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RESEARCH
UDOT Keeping Utah Moving
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16. Abstract
This report presents the quantitative short-term (one year after) and long-term (four years after) effects of the Provo-Orem Transportation Improvement Project (TRIP). TRIP consists of a number of transportation improvements, including the construction of the new Bus Rapid Transit (BRT). In this study, to achieve an understanding of the quantitative effects of BRT, we studied traffic volume, transit ridership, nearby land use, trip generation, automobile traffic speeds, traffic safety, parking supply, and vehicle emissions in the 0.5-mile buffer area of the UVX alignment from 2013 to 2022. BRT was constructed and opened from 2016 to 2018. In particular, we used quasi-experiment methods to estimate the causal impacts of an intervention (BRT) on the target area before and (short and long-term) after BRT operation. This comes as close to a true scientific experiment as one typically can come in the social sciences. As a result, although population, university enrollments, land use, and trip generation in the study area increased, the traffic volume along the BRT alignment decreased significantly, especially in the long term, due to the increased bus ridership. In detail, due to the BRT, total floor area, the number of residential units, land market value, total trip generation, parking supply, and traffic speed increased, and vacant land, crash rates, and estimated vehicle emissions decreased significantly, particularly in the long term. In other words, the introduction of BRT in Provo and Orem was successful, especially in the long term, though less so than the introduction of LRT in Salt Lake County along 400/500 South corridor. The likely reason is that the BRT in Utah County doesn't meet the gold standard of exclusive right-of-way along its entire length and does not connect origins and destinations that are as likely to exchange trips.

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Bus Rapid Transit, Transit Ridership, Traffic Volume, Travel Time, Land Use, Trip Generation, Parking Supply and Occupancy, Traffic Safety, Vehicle Emission

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

UNIT CONVERSION FACTORS

Units used in this report and not conforming to the UDOT standard unit of measurement (U.S. Customary system) are given below with their U.S. Customary equivalents:

- 1 meter (m) = 3.28 feet (ft)
- 1 kilometer (km) = 0.62 mile (mi.)
- Etc.

(Alternatively, the following conversion factors table may be included. Enlarge to fit.)

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. (Adapted from FHWA report template, Revised March 2003)

LIST OF ACRONYMS

UDOT	Utah Department of Transportation
UTA	Utah Transportation Authority
WFRC	Wasatch Front Regional Council
MAG	Mountainland Association of Governments
FHWA	Federal Highway Administration
BRT	Bus Rapid Transit
NHTSA	National Highway Traffic Safety Administration
UVX	Utah Valley Express
UVU	Utah Valley University
BYU	Brigham Young University
LRT	Light Rail Transit
CBD	Central Business District
ITS	Intelligent Transportation System
AADT	Annual Average Daily Traffic
CCS	Continuous Count Stations
VPD	Vehicles Per Day
EIA	Energy Information Administration
VMT	Vehicle Miles Traveled
ITE	Institute of Transportation Engineers
TTI	Travel Time Index
EPA	Environmental Protection Agency
CCD	A Census County Division

EXECUTIVE SUMMARY

This study seeks to quantify the short-term and long-term effects of implementing a new Provo-Orem Bus Rapid Transit (BRT) line on traffic volumes, transit ridership, nearby land use development, land market value, trip generation, automobile traffic speed, traffic safety, parking supply, and vehicle emission reduction, providing quantitative data that can be used for future transportation policies aimed at reducing traffic impacts.

Our study compared observed traffic volumes in the BRT corridor to those predicted using three different quasi-experimental methods. The first and weakest quasi-experimental design simply compares observed traffic volumes before BRT (2017) to observed traffic volumes short-term after (2019) and long-term after BRT (2022) and assumes that any change in traffic on the alignment is due to the "treatment," that is, the initiation of BRT. The observed weighted average traffic volume along the BRT alignment held steady, increasing by only 0.01 percent or 2 vehicles per day (VPD) between 2017 and 2019, which incorrectly suggests that BRT had no effect on traffic volume in the corridor. However, in the long-term aspect, it decreased by 2.10 percent or 662 VPD between 2017 and 2022. The second quasi-experimental design, referred to as interrupted time series, assumes the trends in traffic on BRT segments from 2013 to 2017 continue through to 2022 after BRT was in place. Making that assumption, traffic volume on the BRT segments is 2,514 VPD lower (-7.38%) than one would expect based on the preexisting trend in 2019 and 6,613 VPD lower (-17.63%) than the expected value in 2022. Also, BRT appears to reduce vehicular traffic on the different sections of BRT by anywhere from 2,864 to 9,736 per day in 2022. The third quasi-experimental design is called a before-after design with a control group, which assumes that traffic volume on the BRT route would increase by as much as the percentage increases in traffic on the neighboring streets (0.5 miles away from BRT), that relative reduction is 2.30 percent or 645 VPD between 2017 and 2019 and 2.86 percent or 875 VPD between 2017 and 2022. Regarding all three research designs, BRT appears to reduce vehicular traffic on BRT alignment by 3.22 percent or 1,052 VPD between 2017 and 2019. Also, it reduced by 7.53 percent or 2,717 VPD between 2017 and 2022. Meanwhile, transit ridership in the corridor increased more than expected by 8,840 passengers per day (127.05%) in 2019 and 3,438 passengers per day (42.56%)

in 2022 with the introduction of BRT, which accounts for the effective reduction of vehicular traffic on the streets that comprise the BRT alignment.

Also, to determine whether the reduction in traffic volume was truly due to the BRT operation, we analyzed other factors that could affect traffic. Before and after the BRT operation, the population in Provo-Orem CCD increased by 3.15 percent between 2017 and 2019, and 3.94 percent between 2017 and 2022. The enrollment numbers of BYU and UVU increased by 6.27 percent between 2017 and 2019 and 9.45 percent between 2017 and 2022. In terms of land-use change, vacant land in the corridor decreased by 5.78 percent between 2017 and 2019 and decreased by 15.97 percent between 2017 and 2022. Total floor area increased by 6.03 percent between 2017 and 2019 and increased by 20.89 percent between 2017 and 2022. Total land market value per area increased by 18.88 percent between 2017 and 2019 and 82.49 percent between 2017 and 2022. In terms of trip generation, total trips in the corridor increased by 33.25 percent between 2017 and 2019 and by 38.12 percent between 2017 and 2022. This is expected to increase further in the future, mainly due to the increase in the number of recently built multifamily and single-attached housing. Also, we were able to dismiss bypass trips, fuel price changes, and construction effects as causes of the relative traffic volume reduction along the BRT line. Based on this, we can conclude that BRT had some effect on easing vehicle traffic congestion in the Provo-Orem metropolitan area. However, it does not have nearly as great a documented impact on traffic volumes as an LRT line in the same region (University TRAX line in Salt Lake County), perhaps because the BRT operation in question is not Full-BRT but instead is classified as BRT-Lite. In fact, the results of sections 1, 2, and 4, which almost meet the gold standard, showed a close level of impact to that of LRT in long-term after.

In addition, between before and after the BRT operation, the annual average traffic speed along the BRT alignment was temporarily lower than expected by 5.02 percent in 2019 but higher than the expected value in 2022 by 1.29 percent. From this, we conclude that the introduction of BRT had no significant effect on congestion. Considering the estimated traffic speed based on the previous trend, traffic flow slightly improved, especially in the long term after the BRT operation. In terms of crash rates, the total crash rate along the BRT line was lower than the expected value by 39.36 percent in 2019 and by 44.60 percent in 2022. The injury crash rate along the BRT line decreased more significantly after the BRT operation by 44.84 percent in 2019 and by 64.03

percent in 2022, relative to the projected value. In parking supply, BYU and UVU's parking supply increased by 6.67 percent between 2017 and 2019 and increased by 4.49 percent between 2017 and 2022. In vehicle emissions, due to the reduced vehicular traffic on the BRT alignment, annual savings of 450,999 gallons of gasoline and 8,819,761 pounds of CO_2 were estimated in 2022. Based on these analyses, we conclude that the introduction of BRT in Provo and Orem was successful, particularly in the long-term aspects. This research provides strong justification for the introduction of BRT/UVX in Utah County.

1.0 INTRODUCTION

This study seeks to quantify the before and after effect of implementing a new Provo-Orem Bus Rapid Transit (BRT) line on traffic volume, transit ridership, nearby land-use, trip generation, automobile travel time, traffic safety, parking supply and occupancy, and vehicle emissions, providing quantitative data that can be used for future transportation policies aimed at reducing traffic impacts.

Following the success of the Emerald Express in Eugene, Oregon, in 2007, many metropolitan areas are making plans for BRT. Simultaneously, many cities are also experimenting with packages of service and infrastructure improvements, frequently labeling these upgrades as ’BRT’ although few routes meet the most stringent criteria.

BRT has long been suggested since the 1960s as a solution to the urban transportation problem (Meyer et al., 1965). The concept has only recently become popular in American transportation policy. Cities and regions across the nation are experimenting with ways in which to make a ’better bus.’ Like other forms of rapid transit, BRT has been promoted as a means of reducing congestion, improving air quality, reducing automobile dependence, and inducing redevelopment with a relatively low installation cost.

This concept is becoming popular in Utah as well. According to the Mountainland Association of Governments (MAG) report, because of Brigham Young University (BYU) and Utah Valley University (UVU) growth, coupled with new housing and economic development opportunities, highway capacity was rapidly reaching its limit, and mobility improvement was required in the travel corridor between the universities. In Utah County, to meet this growing travel demand, they agreed on the need for more frequent, higher-capacity transit services connecting the university campuses to housing in Provo and Orem and employment centers within the corridor. Therefore, transportation agencies opened the Utah Valley Express (UVX) line in Central Utah County in August 2018 (full operation opened in December 2018).

Provo-Orem BRT is operated by the Utah Transit Authority (UTA) and consists of 18 stations along a 10.5-mile-long BRT alignment connecting the Orem Intermodal Center to the Provo Intermodal Center. Intermediate destinations include Utah Valley University (UVU), Utah

Valley Medical Center, University Mall, Brigham Young University (BYU), the Provo Central Business District (CBD), and Provo Town Center Mall.

In some previous papers, researchers have reported that BRT leads to increased economic development, such as job growth, land price premiums, accessibility to jobs and healthcare, output, and labor market access (Nelson, 2013; Cervero & Kang, 2011; Suzuki et al., 2013; Lee & Miller, 2018; Tsivanidis, 2019). Some of the previous studies have found that BRT leads to a decrease in emissions such as PM 10, CO, NOx, SO2, and ozone (Budi-Nugroho, 2011; Turner et al., 2012; Salehi, 2016; Bel & Holst, 2018). In addition, some studies have found that BRT increases ridership and decreases the travel time of buses (Weinstock et al., 2011; City and County of Honolulu, 2001; National BRT Institute, 2003; Yazici et al., 2013; Currie, 2006; Heddebaut et al., 2010).

However, most of the previous studies were largely focused on ridership outcomes or economic development. While there are numerous BRT systems in other countries, there has been limited exploration of BRT's comprehensive impact on traffic conditions (traffic volume, automobile travel time, traffic safety), land use (nearby land use, trip generation, parking supply and occupancy), and vehicle emissions in previous papers. Since these factors influence each other and cause a chain reaction, understanding the comprehensive impact of BRT is necessary to obtain a justification for BRT. Particularly, studies about the quantitative effect of BRT on traffic patterns (traffic volume, automobile travel time, and crash rate) are almost nonexistent. The closest we can come to this study is the previous study of the implementation of LRT on traffic in the 400-South corridor of Salt Lake County (Ewing et al., 2014). This previous study showed that the introduction of LRT took roughly 10,000 vehicles per day off 400 South and its 0.5-mile buffer. What motivates this study is a desire to determine if BRT has similar traffic impacts as does LRT.

Therefore, in this study, we would like to understand the quantitative effect of the Provo-Orem BRT on traffic volume, transit ridership, nearby land use, trip generation, automobile travel time, traffic safety, parking supply and occupancy, and vehicle emissions, using quasi-experimental research methods.

2.0 LITERATURE REVIEW

2.1 Overview

The Federal Transit Administration (FTA) defines Bus Rapid Transit (BRT) as “a rapid mode of transportation that can combine the quality of rail transit and the flexibility of buses” (Thomas, 2001). Many regions around the US and foreign countries are developing BRT systems as an alternative to the automobile. BRT has become an attractive option because of its efficiency and relatively low construction cost compared to rail modes. It can carry many people simultaneously, and it is more reliable than conventional bus service. Living near a BRT line offers an array of benefits that have been measured in several previous studies. According to previous research, BRT can provide lower transportation costs, more compact development patterns, higher property values, and reduced air pollution. However, the impact of BRT on congestion, traffic volume, and safety is not clear.

2.2 History of the Bus Rapid Transit (BRT)

In 1974, the first BRT system was launched, without any ITS tools, to offer efficient and effective bus travel within the fast-expanding city of Curitiba, Brazil. Then, Ottawa, Canada (1983) and Quito, Ecuador (1994) started BRT systems, which integrated ITS (Finn, 2011). Early BRT adopters, such as Curitiba and Ottawa, built the BRT system mainly because it is more affordable than Light Rail Transit (LRT) (Cervero, 1998). Because of this benefit, congested cities such as Bangkok, Jakarta, and Sao Paulo, Brazil, have been drawn to BRT to solve congestion problems. This is because, with relatively low fares, high-capacity public transport can be quickly built and expanded (Cervero, 2014). The TransMilenio, the most recognized BRT with the highest capacity, was opened in 2000 in Bogota, Columbia. In addition, Guangzhou, China, and Istanbul, Turkey, operate high-capacity BRT systems, and BRT operates in about 177 cities worldwide. In the US, the first BRT system, which focused on speed, was launched in the 1990s. The first guideline was written in 2004. Currently, BRT is in operation in 38 cities in the United States, including the Provo-Orem BRT, and BRT is under construction in several other cities in the US (BRTdata.org).

BRT is divided mainly into "BRT-Lite," "BRT-Heavy," and "Full-BRT" categories according to its characteristics. BRT-Lite is the lower limit of BRT and is faster than a regular bus. It usually has greater stop spacing and priority at signalized intersections. BRT-Lite is the most common style of BRT in North America (e.g., Los Angeles, Chicago, Vancouver). The Provo-Orem BRT would be classified as BRT-Lite because only half of the alignment has bus-only lanes, the bare minimum to qualify as BRT. Full-BRT can achieve LRT-style performance. It requires full grade-separated transitways, off-board fare collection, frequent and rapid services, and modern and clean vehicles (e.g., Bogotá, Brisbane, Ottawa). BRT-Heavy is the concept between BRT-Lite and Full-BRT, emphasizing dedicated on-street right-of-way (e.g., Cleveland, Eugene) (Wright & Hook, 2007; Hoffman, 2008; Kantor et al., 2008).

2.3 Impact of BRT

Previous research about the impact of the BRT is extensive. However, some people still have doubts about the potential of BRT because of their belief that BRT provides fewer regional accessibility benefits than rail. Also, it is because of the social stigma of bus-based transit. For these reasons, despite the success of several BRT systems, such as Curitiba and Ottawa, some people still question BRT's ability to reduce car dependence and promote sustainable urban growth (Cervero, 1998; Cervero, 2014).

2.3.1 Economic Impact of BRT

In previous research about the impact of BRT on economic development, Nelson (2013) found that Eugene-Springfield's BRT increased job growth within 0.25 miles of BRT stations, while the metropolitan area lost jobs between 2004 and 2010. Also, Cervero and Kang (2011) found that BRT in Seoul affected a 10% increase in land price premiums and a 25% increase in retail employment in a 300m buffer area of BRT stops. Lee and Miller (2018) also found that BRT in Columbus, OH, increased residents' accessibility to jobs and healthcare and decreased delay. In Guangzhou's BRT corridor, real estate prices increased by 30 percent during the first two years of BRT operations (Suzuki et al., 2013). In addition, Tsivanidis (2019) found that the Transmilenio BRT increased economic output by about 1.09% and improved labor market access in Bogota. In addition, many single transit systems have been analyzed in terms of effects on urban development and property values (Cervero, 1984; Knowles, 1996; Dueker & Bianco, 1999; Currie, 2006; Cao & Schoner, 2014; Stokenberga, 2014).

2.3.2 Emissions Impact of BRT

In previous research about the impact of BRT on vehicle emissions, Cervero and Murakami (2010) found that BRT could reduce vehicle miles traveled and related emissions by attracting former motorists. Budi-Nugroho (2011) found a reduction in PM10 and ozone after BRT operation, and this phenomenon was linked to a modal shift of commuters. In Bogota, Hidalgo (2013) estimated that health-cost savings from the emission reduction due to the TransMilenio (BRT) was about $114 million over 20 years. In addition, the government of Bogota reported that after the TransMilenio operation, the emission reduction was about 43% in SO_2, 18% in NO_x, and 12% in particulate matter (Turner et al., 2012). Hodgson (2013) compared the emissions from light rail and BRT in the UK, and he found that BRT produced lower PM10 but higher NO_x. Also, Salehi (2016) found that BRT reduced air pollution in Tehran by about 5.8% in PM 10, 6.7% in CO, 6.7% in NO_x, and 12.5% in SO_2. Bel and Holst (2018) found an emission reduction after the BRT operation in the city by about 5.5-7.2% in CO, 4.7-6.5% in NO_x, and 7.3-9.2% in PM10. Hence, the impact of the BRT on emission reductions showed significant differences from system to system depending on the type, design, and surrounding context.

2.3.3 Ridership and Travel Time Impact of BRT

Previous research has focused on changes in ridership and travel time of buses before and after BRT operation. In Cleveland, Ohio, ridership increased about 60%, and speed increased by 34% after the BRT operation began. In Eugene, Oregon, ridership increased by 74%, and speed increased by 30.4% after BRT. In Las Vegas, Nevada, ridership increased about 25%, and speed increased about 20% after BRT. In New York, ridership increased by 7% on Fordham Rd, and speed increased about 20% (Weinstock et al., 2011). In Honolulu, ridership increased by 59% after one year of BRT operation, and travel time decreased by 49% (City and County of Honolulu, 2001). After the BRT operation began, ridership increased about 50% in Miami, and travel time decreased less than 10% (National BRT Institute, 2003).

In foreign cases, ridership increased about 150% in Istanbul, and travel time decreased by 65% due to the fully segregated BRT (Yazici et al., 2013). In Brisbane, ridership increased by 56%, and travel time decreased about 70% due to the segregated system with signal priority and high frequency of service. In Sydney, ridership increased by 56%, and travel time decreased by 51% due to the dedicated busway and intelligent transport system (ITS) technology, including traffic signal priority, real-time passenger information, and some off-board fare collection (Currie, 2006). In Madrid, ridership increased by 85%, and travel time decreased by 33% due to the fully segregated BRT and strongly connected metro network (Heddebaut et al., 2010).

Previous BRT travel time research indicates that implementing the dedicated right of way, signal priority, and other Advanced Public Transport System (APTS) elements are needed to obtain high speed with BRT (Ingvardson et al., 2015). So, completely segregated bus lanes, bus stops with ticketing systems on the platform, real-time information, and signal priority along the entire corridor are recommended. However, one or several elements are often omitted due to construction costs (Rodríguez & Targa, 2004). Thus, huge differences in the efficiency of BRT exist between the various systems in the world, and it is hard to assess the general impacts of BRT (Ingvardson & Nielsen, 2017).

2.3.4 Congestion Impact of BRT

The impact of BRT on the travel time of personal vehicles, or congestion, depends on the BRT's setting and configuration, and relatively fewer studies exist. In Bogota, Tsivanidis (2019) found that there was no significant change in car speeds after BRT. This was attributed to the substitution across modes and routes arbitraging any initial speed difference caused by the BRT and to small elasticities of driving speeds with respect to vehicle volumes at high levels of rush hour traffic. In Lahore, Majid (2018) found that due to 40% of riders switching from using private transport to public transport after the BRT operation, commute times declined as congestion was reduced. In Mexico City, in a related study, Anderson (2014) found that the interruption of public transit significantly increased congestion in LA through the LA strike case.

On the other hand, in Delhi and Taichung, poor implementations led to congestion problems and, eventually, abandonment of BRT systems. Even though BRT might promote shifting commuters into public transportation, some BRT systems take lanes from private transport, and for this reason, congestion can increase (Pojani & Stead, 2017; Majid, 2018). Where BRT lanes are added to the existing cross-section, it should have the opposite effect.

2.3.5 Safety Impact of BRT

In previous research about the relationship between BRT and safety, Bocarejo et al. (2012) found that BRT was correlated with an overall reduction (60%) in traffic crashes along its corridor in Bogota. However, crashes increased in some areas, seemingly related to higher speeds in mixed traffic and more pedestrians around stations (Bocarejo et al., 2012). Duduta (2012) found that BRT is correlated with a reduction in crashes in Bogota, Guadalajara, and Delhi, but not to a statistically significant degree. The safety benefits occurred from changes in street geometry (the debut of a BRT lane), which (a) reduced the number of legs at certain intersections, (b) reduced the number of lanes to accommodate stations, (c) restricted left turns, and (d) shortened pedestrian crossings with a central median refuge island. In Bogota, fatalities decreased by 60%. In Guadalajara, monthly crashes along the corridor decreased by nearly 50%. Duduta (2013) found that BRT reduced road crashes by 56% over a period of three years in Guadalajara. Goh (2013) found a 14% reduction in road crashes in Melbourne; the audit review also found negative qualitative impacts of the BRT, such as more complex side street exits. However, in Delhi, traffic fatalities more than doubled after BRT, possibly due to increased pedestrian exposure to buses (Duduta et al., 2012).

Several previous research studies focused on the relationship between BRT design and safety.

BRT System Lanes: Duduta et al. (2015) estimated that 9% of all crashes occur in the BRT lanes, while the vast majority of traffic crashes occur in the general traffic lanes and do not involve buses at all. One of the worst-designed lanes one could have for a BRT is a counter-flow (meaning, going the opposite direction as traffic) lane. Counter-flow BRT lanes have been correlated with higher crash rates for both vehicles and pedestrians (Duduta et al., 2015; Duduta et al., 2013; Miller, 2009; Vecino-Ortize & Hyder, 2015). Contrarily, center lane configurations for BRT systems have repeatedly been said to reduce collisions (Duduta et al., 2015; Duduta et al., 2013; Miller, 2009; Santos-Reyes & Avalos-Bravo, 2014; Vecino-Ortize & Hyder, 2015). Then again, Miller (2009) simply states that any fully grade-separated, segregated BRT lane has the highest level of safety (among other characteristics—highest cost, reliability, etc.) of any BRT running way type.

Intersections: Duduta et al. (2015) found that the size and complexity of intersections, as well as road width, are the most reliable predictors of crash frequencies along BRT corridors. The number of approaches per intersection, the number of lanes per approach, and the maximum pedestrian-crossing distance are some of the key factors that influence intersection safety.

Pedestrian safety: Pedestrians account for a majority of traffic fatalities along BRT corridors (Duduta et al., 2012), specifically when pedestrians attempt to cross the street and are struck by vehicles. Mid-block signalized crossings and/or traffic calming measures have made positive safety impacts in other traffic studies but have not been measured for BRT operations (Diogenes & Lindau, 2010; Duduta et al., 2012; Duduta et al., 2013; Elvik & Vaa, 2004). In fact, Wright and Fjellstrom (2003) believe that the smart design of dedicated pedestrian zones around BRTs can be mutually beneficial for both pedestrians and the BRT system. Miller (2009) also emphasized pedestrian/BRT environment relations, stating crosswalks should reach median bus lanes, bus stops should be positioned at signalized locations when possible, and all components should be designed to discourage errant crossings.

Limitations: Vecino-Ortize and Hyder (2015) identified several issues with previous studies:

(1) the heterogeneity of BRT systems' surrounding environments is seldom considered, and therefore, it is challenging to compare different BRT systems' effects

(2) many cities that implement BRT concurrently invest in other road safety infrastructure and policies, which implies unobserved actions may also affect reduced crash rates

(3) many studies lack appropriate designs to infer causality with observational and nonexperimental data, especially using before/after studies without bona fide counterfactuals

(4) instead of empirical data, some BRT support is founded on modeling infrastructure changes, which implies an urgent need for real-world evaluations.

Also, Vecino-Ortize and Hyder (2015) concluded that no comprehensive before and after studies have been conducted on the safety effects of arterial BRT systems in the U.S. context and emphasized the need for this.

2.4 Summary of Literature Review

This literature review found that most of the previous research focused on operational performance, project implementation, or economic development impacts. However, there has been limited and unclear exploration of BRT's impact on traffic volumes, automobile travel times, and crash rates. In particular, understanding the relationship between BRT and traffic volume is necessary for future sustainable transportation planning because traffic volume is highly related to congestion and emissions. Since the effects of BRT do not exist independently but influence each other, integrated understanding is essential.

3.0 PROJECT DESCRIPTION

Provo Orem TRIP (Transportation Improvement Project) includes roadway, transit, bicycle, and pedestrian improvements to meet growing transportation needs in Orem and Provo. Roadway improvements include roadway widening, bridge replacement, installing pedestrian-friendly crosswalks, and improving various intersections along University Parkway and University Avenue. Transit improvements include Provo-Orem Bus Rapid Transit (UVX) implementation, exclusive bus lanes, transit signal priority, station amenities such as ticket vending machines, level boarding platforms, high-end shelters, benches, landscaping, and connected FrontRunner commuter rail. Roadway, bicycle, and pedestrian improvements include the following improvements:

Roadway Improvements:

- Widen University Parkway, 800 East to University Avenue, adding one new lane in each direction.
- Replace University Parkway bridges over the Provo River.

- Make intersection improvements on University Parkway at 200 East, Main Street, 800 East and 2230 North and in Provo at Freedom Boulevard, 400 West, University Avenue and 300 South.

- Add a new intersection at The Mix at River's Edge (2250 North University Parkway).

- Noise walls along University Parkway from 800 East to Carterville Road.

Bicycle and Pedestrian Improvements:

- New and wider sidewalks in many areas where sidewalks were narrow in width or in disrepair.

- Wider pedestrian ramps at intersections along the College Connector Trail.

- A bike lane in each direction along University Avenue from 400 South to 700 North.

- A safer gutter adjacent to the bike lanes along 700 North in Provo.

- A median curb along 700 North directing pedestrians and bicyclists to cross only in designated areas.

- A crossing in Provo at 200 East that directs bicyclists into their own lane across 700 North.

- Improvements to widen existing sidewalks along 900 East in Provo to 10-foot-wide multi-use paths.

- Increased width and height for the Provo River Trail where it crosses under University Parkway.

- Upgraded pedestrian ramps in many locations where the current ramps do not meet the most recent standards.

The UVX operates from the Orem Intermodal Center to the Provo Intermodal Center. Provo BRT's total length is 10.5 miles, at-grade right-of-way for approximately 5.3 miles, and mixed traffic at-grade for an estimated 5.2 miles. This BRT line includes 18 stops, including Utah Valley University, the University Mall in Orem, Brigham Young University, Downtown Provo, and the Provo Towne Centre (Figure 1). Moreover, this project has included the purchase of 25 new BRT vehicles. Service is provided every five minutes during weekday peak periods, every 10 minutes during weekday off-peak periods, every 15 minutes during weekday evenings, and every 20 minutes on Saturdays.

UTA and MAG initiated a corridor planning study in 2007, which was completed with the selection of a locally preferred alternative (LPA) in September 2010. The LPA was adopted in the region's fiscally constrained long-range transportation plan in May 2011. The project entered Small Starts Project Development in April 2013. The environmental review process was completed with the issuance by FTA of a Finding of No Significant Impact in March 2015. UTA received a Small Starts Grant Agreement in the Spring of 2016. Construction started in 2016. Sections 2 and 3 began in July 2016, and sections 1 and 4 in October. The final construction was completed in November 2018. Soft operation (revenue service) was initiated in August 2018, and regular operation started in December 2018.

Total capital cost was about 160 million dollars, and annual operating cost was about 3.5 million dollars. About half of the construction costs were covered by the Federal Transit Administration, whose program was capped at $75 million per project. The local match of $75 million came from transit taxes already being paid and collected in Utah County.

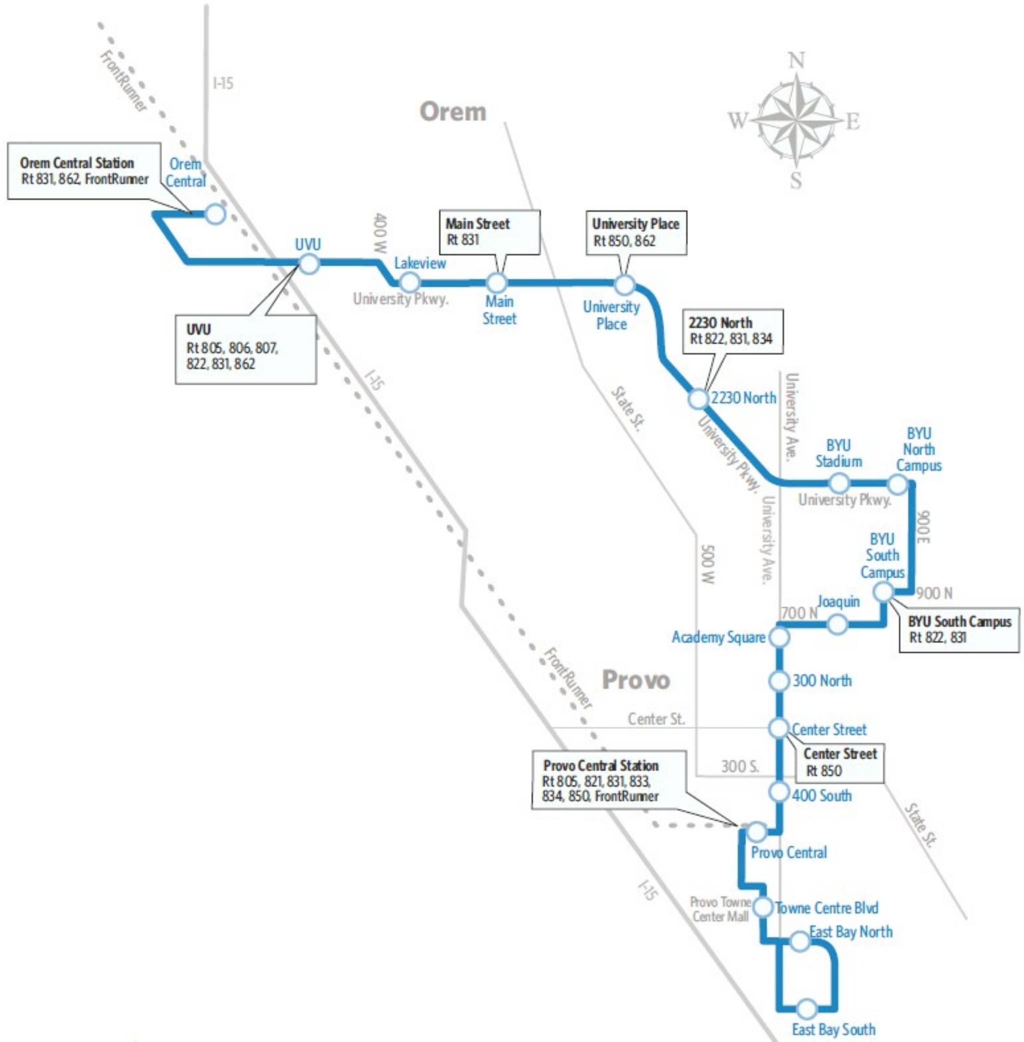

Figure 1 Provo-Orem BRT Map (From UTA)

4.0 STUDY AREA AND TIME FRAME

We selected a 0.5-mile buffer area on either side of the UVX alignment from 2013 to 2019 and 2022 as the study area (corridor) and timeframe of this study. The 0.5-mile buffer area was selected by analogy with light rail studies (Ewing et al., 2014) and as a rule of thumb on how far users are willing to walk to high-capacity transit lines. In choosing the timeframe of this study, we used a before-after design, focusing on one year before and one and four years after construction and full operation as the minimum timeframe to understand the Provo-Orem BRT's short- and long-term effects. We also looked at longer-term trends in traffic volumes from 2013 to 2017 and 2022.

Because new transit lines have a break-in period when travel patterns evolve as riders "discover" the new transit option, 2019, one year after opening, could not be enough time for transportation analysis purposes. Therefore, in this study, we monitored trends in 2022, four years after the opening of the BRT, to examine the long-term impact of BRT on travel behavior. In this study, 2020 and 2021 were excluded due to COVID-19 outbreak. According to the CDC report, 2020 and 2021 are the most affected years by the pandemic, which has completely altered travel behavior. It is difficult to judge that there has been a complete recovery in 2022, but since January 2022, patient numbers have significantly dropped, and travel behavior has also substantially normalized to pre-pandemic levels. Therefore, we monitored travel behavior in 2022, four years after the BRT implementation, and conducted a comparative analysis between one year after (short-term) and four years after (long-term) BRT implementation. However, to measure the long-term effect more accurately, it could be necessary to measure beyond May 2023, when the pandemic has officially ended. For this study, the study area and timeframe are as indicated in Table 1 and Figure 2.

Table 1 Timeline of the Provo-Orem BRT and Timeframe of the Study

<table>
<tr><th colspan="2">Description</th><th>Date</th></tr>
<tr><td colspan="2">Start of construction</td><td>2016 (July: section 2,3, Oct: Section 1,4)</td></tr>
<tr><td colspan="2">Construction ended</td><td>Nov 2018</td></tr>
<tr><td colspan="2">Soft opening</td><td>Aug 2018</td></tr>
<tr><td colspan="2">Full operation</td><td>Dec 2018</td></tr>
<tr><td rowspan="2">Timeframe of the study</td><td>Phase 1</td><td>2013 - 2019</td></tr>
<tr><td>Phase 2</td><td>2020 – 2022
(2020 and 2021 excluded due to pandemic)</td></tr>
</table>

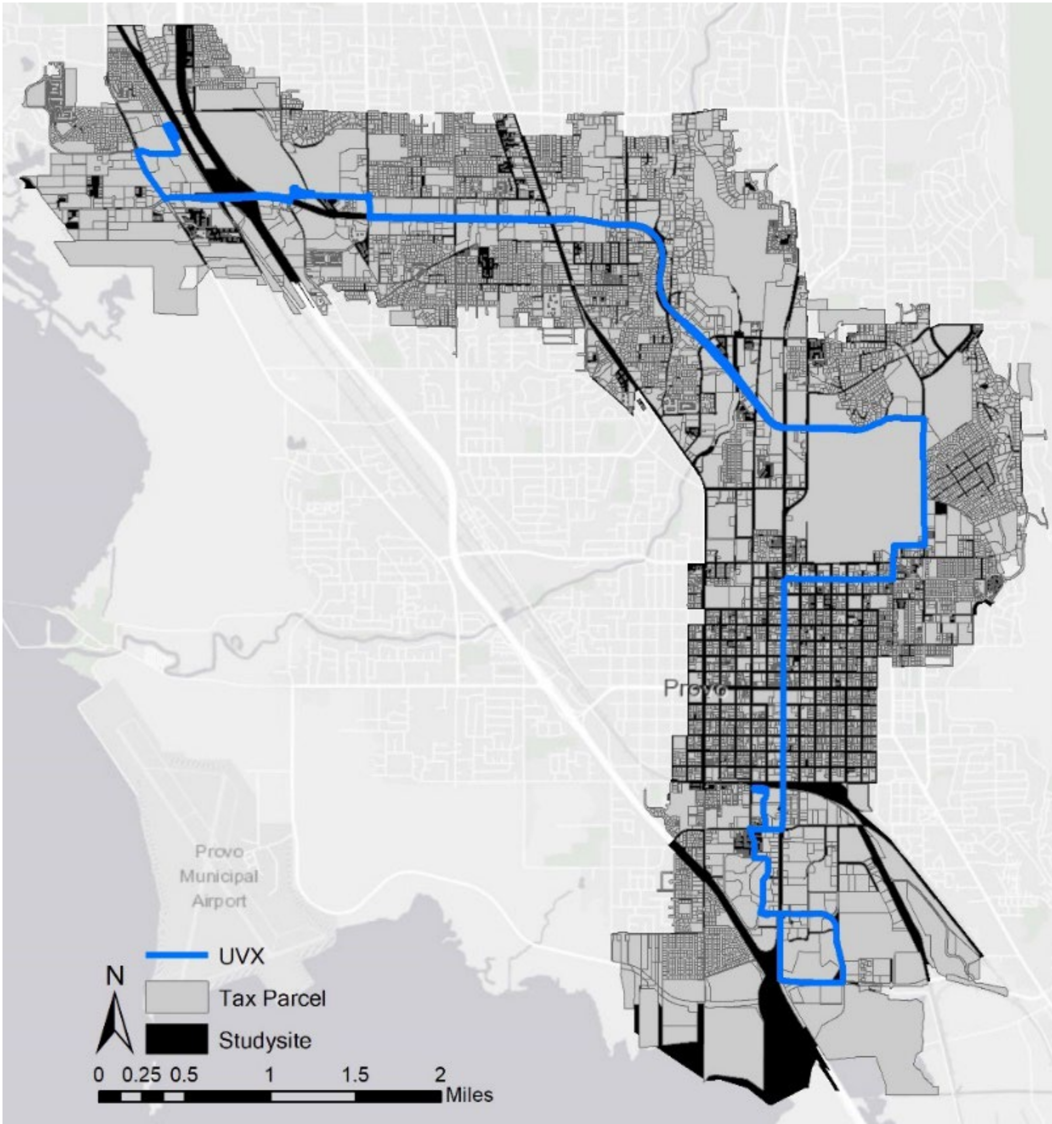

Figure 2 BRT line and Study Area (0.5 miles buffered area from BRT line)

5.0 TRAFFIC VOLUME AND TRANSIT RIDERSHIP

5.1 Data Collection

5.1.1 Traffic Counts

The traffic counts used in this evaluation were provided by the Utah Department of Transportation (UDOT). Our study used annual average daily traffic (AADT) as the traffic count variable, and AADT was defined as the average 24-hour traffic volume at a given location over a full 365 days/year (Molugaram et al., 2017). UDOT provides AADT values by calculating the total volume of vehicle traffic for a year divided by 365 days (UDOT, 2020).

$$AADT = \frac{Totalnumbersofvehiclespassingthesite \in year}{365}$$

Traffic data are analyzed and combined from various traffic counters throughout the state to obtain annual average daily traffic (AADT) numbers and other traffic statistics such as design hour volume and directional factor. The Traffic Monitoring Unit collects traffic count data (48-hour mobile traffic counts) on a sample basis throughout the state and maintains the permanent counters. The Traffic Analysis Unit uses the counts from these sources to obtain AADT numbers.

Mobile counts are completed using Wavetronix radar counters, Timemark, and Peek manufactured counters and hoses. Traffic counts are taken on all state highways and all federal aid-eligible roadways. There are also classification counts used to determine truck traffic and establish axle correction factors for volume counts.

All traffic data received in the office is checked to see that all hours are accounted for and that the site description matches where the count was taken. AADTs are then calculated using 111 permanent continuous count stations (CCS) data throughout the state to develop temporal factors (daily and monthly) and are then expanded to approximately 6033 short time counts (48 hours). Unfortunately, there is no continuous count station located in the Provo-Orem BRT corridor.

5.1.2 Transit Ridership

The transit ridership data used in this evaluation were provided by the Utah Transit Authority (UTA). Ridership data from UTA buses and trains is collected through an automated passenger counting system (APC). APC units are located on all vehicle doors. UTA has high confidence in the data. All of the data is available through the UTA data portal. For the bus ridership analysis, the average daily boarding on weekdays was used. In route selection, we selected all bus routes passing through the corridor except bus routes that have no data.

5.2 Methods

5.2.1 Quasi-Experimental Design

A quasi-experiment is an empirical study used to estimate an intervention's causal impact on its target population. Quasi-experimental research designs share some characteristics with traditional experimental methods, such as treating one group but not another. The two designs differ in the lack of random assignment of subjects to treatment and control groups in a quasi-experiment. Causal inference from any quasi-experiment must meet the basic requirements for all causal relationships: that cause precedes effect, that cause covaries with effect, and that alternative explanations for the causal relationships are implausible (Shadish et al., 2002).

The "treatment" in this quasi-experiment is the 10.5 miles of Provo-Orem BRT from Orem Intermodal Center to Provo Intermodal Center in August 2018 (full operation started December 2018). The year 2017 represents the last year before the initial treatment, and 2019 represents the first year after the treatment. As a long-term impact, 2022 represents four years after the treatment.

This research assumes that trends for the period before BRT implementation continued through the first year after the BRT implementation (interrupted time series) and that the relative increase in traffic outside the corridor between 2017, 2019, and 2022 would have occurred within the corridor in the absence of BRT (before-after research design with a control group). The latter is sometimes referred to as the difference in difference (DiD) analysis with a control group.

5.2.2 Study Sections of BRT Alignment

Since the BRT line's total length is about 10.5 miles from Orem Central Station to Provo Central Station, it includes several roads with different characteristics, such as University Parkway, 900 East, and University Avenue. However, since the functional class of roads, road width, average traffic volume, average traffic speed, and distance from the universities are significantly different, we decided that it was necessary to classify the sections to correctly understand the quantitative effect of the BRT on traffic volume. Therefore, according to geographical location and road characteristics, we divided the BRT line into four sections and analyzed each section separately. The division of the corridor is as follows (Figure 3).

- Section 1: W & E University Parkway (Principal Arterial)

- Section 2: N University Parkway (Principal Arterial)

- Section 3: E University Parkway, 900 E, E 700 N (Minor Arterial, Major Collector)

- Section 4: N University Avenue (Principal Arterial, Minor Arterial, Major Collector)

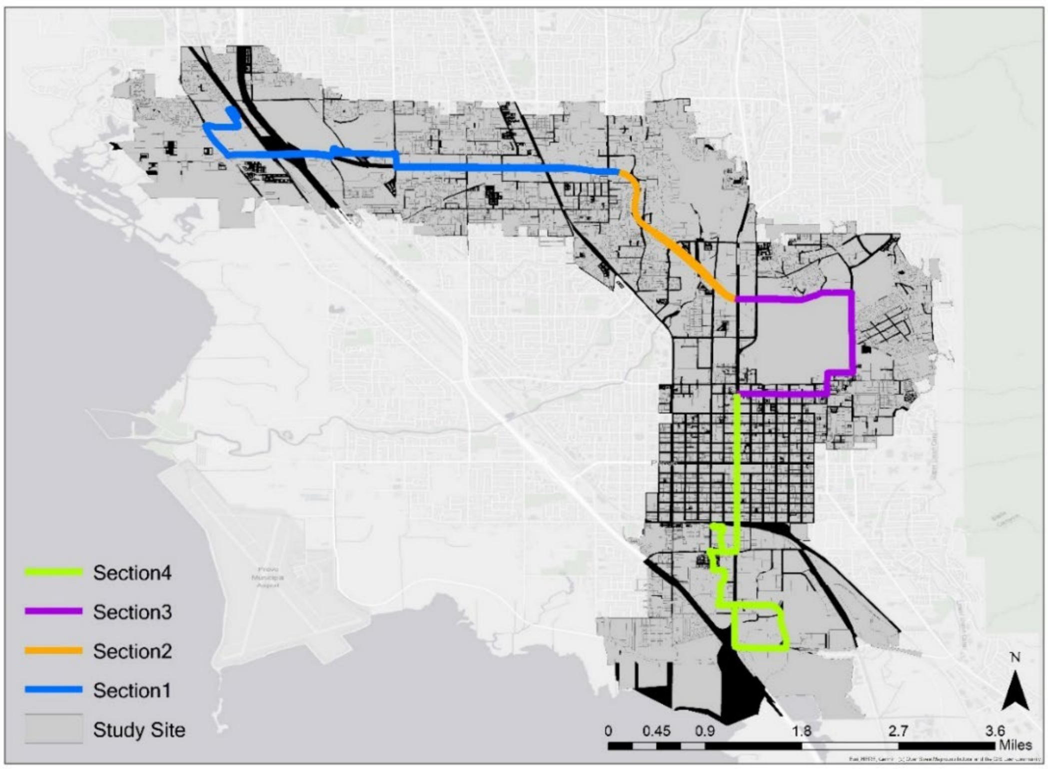

Figure 3 BRT Line by Sections, and Study Area (0.5 miles buffered area from BRT line)

5.2.3Weighted Average Traffic Counts

To analyze average AADT, our study used weighted average AADT, which was modified from the existing raw AADT data using the weighted mean method. In the AADT data, the length of segments was different for different sections. However, it has one unique value per segment. Using the simple arithmetic mean method to calculate average AADT can produce distorted and biased values because of length differences. For this reason, our study weighted AADT by the length of the highway segment.

$$WeightedAADT = \frac{(\sum_{k=1}^{n} AADT_k \times Length_k)}{\sum_{k=1}^{n} Length_k}$$

5.2.4 Traffic Volume – Before-After without a Control Group

Our first analysis uses the most straightforward quasi-experimental design, a one-group pre-treatment, post-treatment design with no control group. This can be diagrammed as follows, where the O is an observation, and the X is a treatment. The "treatment" in this case is the opening of the Provo-Orem BRT.

$$O_1 X O_2$$

This research design is classified as a "weak" quasi-experimental design because it lacks a control or comparison group. All of the differences in an outcome from before the treatment to after the treatment are attributed to the treatment itself. In this simple model of the world, we would assume that the Provo-Orem BRT line effect on traffic is the change in AADT from 2017 to 2019, and from 2017 to 2022 observed values. There was actually a small increase between 2017 and 2019, so in this simple comparison, the treatment would be seen to increase traffic by 2 VPD or 0.01% (Δ1). However, the treatment would be seen to decrease traffic by 662 VPD or 2.10% between 2017 and 2022. Of course, this is not a valid estimate because it ignores general increases in traffic volumes independent of BRT.

5.2.5 Traffic Volume – Interrupted Time Series

The second quasi-experimental design is an interrupted time-series design. In this design, we use the trend in AADT between 2013 and 2017 to predict the value for 2019 and 2022 in the absence of intervention (BRT). The time series refers to the data over the period, while the interruption is the intervention. The effects of the intervention are evaluated by changes in the level and slope of the time series and the statistical significance of the intervention parameters (Ferron & Rendina-Gobioff, 2005; Schweigert, 2011; Freilich & LaFree, 2017).

This study analyzed the weighted average AADT for the four sections of the BRT line, and ridership of the total buses, BRT, and other buses combined. Using the linear regression based on the trend before the BRT operation (2013-2017), we calculated a 2019 and 2022 predicted value. In terms of AADT and bus ridership, we calculated the absolute change and percentage change between observed and predicted values for 2019 and 2022. For most sections, the observed AADT of the BRT alignment is below the trend line, and the observed AADT is below the predicted AADT, so the implementation of BRT is estimated to have taken traffic off the roadways (Δ2). A significant decrease in the observed value compared to the predicted value was found in 2022 compared to 2017. This can be diagrammed as follows, where O1 to O5 refers to the years from 2013 to 2017, the period before the intervention, O6 to O9 refers to the years from 2019 to 2022, the period after the intervention, and X refers to treatment.

$$O_1 O_2 O_3 O_4 O_5 X O_6 O_7 O_8 O_9$$

5.2.6 Traffic Volume – Before-After with a Control Group

Before-after comparison with a control group is a powerful method to prove the treatment's effect. Still, it requires a more sophisticated quasi-experimental design, a design that includes both a pre-treatment observation and a control or comparison group. For the quasi-experimental analysis with the control group, we used the difference in difference (DiD) method in this analysis.

The difference in difference (DiD) is one of the quasi-experimental analysis methods. It attempts to mimic an experimental research design using observational study data by comparing the differential effect of a treatment on a 'treatment group' and a 'control group' in a natural experiment (Angrist & Pischke, 2008), as diagrammed below. Where O1 to O9 refers to the treatment group and O10 to O18 refers to the control group. Where O1 to O5 refers to the years from 2013 to 2017, the period before the intervention, in the control group, O6 to O9 refers to the years from 2019 to 2022, the period after the intervention, in the control group, and X refers to treatment.

$$O_1 O_2 O_3 O_4 O_5 X O_6 O_7 O_8 O_9$$

$$O_{10} O_{11} O_{12} O_{13} O_{14} O_{15} O_{16} O_{17} O_{18}$$

Prior to the quasi-experimental analysis, we set up the control group. Ideally selecting roads that have the same road characteristics as the BRT line and the same surrounding context (such as socio-demographic characteristics, traffic behaviors, and geographical characteristics) but not affected by the BRT, would serve the best as a control group. However, the surrounding area from the BRT line has special socio-demographic characteristics, such as the large student population due to the UVU and BYU campuses, which leads to a significant number of public transit users. Additionally, there are also special geographical characteristics near the BRT line, which is surrounded by lakes in the west and mountains in the east. Due to these special contexts near the BRT line, it is impossible to select an ideal control group that has a similar nearby context and is not particularly affected by BRT in the Provo and Orem areas. Considering this special context near the BRT line, we selected three roads (800 S: 0.6 miles away from section 1, State Street: 0.4 miles from section 2, 500W: 0.45 miles from section 4) as our control group. These streets are parallel to the BRT line and have similar road characteristics (functional class: principal arterials), and similar surrounding socio-demographic contexts, travel behavior, and geographical characteristics with the BRT line. The reason for selecting three roads as a control group instead of one road was to find a reasonably representative sample of roads just off the corridor. The limitation of this control group is that these streets are approximately 0.5 miles away from the BRT line, and based on the previous LRT research, these roads could be affected by the BRT, and it is hard to say that BRT's impact was completely ruled out. However, because the number of passengers for BRT is significantly lower than for LRT, 0.5 miles can be considered to be a distance where the impact of BRT is significantly reduced. Additionally, there is the possibility of a temporary detour from the treatment street to the control street. To assess this possibility, traffic volume changes on all roads within 0.5 miles of the BRT line (study area) were also investigated. For the control group, we calculated the weighted average AADT for the three roads in question. For the traffic volume changes on all roads within 0.5 miles of the BRT line, we calculated the weighted average AADT for all roads inside the BRT corridor. The treatment (BRT line), control group (neighboring streets), and within the corridor (every street's traffic volume within the study area) can be described as follows (Figure 4, Table 2).

- BRT line: The BRT line is a road shared by BRT in an at-grade right-of-way or mixed traffic at-grade configuration and is a road directly affected by the BRT.

- Neighboring streets (500W, 800S, and State Street): The neighboring streets are located within or just outside the 0.5-mile buffer area from BRT. These roads have similar surrounding socio-demographic contexts, travel behavior, and geographic contexts as the BRT line.

- Within the corridor: Every street inside the corridor, which is located in the 0.5-mile buffer area from BRT. These streets are assumed to be affected by BRT at an intermediate level between the treatment and control groups.

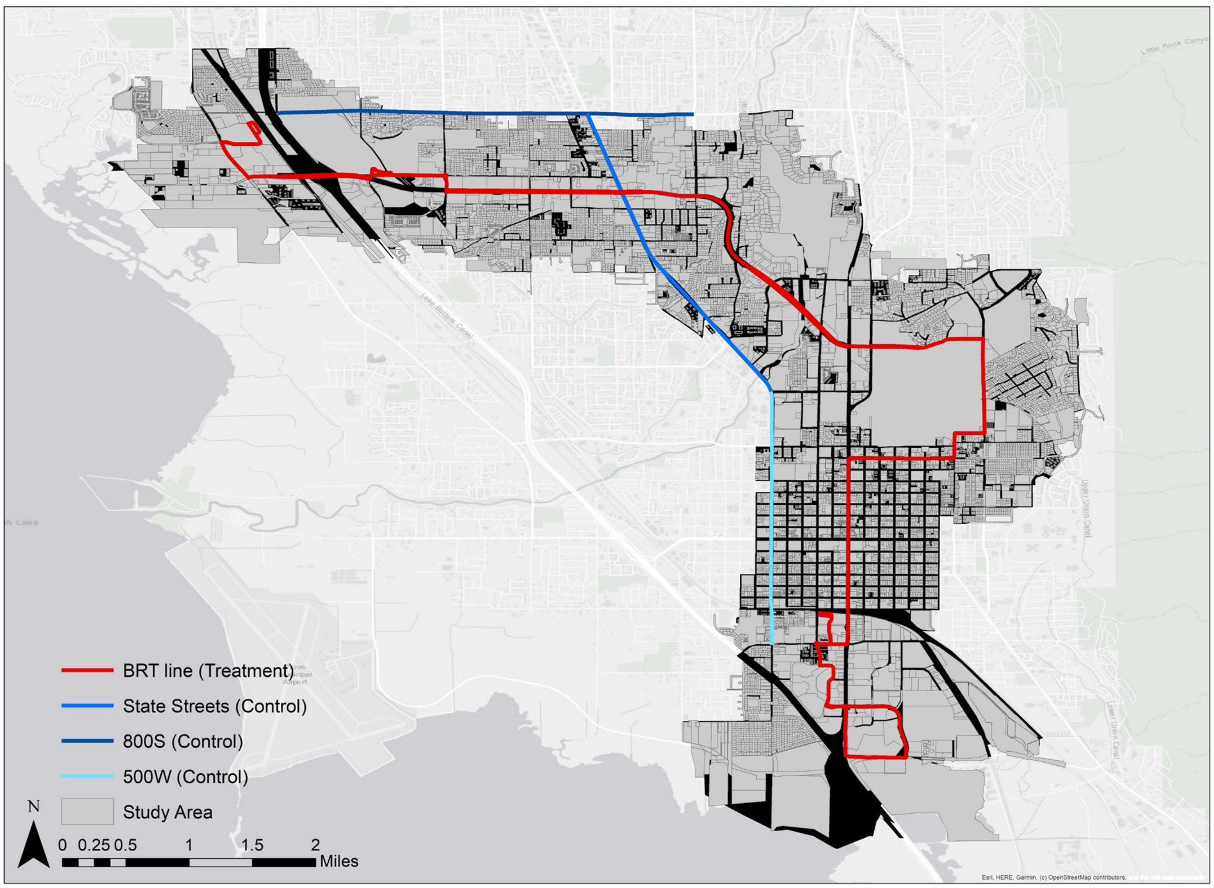

Figure 4 BRT Line and Neighboring Streets (500W, 800S, and State St.)

Table 2 Characteristics of the Neighboring Streets

	Distance from BRT line (miles)	Functional Class
800 South	0.6 (from Section 1)	Major Collector
State Street	0.4 (from Section 2)	Principal Arterial
500 West	0.45 (from Section 4)	Principal Arterial

In this analysis, we knew that because the BRT line and neighboring streets (control group) have different starting values, it is necessary to standardize values using the percentage change of the values for subsequent years. First, we analyzed the absolute and percentage change of AADT along the BRT line and neighboring streets between 2017 (one year before BRT operation), one year (2019), and four years (2022) after BRT operation. Second, using the difference in differences method, we applied the percentage change in our two control groups to the 2017 weighted average AADT for the BRT line to predict the 2019 and 2022 weighted average AADT along the BRT line in the absence of BRT. The difference of AADT in 2019 and 2022 along the BRT line versus the control group is our estimate of the impact of BRT.

Generally speaking, percentage increases in weighted average AADT for the control group were greater than percentage increases for the treated (BRT line) group, so the differences in AADT for all sections of the BRT alignment were negative numbers. That is to say that BRT is shown to have generally reduced traffic along the BRT sections. Additionally, in the case of roads within the corridor, an intermediate decrease in traffic between the BRT alignment and control group was observed. This suggests that the BRT operation not only reduced AADT on the BRT alignment itself but also reduced traffic in an area up to 0.5 miles from the BRT line. This result also suggests that it was not a temporary reduction due to detouring.

5.2.7 Population, Employment, Student Enrollment, Land-Use, Land Market Value, and Trip Generation

To determine whether traffic pattern change is truly due to the BRT operation, it is necessary to understand changes in other factors that can affect traffic. Therefore, we checked the population, employment, student enrollment, land use, land market value, and trip generation factors' change from before to after the BRT operation.

First, we checked the population and employment change within the corridor using the American Community Survey 5-Year Data. If the population and employment increased during the period, it could be assumed that traffic volume would also increase. If the reverse were true, it would have the opposite effect.

Second, we checked the enrollment change of UVU and BYU using the enrollment data from the two universities. Since the BRT passes through UVU and BYU, if the enrollments of these universities were increasing (or decreasing) during the period, it could be expected that traffic volume would similarly increase (or decrease).

Third, we checked the land-use changes during the period. If commercial and residential development increased and vacant land decreased after BRT operation, it could mean that BRT positively affected the surrounding area by increasing vitality and land value. Trip generation would also increase in this case. Conversely, if negative land-use change occurred, trip generation would decrease. To understand the land-use change in the study area, first, we analyzed the distribution of the altered land-use parcels from 2017 to 2022 by land-use types using tax assessment records from Utah County focusing on commercial and residential areas (High density residential, Apartment, and Single-family residential). The strength of this analysis is that it provides geographical information on where specific types of land uses are distributed within the study area and which parcels have changed use. However, visual comparison has limitations in determining specific quantitative land-use changes before and after BRT operation. Thus, we conducted quantitative analysis using the numerical value of specific land-use changes from 2017 to 2019 and 2022 using tax assessment data. All parcels that have land-use type information were reclassified into four categories (commercial, residential, public, and vacant) and analyzed. In the case of residential, we specifically conducted the analysis divided into three residential types (single detached housing, single attached housing, and multifamily housing). Specifically, we analyzed parcel area changes first. However, since parcel area changes are simply the meaning of the change of the cross-sectional area of buildings, the vertical changes in land use could not be considered through this. Thus, to identify vertical and horizontal changes simultaneously, we first identified changes in the number of units by residential type in the case of residential areas. Second, we identified changes in the total floor areas of residential (apartments) and commercial areas. Additionally, we identified changes in land market value by land use types (commercial and residential). Specifically, first, total land market value changes, and second, total land market value per area changes were calculated. Next, to identify the relative change in the study area, we checked the average consumer price index (CPI) change in the U.S. cities, the value changes of residential sales across Utah, and taxable value changes in Utah.

Fourth, we computed trip generation changes. Using trip-generation rates from ITE's Trip Generation Manual 10th edition, we estimated the total trips generated by properties within the 0.5-mile buffer area from the BRT line. This manual, one of the mainstays of transportation planning, reports rates derived from field-collected data for different land-use categories as an average number of trips per unit of land use, or for some categories as a linear or non-linear function (Handy, 2015). In this analysis, the weekday average trip rate was used to calculate total trips. For this, we used tax assessment data from Utah County, used in the previous land-use analysis. Due to the special nature of tax assessment data, trip generation was calculated only for commercial and residential uses.

5.3 Results

5.3.1 Traffic Volume and Bus Ridership – Before-After and Interrupted Time Series

Annual Average Daily Traffic (AADT) by section along the BRT line, and bus ridership change in the study area are as follows (Table 3, Figure 5).

Table 3 AADT along the BRT Alignment, and Transit Ridership

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Section 1	41,218	42,900	45,057	46,898	48,258	48,774	49,292	42,974	47,531	48,576
Section 2	31,283	32,710	34,425	35,853	36,853	37,215	37,587	32,700	36,232	37,065
Section 3	14,456	14,913	15,651	16,440	16,665	17,002	17,308	15,456	16,754	16,922
Section 4	29,507	31,402	32,507	33,610	34,159	33,499	31,690	26,430	30,051	30,561
Total Bus Ridership	4,400	5,375	5,636	5,892	6,010	13,541	15,797	8,700	8,631	11,517
BRT Ridership						7,358	9,462	5,213	4,805	6,472
Other Bus Ridership	4,400	5,375	5,636	5,892	6,010	6,182	6,335	3,487	3,826	5,045

*Selected bus routes: 805, 806, 807, 821, 822, 831, 833, 834, 841, 850, 862, 830X (Provo-Orem BRT)

**2020 and 2021 were excluded from the analysis process due to the pandemic.

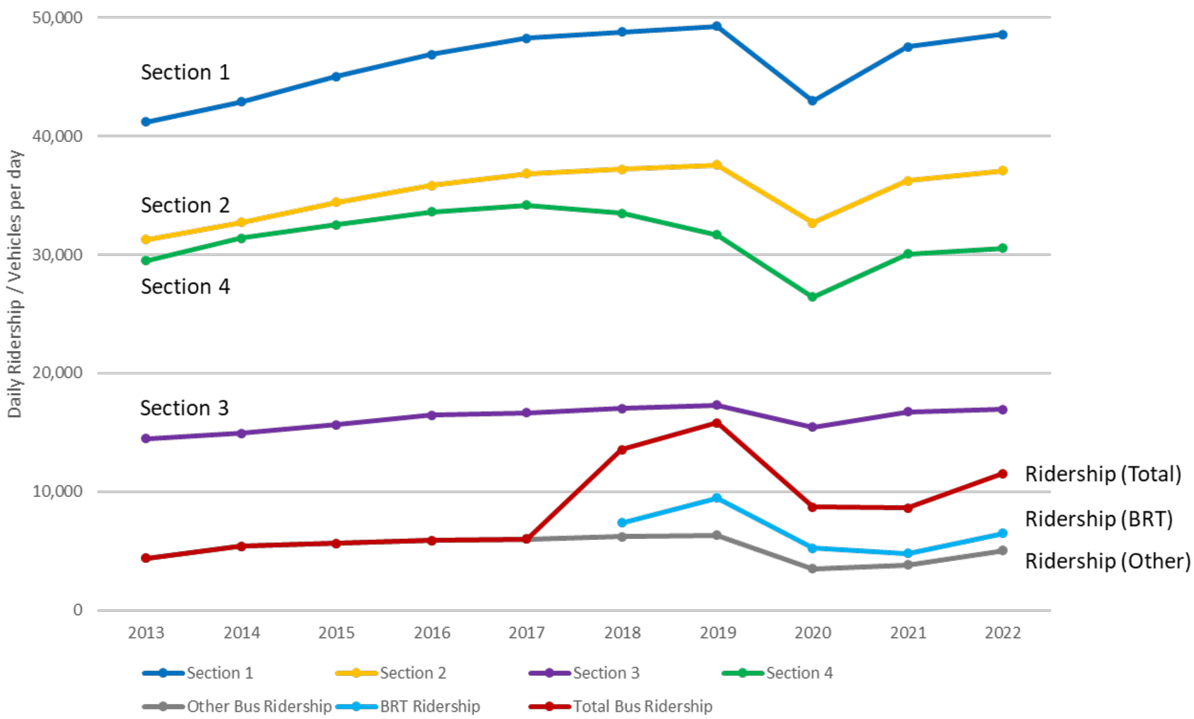

Figure 5 AADT by Sections, and Transit Ridership

As a result of the AADT analysis by section, in section 1, which is a principal arterial, located at Utah Valley University, traffic volume had a sharply rising pattern before the opening of BRT. However, the average traffic volume along the BRT line in section 1 in 2022 (4 years after the BRT operation) has almost the same value as the average traffic volume in 2017 (before the BRT operation), with a difference of only 0.66 percent or 318 Vehicles Per Day (VPD). Furthermore, relative to the trend from 2013 through 2017, extended through 2022, average traffic volume along the BRT alignment is actually lower than one would expect by 15.55 percent or 8945 VPD (Figure 6, Tables 4,5). Delta 1 in Table 4 represents the absolute change of AADT between previous and short-term/long-term after periods. Delta 2 in Table 5 represents the AADT difference between the observed value and predicted value based on the previous trend before the treatment involved in short-term and long-term after periods. In addition, compared to 2019, which is one year after the BRT opening, the absolute value decreased by 1.48 percent or 717 VPD in 2022. Considering the expected value based on the interrupted time series analysis, which is considered past trends before the BRT line, traffic volume in section 1 decreased by 10.17 percent or 6,140 VPD more in 2022 than in 2019.

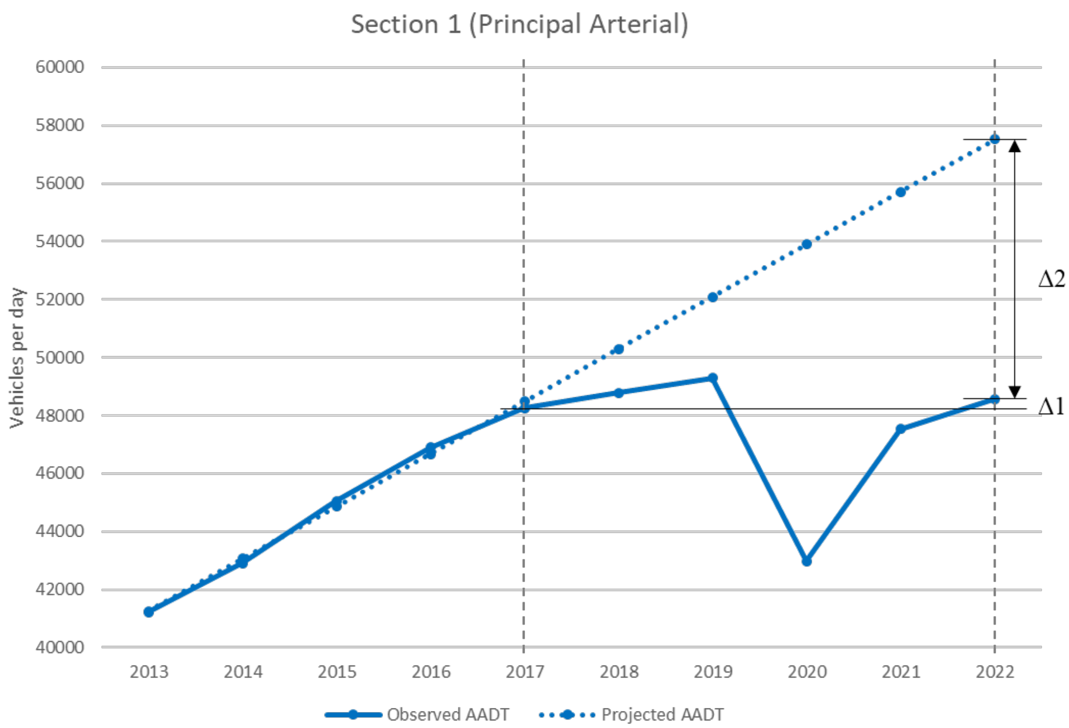

Figure 6 AADT in Sections 1 (observed and predicted AADT)

Table 4 Absolute Change of AADT in Section 1 from 2017 to 2019 and 2022

	2017 to 2019		2017 to 2022	
	Absolute Change	Percentage (%)	Absolute Change	Percentage (%)
Δ1	1035	2.14%	318	0.66%

Table 5 AADT Difference in Section 1 between the Observed and Predicted Value

	2019		2022	
	Relative Change	Percentage (%)	Relative Change	Percentage (%)
Δ2	-2805	-5.38%	-8945	-15.55%

In section 2, which is a principal arterial located between Utah Valley University and Brigham Young University, traffic volume had also sharply risen before the opening of BRT. However, similar to section 1's results, the average traffic volume along the BRT line in section 2 in 2022 is almost the same as the average traffic volume in 2017, with a difference of only 0.58 percent or 212 VPD. In addition, relative to the trend from 2013 through 2017, extended through 2022, average traffic volume along the BRT alignment in section 2 is actually lower than one would expect by about 7159 VPD or 16.19 percent (Figure 7, Tables 6,7). Compared to 2019, the absolute value decreased by 1.41 percent or 522 VPD in 2022. Considering the expected value based on the interrupted time series analysis, traffic volume in section 2 decreased by 10.30 percent or 4,807 VPD more in 2022 than in 2019.

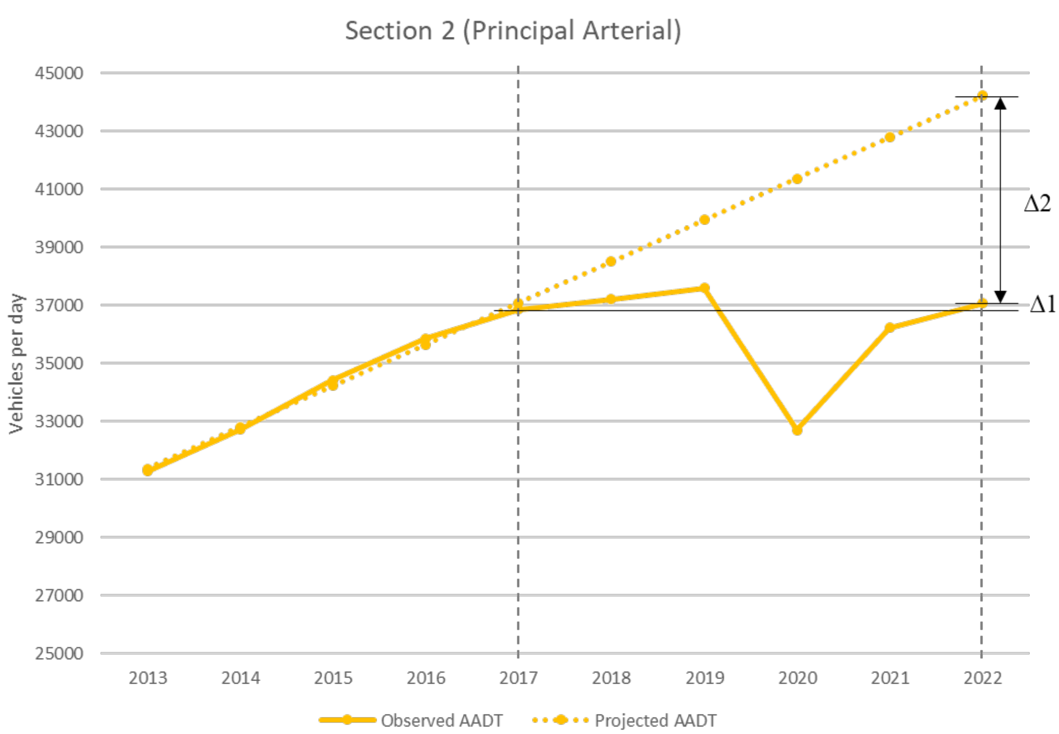

Figure 7 AADT in Section 2 (observed and predicted AADT)

Table 6 Absolute Change of AADT in Section 2 from 2017 to 2019 and 2022

	2017 to 2019		**2017 to 2022**	
	Absolute Change	Percentage (%)	Absolute Change	Percentage (%)
Δ1	734	1.99%	212	0.58%

Table 7 AADT Difference in Section 2 between the Observed and Predicted Value

	2019		2022	
	Relative Change	Percentage (%)	Relative Change	Percentage (%)
Δ2	-2352	-5.89%	-7159	-16.19%

In section 3, which includes a minor arterial and a major collector located within Brigham Young University, traffic volume had a steadily rising pattern before the opening of BRT. The average traffic volume along the BRT line in 2022 was 1.54 percent or 257 VPD, higher than the average traffic volume in 2017. However, relative to the trend from 2013 through 2017, extended through 2022, average traffic volume along the BRT alignment in section 3 is actually lower than one would expect by about 2864 VPD or 14.48 percent (Figure 8, Tables 8,9). Compared to 2019, the absolute value decreased by 2.32 percent or 386 VPD in 2022. Considering the expected value based on the interrupted time series analysis, traffic volume in section 3 decreased by 10.62 percent or 2,169 VPD more in 2022 than in 2019. Section 3 is composed mainly of minor arterials, it has a very narrow road width, and section 3 passes through the university boundary. Because of these characteristics, we had not expected a significant reduction in traffic volume. Actually, this proved to be the case in 2019, one year after the BRT operation. However, in 2022, four years after the BRT opening, a significant decrease in traffic volume in section 3 was found as well.

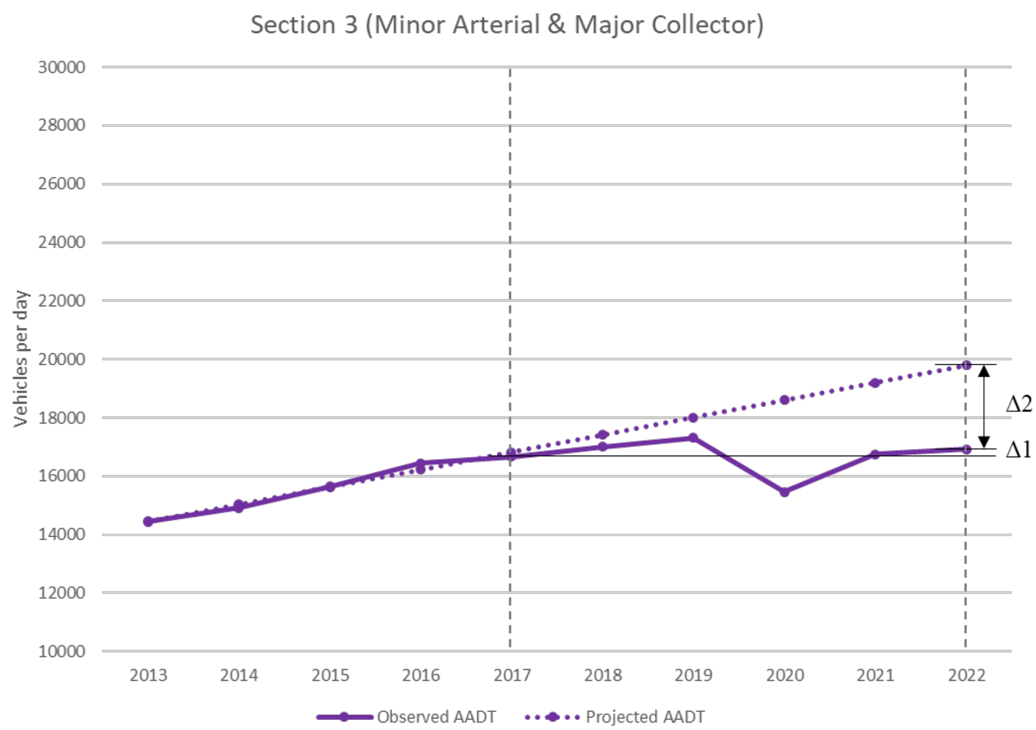

Figure 8 AADT in Section 3 (observed and predicted AADT)

Table 8 Absolute Change of AADT in Section 3 from 2017 to 2019 and 2022

	2017 to 2019		**2017 to 2022**	
	Absolute Change	Percentage (%)	Absolute Change	Percentage (%)
Δ1	643	3.86%	257	1.54%

Table 9 AADT Difference in Section 3 between the Observed and Predicted Value

	2019		**2022**	
	Relative Change	Percentage (%)	Relative Change	Percentage (%)
Δ2	-695	-3.86%	-2864	-14.48%

In section 4, which mainly consists of a principal arterial and is located south of Brigham Young University, traffic volume had a sharply rising pattern before the opening of BRT. However, the average AADT along the BRT line in 2022 sharply decreased by 10.53 percent or 3598 VPD relative to the average traffic volume in 2017. Also, relative to the trend from 2013 through 2017, extended through 2022, average traffic volume along the BRT alignment in section 4 is actually lower than one would expect by about 9736 VPD or 24.16 percent (Figure 9, Tables 10,11). Compared to 2019, the absolute value decreased by 3.30 percent or 1,129 VPD in 2022. Considering the expected value based on the interrupted time series analysis, traffic volume in section 4 decreased by 10.18 percent or 4,584 VPD more in 2022 than in 2019. Section 4 appeared to be the section that showed the most significant decrease in traffic volume after the BRT operation, and it also showed a more significant decrease in the long-term than short-term after the BRT operation.

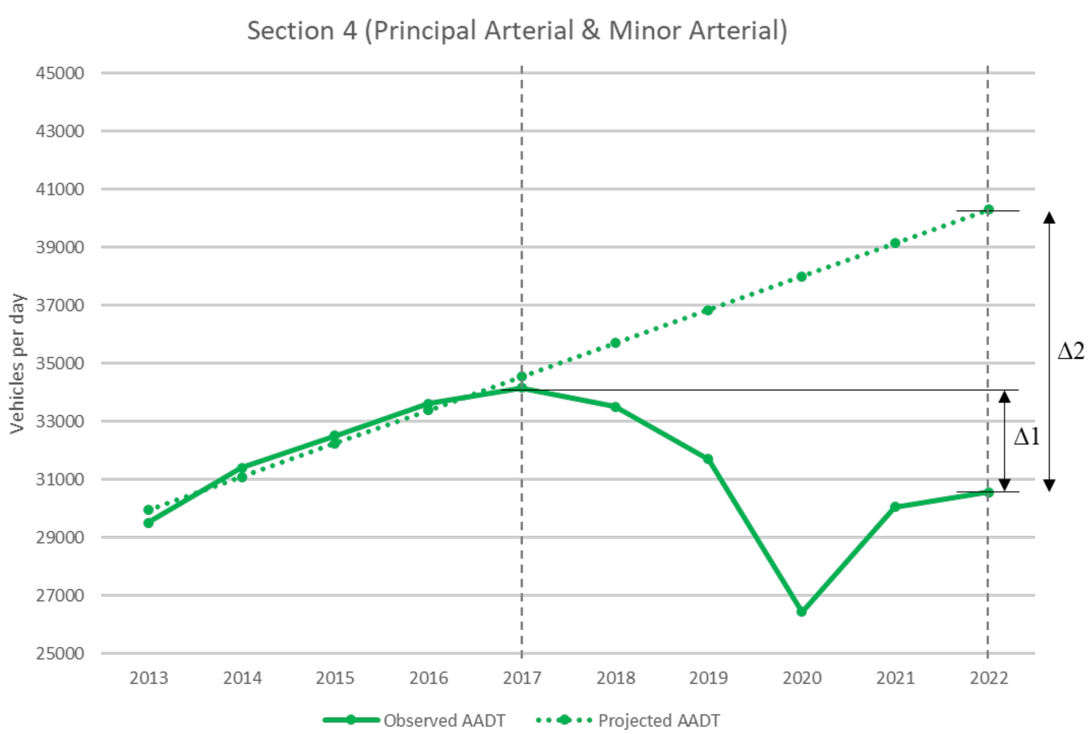

Figure 9 AADT in Section 4 (observed and predicted AADT)

Table 10 Absolute Change of AADT in Section 4 from 2017 to 2019 and 2022

	2017 to 2019		2017 to 2022	
	Absolute Change	Percentage (%)	Absolute Change	Percentage (%)
Δ1	-2469	-7.23%	-3598	-10.53%

Table 11 AADT Difference in Section 4 between the Observed and Predicted Value

	2019		2022	
	Relative Change	Percentage (%)	Relative Change	Percentage (%)
Δ2	-5152	-13.98%	-9736	-24.16%

From this analysis, all sections of the BRT line showed similar patterns. In every section, traffic significantly increased before the BRT operation; however, after the BRT operation, the trend of increasing traffic was significantly altered. During the pandemic period, traffic volume dropped sharply in 2020, but it recovered significantly by 2021. Then, traffic volume in 2022 slightly increased relative to 2021 but remained at a lower level in every section than in 2019. Even though the impact of the pandemic was still not completely eliminated by 2022, considering the rapid traffic growth before BRT opening, these results suggest a significant reduction in traffic after BRT operation, in particular, in the long term.

We could infer that the most important cause of the change in the rate of traffic growth along the BRT alignment is a change in transit ridership, the "treatment." Therefore, we analyzed all bus ridership changes passing through the study area, 0.5 miles buffered area from the BRT line, from 2013 to 2022, and the results are as follows.

In the total transit ridership in the study area, 0.5 miles buffered area from the BRT line, total transit ridership had a slightly rising pattern before the opening of BRT. However, after the BRT operation, the rising pattern of ridership increased exponentially. The average total bus ridership in 2019 was 162.4 percent higher than the average total bus ridership in 2017. Also, relative to the trend from 2013 through 2017, extended through 2019, the average total bus ridership is higher than one would expect by about 122.7 percent or 8,687 passengers per day. This increasing transit ridership trend dropped sharply in 2020 and 2021 due to the pandemic. However, a significant recovery occurred in 2022. As a result, the average total bus ridership in 2022 was 91.6 percent or 5,507 persons per day higher than the average total bus ridership in 2017. In addition, considering the trend from 2013 through 2017, extended through 2022, the average total bus ridership is higher than one would expect by about 42.6 percent or 3,438 persons per day. This can be said to be a very unusual recovery, considering the sharp decline in public transportation use due to the pandemic. In particular, compared to the ridership recovery between BRT and other buses, the recovery speed of BRT was more rapid than one might expect (Figure 10, Tables 12,13).

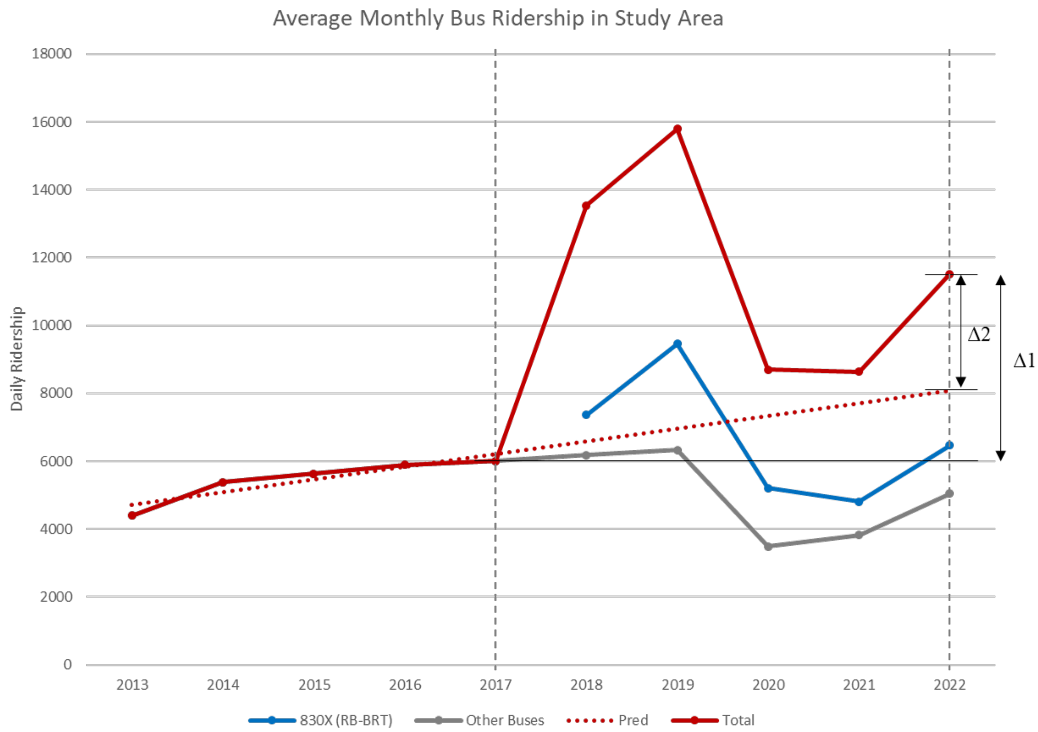

Figure 10 Ridership of Total Transit, BRT Line, and Other Buses

Table 12 Absolute Total Transit Ridership Change from 2017 to 2019 and 2022

	2017 to 2019		2017 to 2022	
	Absolute Change	Percentage (%)	Absolute Change	Percentage (%)
Δ1	9,787	162.84%	5,507	91.63%

Table 13 Total Transit Ridership Difference Between the Observed and Predicted Value

	2019		2022	
	Absolute Change	Percentage (%)	Absolute Change	Percentage (%)
Δ2	8,840	127.05%	3,438	42.56%

In 2022, BRT's ridership accounted for 56.2 percent of total ridership, while other buses' ridership accounted for 43.81 percent. Interestingly, BRT does not appear to have diverted ridership from regular bus service, or if it did, the effect was small, as indicated in Figure 10.

5.3.2 Traffic Volume– Before-After with a Control Group

In a before-after research design with a control group, the control group consisted of neighboring streets approximately one-half mile from the BRT line (500W, 800S, State Street). The standardized AADT change from 2017 to 2022 along the BRT line and control group (neighboring streets) are as shown in Figure 11, Table 14. In Table 14, delta 1 represents the absolute change of AADT in the treatment group (BRT alignment) between previous and short-term/long-term after periods, and delta 3 represents the absolute change of AADT in the control group between previous and short-term/long-term after periods.

The control group's traffic volume increased prominently between 2017 and 2019. However, the traffic volume along the BRT line between 2017 and 2019 showed almost no change, so relative to the controls, it experienced a decline in traffic. Specifically, the weighted average traffic volume along the BRT line increased by only 0.01 percent or 2 VPD between 2017 and 2019. It was essentially flat. In contrast, neighboring streets' weighted average traffic volume rose by 2.31 percent or 647 VPD between 2017 and 2019. This means that the short-term change in traffic volume for the treated group, the BRT streets, was a decline relative to the control group.

During the pandemic, the treatment and the control group showed a similar pattern of decrease followed by increase. However, between 2021 and 2022, the increase in traffic volume in the control group was more than in the treatment group. As a result, the difference in traffic volume between the two groups became more pronounced in 2022. In summary, the weighted average traffic volume along the BRT line decreased by 2.10 percent or 662 VPD between 2017 and 2022. However, neighboring streets' weighted average traffic volume increased by 0.76 percent or 213 VPD between 2017 and 2022.

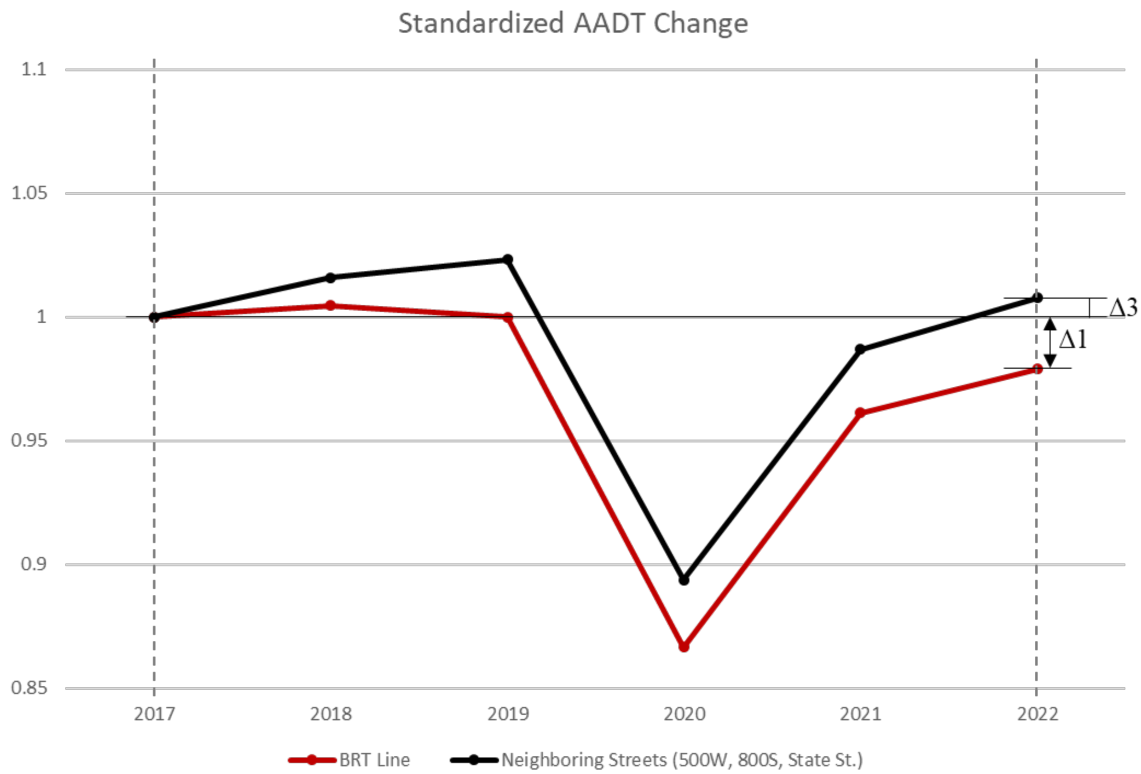

Figure 11 Standardized AADT along the BRT Alignment and Neighboring Streets

Table 14 Absolute Change of AADT from 2017 to 2019 and 2022

	2017 to 2019		**2017 to 2022**	
	Absolute change	Percentage (%)	Absolute change	Percentage (%)
BRT line (Δ1)	2	0.01 %	-662	-2.10%
Neighboring Streets (Δ3)	647	2.31 %	213	0.76%

Second, the results of the difference-in-differences estimation in short-term and long-term between the treatment and the control group are as follows. This was measured as the difference in absolute change of AADT in the treatment group (delta 1) and control group (delta 3) between previous and short-term/long-term after periods. In short-term change, the BRT line's AADT decreased by 2.30 percent or 645 VPD relative to neighboring streets. In long-term change, the treatment's AADT decreased by 2.86 percent or 875 VPD relative to the control group. This result showed that in a similar geographical and socio-economical surrounding context, the amount of traffic increases as the distance from the BRT increases. In particular, this trend appeared more significant in long-term change than short-term change, and the gap widened further over time, even though the pandemic interrupted the time series (Table 15).

Table 15 Difference-in-Difference in Traffic Volumes between the BRT Alignment and Neighboring streets

Difference in Difference	**2017 to 2019**		**2017 to 2022**	
	Absolute change	Percentage (%)	Absolute change	Percentage (%)
Neighboring Streets (Δ3) - BRT line (Δ1)	-645	-2.30 %	-875	-2.86%

Additionally, to check the possibility of a temporary detour from the BRT alignment to the neighboring streets, the results of traffic volume change on every street within the study area, 0.5 miles buffered area, are as follows. In absolute value change, traffic volume on every street within the study area (for which traffic data was available) was slightly increased by 95 VPD or 0.46 percent between 2017 and 2019. However, it decreased by 324 VPD or 1.57 percent between 2017 and 2022. In interrupted time series analysis, traffic volume on every street within the study area was lower than the expected value by 1,514 VPD or 6.81 percent in 2019, and it was lower than the expected value by 4,185 VPD or 17.10 percent in 2022 (Figure 12, Table 16, 17). This result clearly shows that traffic volume has decreased not only on the BRT alignment but also in every street within the study area, even though development significantly increased. Recovering from the pandemic may account for the long-term decrease. Additionally, the amount of reduction is shown at an intermediate level between the treatment and the control group. In other words, this result shows more clearly that the amount of traffic decreases as the distance from the BRT decreases. This also shows that traffic reduction on the BRT alignment is not because of a temporary detour from the BRT line into neighboring streets.

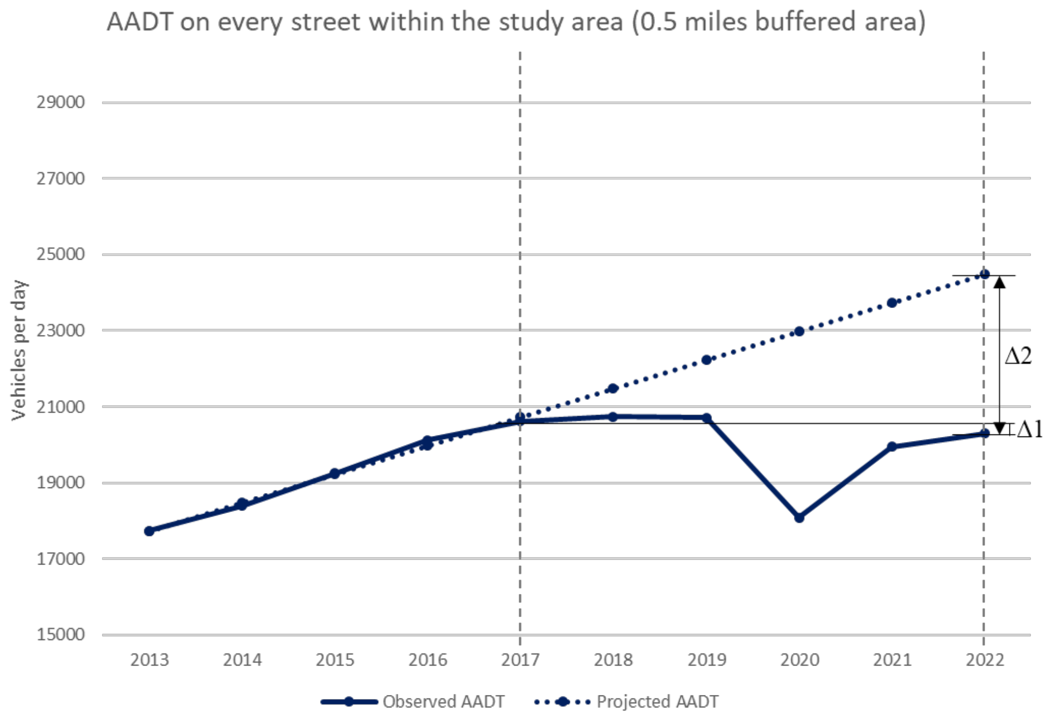

Figure 12 AADT within the Study Area (every street within the study area)

Table 16 Absolute Change of AADT within Study Area from 2017 to 2019 and 2022

	2017 to 2019		**2017 to 2022**	
	Absolute change	Percentage (%)	Absolute change	Percentage (%)
Study Area (Δ1)	95	0.46%	-324	-1.57%

Table 17 AADT Difference within Study Area between the Observed and Predicted Value

	2019		**2022**	
	Relative change	Percentage (%)	Relative Change	Percentage (%)
Study Area (Δ2)	-1514	-6.81%	-4185	-17.10%

5.3.3 Population, Employment, Enrollment, Land-Use, Land Market Value, and Trip Generation

To determine whether this decreasing traffic pattern is truly due to the BRT operation, we checked the other factors that can affect traffic volume from before the BRT operation to after the BRT operation. The results are as follows.

First, demographic change was checked using ACS 5-year data (Table 18). the population growth in Provo-Orem CCD was a 3.15 percent increase between 2017 and 2019 and a 3.94 percent increase between 2017 and 2022 (American Community Survey, 2022). The Census Bureau stated that the Provo-Orem metropolitan area is one of the fastest-growing areas in the country, ranked 10th in the nation for the percentage of growth in a metro area from 2017 to 2018 (Census Bureau, 2019). From this fact, we found that even though the population significantly grew after the BRT operation, the traffic volume in the study area significantly decreased.

Table 18 Population Change in Provo-Orem CCD from 2017 to 2019 and 2022

2017 to 2019		**2017 to 2022**	
Absolute change	Percentage (%)	Absolute change	Percentage (%)
6723	3.15	8409	3.94

** ACS 2017, 2019, and 2021 5-year data*

Second, total enrollment at Utah Valley University (UVU) and Brigham Young University (BYU) grew by 6.27 percent between 2017 and 2019 and increased by 9.45 percent between 2017 and 2022. However, the enrollment changes at the two universities were significantly different. UVU's enrollment number increased significantly after the BRT operation by 11.93 percent between 2017 and 2019 and by 15.60 percent between 2017 and 2022. However, BYU's enrollment number decreased by 0.02 percent between 2017 and 2019 and increased only by 2.60 percent between 2017 and 2022. Therefore, it can be inferred that the significant reduction in traffic volume on University Avenue, where BYU is located, compared to University Parkway, where UVU is located, is related to enrollment changes (Table 21). Also, we found that even though the number of students increased significantly in the two universities, the traffic volume decreased notably, particularly in the long term.

Table 19 Total Student Enrollment Change from 2017 to 2019 and 2022

	2017 to 2019		2017 to 2022	
	Absolute Change	Percentage Change	Absolute Change	Percentage Change
Brigham Young University	-6	-0.02 %	873	2.60%
Utah Valley University	4446	11.93 %	5817	15.60%
Total enrollment	**4440**	**6.27 %**	**6690**	**9.45%**

Third, as a result of examining the changed land use distribution between 2017 and 2022 using tax assessor data, we found that many vacant parcels have been converted to commercial buildings or residential buildings. Also, many newly created commercial and apartment parcels in 2022 in the corridor were found. Moreover, we found that new buildings were under construction or existing buildings were under expansion. The results of the changed distribution of commercial areas and residential areas (Apartments, High-density residential housing, single-family housing) were as follows. In the below figure, black parcels mean the same tax-type parcels between 2017 and 2022. Red parcels mean the newly added parcels in 2022 by land use type. In commercial area change, development near BRT alignment shows prominently. This is particularly true near UVU and BYU. In residential area change, the creation of new apartments was found to be noticeably occurring near UVU. However, the new development of single-family housing appears insignificant compared to the development of apartments (Figure 13).

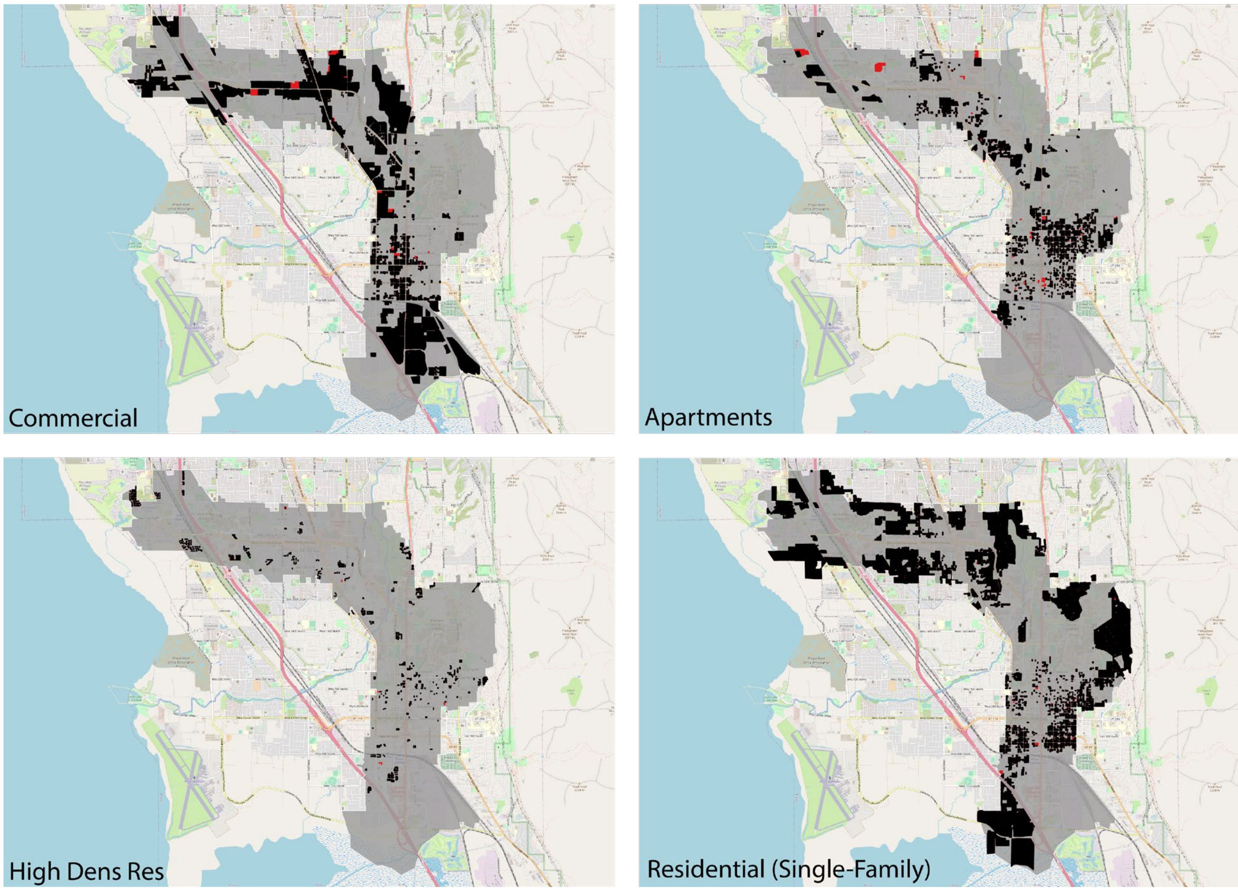

Figure 13 Changed Land Use Parcels Distribution from 2017 to 2022

(Black: Not Changed, Red: Changed Parcels)

Multifamily housing's number of units increased by 16.97 percent in 2019 compared to 2017 and increased by 17.62 percent in 2022 compared to 2017. The number of units in single-family attached housing slightly increased by 2.57 percent in 2019 compared to 2017 and increased by 6.36 percent in 2022 compared to 2017. However, the single-detached housing number of units was almost flat, with a 0.07 percent increase in 2019 and 2022 compared to 2017 (Table 20).

Table 20 Number of Units Change in Residential Area from 2017 to 2019 and 2022

Residential Type (Number of Units)	2017	2019	2022	2017-2019	2017-2022
Single Detached Housing	5,623	5,627	5,627	0.07%	0.07%
Single Attached Housing	3,190	3,272	3,393	2.57%	6.36%
Multifamily Housing	13,037	15,249	15,334	16.97%	17.62%
Total	21,850	24,148	24,354	10.52%	11.46%

Total floor area significantly increased in both residential (apartments) and commercial areas, in particular, long-term changes. Here, apartments in residential areas are defined as those classified as apartments in the tax account type, and single-detached housing is not included. The total floor area of residential areas (apartments) increased by 8.71 percent in 2019 compared to 2017 and increased by 44.69 percent in 2022 compared to 2017. The total floor area of commercial areas increased by 4.59 percent in 2019 compared to 2017 and increased by 8.17 percent in 2022 compared to 2017 (Table 21). As with the previous results, single-attached housing and multifamily housing have increased significantly, especially in the long term. Also, considering that vacant buildings were included in this calculation, it is expected that residences in apartments will further increase in the future. In addition, it was observed that the total floor area of commercial areas also continuously increased.

Table 21 Total Floor Area Change from 2017 to 2019 and 2022

Land-Use Type (ft2)	2017	2019	2022	2017-2019	2017-2022
Residential (Apartments)	11,041,302	12,003,542	15,975,665	8.71%	44.69%
Commercial	20,661,569	21,610,347	22,350,223	4.59%	8.17%
Total	**31,702,871**	**33,613,889**	**38,325,888**	**6.03%**	**20.89%**

**Vacant buildings were included, Definition of apartments: In the case of classified as an apartment in tax account types. All types except single detached housing.*

The land market value after the BRT operation significantly increased in both residential and commercial areas, especially long-term after the BRT operation. The total land market value increased by 18.53 percent in 2019 compared to 2017 and increased by 83.15 percent in 2022 compared to 2017. The land market value per unit area was also calculated, and as a result, the residential land market value per area increased by 21.12 percent in 2019 compared to 2017 and increased by 98.02 percent in 2022 compared to 2017. The commercial land market value per area increased by 12.26 percent in 2019 compared to 2017 and increased by 61.31 percent in 2022 compared to 2017.

In the relative change in the study area, first, the average CPI in U.S. cities increased by 4.30 percent between 2017 and 2019 and 19.39 percent between 2017 and 2022 (U.S. Bureau of Labor Statistics, 2023). Thus, the inflation-adjusted total land market value increased by 14.58 percent in 2019 compared to 2017 and increased by 63.10 percent in 2022 compared to 2017. Second, the value of residential sales across Utah increased by 23.67 percent between 2017 and 2019 and increased by 68.26 percent between 2017 and 2022 (Wood & Eskic, 2023). Comparing this result with the residential land market value per area changes in the study area, in 2019, immediately after the BRT opening, the rate of increase was almost similar. However, in 2022, about four years after the opening, the study area's relative increase rate was 29.76 percent higher than the average of Utah's value of residential sales. Third, the taxable value change across Utah was checked (Ulibarri & Parkinson, 2023). In the taxable value in Utah, 2011 to 2021 data were available, and the 2022 value was estimated based on the 2019 to 2021 value using linear regression. As a result, in 2022, the study area's increased rate of land market value per area was 24.96 percent higher in residential areas and 15.35 percent higher in commercial areas than the taxable value increase across Utah (Table 22, Figure 14).

Table 22 Land Market Value Change from 2017 to 2019 and 2022

	2017	2019	2022	2017-2019	2017-2022
1. Total Land Market Value	$1,782,968,398	$2,113,392,600	$3,265,578,867	18.53%	83.15%
1.1. Residential Land Market Value	$1,061,196,361	$1,288,176,021	$2,110,181,291	21.39%	98.85%
1.2. Commercial Land Market Value	$701,647,637	$795,431,179	$1,071,496,476	13.37%	52.71%
2. Total Land Market Value Per Area (ft2)	$6.09	$7.24	$11.11	18.88%	82.49%
2.1. Residential Land Market Value Per Area (ft2)	$10.84	$13.13	$21.46	21.12%	98.02%
2.2. Commercial Land Market Value Per Area (ft2)	$11.52	$12.93	$18.58	12.26%	61.31%
3. Total Land Market Value Per Area than CPI				14.58%	63.10%
3.1. Residential Land Market Value Per Area than CPI				16.82%	78.63%
3.2. Commercial Land Market Value Per Area than CPI				7.96%	41.92%
4. Value of Residential Sales in Utah (Millions)	14,859.20	18,376.50	25,001.50	23.67%	68.26%
5.1. Taxable Value in Utah (Residential, Billions)	151	190.3	325.5 (Est.)	26.03%	73.06%
5.2. Taxable Value in Utah (Commercial/Industrial, Billions)	57.2	69.3	95.1 (Est.)	21.15%	45.96%

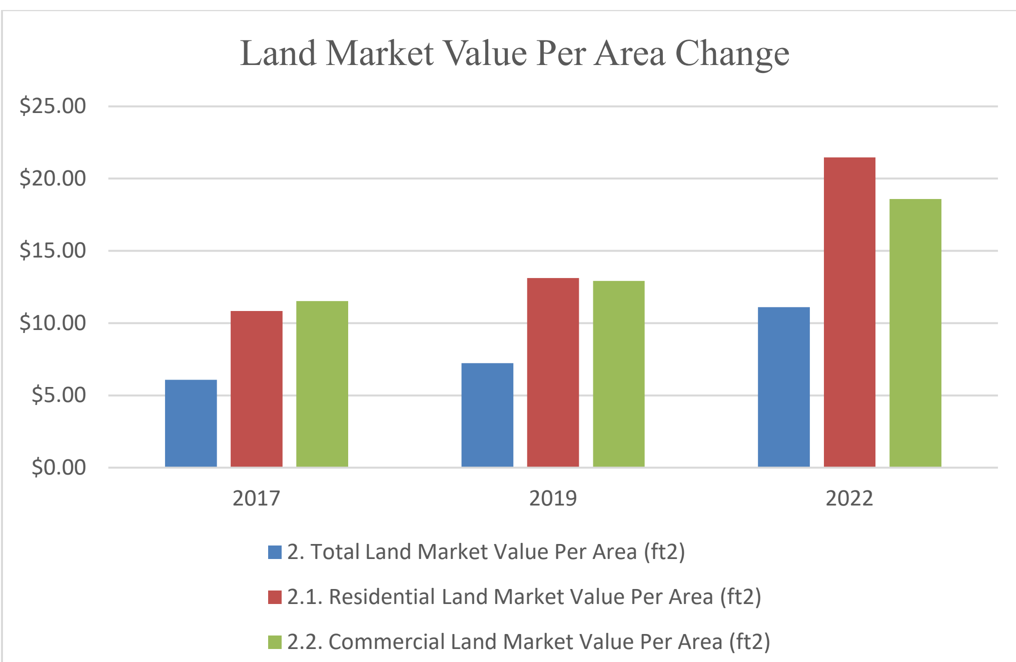

Figure 14 Change of the Land Market Value Per Area

Total trip generation (unit: trips per day) in the study area increased by 33.25 percent between 2017 and 2019 and increased by 38.12 percent between 2017 and 2022. Specifically, the total trips in residential areas increased by 8.83 percent between 2017 and 2019 and increased by 9.78 percent between 2017 and 2022. Total trips in commercial areas increased by 41.13 percent between 2017 and 2019 and increased by 47.25 percent between 2017 and 2022 (Table 23, Figure 15).

Table 23 Total Trip Generation Change in the Corridor from 2017 to 2019 and 2022 (trips per day)

Land-Use Type (Trips)	2017	2019	2022	2017-2019	2017-2022
Residential	157,434	171,335	172,824	8.83%	9.78%
Commercial	488,354	689,210	719,120	41.13%	47.25%
Total	**645,788**	**860,544**	**891,944**	**33.25%**	**38.12%**

**Vacant or no designated purpose buildings were not included*

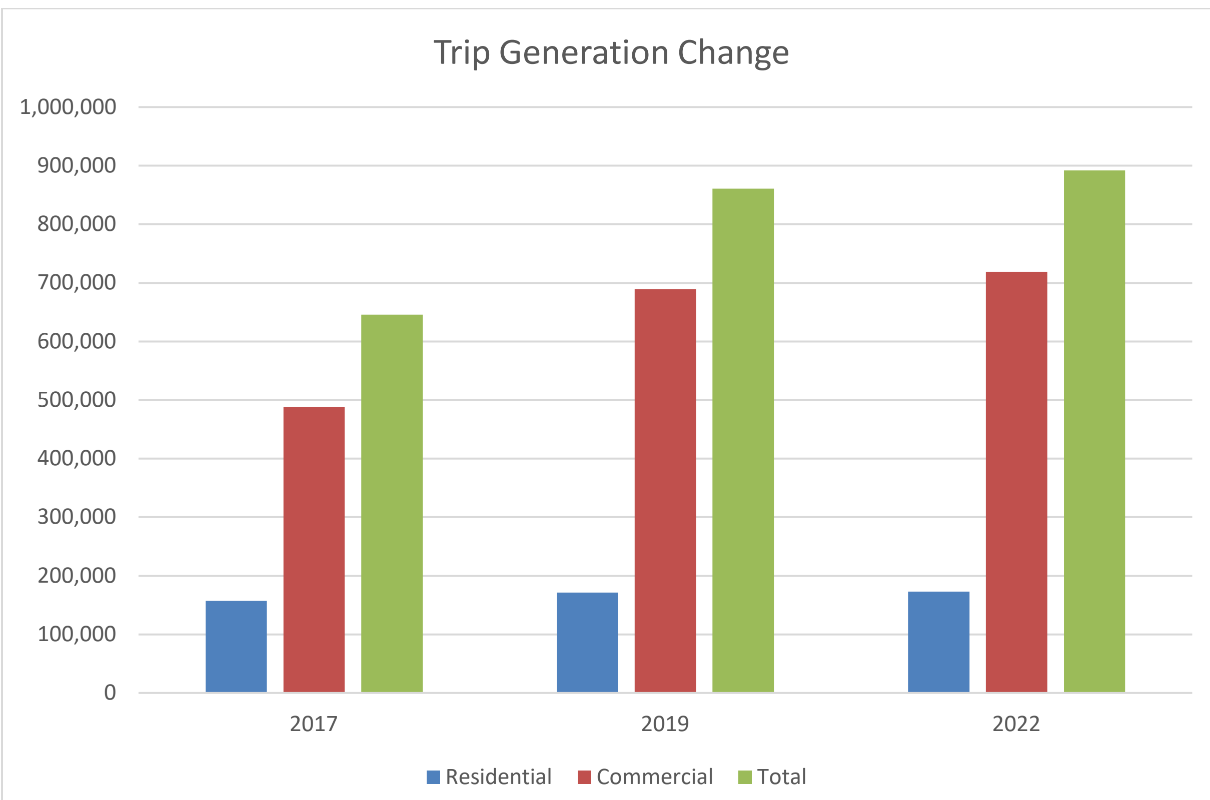

Figure 15 Trip Generation Change

Total trips in multifamily housing between 2017 and 2019 increased by 16.37 percent, and between 2017 and 2022 increased by 17.12 percent. Total trips in single attached housing slightly increased by 2.57 percent between 2017 and 2019 and 6.36 percent between 2017 and 2022. However, the total trips in single detached housing is almost flat, 0.07 percent between 2017 and 2019, and 0.07 percent between 2017 and 2022 (Table 24, Figure 16).

Table 24 Residential Trip Generation Change from 2017 to 2019 and 2022

Land-Use Type (Trips)	2017	2019	2022	2017-2019	2017-2022
Single detached housing	53,081	53,119	53,119	0.07%	0.07%
Single attached housing	23,351	23,951	24,837	2.57%	6.36%
Multifamily housing	81,002	94,265	94,868	16.37%	17.12%
Total	**157,434**	**171,335**	**172,824**	**8.83%**	**9.78%**

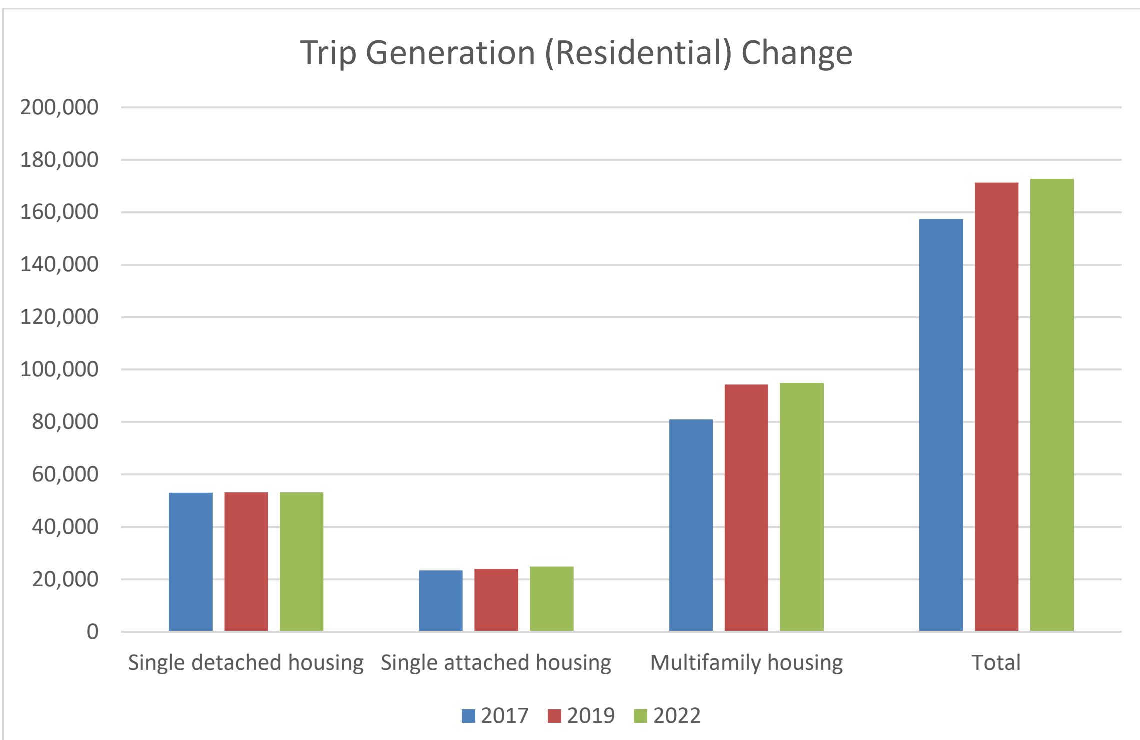

Figure 16 Residential Trip Generation Change

The trip generation changes' pattern showed a slight difference from the total floor area changes. The main reasons are as follows. First, in the residential total floor area calculation, apartments were considered, and single-detached housing was not included. However, in the residential trip generation calculation, every type of housing was considered. Second, in the trip generation calculation, the residential area's total trips were calculated based on the number of units, and mostly, the commercial area's total trips were calculated based on the total floor area, according to the trip generation manual. Third, in the trip generation calculation, vacant or no designated purpose buildings were not considered. Considering that a lot of multifamily and single-attached housing was constructed between 2021 and 2022, total residential trips are expected to increase further in the future.

Also, previous trip generation results showed that total trips in commercial areas increased significantly, especially in the long term. It can be inferred that there were two reasons for this. The first reason is the increase in the total floor area in commercial buildings. The second reason is the increase in commercial buildings with high trip rates. Trip rates are extremely different depending on the type of business, and there was a significant increase in buildings with high trip rates, such as service stations, restaurants, etc. However, the buildings with low trip rates, such as storage, manufacturing, etc., decreased. On balance, we can conclude that overall trips increased significantly, especially in the long term after the BRT operation. This fact occurred despite a decrease in traffic volume on the BRT alignment and study area between 2017 and 2022. It is reasonable to assume that BRT accommodated much of that increase in trips.

6.0 AUTOMOBILE TRAFFIC SPEEDS

6.1 Data Collection

Our study used the annual average traffic speed to evaluate the historical traffic speed along the BRT line using the Iteris Performance Measurement System (iPeMS, now Iteris ClearGuide). Iteris ClearGuide data is collected from probe vehicles with onboard navigation and cell phone applications, and UDOT provides speed data for all state roads. It provides data down to major collectors officially. The data is an aggregate of all probes collected in 5-minute bins.

6.2 Methods

In this analysis, the annual average traffic speed between 7 am and 12 pm from 2014 to 2022 was calculated, where data exists. The annual average traffic speed unit is a mile per hour (mph). The specific route needs to be set to calculate average traffic speeds using UDOT's iPeMS data. For the calculation, only one direction of travel at a time can be considered. Therefore, the southbound direction was selected in this study, and the annual average traffic speed along the BRT line was analyzed. For this analysis, we first analyzed the annual average traffic speed between 2017 and 2022 for the entire BRT line and also for the four sections of the BRT line individually. The sections were the same as in the previous traffic analysis. Second, we used an interrupted time-series design considering the trend in annual average traffic speed between 2014 and 2017 using linear regression to predict the value for 2019 and 2022 in the absence of the intervention (BRT). The effects of the intervention were evaluated by the gap between predicted and observed values in 2019 and 2022. In the interrupted time-series design, the entire BRT line's annual average traffic speed was used to understand the overall effect of BRT.

6.3 Results

In the annual average traffic speed analysis, BRT alignment's traffic speed temporarily decreased one year after the BRT opening, in 2019. However, four years after the opening of the BRT, in 2022, a significant recovery was shown, and the average traffic speed showed a similar level compared to before the BRT operation. The BRT alignment's annual average traffic speeds decreased in 2019 by 3.99 percent compared to 2017. However, it increased significantly from 2019 to 2022, and the difference in traffic speeds showed only 0.35 percent between 2017 and 2022.

Specifically, traffic speeds increased in sections 1, 2, and 4, where the road was relatively wide, long-term after the BRT operation, especially in section 2. Section 1's traffic speed slightly decreased between 2017 and 2019 by 0.57 percent. However, it increased between 2017 and 2022 by 1.96 percent. Section 2's traffic speed slightly increased between 2017 and 2019 by 1.62 percent. Also, it increased significantly between 2017 and 2022 by 13.03 percent. Section 4's traffic speed temporarily decreased between 2017 and 2019 by 5.77 percent. However, it increased between 2017 and 2022 by 4.05 percent. On the other hand, traffic speeds decreased in section 3, which surrounds BYU, with a narrow road width. Section 3's traffic speed decreased between 2017 and 2019 by 9.61 percent, and it decreased between 2017 and 2022 by 16.03 percent. In section 3, which consisted of a minor arterial and a major collector, a small number of probes were located due to the characteristics of the road with a narrow width. For this reason, data reliability was lower than the principal arterials' annual average traffic speed values.

Although the opening of BRT reduced traffic speeds temporarily, considering the long-term impact, it contributed to improving traffic speeds overall. Except for section 3, which was an exceptional case due to the narrow road width, we found that traffic speeds increased in the long term in all sections, and BRT operation contributed to improved traffic flow (Figure 17, Table 25).

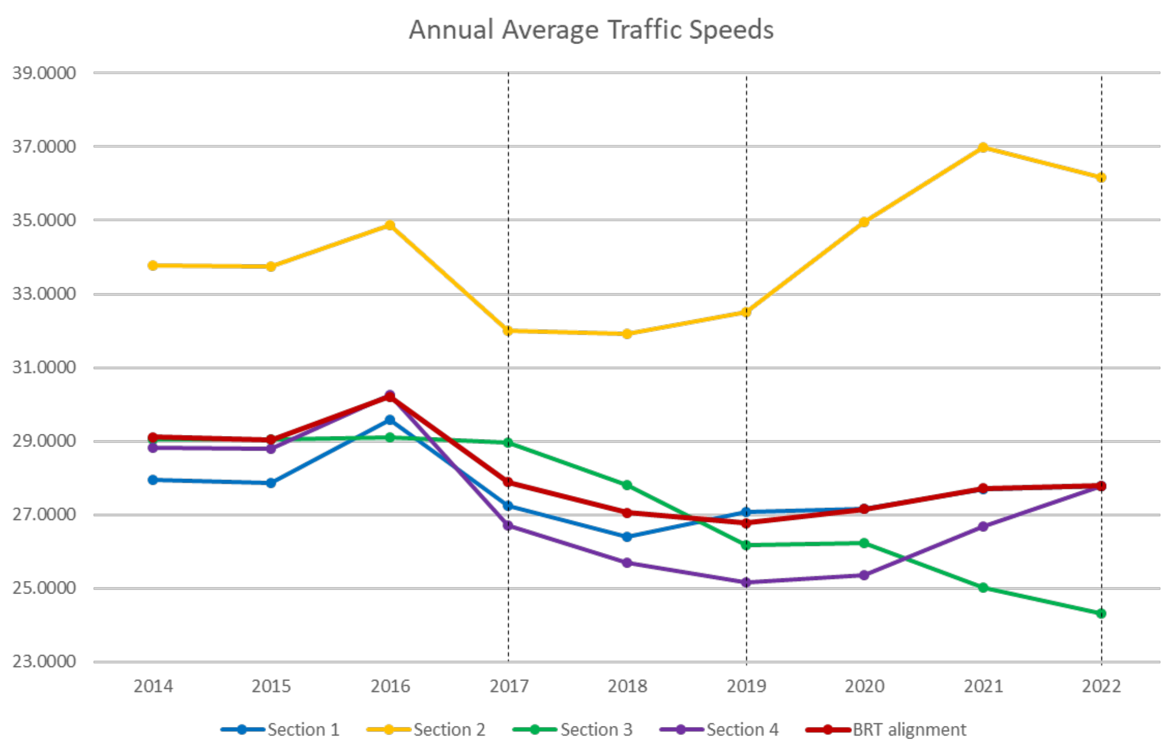

Figure 17 Annual Average Traffic Speed in All Sections and the Entire BRT Alignment

Table 25 Annual Average Traffic Speed Change from 2017 to 2019 and 2022

	2017 to 2019		**2017 to 2022**	
	Absolute Change	Percentage (%)	Absolute Change	Percentage (%)
BRT Alignment	-1.1129	-3.99%	-0.0985	-0.35%
Section 1	-0.1565	-0.57%	0.5328	1.96%
Section 2	0.5171	1.62%	4.1707	13.03%
Section 3	-2.7816	-9.61%	-4.6410	-16.03%
Section 4	-1.5406	-5.77%	1.0821	4.05%

The interrupted time series analysis result for the annual average traffic speed on the BRT alignment is as follows. Relative to the trend from 2014 through 2017, extended through 2019 and 2022, the annual average traffic speed for the entire BRT line was temporarily lower than one would expect by 5.02 percent in 2019. However, this recovered long-term, traffic speed showed higher than the expected value in 2022 by 1.29 percent (Figure 18, Table 26). This result shows that BRT operation can reduce the traffic speed of BRT alignment in the short term but improve it in the long term.

In various cities, previous papers reported that after BRT implementation, the number of lanes for automobiles is reduced because BRT takes a whole lane in each direction, and travel times rapidly increase and traffic speed decrease, resulting in severe congestion. However, a severe decrease in automobile traffic speed did not occur in the Provo-Orem BRT alignment, where BRT lines were added. Instead, traffic speeds increased slightly, and traffic flow improved in the long term. A decrease in traffic speed occurred only in section 3, where the road was extremely narrow. Therefore, these results clearly show that the introduction of BRT can actually improve the traffic flow. In addition, considering the construction period of the BRT, traffic speed reduction in the 2019, short term, could be because of the channelization effect. Therefore, we could infer that because this effect was removed long-term, traffic speed recovered in 2022.

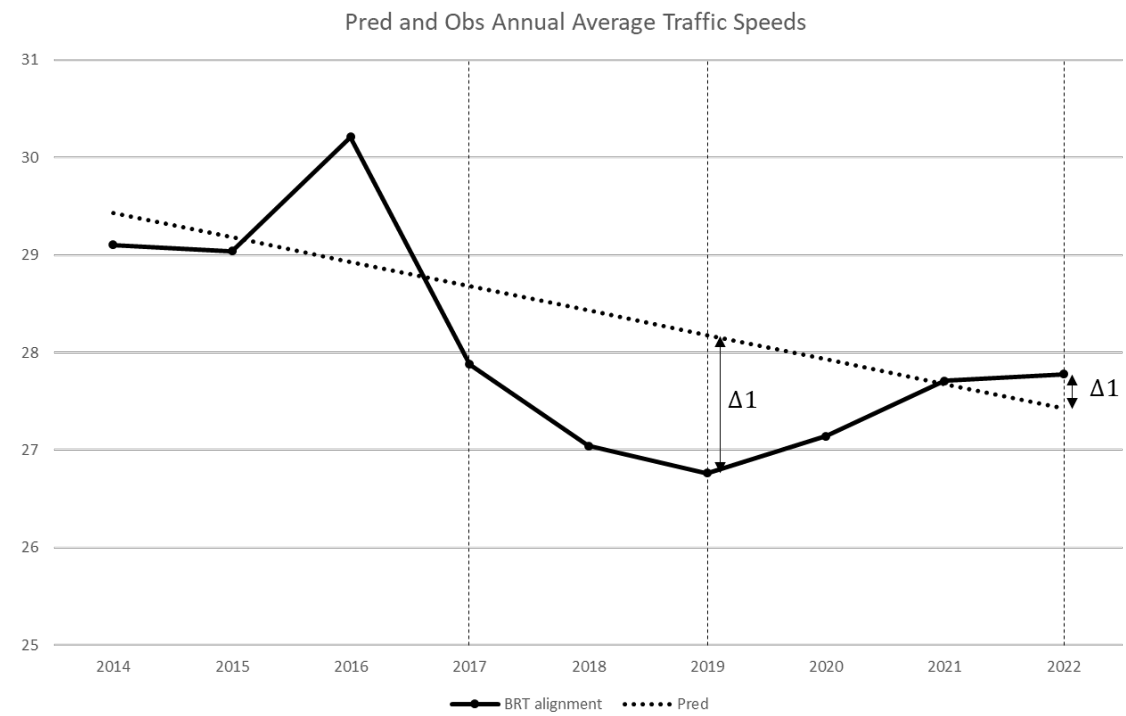

Figure 18 Annual Average Traffic Speed on entire BRT Line (predicted and observed values)

Table 26 Annual Average Traffic Speed Difference on the BRT Alignment between Observed and Predicted Value

	2019		2022	
	Relative Change	Percentage (%)	Relative Change	Percentage (%)
Δ1	-1.4132	-5.02%	0.3545	1.29%

7.0 CRASH RATE

According to previous research, driving speed and crash rate have a positive relationship. Higher driving speeds lead to higher collision speeds and lead to higher injury crash rates. Moreover, higher driving speeds also provide less time to react, and the braking distance is longer. Therefore, higher driving speeds make it hard to avoid a collision. From the previous traffic speed analysis, we found that the annual average traffic speed along the BRT line increased in 2022 compared to the expected value and improved traffic flow, which means that it might provoke an increased crash rate.

7.1 Data Collection

In the crash analysis, crash count data from UDOT between 2014 and 2022 was used. The crash count data included the geographic location information of all crashes and each accident's severity information. Crash severity is measured on a 1 to 5 scale. Each score's meaning is 1: No injury, 2: possible injury, 3: minor injury, 4: serious injury, 5: fatal (UDOT, 2022).

7.2 Methods

First, to analyze the crash rate along the BRT line, we extracted all crash count data within a 0.1-mile buffered area from BRT between 2014 and 2022. Second, to understand total crash and injury crashes separately, we divided the crash count data into total and injury crashes. For the latter, we extracted points with severity from 2 to 5. Third, we used the weighted average AADT along the BRT line from 2014 to 2022 calculated in the previous section of this report to calculate the crash rate. Figure 19 represents a visual comparison of the total crash count along the BRT line in 2017, 2019, and 2022. Through simple comparisons, a decreased total number of crashes occurred after the BRT operation. Focusing on 2022, a decreased number of crashes, especially in sections 2 and 3 near BYU, occurred. However, simple comparisons with the distribution map can provide information on the distribution of decrease (or increase) in crash counts, but there are limitations to these comparisons. Therefore, total and injury crash counts, and weighted average AADT along the BRT line from 2014 to 2022 were checked and these are below (Table 27).

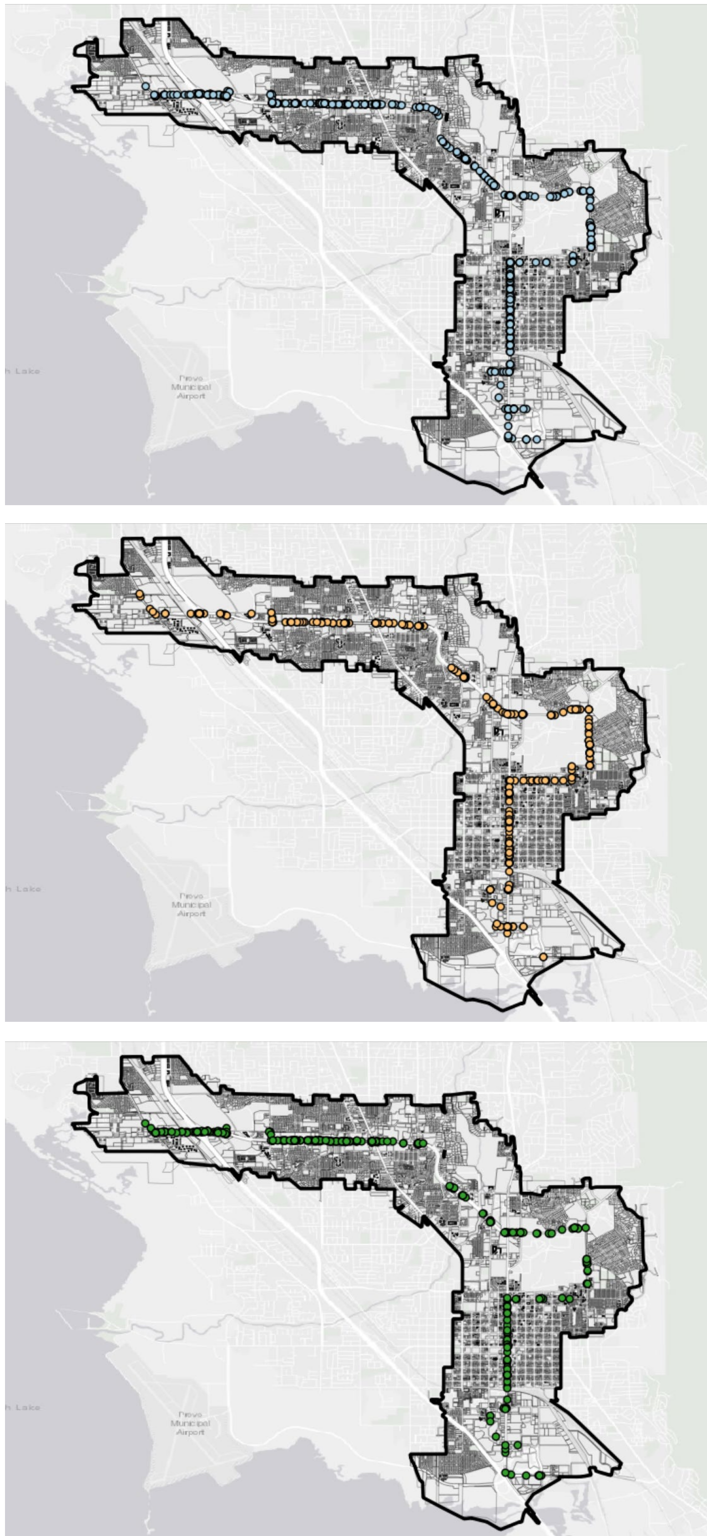

Figure 19 Distribution of Total Crashes along the BRT line in 2017, 2019 and 2022 (top: 2017, middle: 2019, and bottom: 2022).

Table 27 Crash Count and Weighted Average AADT along the BRT Alignment

	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total Crash Count (Severity: 1-5)	559	656	621	634	628	386	283	399	340
Injury Crash Count (Severity: 2-5)	191	210	201	218	193	118	105	108	75
Weighted Average AADT (Total Length: 10.5 miles)	28,313	29,622	30,887	31,567	31,714	31,570	27,353	30,340	30,905

Through Table 27, we found that total and injury crash counts decreased after the opening of the BRT, in particular, these decreased significantly in 2022. However, there is a limitation that the crash count does not consider the traffic volume and length of the roadway. For accurate analysis, using the crash rate rather than the simple count is more reasonable for understanding the safety impacts of BRT. Therefore, we calculated the total crash rate and injury crash rate using the formula from the Federal Highway Administration. The crash rate formula is as follows (Federal Highway Administration, 2011).

$$R = \frac{(C * 100{,}000{,}000)}{V * 365 * N * L}$$

R = Roadway Departure crash rate for the road segment expressed as crashes per 100 million vehicle-miles of travel,

C = Total number of roadway departure crashes in the study period

V = Traffic volumes using Average Annual Daily Traffic (AADT) volumes

N = Number of years of data

L = Length of the roadway segment in miles

After calculation of the total and injury crash rate along the BRT line from 2014 to 2022, the quasi-experimental analysis was conducted using a before-after design (pre-treatment and post-treatment) between 2017 and 2022. Also, we did an analysis using an interrupted time-series design. In this design, we use the trend in total and injury crash rates between 2014 and 2017 using linear regression to predict the values for 2019 and 2022 in the absence of intervention (BRT). The effects of the treatment are evaluated by the gap between predicted and observed values in the 2019 and 2022 results.

7.3 Results

The historical total and injury crash rate along the BRT line from 2014 to 2022 is as follows (Table 28). In the overall pattern, the total and injury crash rate remained almost flat before the BRT operation from 2014 to 2017. However, after the BRT operation, both total and injury crash rates significantly decreased, particularly recently.

Table 28 Total and Injury Crash Rates along the BRT Alignment

	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total Crash Rate along the BRT line (Severity: 1-5)	515.16	577.84	524.61	524.05	516.69	319.03	269.96	343.14	287.06
Injury Crash Rate along the BRT line (Severity: 2-5)	176.02	184.98	169.80	180.19	158.79	97.53	100.16	92.88	63.32

In the total crash rate along the BRT alignment, the absolute value was 39.12 percent lower in 2019 than in 2017 and 45.22 percent lower in 2022 than in 2017. Relative to the trend from 2013 through 2017, extended through 2022, the total crash rate along the BRT line in 2019 was lower than one would expect by 39.36 percent, and it was lower than the expected value by 44.60 percent in 2022 (Figure 20, Table 29, 30).

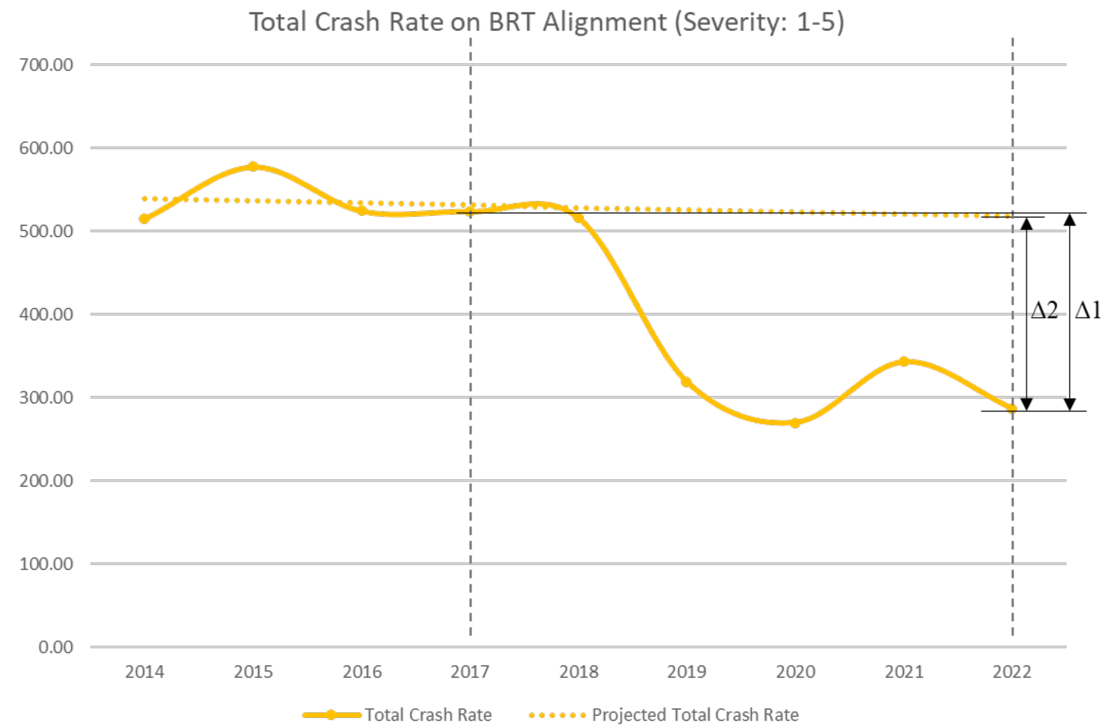

Figure 20 Total Crash Rate along the BRT Alignment (Observed and Predicted Values)

Table 29 Absolute Change of Total Crash Rate along the BRT Alignment from 2017 to 2019 and 2022

	2017 to 2019		**2017 to 2022**	
	Absolute Change	Percentage (%)	Absolute Change	Percentage (%)
Δ1	-205.02	-39.12 %	-236.99	-45.22%

Table 30 Total Crash Rate Difference along the BRT Alignment between the Observed and Predicted Value

	2019		**2022**	
	Relative Change	Percentage (%)	Relative Change	Percentage (%)
Δ2	-207.09	-39.36 %	-231.09	-44.60%

The injury crash rate along the BRT alignment showed a pattern that was similar to the total crash rate; however, it had a larger decrease. The injury crash rate along the BRT alignment in 2019 was 45.88 percent lower than in 2017. In 2022, it was 64.86 percent lower than in 2017. Relative to the trend from 2013 through 2017, extended through 2022, the injury crash rate along the BRT alignment in 2019 was lower than one would expect by 44.84 percent, and it was lower than the expected value by 64.03 percent in 2022 (Figure 21, Table 31, 32).

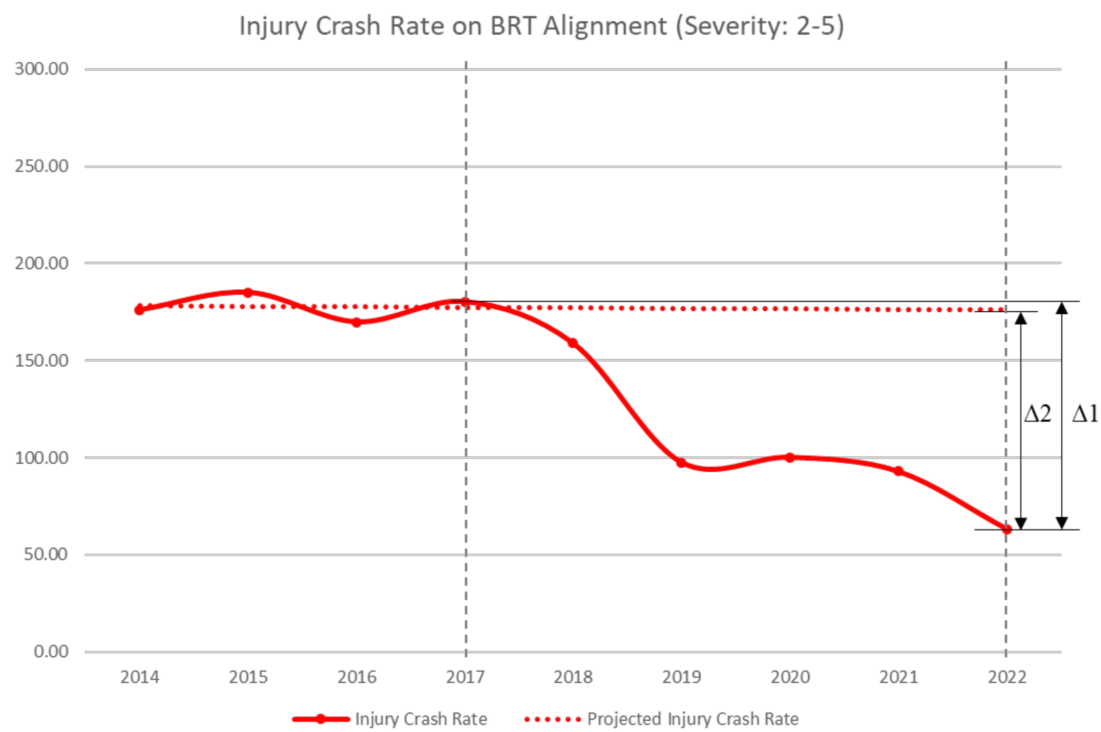

Figure 21 Injury Crash Rate along the BRT Alignment (Observed and Predicted Values)

Table 31 Absolute Change of Injury Crash Rate along the BRT Alignment from 2017 to 2019 and 2022

	2017 to 2019		**2017 to 2022**	
	Absolute Change	Percentage (%)	Absolute Change	Percentage (%)
Δ1	-82.67	-45.88 %	-116.87	-64.86%

Table 32 Injury Crash Rate Difference along the BRT Alignment between the Observed and Predicted Value

	2019		**2022**	
	Relative Change	Percentage (%)	Relative Change	Percentage (%)
Δ2	-79.29	-44.84 %	-112.69	-64.03%

The above results showed that even though the traffic speed along the BRT alignment increased and traffic flow was improved, especially recently, the crash rate along the BRT alignment decreased markedly. The best explanation is other roadway, bicycle, and pedestrian design improvements, such as exclusive bus lanes, transit signal priority, new and wider sidewalks, wider and upgraded pedestrian ramps, new bike lanes, new safer gutter, and new median curb, made as part of the TRIP have made the difference.

In addition, the total and injury pedestrian-involved crash count was also checked, and the results are as follows (Table 33). The total pedestrian-involved crash count along the BRT alignment increased by 3 cases between 2017 and 2019, and by 1 case between 2017 and 2022. The injury pedestrian-involved crash count increased by 2 cases between 2017 and 2019, and by 2 cases between 2017 and 2022.

Table 33 Total and Injury Pedestrian Involved Crash Count on the BRT Alignment

	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total Pedestrian Involved Crash Count (Severity: 1-5)	10	10	7	7	9	10	7	12	8
Injury Pedestrian Involved Crash Count (Severity: 2-5)	8	10	7	6	9	8	7	11	8

Although crash rates fluctuated somewhat from year to year, the data do not suggest a significant trend or overall change in pedestrian-involved crash numbers over the long term. However, because of the opening of the BRT, increased population, and enhanced land use, we could reasonably assume that the number of pedestrians increased significantly over this period. Unfortunately, we do not have pedestrian counts with which to estimate exposure before and after the BRT, and ultimately calculate pedestrian-involved crash rates before and after BRT. For the reasons noted above, we can assume that pedestrian volumes increased, so pedestrian-involved crash rates probably decreased.

8.0 PARKING SUPPLY

In this study, we identified changes in parking supply before and after the BRT operation, focusing on two universities, BYU and UVU. According to previous empirical studies, traffic volume and parking capacity have a positive relationship (Sulistyono, 2018). Comparing 2017, before the BRT operation, and 2019 and 2022, after the BRT operation, student enrollment numbers at BYU and UVU increased by 6.27 percent (BYU: -0.02%, UVU: 11.93%) between 2017 and 2019 and increased by 9.45 percent (BYU: 2.60%, UVU: 15.60%) between 2017 and 2022. If the parking supply did not keep pace with enrollment increases, it could slow traffic growth and induce increased public transit use. This is particularly true at universities, as a previous study of LRT at the University of Utah demonstrated. While we cannot estimate parking demand at the universities based on aerial imagery (particularly since the images mostly come from the summer months, when classes weren't in session), parking supply can be accurately measured, and we can draw inferences about BRT impacts on supply. Our research hypothesis is that the two universities were able to convert surface parking into active academic uses.

8.1 Data Collection and Methods

This analysis was conducted using high-resolution Google imagery from Google Earth Pro software. The resolution of Google imagery is 6" (15cm), and the positional accuracy is about 1 m. Google imagery is collected using cameras on satellites and aircraft and finally extracted using the mosaicking technique. High-resolution imagery is required to determine the change in the number of parking stalls. For this reason, Google imagery data was used in this analysis.

In the case of Google imagery, images were extracted considering such factors as sun angle (>30 degrees), smoke and haze (<1 percent), and clouds (<1 percent). Before and after the BRT operation periods, six Google satellite images of the corridor were available (June 2017, July 2019, October 2019, May 2022, June 2022, and July 2022). Due to the characteristics of the study area, traffic patterns between semester and vacation periods are totally different. Therefore, we chose three relatively similar periods (6/17/2017, 7/18/2019, and 6/20/2022). Because these time points were both schools' (BYU and UVU) vacation periods, parking occupancy was doubtless lower than during the school year. But that is not the issue here. In this analysis, due to the limitation of private indoor parking garage data, analysis was conducted only on surface parking lots. In this analysis, occupied parking spaces were examined but eliminated because Google imagery for the five years represents different times of day and week, which may not be comparable. In fact, June 17, 2017, was on a Saturday, but July 18, 2019, was on a Monday, and June 20, 2022, was on a Tuesday. Therefore, our overall comparison was limited to parking supply changes on surface lots. The theory is that the availability of UVX may have caused trip attractions in the corridor to supply less parking than growth would have otherwise dictated.

Parking Lots at UVU are divided into five classes, with four classes of parking passes. Green lots are reserved for employees and are provided free of charge. Yellow lots are \$115 a year or \$65 a semester (as are disabled lots). The parking garage is \$750 a year. The purple lot, the most distant, is a free lot (see the parking map below in Figure 22).

Figure 22 UVU Parking Map

Parking lots at BYU are divided into nine categories: Student, Graduate Student, Faculty/Staff, Restricted Visitor, Visitor, Timed, Motorcycle, Student Housing, and Free.

Motorcycle parking has been disregarded for the purpose of this study. Prior to 2015, all parking was free on the BYU campus. Since 2015, the student and graduate lots require a pass, which costs $60 per semester. Three outlying lots remain free. All student parking lots at BYU are outside the Campus Drive orbital ring road, and (barring two lots at 600 East and University Parkway) all student lots are on the periphery of BYU campus so that access to the core of campus requires between 1600-3200' of walking. The free lots are about 2500', 4,000', and 4,600' from the center of campus. In this analysis, BYU's parking lots are reclassified into six categories (Student, Faculty/Staff, Restricted Visitor, Visitor, Student Housing, and Free parking) for intuitive understanding. The BYU parking map is shown below (Figure 23).

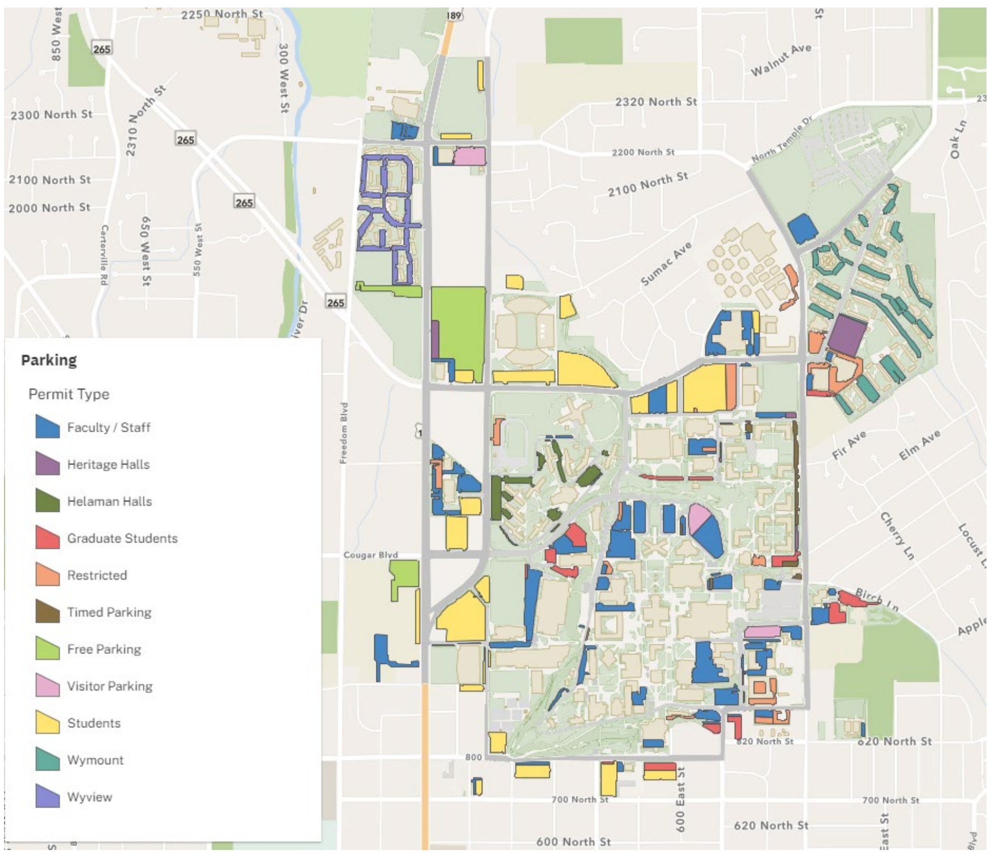

Figure 23 BYU Parking Map

In UVU's and BYU's parking supply calculations, based on the parking maps of BYU and UVU, counts were done by detailed parking parcels according to the reclassified parking type. All parking types and numbers of parking stalls were calculated for each parcel using the naked eye. Figure 24 is an example of the parking stall calculation for the two universities.

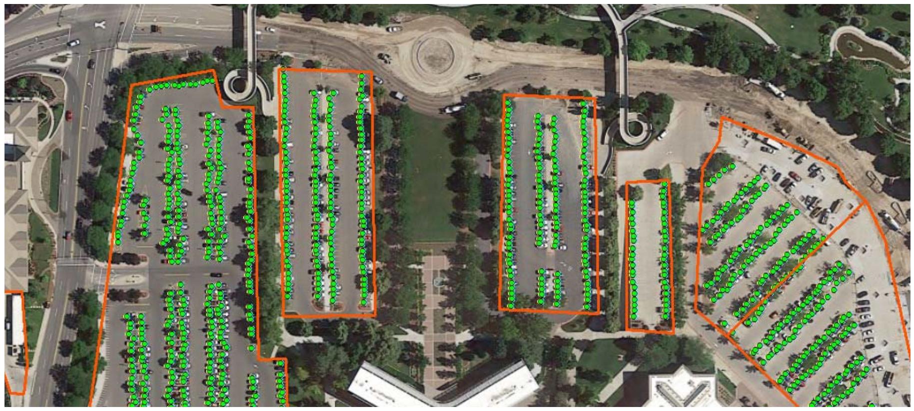

Figure 24 Process of Parking Stalls Calculation

8.2 Results

The results of the parking supply at BYU and UVU are as follows (Table 34). BYU and UVU parking supply increased by 6.67 percent between 2017 and 2019 and increased by 4.47 percent between 2017 and 2022. Based on the fact that the enrollment changes of BYU and UVU between 2017 and 2019 were 6.27 percent, we would conclude that UVX had no effect on parking supply at the universities in the aggregate. Between 2017 and 2022, the enrollment changes of BYU and UVU were 9.45 percent. This level can be said to be slightly higher than the increase in parking supply. Considering this fact, this may have had some impact on traffic patterns. However, we found that a significant number of parking spaces were under construction in 2022. Additionally, a very low occupied parking rate was found at the time of observation (2017: 18.17%, 2019: 24.93%, and 2022: 33.68%). There will be fluctuation depending on the peak time during the semester, but it is somewhat premature to conclude that UVX had a significant effect, considering the level of change. It certainly didn't cause the universities to capitalize on reduced parking demand thanks to BRT.

In detail, in the case of UVU, the total parking supply increased by 16.08 percent between 2017 and 2019 and increased by 14.77 percent between 2017 and 2022. In particular, when focused on students' parking supply (Yellow and Purple) change, the increase was 17.02 percent between 2017 and 2019 and 14.54 percent between 2017 and 2022. From the previous results (Table 19), considering that the increase in UVU enrollment between 2017 and 2019 was 11.93 percent, and between 2017 and 2022 was 15.60 percent. Therefore, we see no positive effect of UVX between 2017 and 2019. However, it could have a slight positive effect on UVX between 2017 and 2022.

In the case of BYU, the total parking supply increased by 2.58 percent between 2017 and 2019 and by 0.02 percent between 2017 and 2022. In particular, when focused on students' parking supply (Student and Free parking), the increase was 4.50 percent between 2017 and 2019 and 3.42 percent between 2017 and 2022. From the previous results, considering that BYU's enrollment changes between 2017 and 2019 were nil and between 2017 and 2022 were 2.60 percent, we see no positive effect of UVX. From this result, we conclude that the use of automobiles became easier over the period, at least in terms of parking availability.

Table 34 Parking Supply Change in BYU and UVU

UVU (Parking Stalls)	**2017**	**2019**	**2022**	**2017-2019**	**2017-2022**
Student	5069	5941	5806	17.20%	14.54%
Employee	1294	1382	1430	6.80%	10.51%
Visitor	277	385	385	38.99%	38.99%
Total	6640	7708	7621	16.08%	14.77%
BYU (Parking Stalls)	**2017**	**2019**	**2022**	**2017-2019**	**2017-2022**
Student	8532	8916	8824	4.50%	3.42%
Employee	3928	3967	3640	0.99%	-7.33%
Visitor	2799	2769	2798	-1.07%	-0.04%
Total	15259	15652	15262	2.58%	0.02%
UVU & BYU	**2017**	**2019**	**2022**	**2017-2019**	**2017-2022**
Total	21899	23360	22883	6.67%	4.49%

Based on these results, our research hypothesis is rejected. Apparently, traffic volumes along the BRT alignment are only weakly related to parking supplies, contrary to existing theory.

The increase in transit use with UVX did not lead to a decline in surface parking stalls in UVU and BYU.

9.0 ENERGY AND VEHICLE EMISSION REDUCTION

9.1 Methods

In preceding analyses, we have produced several estimates of the impact of BRT on traffic along the BRT alignment, taking into account changes in weighted average AADT using three quasi-experimental designs. We choose a conservative traffic reduction estimate to calculate energy and vehicle emissions reduction using the average reduction in weighted average AADT for the three previous quasi-experimental designs (absolute change, interrupted time series, and before and after relative to neighboring streets) (Table 35).

According to our analysis, the decrease in BRT alignment traffic volume in 2022, four years after opening, compared to 2017, before BRT opening, was 2,717 VPD or 7.53 percent, which is a decrease of 1,665 VPD or 4.31 percent compared to 2019, one year after opening. Although traffic volume on the BRT alignment showed a significant traffic reduction in 2022, this is somewhat underestimated, since absolute change ($\Delta 1$) could not reflect the increased traffic volume trend before the BRT operation. Also, the difference in differences ($\Delta 2$) between the BRT alignment and neighboring streets was also underestimated because some of the influence of BRT remained on neighboring streets, considering they were located only 0.5 miles away from the BRT alignment. In addition, since population, university enrollment, parking supply, and trip generation all increased, the actual traffic reduction relative to the counterfactual (no BRT) might be larger than our estimate of 2,717 VPD or 7.53 percent in 2022.

Table 35 Estimates of Traffic Reduction along the BRT Alignment from 2017 to 2019 and 2022

Estimation Method	2017-2019		2017-2022	
	Average Daily Traffic Reduction	Average Daily Traffic Reduction (%)	Average Daily Traffic Reduction	Average Daily Traffic Reduction (%)
Absolute Change (Δ1)	2	0.01%	-662	-2.10%
Interrupted Time-series (Δ2)	-2514	-7.38%	-6613	-17.63%
Difference in Differences (Δ3)	-645	-2.30%	-875	-2.86%
Average	-1052	-3.22%	-2717	-7.53%

With a traffic reduction of 2,717 VPD along the BRT alignment, less fuel is consumed, and less pollution is emitted. According to EPA data, the average emissions and fuel consumption for passenger cars are shown in Table 36. Multiplying the reduction in vehicle miles by fuel consumption and pollutant emissions per vehicle mile in Table 36, we obtain the results in Table 37.

Table 36 Average Emissions and Fuel Consumption for Passenger Cars

Pollutant/Fuel	Emission & Fuel Consumption Rates (per mile driven)
VOC	1.034 grams (g)
THC	1.077 g
CO	9.400 g
NOX	0.693 g
CO2	368.4 g
Gasoline Consumption	0.04149 gallons (gal)

Source: Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks, EPA, http://www.epa.gov/otaq/consumer/420f08024.pdf.

9.2 Results

Due to the BRT, we estimate that 1,236 gallons of gasoline are saved, and 24,164 pounds of CO2 are not emitted each day along the BRT line. Annually, this translates into savings of 450,999 gallons of gasoline and a reduction of 8,819,761 pounds of CO2 along the BRT line in 2022, four years after the BRT opening (Table 37).

Table 37 Effect of BRT on Energy Consumption and Emission Reduction along the BRT Line in 2022

Pollutant/Fuel	Emission & Fuel Consumption Rates (per mile driven)	Traffic Reduction	Calculation	Daily Reduction of Emission & Fuel Consumption	Annual Reduction of Emission & Fuel Consumption
VOC	1.034 grams (g)	2717 vehicles per day (VPD)	(1.034 g/mi) x (10.96 mi) x (2717 VPD) x (1 lb./454 g)	67.82 lb.	24,755 lb.
THC	1.077 g		(1.077 g/mi) x (10.96 mi) x (2717 VPD) x (1 lb./454 g)	70.64 lb.	25,784 lb.
CO	9.400 g		(9.400 g/mi) x (10.96 mi) x (2717 VPD) x (1 lb./454 g)	616.56 lb.	225,043 lb.
NO_X	0.693 g		(0.693 g/mi) x (10.96 mi) x (2717 VPD) x (1 lb./454 g)	45.45 lb.	16,591 lb.
CO_2	368.4 g		(368.4 g/mi) x (10.96 mi) x (2717 VPD) x (1 lb./454 g)	24,164 lb.	8,819,761 lb.
Gasoline Consumption	0.04149 gallons (gal)		(10.96 mi) x (2717 VPD) / (24.1 mi/gal)	1,235.61 gal	450,999 gal

Comparing one year and four years after the BRT operation, 757 more gallons of gasoline are saved, and 14,808 more pounds of CO2 emissions are not emitted each day along the BRT alignment. Annually, 276,376 gallons of gasoline were saved, and 5,404,822 pounds of CO2 were reduced along the BRT line in 2022 compared to 2019 (Table 38). This quantitative result shows that energy consumption and emission reduction also decreased further as traffic volume decreased more in the long term than the short term after the BRT operation.

Table 38 Energy Consumption and Emission Reduction on the BRT Line in 2019 and 2022

	Daily Reduction		Annual Reduction	
	2017-2019	**2017-2022**	**2017-2019**	**2017-2022**
VOC	26.26 lb.	67.82 lb.	9,585 lb.	24,755 lb.
THC	27.35 lb.	70.64 lb.	9,983 lb.	25,784 lb.
CO	238.73 lb.	616.56 lb.	87,135 lb.	225,043 lb.
NO_X	17.60 lb.	45.45 lb.	6,424 lb.	16,591 lb.
CO_2	9,356 lb.	24,164 lb.	3,414,939 lb.	8,819,761 lb.
Gasoline Consumption	478.42 gal	1,235.61 gal	174,623 gal	450,999 gal

10.0 CONCLUSION AND DISCUSSION

From this study, we can better understand the short-term and long-term effects of the Provo-Orem BRT on traffic volumes, transit ridership, nearby land use development, land market value, trip generation, automobile traffic speed, traffic safety, parking supply, and energy consumption and vehicle emissions.

From a simple before-after traffic volume analysis, controlling for nothing, weighted average traffic volume on the BRT streets was essentially flat short-term after and decreased long-term after. Traffic volume was 0.01 percent or 2 VPD higher in 2019 (one year after BRT operation) compared to 2017 (one year before BRT operation) and 2.10 percent or 662 VPD lower in 2022 (four years after BRT operation) compared to 2017. In interrupted time series analysis, assuming that trends in traffic on BRT alignment from 2013 to 2017 continue through 2022 after BRT is in place, traffic volume on the BRT alignment is lower than one would expect by 2514 VPD or 7.38 percent in 2019, and 6613 VPD or 17.63 percent in 2022. Also, BRT appears to reduce vehicular traffic on the different sections of BRT by anywhere from 2,864 to 9,736 per day in 2022. In a before-after analysis with a control group, the weighted average traffic volume of neighboring streets, about 0.5 miles away from the BRT, increased by 2.31 percent or 647 VPD between 2017 and 2019 and increased by 0.76 percent or 213 VPD between 2017 and 2022. Applying these percentages to the BRT alignment, the reduction of traffic volume on the BRT alignment relative to neighboring streets was by 2.30 percent or 645 VPD between 2017 and 2019 and by 2.86 percent or 875 VPD between 2017 and 2022. Through this, we found that the traffic volume for the treatment group was reduced compared to the control group and could deduce that as the distance from the BRT increased, the reduction of traffic volume decreased. On the other hand, transit ridership in the corridor increased more than expected from prior trends in transit ridership due to the introduction of BRT: by 8,840 more passengers per day or 127.05 percent in 2019 and by 3,438 more passengers per day or 42.56 percent in 2022, which helps account for the relative reduction of vehicular traffic on the streets that comprise the BRT alignment.

Also, when analyzing other factors that can affect the traffic to determine whether this decreasing pattern of traffic is truly due to the BRT operation, first, the enrollment number of BYU and UVU increased by 6.27 percent between 2017 and 2019 and 9.45 percent between 2017 and 2022, which we would expect to increase traffic on the BRT alignment when the opposite is the case. Second, in terms of land-use change, overall, residential units increased by 10.52 percent between 2017 and 2019 and 11.46 percent between 2017 and 2022. In particular, the number of multifamily units increased by 16.97 percent between 2017 and 2019 and increased by 17.62 percent between 2017 and 2022. In terms of the total floor area change, the residential total floor area (apartments) increased by 8.71 percent between 2017 and 2019 and by 44.69 percent between 2017 and 2022. The commercial total floor area increased by 4.59 percent between 2017 and 2019 and by 8.17 percent between 2017 and 2022. As the total floor area increased, land market value also increased significantly, in particular in the long term. The total land market value per area increased by 18.88 percent between 2017 and 2019 and by 82.49 percent between 2017 and 2022. Specifically, inflation-adjusted residential land market value increased by 21.12 percent between 2017 and 2019 and by 98.02 percent between 2017 and 2022. Commercial land market value increased by 12.26 percent between 2017 and 2019 and by 61.31 percent between 2017 and 2022. Compared with the taxable value across Utah, in 2022, the increased rate of land market value per area was higher by 24.96 percent in residential areas and by 15.35 percent in commercial areas. Third, the total trips generated in the corridor increased by 33.25 percent between 2017 and 2019 and by 38.12 percent between 2017 and 2022. Specifically, the total trips in commercial areas increased by 41.13 percent between 2017 and 2019 and by 47.25 percent between 2017 and 2022. The total trips in residential areas increased by 8.83 percent between 2017 and 2019 and by 9.78 percent between 2017 and 2022. This is expected to increase further in the future due to the increase in the number of recently built multifamily and single-attached housing. Considering the above facts showing increased activity in the BRT corridor, we can infer that BRT operation is likely responsible for the relative traffic reduction along the BRT line.

Whatever the effect of BRT on traffic volumes on streets that comprise the alignment, it is certainly less than the effect of LRT on traffic volumes along the University TRAX line in Salt Lake County. That short-term impact was previously estimated to be about a reduction of 10,000 vehicles per day. By no calculation, even in relative terms, did BRT (UVX) reach that level of traffic reduction. We suspect the difference isn't due to the different technologies, as BRT is often described as rubber-tired LRT. Rather, it is likely that BRT was not fully implemented in Utah County. Only half of the alignment consisted of exclusive bus lanes, whereas the entire alignment of LRT was exclusive. Also, the alignment of University TRAX was near perfect for traffic reduction, as it connects downtown and southwest Salt Lake County to the University of Utah, where students have to pay significantly for parking. BRT (UVX) connects two universities that are likely to have much less trip interchange and smaller parking charges at the universities themselves.

In addition, from the automobile traffic speed analysis, the annual average traffic speed along the BRT alignment showed a temporary decrease one year after the BRT operation. However, the pattern changed four years after the BRT operation, and traffic speed recovered, and traffic flow improved. Using an interrupted time-series design, the annual average traffic speed along the entire BRT alignment was temporarily lower than expected by 5.02 percent in 2019 but higher than the expected value in 2022 by 1.29 percent.

In the crash rate analysis, the total and injury crash rates reduced significantly after the BRT operation. The total crash rate along the BRT line was lower than the expected value by 39.36 percent in 2019 and by 44.60 percent in 2022. The injury crash rate along the BRT line was lower than the expected value by 44.84 percent in 2019 and by 64.03 percent in 2022.

In terms of other benefits from BRT, 1,236 gallons of gasoline and 24,164 pounds of CO_2 emissions are saved each day along the BRT alignment due to a reduction of about 2,717 VPD relative to what might have been expected in 2022. Annually, this translates into savings of 450,999 gallons of gasoline and 8,819,761 pounds of CO_2.

Considering the above results, introducing the BRT in Provo and Orem was successful. In particular, after the break-in period, as riders "discovered" the new transit option, more significant positive effects appeared in the long term after the BRT operation. However, we cannot say that the introduction of BRT was as successful as the introduction of LRT in Salt Lake County along 400/500 South. The likely reason is that BRT in Utah County does not meet the gold standard of exclusive right-of-way along its entire length and also does not connect origins and destinations that are as likely to exchange trips. This result is significantly evident in the section analysis. While the results of sections 1, 2, and 4 showed a level of impact closer to that of LRT, section 3's impact, which did not meet the gold standard, is significantly less than that of other sections.

Limitations of this study also exist. In this study, the year 2022 was used to examine the long-term impact of BRT introduction. 2022 is a year in which the impact of the pandemic continued to be felt. Therefore, to accurately measure the net long-term impact of a fully established BRT after the break-in period, supplemented monitoring will be necessary. Also, a quasi-experimental research design like those above is nothing like a true experiment when it comes to causal inference. We are simply inferring the effect of the BRT on traffic within the BRT corridor when many other factors are at play.

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