friendly alternative. Additional enhancements such as real-time passenger information, fare machines, boarding platforms, and special branding were implemented to create a distinctive identity for the service. The idea of introducing BRT to Fresno was first studied in 2008, and after several revisions, the construction of the Q Line began in June 2016. The Q Line began service in February 2018, offering frequent and reliable operations with buses running every 10 minutes during peak periods and every 15 minutes during off-peak hours. Figure 1 illustrates the annual ridership trends for the Q Line since its launch. By 2019, the Q Line had exceeded 2.5 million passengers, establishing itself as a vital component of Fresno's public transit network. Ridership declined in 2020 and 2021 due to the COVID-19 pandemic but has since rebounded. In 2023,

[1] https://www.fresno.gov/transportation/fax/

[2] https://www.fresno.gov/transportation/fax/

the Q Line served over 2 million passengers. Notably, ridership data for 2024 extends only through August; however, projections indicate it will surpass the previous year's figures by the end of 2024.

Figure 1. Q Line Annual Ridership



This study focuses on two core objectives: analyzing the housing market in Fresno and assessing passenger satisfaction on the Fresno Area Express (FAX) Q Line. The first objective examines residential properties in Fresno, specifically those sold between 2012 and 2024. The analysis concentrates on understanding the impact of the Q Line's implementation on the housing market. Using Geographic Information System (GIS) mapping techniques, we define spatial boundaries to identify and segment the residential properties into three key areas: the Q Line corridor, an outer buffer zone, and the remaining areas of Fresno. By segmenting these properties geographically, we are able to analyze and compare housing market dynamics across the defined regions. Metrics such as property prices, sales trends, and appreciation rates are explored to uncover any notable differences or trends that may suggest the influence of the Q Line on housing values and market activity in its vicinity.

The second objective centers on evaluating passenger satisfaction using survey data provided by FAX, with a specific focus on the Q Line service. To identify potential factors affecting overall passenger satisfaction, we begin by conducting statistical independence tests. These tests allow us to determine relationships between various survey attributes and satisfaction outcomes. Building on this foundation, we develop advanced machine learning models to analyze the full range of survey data characteristics. By leveraging these models, we aim to uncover complex patterns and interactions within the data, enabling a deeper understanding of the key drivers of passenger

satisfaction. Factors such as timeliness, comfort, cleanliness, customer service, and reliability are explored to determine their relative impact on overall ride experience and satisfaction levels.

In the literature, various methods are used to analyze transportation quality and passenger satisfaction, including choice-based models, Structural Equation Modeling (SEM), and machine learning methods. Choice-based models, such as multinomial logit and ordered probit, are frequently employed (Quddus et al., 2019; Cao et al., 2016; Cao & Cao, 2017; Zheng et al., 2021). SEM is applied to assess user-perceived quality and attitudes (Chou et al., 2014; Eboli & Mazzulla, 2007; Wan et al., 2016). The increasing popularity of machine learning has introduced advanced tools for transportation quality and passenger satisfaction studies. Machine learning techniques, including neural networks, Bayesian networks, and decision trees, have also been used (Garrido et al., 2014; Wu et al., 2016). Ruiz et al. (2024) recently evaluated ML models with data from the Transantiago bus system in Chile. In our study, machine learning models are similarly developed to analyze the full range of passenger survey data characteristics, providing deeper insights into satisfaction drivers and improving our understanding of passenger experiences on the Q Line.

Through this dual analysis, the study aims to provide valuable insights into both the housing market response to the Q Line and the factors shaping passenger satisfaction, offering a comprehensive assessment of its broader impact in Fresno.

2. Data, Methods, and Results

As described above, this study evolves around two objectives. For the housing market analysis, we examine residential properties sold between 2012 and 2024 to assess the Q Line's impact on property value. Using GIS mapping, we segment properties into the Q Line corridor, an outer buffer zone, and the rest of Fresno, comparing property prices and other characteristics across these areas. For passenger satisfaction, we analyze survey data provided by FAX. Statistical independence tests and advanced machine learning models are used to identify key factors influencing overall ride satisfaction, such as timeliness, comfort, cleanliness, and reliability.

2.1 Analyze Residential Properties Along the Q Line Corridor

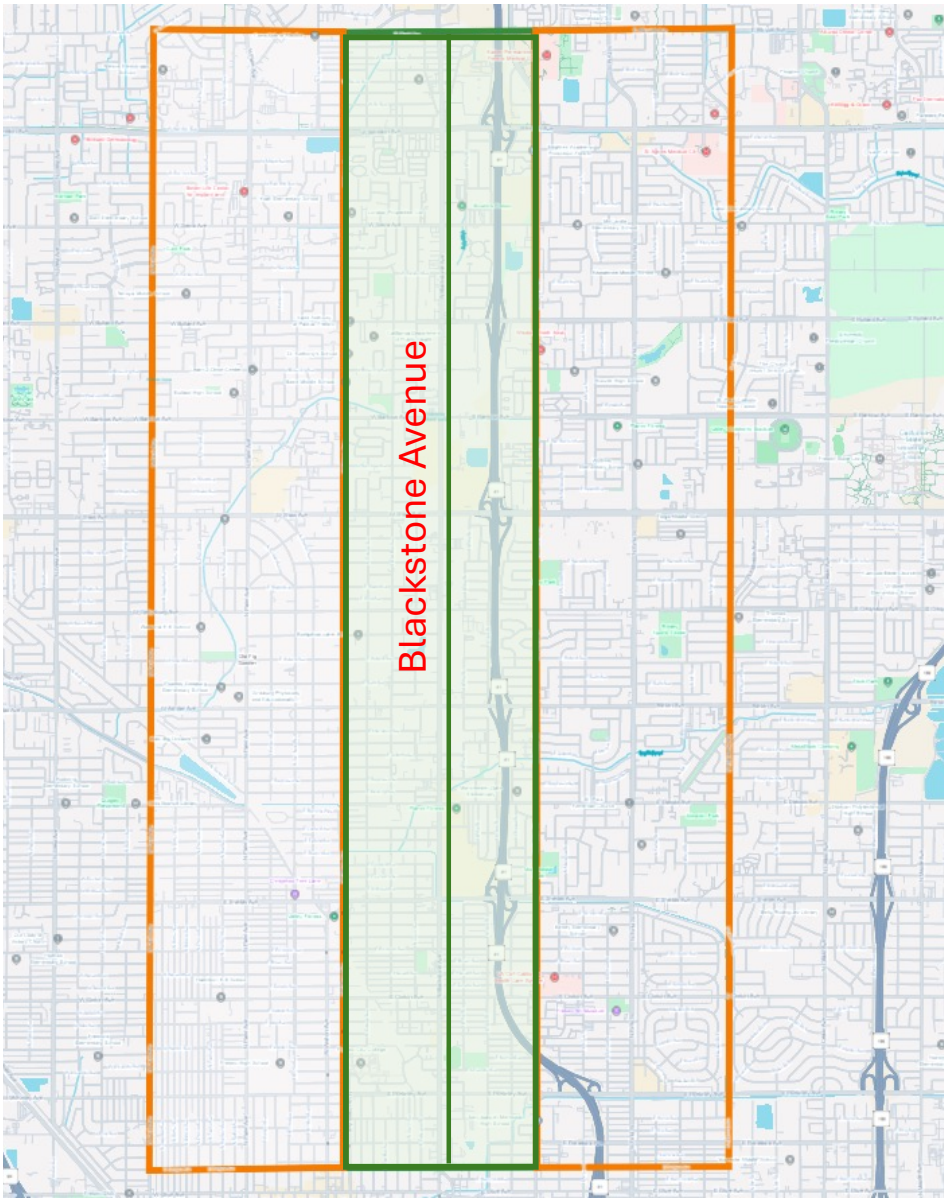
As outlined earlier, we analyze housing data for Fresno city spanning from 2012 to mid-2024. The dataset, which contains detailed characteristics of sold residential properties, can be requested from the authors. Over this period, 65,417 houses were sold, though we note that some properties may have been listed and sold multiple times.

Our primary variable of interest is the selling price of houses, which we use to compare trends across defined regions. To evaluate the impact of the Q Line on Fresno's housing market, we utilize GIS mapping techniques to segment properties into three regions: the Q Line Corridor (±0.5-mile distance from Blackstone Ave), the Outer Boundary (±1-mile distance from Line corridor), and the rest of Fresno. Table 1 outlines the boundaries for each segment, while Figure 2 provides a visual representation of the Q Line and the corresponding Outer Boundary regions.

Table 1. Boundaries Around the Q line

Q Line Corridor	**Outer Boundary**
0.5 miles (walking distance) from the line (Blackstone Ave)	1 mile within East/West of Line Corridor
5.85 miles length	5.85 miles length
North: Alluvial Avenue	North: Alluvial Avenue
South: Hedges Avenue	South: Hedges Avenue
West: Maroa Avenue	West: Fruit Avenue
East: Fresno Street	East: Millbrook Ave

Figure 2. Q Line Boundaries (Green – Line Corridor, Orange – Outer Boundary)



We further divide the timeframe into two parts. The first period spans between the years 2012 and 2017, which can be defined as the period before the Q Line's implementation. The second period, from 2018 through 2024, marks the years after the Q Line's implementation. Table 2 presents the characteristics and basic statistics of houses sold across each specified period and segment. It is evident that houses in the Line Corridor are generally cheaper compared to other regions. This can be attributed to Blackstone Avenue, particularly its southern section, which has long been associated with issues such as crime, poverty, and vacant buildings. These factors reflect the consequences of failed land use policies and a lack of innovative development strategies. Moreover, one can also observe that houses sold in the Line corridor are smaller as compared to other regions.

Table 2. Summary of Houses Sold

	Q Line Corridor		Outer Boundary		All Other Fresno	
	2012–2017	*2018–2024*	*2012–2017*	*2018–2024*	*2012–2017*	*2018–2024*
Count	1510	1591	4233	4311	27315	26457
Avg. Lot Size	7802.1	8021.6	8575.3	9266.7	10099.7	9960.4
Avg. Square Footage	1424.8	1559.4	1663.5	1711.2	1772.7	1768.8
Avg. Bathrooms	1.7	1.8	1.9	1.9	2.1	2.1
Avg. Bedrooms	2.9	3	3	3.1	3.2	3.2
Avg. Selling Price ($000)	152	294.6	192.3	328.1	219.7	349.1

Figures 3 and 4 show the average and median selling price, respectfully. As one can observe, while both metrics reveal that there is an uptick in housing prices in the entire region, there is a notable sharp increase in the housing prices along the Q Line corridor after the line's operational launch. Remarkably, the increase in the average price within the Q Line corridor surpasses that of both the Outer Boundary and the rest of Fresno by 2020, just before the onset of the COVID-19 pandemic.

Figure 3. Average Selling Prices of Houses

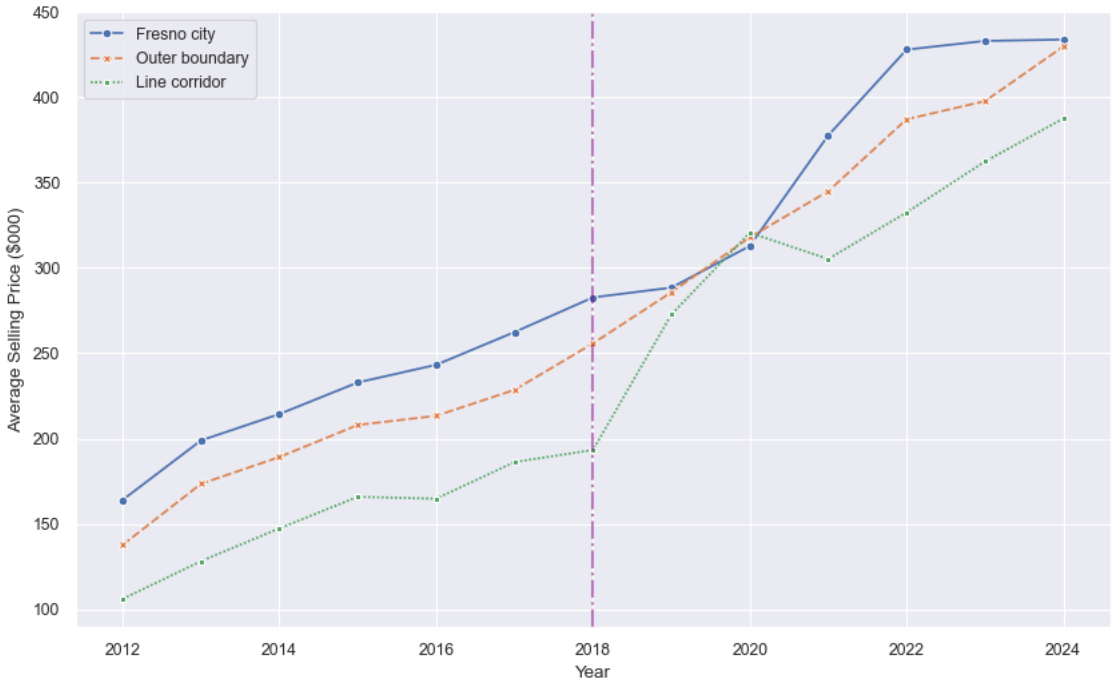


Figure 4. Median Selling Prices of Houses

Figures 5 and 6 show the percent changes in both average and median selling prices. Both figures highlight the sharp increase in prices for the Q Line corridor, demonstrating its distinct growth compared to other regions during 2018–2019. However, the average selling price in the Q Line corridor declined between 2020 and 2021, while prices in the other two segments continued to rise during this period.

Figure 5. Percent Changes in Average Selling Price

This observation prompted further analysis of monthly price changes by dividing the timeline into three periods: 2012–2017, 2018–2019, and 2020–2024. The goal is to determine whether the COVID-19 pandemic negatively impacted residential property prices along the Q Line corridor. Given the three regional segments and three time periods, we conducted a Two-Way Analysis of Variance (ANOVA) to determine whether the mean percent changes in each segment differ significantly. This analysis involves two factors, each with three levels. The region factor includes the Q Line Corridor, the Outer Boundary, and the rest of Fresno. The time period factor includes the years 2012–2017, 2018–2019, and 2020–2024. The primary objective is to assess whether there is an interaction effect between regions and time periods or if significant changes exist within each factor independently.

Figure 6. Percent Changes in Median Selling Price

Figure 7 presents the distribution boxplots of percent changes in average selling prices for the defined groups. Visually, the distributions do not suggest any significant statistical differences among the groups. This observation is further confirmed by the ANOVA test results in Table 3. The test statistic and p-value indicate that all means are equal, showing neither an interaction effect nor significant factor effects.

This analysis demonstrates that, while there is a visually sharper increase in selling prices in the Q Line corridor, the effect is not statistically significant. Therefore, the impact of the Q Line implementation on residential property values around the bus line has not yet been realized.

Figure 7. Group Distributions

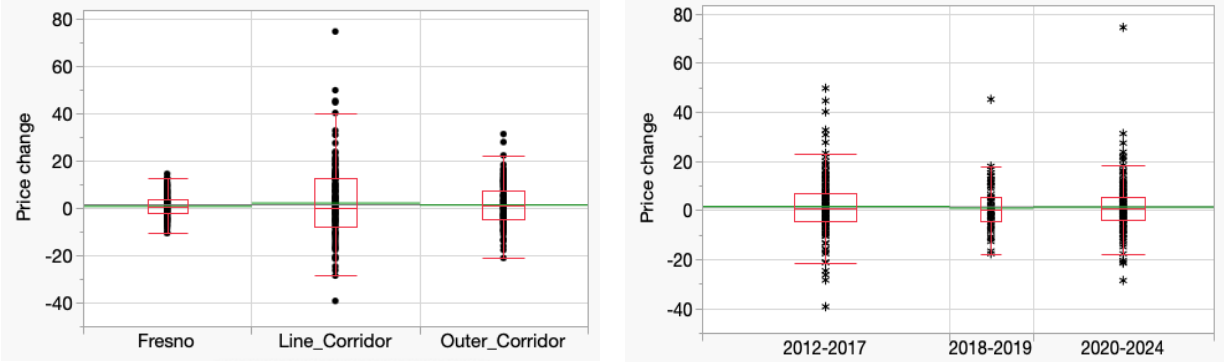


Table 3. Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	8	186.993	23.374	0.1902	0.9922
Error	432	53101.290	122.920		
C. Total	440	53288.283			

2.2 Independence Test for Passenger Satisfaction Survey

Fresno Area Express (FAX) conducts a customer satisfaction survey every four years to gather insights on passenger satisfaction, travel behavior, and demographics. The 2022 survey by Rea & Parker Research (2022) updates previous findings from 2014 and 2018 surveys and highlights changes in ridership, including the impact of the COVID-19 pandemic.

The most recent survey in 2022 was conducted by Rea & Parker Research through bus stop intercepts, online surveys via FAX's Survey Monkey account, and onboard interviews. Surveys were provided in both English and Spanish to ensure accessibility. A total of 876 passengers participated, resulting in a margin of error of +/- 3.3 percent at a 95 percent confidence level (Rea & Parker Research, 2022). Among these, 268 surveys were returned specifically for the Q Bus Line (Route 1). Normally, the focus would be on customer satisfaction for the Q Bus Line. However, due to the small sample size for this route, this chapter examines customer satisfaction across the entire FAX transportation system.

Key components of the survey included demographic statistics and respondent characteristics, customer travel behavior and patterns, customer satisfaction with key features of FAX bus service, and availability of information and communication.

The primary objective of this section is to investigate the relationship between overall passenger satisfaction and various demographic characteristics obtained from the 2022 passenger satisfaction survey. Specifically, the focus is on determining whether significant differences exist between satisfaction levels across categories such as age, gender, education, income, household size, and work status. To achieve this, the Chi-Square Test of Independence is applied to assess the statistical significance of associations between overall satisfaction scores and these demographic variables.

The survey initially consisted of 11 sub-questions relating to demographic characteristics. However, during the analysis, challenges arose due to a small sample size and the original six-point satisfaction scale. These challenges required modifications to ensure the statistical validity of the Chi-Square Test results.

While The Chi-Square Test of Independence is employed to evaluate whether an association exists between passenger satisfaction levels and demographic variables, challenges arise due to the small sample size, which has led to low observed frequencies across many demographic categories.

To elaborate, the survey original satisfaction scale consisted of six levels as seen in Table 4 below.

Table 4. Passenger Satisfaction Scale

Satisfaction Scale	
1=	Very Satisfied
2=	Satisfied
3=	Slightly Satisfied
4=	Slightly Dissatisfied
5=	Dissatisfied
6=	Very Dissatisfied

Also, each demographic characteristic variable has multiple categories. For example, the Education Level question had six original categories as seen in Table 5.

Table 5. Education Level

What is the last grade you have completed?	
1=	Less than 8th Grade
2=	Some High School
3=	High School Graduate
4=	Vocational/Technical School
5=	College Graduate
6=	Postgraduate Education

With six levels of satisfaction and multiple demographic variable categories, the combination of categories produced contingency tables with many small, expected frequencies. To address the issues caused by small sample sizes, the simplification modifications are implemented where the simplifications reduced the complexity of the contingency tables while preserving the overall structure of the data. Specifically, the six satisfaction levels are collapsed into three broader categories, as shown in Table 6 below. Satisfied combines "Very Satisfied" and "Satisfied," Neutral merges "Slightly Satisfied" and "Slightly Dissatisfied," and Dissatisfied includes "Dissatisfied" and "Very Dissatisfied" from the original scale.

Table 6. Passenger Updated Satisfaction Scale

Updated Satisfaction Scale	
1=	Satisfied
2=	Neutral
3=	Dissatisfied

Similarly, the Education Level variable was simplified to three categories, as seen in Table 7 below. By combining categories with low frequencies, the expected counts in each cell increased, satisfying the Chi-Square Test assumption.

Table 7. Updated Education Level

What is the last grade you have completed?	
1=	< High School Degree
2=	High School Degree
3=	College/Vocational Education

While we successfully combined certain demographic characteristics into broader categories, others, such as Ethnicity and Primary Language, could not be re-categorized due to the nature of their classifications. Consequently, the independence test is conducted on six demographic characteristics, with the results presented in Table 8 through Table 13.

At a significance level of 0.05, the test results indicate no significant differences in passenger satisfaction scores among the categories of Age, Work, Gender, and Education. This suggests that passenger satisfaction with FAX system services is relatively consistent across these demographic factors, regardless of age group, employment status, gender identity, or education level.

However, significant differences are observed for Household Size and Income, as shown in Tables 7 and 8. Specifically, as household size increases, overall satisfaction scores tend to rise, indicating that passengers from larger households are generally more satisfied with the FAX system services. In contrast, passengers from smaller households report greater dissatisfaction, potentially pointing to unique challenges or unmet needs for this group.

Similarly, income level demonstrates a notable impact on satisfaction. Passengers with higher income levels consistently report greater satisfaction with FAX system services, whereas those with lower incomes express more dissatisfaction, offering lower scores and raising more complaints. This pattern highlights potential differences in service perception and experience, emphasizing the need to better address the concerns of lower-income passengers to enhance overall satisfaction.

Table 8. Age vs. Overall Satisfaction

		Overall			
	Count	Dissatisfied	Neutral	Satisfied	Total
Age	< 35 Years	9	49	213	271
	Between 35 and 55 Years	8	46	198	252
	>=55 Years	9	16	141	166
	Total	26	111	552	689

Tests

N	DF	-LogLike	RSquare (U)
689	4	4.2249895	0.0103

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	8.450	0.0764
Pearson	7.905	0.0951

Table 9. Work vs. Overall Satisfaction

		Overall			
	Count	Dissatisfied	Neutral	Satisfied	Total
Work	At least Part-Time Employed	17	66	310	393
	Not Employed	9	52	298	359
	Total	26	118	608	752

Tests

N	DF	-LogLike	RSquare (U)
752	2	1.4329823	0.0033

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	2.866	0.2386
Pearson	2.828	0.2432

Table 10. Gender vs. Overall Satisfaction

		Overall			
	Count	Dissatisfied	Neutral	Satisfied	Total
Gender	Female	11	54	312	377
	Male	15	61	284	360
	Total	26	115	596	737

Tests

N	DF	-LogLike	RSquare (U)
737	2	0.98397071	0.0023

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	1.968	0.3738
Pearson	1.966	0.3742

Table 11. Education vs. Overall Satisfaction

		Overall			
	Count	Dissatisfied	Neutral	Satisfied	Total
Education	< High School Degree	6	19	115	140
	College and Vocational	9	53	223	285
	High School Degree	12	43	256	311
	Total	27	115	594	736

Tests

N	DF	-LogLike	RSquare (U)
736	4	1.6571107	0.0039

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	3.314	0.5067
Pearson	3.360	0.4994

Table 12. Household Size vs. Overall Satisfaction

		Overall			
	Count	Dissatisfied	Neutral	Satisfied	Total
HH Size	1	14	26	137	177
	2	6	31	121	158
	>=3	6	54	296	356
	Total	26	111	554	691

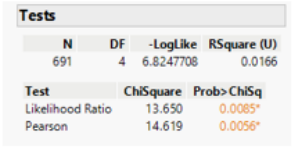
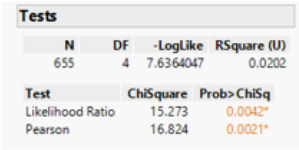


Table 13. Income vs. Overall Satisfaction

		Overall			
	Count	Dissatisfied	Neutral	Satisfied	Total
Income	< $10000	14	37	144	195
	$10000 to $39999	3	29	166	198
	>=40000	4	39	219	262
	Total	21	105	529	655



2.3 Machine Learning Models to Predict Passenger Satisfaction on the Q Line

This section outlines the machine learning models developed to predict passenger satisfaction rates on the Q Line, based on the 2022 survey. The dataset includes detailed information about passengers, bus and stop characteristics, as well as service and time-related variables. In total, 37 features (independent variables) are utilized to predict the target variable: overall passenger satisfaction. The complete list of all variables and descriptions are provided on FAX report in Rea & Parker Research (2022).

For data transformation and imputation, categorical and numerical variables are preprocessed separately. Missing values in categorical variables are imputed with the mode if missing values constitute less than 5%. For variables with over 5% missing values, an additional "unknown" category is created. Subsequently, the Weight of Evidence (WOE) technique is applied to categorical variables for inclusion in the prediction model. WOE, a simple yet powerful method for attribute analysis, offers high interpretability and is calculated as follows:

$$\text{WOE} = \ln\left(\frac{\%\ \text{of events}}{\%\ \text{of non} - \text{events}}\right)$$

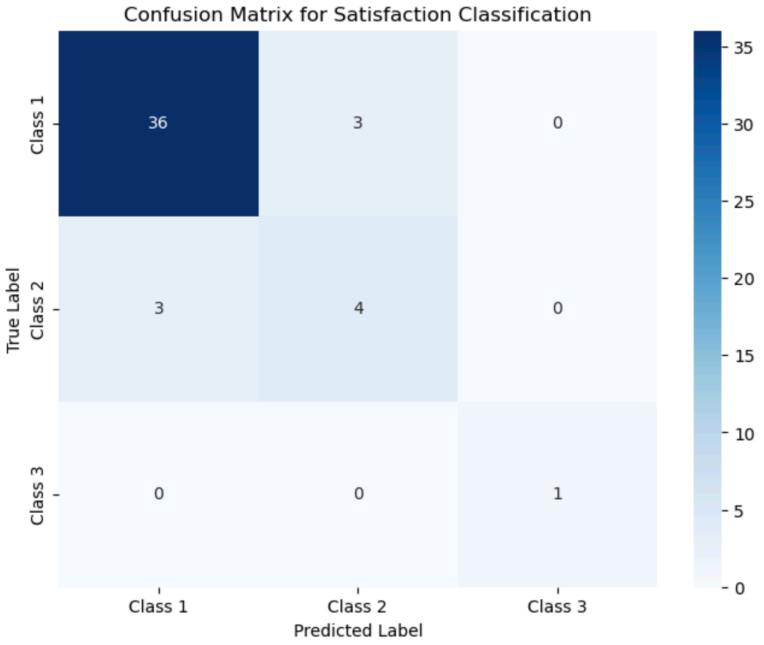
Fundamentally, WOE measures the predictive power of an exploratory variable with respect to the target variable. For example, if a category of a variable has a higher proportion of events relative to non-events, WOE assigns it a higher value, indicating better separation between events and non-events. WOE is often better suited for machine learning models with large datasets than one-hot encoding, which requires creating $(c-1)$ variables for a categorical variable with c categories. For this study, which includes 34 categorical variables, one-hot encoding would necessitate the creation of $\sum_i^{34}(c_i-1)$ additional variables. In contrast, WOE transforms a categorical variable into a single continuous variable, simplifying the modeling process. For continuous variables, missing values are imputed with the median.

As described above, the target variable is the overall satisfaction rate for a passenger, which has three categories: 1-satisfied, 2-neutral and 3-dissatisfied. Following the preprocessing and data cleaning steps, the dataset resulted in 232 observations, which are used to develop the prediction models.

We employed three classification models: decision trees, random forest, and support vector machine (SVM). Utilizing multiple well-established models helps mitigate the risk of overfitting while maintaining low bias error (Khan et al., 2020). To evaluate the accuracy of our predictive models, we applied the five-fold cross-validation technique, a standard practice in the industry (see, for example, Delen et al. 2020; Olaya et al., 2020; Tanai & Ciftci, 2023). In cross-validation, the dataset is divided into five equal parts, ensuring the response rate distribution is preserved in each segment through stratification. For each iteration, one segment (20%) serves as the test set, while the remaining segments (80%) are used to train the model. The overall performance is determined by averaging the results across all iterations, with the standard deviation indicating the model's stability. Additionally, we employed the GridSearch algorithm to optimize hyperparameters for each model, ensuring the best possible performance.

All three models demonstrated similar performance, achieving an accuracy score of 87.2%. Figure 8 presents a heatmap that visualizes the confusion matrix for the decision tree model, illustrating how effectively it classifies the three target classes. The diagonal elements of the matrix represent correctly predicted classes. While there is some overlap in the classification between the neutral and satisfied categories, the overall model fit appears strong.

Figure 8. Classification Matrix for Decision Tree



Finally, to enhance model comprehensibility and interpretability, we analyze the characteristics of each variable and identify the top influential features/predictors that significantly impact passenger satisfaction across all three models. Feature importance scores are calculated using the 5-fold-cross-validation method discussed earlier. Subsequently, we select the variables with the highest average importance scores. The list of top common features ranked by their importance scores is provided in Table 14.

Table 14. Most Impactful Variables That Affect Passenger Satisfaction

Audio Visual Quality
Value
Closeness Home
Comfort
Driver Helpful
Disability Access
Closeness Destination
Weekend Hours

Audio-visual quality, which includes clear announcements and displays, emerged as a critical aspect, as it ensures passengers feel informed and comfortable during their journey. The perceived value of the service, likely reflecting affordability and the quality-to-cost ratio, also plays a significant role. Closeness to home and closeness to destination are important predictors,

highlighting the convenience of the Q Line in meeting passengers' commuting needs. Comfort on the bus, including seating and ride smoothness, directly affects satisfaction levels, as does the helpfulness of the driver, who can create a positive experience through courteous and supportive interactions. Accessibility for passengers with disabilities (disability access) ensures inclusivity, enhancing satisfaction among a broader demographic. Finally, the availability of weekend hours is vital, as it supports flexibility and reliability for those who rely on public transit beyond regular workdays. We believe these factors collectively underline the importance of a well-rounded and passenger-focused service in ensuring high satisfaction rates.

3. Summary & Conclusions

The study provides a comprehensive evaluation of the Q Line Bus Rapid Transit (BRT) system's impact on Fresno's housing market and passenger satisfaction. Despite initial expectations of increased residential property values near the Q Line corridor, the analysis of housing prices reveals no statistically significant changes compared to other regions in Fresno. This challenges the assumption that public transit improvements universally drive property appreciation and suggests that other factors may be influencing Fresno's housing market dynamics.

Passenger satisfaction was assessed using FAX survey data, with statistical independence tests and advanced machine learning models providing insights into satisfaction drivers. The Chi-Square Test of Independence found no significant variations in satisfaction scores across demographic factors like age, gender, work status, and education. However, household size and income levels significantly influenced satisfaction, with larger households and higher-income passengers reporting higher satisfaction levels. Conversely, smaller households and lower-income riders expressed lower satisfaction, indicating disparities in service perception that merit further attention.

Machine learning analysis identified eight critical factors driving passenger satisfaction on the Q Line: audio-visual quality, value, proximity to home and destination, comfort, driver helpfulness, disability access, and weekend hours. These findings underscore the importance of a passenger-centered, inclusive, and comprehensive transit service to enhance the commuting experience.

Adjustments made to the demographic and satisfaction categories during the independence tests highlight a key methodological challenge. Simplifying categories to address low sample sizes and expected frequencies ensured statistical validity but introduced limitations, such as reduced sensitivity and potential masking of nuanced relationships. This methodological trade-off underscores the importance of larger and more detailed datasets in future research to better capture the complexities of passenger satisfaction and demographic interactions.

In conclusion, the Q Line has become a cornerstone of Fresno's public transit network, significantly enhancing the commuting experience for many passengers. However, its impact on the housing market remains limited, and disparities in satisfaction among specific demographic groups indicate areas for improvement. Policymakers and transit authorities are encouraged to prioritize inclusive, passenger-centered enhancements, addressing the concerns of lower-income and smaller household riders while leveraging insights into the factors driving satisfaction. Building on these findings, further research might utilize more detailed and comprehensive datasets to deepen insights into the Q Line's broader social and economic impacts, with a particular focus on improving ridership experience and understanding transit-related housing dynamics.

A critical area for future research might involve analyzing ridership patterns, particularly for lower-income and smaller household passengers who rely on multiple buses to complete their journeys. Studying trip duration, wait times, and transfer efficiency might reveal key service gaps that affect satisfaction and accessibility. Evaluating existing transit policies and identifying areas for refinement might help improve service design, particularly through initiatives such as fare assistance programs, increased service frequency, and extended off-peak hours. Additionally, expanding qualitative research—through rider interviews and focus groups—might provide richer insights into the lived experiences of different demographics, ensuring that future transit improvements align with their needs. Beyond individual transit experiences, a broader examination of transit accessibility in relation to job centers, essential services, and affordable housing locations might offer practical strategies for optimizing route planning and service expansion.

Similarly, a more comprehensive approach to studying Fresno's housing market might clarify the factors influencing property values near the Q Line. Examining planned developments and infrastructure projects in the near future might provide a clearer picture of their immediate and long-term effects on neighborhood growth. Additionally, assessing how transit accessibility interacts with upcoming commercial, residential, and mixed-use projects might reveal evolving trends that were not evident in past data. A deeper analysis of policy changes—including zoning reforms, incentives for transit-oriented development, and shifts in housing regulations—might help identify potential catalysts for market change. By comparing Fresno's experience with similar cities undergoing transit expansions, researchers might further uncover the specific conditions that enable public transit investments to shape housing markets effectively. Integrating these perspectives might not only enhance understanding of the Q Line's economic impact but also inform more strategic planning efforts for Fresno's future development.

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