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Countermeasures to Improve Pedestrian Safety on Arterials:

Lessons Learned from Central Avenue in Albuquerque

Final Report

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16. Abstract

This work analyzed the pedestrian safety and overall traffic safety impacts – in terms of both motor vehicle speeds and crash outcomes – of several countermeasures applied to the Central Avenue arterial corridor in Albuquerque, New Mexico. Countermeasures included a bus rapid transit (BRT) system, a road diet, and High-Intensity Activated Crosswalk (HAWK) signals. Vehicle speed data was collected from StreetLight Data and crash data was provided by New Mexico Department of Transportation (NMDOT).

Findings suggest that the infrastructure changes associated with the BRT system improved traffic safety by reducing vehicle operating speeds. Motor vehicle 85th percentile speeds were reduced by 11.5% on BRT segments (compared to a 5.8% decrease on non-BRT control segments) and average motor vehicle speeds were reduced by 13.6% on BRT segments (compared to a 10.6% reduction on non-BRT control segments). Serious and fatal injuries were reduced by 65.2% on BRT segments (compared to a reduction of 18.6% on non-BRT control segments). These serious and fatal injury reductions were consistent across signalized intersections, unsignalized intersections, and midblock locations. Pedestrian safety outcomes were more variable for the BRT. Serious and fatal pedestrian injuries increased 19.0% on the BRT corridor. However, that was relatively positive compared to the 40.9% increase experienced on non-BRT control segments.

A painted road diet on another section of Central Avenue was also found to reduce vehicle speeds but not to the same level as the BRT. On the road diet section of Central Avenue, 85th percentile vehicle speeds dropped by 1.6% after road diet implementation compared to a 4.5% increase on non-road diet sections. HAWK signals installed on Central Avenue and other arterial roads around the Albuquerque metro area showed no significant improvements for either crash outcomes or pedestrian behavior, largely because crash counts were low in the before period and remained low in the after period. While the HAWK signals did have some attractive power and pedestrians were more likely to cross Central Avenue at the HAWK locations after installation, the HAWK signals were not properly activated or utilized.

Overall, findings suggest that physical changes to traffic calm and reduce conflicts along the entire length of arterial corridors are superior to providing spot treatments such as controlled crossings when trying to improve traffic safety outcomes for both pedestrians and motor vehicle occupants alike.

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COUNTERMEASURES TO IMPROVE PEDESTRIAN SAFETY ON ARTERIALS: LESSONS LEARNED FROM CENTRAL AVENUE IN ALBUQUERQUE

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PREFACE

The research reported herein examines methods of improving safety on arterials. Specifically, this research focuses on countermeasures to improve pedestrian safety, as well as traffic safety in general, on NMDOT roadways. This current report represents the first half of this research project and explores safety outcomes for Central Avenue in Albuquerque, NM. The second half of this research project, which is detailed in a separate report, applies findings to NMDOT roadways.

NOTICE

DISCLAIMER

ABSTRACT

This work analyzed the pedestrian safety and overall traffic safety impacts – in terms of both motor vehicle speeds and crash outcomes – of several countermeasures applied to the Central Avenue arterial corridor in Albuquerque, New Mexico. Countermeasures included a bus rapid transit (BRT) system, a road diet, and High-Intensity Activated Crosswalk (HAWK) signals. Vehicle speed data was collected from StreetLight Data and crash data was provided by New Mexico Department of Transportation (NMDOT).

Findings suggest that the infrastructure changes associated with the BRT system improved traffic safety by reducing vehicle operating speeds. Motor vehicle 85th percentile speeds were reduced by 11.5% on BRT segments (compared to a 5.8% decrease on non-BRT control segments) and average motor vehicle speeds were reduced by 13.6% on BRT segments (compared to a 10.6% reduction on non-BRT control segments). Serious and fatal injuries were reduced by 65.2% on BRT segments (compared to a reduction of 18.6% on non-BRT control segments). These serious and fatal injury reductions were consistent across signalized intersections, unsignalized intersections, and midblock locations. Pedestrian safety outcomes were more variable for the BRT. Serious and fatal pedestrian injuries increased 19.0% on the BRT corridor. However, that was relatively positive compared to the 40.9% increase experienced on non-BRT control segments.

The mechanism behind the overall reduction in serious and fatal injuries was traffic calming through the BRT's road diet (as evidenced by the reductions in motor vehicle operating speeds) and left turn restrictions from both raised medians and signalization control.

A painted road diet on another section of Central Avenue was also found to reduce vehicle speeds but not to the same level as the BRT. On the road diet section of Central Avenue, 85th percentile vehicle speeds dropped by 1.6% after road diet implementation compared to a 4.5% increase on non-road diet sections.

HAWK signals installed on Central Avenue and other arterial roads around the Albuquerque metro area showed no significant improvements for either crash outcomes or pedestrian behavior, largely because crash counts were low in the before period and remained low in the after period. While the HAWK signals did have some attractive power and pedestrians were more likely to cross Central Avenue at the HAWK locations after installation, the HAWK signals were not properly activated or utilized. However, the HAWK signals were installed on roadways with 5 or 7 lanes with 85th percentile motor vehicle speeds in the 35-45 mph range. The lack of proper use of the HAWK signals may be a result of the wide and fast characteristics of the roadway.

Overall, findings suggest that physical changes to traffic calm and reduce conflicts along the entire length of arterial corridors are superior to providing spot treatments such as controlled crossings when trying to improve traffic safety outcomes for both pedestrians and motor vehicle occupants alike. This is further evidence that making unsafe arterial corridors more multimodal can improve traffic operations and safety not only for road users outside of cars, but such multimodal changes can actually improve traffic safety for all road users.

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1. INTRODUCTION

The United States of America (US) is in the midst of a pedestrian safety crisis. Between 2009 and 2021, pedestrian fatalities in the US increased 78.7% while all other traffic fatalities increased only 15.7%. 7,342 pedestrians lost their lives on American roads in 2021. Unfortunately, New Mexico has had especially poor outcomes. For the fifth year in a row in 2021, the Governors Highway Safety Association (GHSA) identified New Mexico as having the highest pedestrian fatality rate in the nation (*1*).

Because more than 81.8% of the additional pedestrian fatalities in the US between 2010 and 2017 occurred on arterials and 99.7% occurred in urban areas (*2*), the research in this report focuses on traffic safety countermeasures applied to urban arterials. Furthermore, despite the fact that New Mexico is the 5th largest state in the US by area, 18.7% of all pedestrian collisions in the state have historically occurred within a quarter mile of a single arterial corridor: Albuquerque's Central Avenue. About a dozen pedestrians are typically killed on Albuquerque's Central Avenue corridor each year and countless others injured. The research in this report therefore specifically focuses on pedestrian safety on the Central Avenue arterial corridor in Albuquerque, New Mexico (NM). If we can understand how to improve safety on this 15-mile east/west corridor, not only can we make significant progress in improving traffic safety on what is possibly one of the least safe corridors in the nation, but we can extrapolate those results to improve safety on other similar arterials across the state, region, and country.

Collaborators on this project include the city of Albuquerque (CABQ) and the New Mexico Department of Transportation (NMDOT). CABQ is invested in this project because of their Vision Zero commitment to eliminate traffic fatalities and serious injuries throughout the city. NMDOT supports that effort on the state level.

CABQ has taken note of traffic safety issues on Central Avenue and has implemented several traffic safety countermeasures. The goal of this work was to perform a comprehensive safety analysis of those countermeasures. The countermeasures that we studied through this research project included corridor treatments (a bus rapid transit (BRT) system and road diet) and crossing treatments (high-intensity activated crosswalk (HAWK) signals). We then extrapolated those results to other locations, allowing for results to not only improve traffic safety in Albuquerque but also in other locations across the state, region, and country. This research has a specific focus on pedestrian safety but also addresses traffic safety outcomes for motor vehicle users.

This research project answers four research questions. First: Has Central Avenue been getting safer? While this research question was specific to Albuquerque, it was a vitally important transportation question for the city and the state at the time of this study.

Second: Which countermeasures have been effective? This research question has wider implications. Because the national pedestrian safety crisis has been concentrated on wide and fast arterials in urban areas, we anticipate that countermeasure effectiveness on Central Avenue may be transferrable to other unsafe locations, possibly through the development of crash modification factors (CMF).

Third: How do land use and street design work together to influence safety outcomes? Answering this research question moves us in the direction of a systemic analysis. As can be seen in Figure 1, Central Avenue has design and land use aspects similar to other NMDOT-owned and NMDOT-maintained roads that run through other New Mexico communities. We hope that transferring results from this Central Avenue-based study will allow us to improve outcomes in cities throughout the state and the country.

FIGURE 1. Similar arterial roadways in cities across New Mexico (clockwise from top left: Central Avenue in Albuquerque; US 285 in Roswell; US 180 in Silver City; US 64 in Farmington).

Fourth: Have the countermeasures diverted traffic and collisions elsewhere? While countermeasures may have reduced collisions along Central Avenue, those reductions may be a result of traffic moving to other roadways to avoid the construction or design changes on Central Avenue. We therefore studied changes to exposure on Central Avenue and surrounding roads and changes in collisions on surrounding roads to more holistically identify the overall effectiveness of the traffic safety countermeasures.

2. OBJECTIVES

The objective of this research was to identify and evaluate strategies for improving pedestrian safety on arterial roadways. This was accomplished through analyses of countermeasures that were installed on Central Avenue in Albuquerque, NM. Countermeasures included a BRT system, road diet, and HAWK signals. We analyzed changes in crash frequency and crash rates for the BRT and HAWK signals, changes in vehicle speeds for the BRT and road diet, changes in pedestrian behavior for the HAWK signals, and changes to vehicle exposure for the BRT and road diet. More details on how we selected the countermeasures for each analysis type are provided in the Methodology section.

We considered findings in different land use and road design contexts so that the findings may be extrapolated to other arterials in other cities across the state, region, and country. The deliverable from this project is this final report detailing traffic safety best practices for pedestrians and other road users relative to specific countermeasures, land use configurations, and roadway design configurations. The potential implementation of this research is high as this project has developed results that can be used immediately by departments of transportation (DOTs) to avoid pedestrian and other motor vehicle collisions. The exploration of solutions to the recent increase in pedestrian injuries and fatalities provides new knowledge to the field of transportation.

3. LITERATURE REVIEW

We first examine past research that explores overall pedestrian safety trends and factors that contribute to pedestrian crashes. We then examine past research that explores the effectiveness of specific pedestrian safety countermeasures.

3.1 PEDESTRIAN SAFETY TRENDS

Between 2009 and 2021, pedestrian fatalities in the US increased 78.7% and serious injuries increased more than 50% (*3*). That trend is juxtaposed against thirty years of relatively consistent decreases in pedestrian fatality counts from 1980-2009. What caused such a sudden and marked degradation in pedestrian safety beginning in 2010? Before we explore specific pedestrian safety countermeasures, we will first think about where and when these pedestrian collisions are occurring and who they are impacting.

Albuquerque and at least seventy other US cities, regions, and states have committed to eliminating fatalities and serious injuries on their roadways through Vision Zero. Understanding how to ensure the safety of vulnerable road users (VRU) such as pedestrians is vital if cities are to meet their Vision Zero commitments because – not only is ensuring pedestrian safety vital to Vision Zero – but ensuring VRU safety can also be effective at accomplishing overall Vision Zero goals by making all road users safer (*4*, *5*).

The increase in fatal pedestrian crashes over the last twelve years has been most strongly correlated with infrastructure factors (*2*). Specifically, non-intersection unmarked locations of 40-45 mph, five-lane urban arterials are host to much of the increase in pedestrian fatalities. Of the total increase in pedestrian fatalities between 2010 and 2017, 81.1% occurred on arterials, 80.8% occurred at non-intersection locations without crosswalks, 40.7% occurred on five-lane roads, and 54.6% occurred on roads with 40 or 45 mph speed limits (*2*). This means that wide, high-speed arterial roads are important to focus on, and especially mid-block locations of such roads. Furthermore, 99.7% of the additional pedestrian fatalities between 2010 and 2017 occurred in urban areas (*2*). These findings identify urban arterial roadways as important to study for the current research project.

In addition to the physical roadway design, urban design and land use are also correlated with pedestrian safety outcomes. One study indicated that commercial and retail areas had higher levels of pedestrian fatalities than any other area within their respective cities (*6*). Higher population density has been linked with increased likelihood of pedestrian collisions, whereas the opposite is true for lower densities (*7*, *8*). The National Highway Traffic Safety Administration (NHTSA) reports that most alcohol-impaired pedestrians that are injured in motor vehicle collisions are taking short trips near the pedestrian's home at the time of collision, suggesting that residential areas may be of interest (*9*). Other research has found lower risk of pedestrian injury in mixed-use neighborhoods (*10*). Specific amenities are important to account for as well. For example, past research identified high child pedestrian fatality rates around parks (*11*). For the sake of this study, Central Avenue transverses several distinct neighborhoods within Albuquerque which contain different land uses and densities. Given the findings detailed above, we believe it is also important to account for land use and other urban design characteristics in our analyses.

In addition to the physical built environment, pedestrian characteristics also play an important role in traffic safety outcomes (*12*). For instance, previous studies have identified sociodemographic characteristics that increase the risk of pedestrian crashes (*13*, *14*). Neighborhoods in Seattle that had higher proportions of Hispanic, non-Hispanic Black, and non-Hispanic Asian populations were found to have higher pedestrian collision rates (*15*). Similarly, research sponsored by NHTSA found that Black adults ages 25 and older, Hispanic adult males ages 15 and older, and Native American adults ages 15 and older were at higher risk to be killed as an alcohol-intoxicated pedestrian than the population as a whole (*16*). Interestingly, Leaf and Preusser found the aforementioned pedestrian safety issue to be most acute in New Mexico, with pedestrian fatality rates nearly twice as high as the state with the second highest rates (*17*). The age of pedestrians who were killed over the last decade has also increased significantly more than the national average (*2*).

Spatial negative-binomial regression analysis of pedestrian casualties showed that lower-income areas have more pedestrian casualties and lower-income individuals are at greater risk for a pedestrian fatality (*17*). Furthermore, several physical attributes of low-income areas have been linked to higher probabilities of pedestrian crashes, such as lack of playgrounds, proximity to high-traffic areas, and hazardous walking connections to schools and other facilities (*7, 18, 19*). These findings are important because there are large Hispanic and Native Americans populations as well as lower-income populations in Albuquerque and across New Mexico, suggesting that these sociodemographic factors may play a role in safety outcomes for our study.

Alcohol involvement remains a key trait to consider when exploring pedestrian collisions and injuries. According to NHTSA, 47.4% of pedestrian fatalities had either a driver and/or a pedestrian under the influence of alcohol in 2017 (*20*). In case-control studies, it was established that intoxication among pedestrians increased the likelihood that a pedestrian was injured in a collision (*21*). Although the previous study suggests that consuming alcohol increases the odds of being injured, recent trends show that the percentage of fatally-injured pedestrians with high blood alcohol concentration (BAC) declined from 45% to 35% between 1982 and 2014. This suggests that while there is still an issue with intoxicated pedestrians, we may be making progress in reducing their prevalence or severity (*22*).

An analysis of the relationship between neighborhood characteristics and alcohol use showed elevated risk for alcohol-involved pedestrian crashes in areas with greater bar densities and where local populations reported drinking more alcohol per drinking occasion (*23, 24*). However, while there has been an increasing prevalence of pedestrian drug and alcohol use over the last decade, it does not seem to be large enough to be a primary cause of the recent increase in pedestrian fatalities (*2*). Also, while pedestrian alcohol and drug use has increased significantly, fatal pedestrian crashes with a driver that had been drinking decreased.

In addition to the built environment and road user characteristics detailed above, the type of vehicle involved in a collision can be an important determining factor for traffic safety outcomes. Specifically for pedestrians, vehicles with high front-end profiles (such as sport utility vehicles (SUVs) and pickup trucks) can be especially dangerous. When a pedestrian is struck by a vehicle with a smaller front-end profile, the vehicle bumper typically contacts the pedestrian below their center of gravity at their lower limbs and then the pedestrian wraps around the front of the vehicle with the head and torso contacting the top of the front hood (*25*). When a pedestrian is struck by a vehicle with a higher front-end profile, the bumper and grille may impact at or above the center of gravity, causing the pedestrian to be projected forward and then possibly run over by the striking vehicle, causing significantly more harmful injury patterns. Although SUVs have become significantly more prevalent over the last two decades (and pickup trucks only slightly more prevalent), the prevalence of SUVs involved in pedestrian fatalities has not exceeded the number we might expect based on vehicle exposure and does not seem to fully explain the near doubling in pedestrian fatalities (*2*). Furthermore, while the prevalence of SUVs has been increasing for more than thirty years, pedestrian fatalities were decreasing for much of that time and the increase in pedestrian fatalities only occurred during the last ten years. The role of vehicle type and design in pedestrian safety trends deserves more exploration.

Interestingly, more than 85% of the additional pedestrian fatalities between 2010 and 2017 occurred at night. Prior studies show that lighting condition is significantly correlated with pedestrian safety outcomes (*21, 26-29*). Pedestrians are at higher risk of a collision in the dark, all else being held equal (*28*). Jensen used pedestrian casualty data from police-reported incidents to identify that in dense urban areas, a pedestrian injury is 2.7 times more likely to occur to a pedestrian struck at night compared to a pedestrian struck in daylight (*30*). Jensen's study was reaffirmed by a study conducted in Florida where results noted that the odds of a fatal injury in daylight were 75% lower at midblock locations and 83% lower at intersections than the odds in darkness with no road lighting (*26*). A summary of injury odds relative to lighting condition found that the risk of pedestrian injuries and fatalities increased more in darkness relative to daylight than the odds for other types of motor vehicle collisions (*31*). Several other studies have also shown that dark conditions are more likely to lead to severe or fatal injury compared with daylight (*21, 27, 29*).

We identified several contributing factors to pedestrian safety, including the built environment, road user characteristics, and vehicle characteristics. However, what can be done about these safety issues? Traffic safety professionals often consider treatments that are organized into four different categories: education, enforcement, emergency response, and engineering. Education includes driver education programs and billboards that raise awareness of traffic safety issues. Enforcement consists of the ticketing of road users when they break a rule of the roadway. Emergency response can also be enhanced to improve traffic safety outcomes, although this is typically outside the purview of transportation planners and engineers (*32*).

While the above approaches may be effective at improving pedestrian safety, we will specifically focus on engineering treatments for this research project. In other words, what physical changes to the road design of Central Avenue have impacted traffic safety outcomes for pedestrians and other road users along that corridor?

We divide pedestrian safety engineering countermeasures into two categories: corridor treatments and crossing treatments. Corridor treatments include roadway design changes than run longitudinally along the roadway. Corridor treatments include countermeasures such as road diets, sidewalks, and bike lanes. These treatments may improve pedestrian safety by either providing protected space for pedestrians or by lowering vehicle speeds, thereby reducing the risk of a collision occurring and reducing the injury severity if a collision does occur. Crossing treatments are focused on one specific point in the roadway and enable pedestrians to cross the street. Crossing treatments include countermeasures such as simple crosswalks. However, if a crosswalk is provided without any traffic control devices, pedestrians may use the crossing without any change in driver behavior, thereby introducing an unsafe situation (*33*). For that reason, crossing treatments also include HAWK signals and rectangular rapid flashing beacon (RRFB). These enhanced crossing treatments include both a designated place for pedestrians to cross and signals to control the flow of vehicular traffic.

The corridor and crossing treatments that were installed on Central Avenue and that we investigate in this research are detailed in the literature review sections below. When discussing traffic safety treatments, it is important to note that safe infrastructure is often not spread evenly to all communities. Similar to our land use and socio-economic/demographic discussions above, engineers and planners should strive for a suitable distribution of these countermeasures and treatments that meet the needs and wants of all communities (*34*).

3.2 BRT

BRT is a bus-based public transportation system that delivers higher quality service than a traditional bus system. To be considered a BRT system, the system must have dedicated bus lanes, a median-aligned busway, intersection treatments to prioritize bus operations, pre-board fare collection, and stations that are level with bus boarding areas (*35*). Signalization along the BRT corridor typically prioritizes the BRT buses and there are turning restrictions for other vehicles to ensure efficient bus operations. These design measures prevent BRT buses from waiting in traffic and avoid delays from queues as passengers are boarding the buses.

The first true BRT was opened in Curitiba, Brazil in 1974 (*36*). Since then, BRT systems have been implemented around the world with many in South America and east Asia. The Institute for Transportation & Development Policy (ITDP) developed a BRT ranking system based primarily on the design criteria detailed above. Rankings include basic BRT, bronze, silver, and gold. Of the 126 BRT systems that are recognized by ITDP worldwide, eight are located in U.S. cities (*37*). While Colombia has six gold-ranked BRT systems and Brazil has four gold-ranked BRT systems, the Albuquerque Rapid Transit (ART) BRT system was the first U.S. BRT system to be awarded the gold standard and remains the only US system to meet those criteria (Figure 2). However, that ranking was based on the system design and is now being reevaluated to account for operating conditions.

FIGURE 2. A station along the Albuquerque Rapid Transit (ART) BRT line.

One of the primary goals of a BRT system is to decrease bus and passenger delay by increasing bus speed. The dedicated bus lanes that are characteristic of BRT systems have been shown to provide substantial increases to bus operating speeds (*38*, *39*). For instance, BRT Line 1 in Beijing increased bus operating speeds from 16 km/h to 22 km/h during peak periods and to 26 km/h during off peak periods, resulting in a 38.3% reduction in average travel time per passenger relative to traditional mixed traffic bus operations (*40*). Such increases in bus speed result in enhanced access to destinations (*41*). For instance, the CMAX BRT system in Columbus, OH, substantially improved accessibility to both jobs and healthcare on weekdays (by an average of 27%) and weekends (by an average of 11%) for residents across the socio-economic spectrum (*42*).

But how does the implementation of a BRT system impact the operating speed of other vehicles on the road? This is a critically important question to answer when considering the traffic safety implications of BRT since lower vehicle speeds are correlated with a lower likelihood of a motor vehicle collisions and less severe injury severity. A study of a proposed BRT corridor design on Chicago's Ashland Avenue suggests that BRT systems may provide traffic calming effects because of the complete street design, although the study did not quantitatively examine that claim (*43*). On the other hand, Cervero and Kang found that a BRT system installation in Seoul, South Korea, correlated with increases of 7.6%, 3.4%, and 6.1% in the operating speeds of cars in lanes other than the designated BRT lanes at three study locations (*44*). Because these two studies exploring the relationship between BRT systems and vehicle speeds are seemingly contradictory and are only presented in limited contexts, there is certainly need for more research on the topic. Furthermore, we were unable to find any research related to BRT impacts on other driver behaviors such as distraction or aggressive driving behavior.

Another possible pathway to improved traffic safety is shifting travel patterns. Specifically, since being a passenger on a bus is approximately 66 times safer than being a passenger or driver in a car or light truck (in terms of fatalities per passenger miles), if a BRT system is able to successfully shift road users out of cars and into buses, the overall road environment may see significant improvements in traffic safety outcomes (*45*).

Past research presents evidence that BRT systems can affect mode shift. An analysis of the Orange Line in Los Angeles, CA, found that although 62% of BRT riders had shifted from other forms of public transportation, 18% of BRT riders had previously used personal vehicles for their trips (*46*). Accordingly, about 17% of the Orange Line BRT riders surveyed said they were new users of the public transportation system. In Istanbul, Turkey, 4.0% of BRT trips were previously performed by private car and 1.0% were previously performed by taxi, while 90.4% were shifted from other forms of public transportation (*47*). An analysis using stated preference surveys of possible BRT users in Khon Kaen City, Thailand, found that there was possibility for mode shift away from private vehicles, and especially from motorcycles, although the majority of private vehicles still preferred their own private vehicles (*48*). These findings suggest that BRT might be able to shift trips away from unsafe private vehicles and into safe public transportation, possibly representing an overall improvement in road safety.

Although mode shifts away from private vehicles are possible, researchers found that a BRT system in Seoul, South Korea, spawned new development that resulted in an increase in trips (*49*). It is unclear whether the increase in trips outweighed the mode shift and whether there was an overall improvement in traffic safety outcomes.

We now transition from our discussion of road user behavior to discuss research exploring the direct relationship between BRT systems and traffic safety outcomes. An exhaustive literature review performed by Vecino-Ortiz and Hyder on the topic found only four pieces of research that empirically explored the relationship, two of which are detailed here (*50*). There was a 60% reduction in serious injuries on the Caracas corridor and a 48% reduction on the Norte-Quito-Sur corridor of the Transmilenio BRT system in Bogota, Colombia. This was better than the 39% reduction in serious injuries observed across the city, although this overall decrease confounded the BRT findings and makes it difficult to prove any causality (*51*). Furthermore, there were localized increases in serious injuries observed along the corridor, possibly due to higher vehicle speeds and increased pedestrian exposure near the BRT stations.

Duduta et al. performed an analysis across several BRT systems and found a 60% reduction in road fatalities on the BRT system in Bogota, Colombia, and a 50% reduction in road fatalities on the BRT system in Guadalajara, Mexico (*52*). However, once again there were general decreases in road fatalities observed across the study cities which confounds the results. As a counterpoint to the other successes detailed here, the BRT system in Delhi, India, saw road fatalities more than double. Roadway factors that were found to increase the probability of a collision included the number of legs and lanes per leg, counterflow, level pedestrian crossing, and left turns.

Preliminary research found that all motor vehicle crashes dropped by 8.2% after the ART installation in Albuquerque and serious and fatal injuries dropped by 64.9% (compared with a 5.7% decrease for control segments along the same corridor) (*53*). Pedestrian crashes also decreased significantly with the installation of ART but changes to pedestrian serious and fatal injuries were more variable over the corridor. However, more work is needed to better understand how any changes in safety outcomes relate to land use and road design factors. Furthermore, findings should be parsed by mid-block and intersection locations and exposure should be better considered.

3.3 ROAD DIET

A road diet is a change in a roadway's lane configuration where – typically – a four-lane undivided road (two lanes in each direction) is reduced to a three-lane road (one lane in each direction plus a center two-way left-turn lane (TWLTL)) (Figure 3) (*54*). Road diets may also consist of changing 7-lane configurations to 5-lane configurations or 5-lane configurations to 3-lane configurations. In the original four-lane configuration of a typical road diet, left-turning drivers often must come to a stop in the inside lanes and wait for an acceptable gap to make their left turn. The four-lane configuration therefore presents elevated risk for rear-end collisions from following drivers and elevated risk because turning drivers must cross two lanes of traffic to make a left turn. In addition to three-lane configurations avoiding the previous issues, three-lane configurations also have fewer lanes for a pedestrian to cross and may allow for bicycle facilities (although bike facilities were not added with the road diet in the Albuquerque corridor that is being studied in this report). By reducing these risks, road diets can calm traffic, improve safety, and provide better mobility and access for all road users.

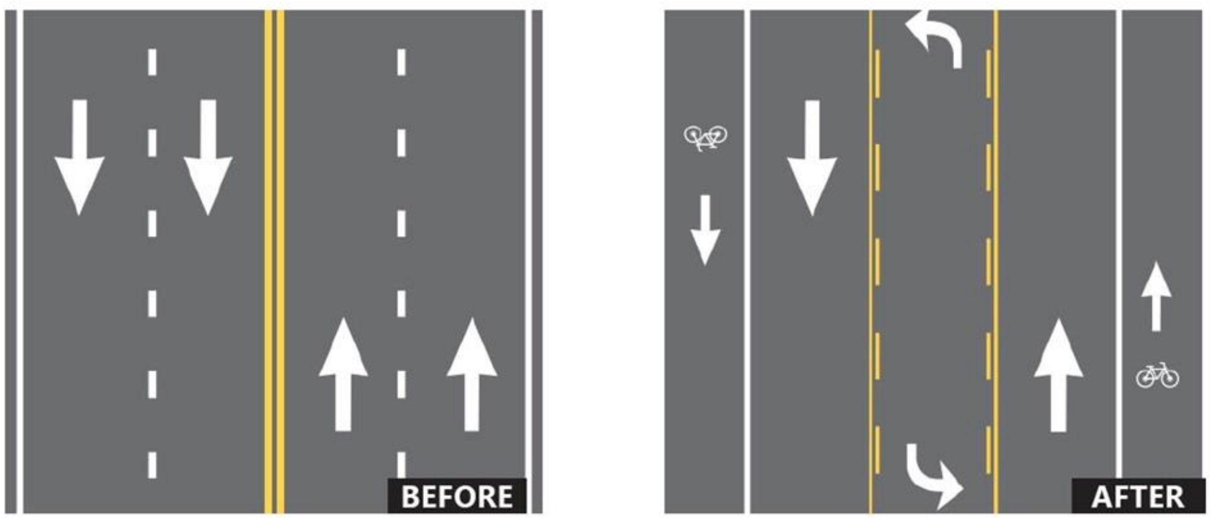

FIGURE 3. Typical road diet lane configuration change.

One of the first road diet installations in the US occurred in Billings, Montana in 1979 (*55*). Over the four proceeding decades, road diets have increased in popularity and have been installed across the country. Although road diets still commonly receive public pushback, reducing a road's configuration to one lane in each direction has not been found to degrade motor vehicle operations nor increase vehicle delay. After countless installations and much study, the Federal Highway Administration (FHWA) still considers road diets to be – in appropriate situations – a worthwhile treatment that improves safety without any detrimental impacts on operations (*54*).

In order to understand how road diets might impact traffic safety, we first examine research that explored the impact that road diets have on vehicle speed. In a study of nine road diet sites in Minnesota (traditional four-lane configuration to three-lane configuration conversions), Gates et al. found reductions of 2 mph in the mean and 85th percentile vehicle speeds (*56*). A study in Iowa found that 85th percentile speeds decreased by 4-5 mph with the installation of a road diet and the proportion of vehicles travelling more than 5 mph over the speed limit dropped by 30% (*57*). In an FHWA compilation of case studies, reductions of 1-4 mph were observed with the installation of a road diet in Grand Rapids, Michigan, and similar decreases in vehicle speeds were found across several other road diet case studies (*58*).

In terms of direct impacts on motor vehicle collisions, a study of thirty sites in Iowa (15 treatment sites and 15 control sites) found a 25.2% reduction in crashes on road diet sites (*59*). And although motor vehicle volumes were found to decrease with the installation of the road diets (due to drivers seeking alternative routes), the road diet sites still experienced an 18.8% reduction in crash rates per vehicle. In Minnesota, road diet sites experienced a 44.2% reduction in overall crashes but negligible changes to injury crashes (56). A study of twelve road diets and twenty-five comparison sites in California and Washington found a more modest 6% reduction in overall crashes and little change in injury severity (*60*).

Overall, road diets appear to have the potential to lower motor vehicle operating speeds by 1-5 mph and reduce motor vehicle collision frequency and rates (although impacts on injury severity appear to be weaker). A synthesis of road diet safety analyses performed by the Pedestrian and Bicycle Information Center (PBIC) concluded that "road diet treatments seem to be one of the success stories with regard to crash and speed reductions" (*61*).

Specifically considering the impacts of road diets on pedestrians, a study examining a road diet in Davis, California, noted a 243% increase in bicyclist traffic after the implementation of the road diet but no statistically significant change in pedestrian volumes (*62*). Case studies of urban 4-lane to 3-lane road diets in Reno, Nevada, and New York City, New York, noted a 54% reduction in pedestrian crashes and a 19% reduction in pedestrian injuries, respectively (*58*). Chen et al. examined 460 road diet sites and – although vehicle volumes were not accounted for – they found a trend of lower (although non-significant) pedestrian crashes on mid-block segments (*63*). Although more research is needed on the topic, existing analyses suggest that road diets can be effective at improving pedestrian safety.

3.4 HAWK SIGNALS

HAWK signals – which are also commonly referred to as Pedestrian Hybrid Beacons (PHBs) – are pedestrian-activated beacons located on mast arms over a major roadway that allow pedestrians to control the flow of motor vehicle traffic away from a traditional signalized intersection (Figure 4).

FIGURE 4. HAWK signal at Alvarado Drive and Lomas Boulevard in Albuquerque.

If the HAWK signal has not been activated by a pedestrian, the overhead beacon will remain blank and motor vehicle traffic should continue travelling normally (Figure 5). When a pedestrian at the roadside activates the HAWK, a flashing yellow beacon and then a solid yellow beacon warn drivers that they should slow and prepare to stop. The pedestrian continues waiting at the roadside until two solid red beacons are illuminated on the overhead mast. Once the overhead mast has two illuminated solid red beacons, motor vehicle traffic should come to a stop and pedestrians should be able to safely cross the roadway.

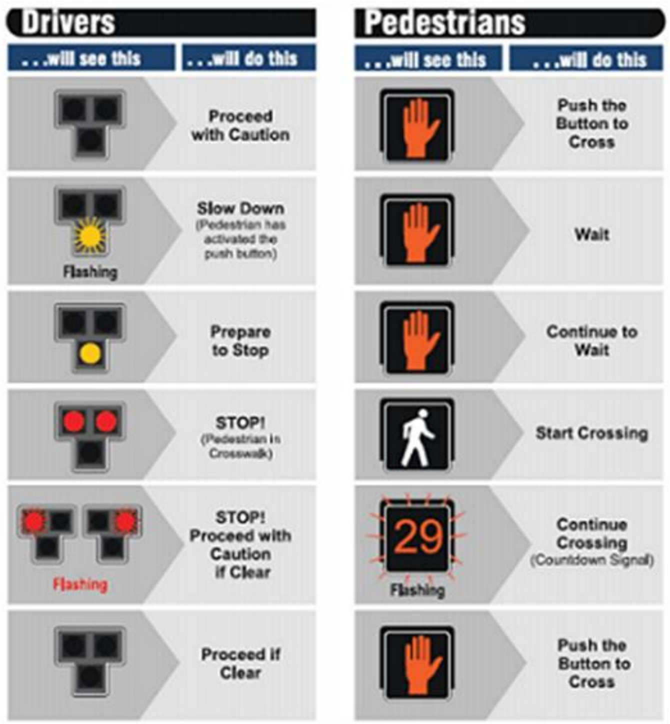

FIGURE 5. HAWK signal operations (*64*).

The HAWK signal was created in Tucson, AZ, and was first included in the 2009 Manual on Uniform Traffic Control Devices. Since that time, HAWKs have been widely adopted across the US.

For a HAWK signal to improve pedestrian safety, it is necessary that drivers comply with the HAWK signal. We therefore first explore research on drivers' HAWK compliance. In a before/after study of a HAWK signal installed on a seven-lane road in an urban environment of Las Vegas, Nevada, Paz et al. found a significant increase in drivers yielding to pedestrians (*65*). 28.2% of pedestrian crossings before the HAWK installation experienced at least one non-yielding driver versus just 8.6% of pedestrian crossings after the HAWK installation. Furthermore, there was an average of 9.82 non-yielding motorists per pedestrian crossing before the HAWK installation versus 4.35 non-yielding motorists per crossing after. Upon finding compliance rates of 97.1% for a HAWK signal on a four-lane undivided roadway in Washington, DC, researchers recommended HAWK signals to improve pedestrian safety, and especially on high-speed major arterials with moderate-to-high pedestrian crossing events (*66*).

In a more suburban context, researchers evaluated the first HAWK signal installed in Vermont (*67*). Located in Colchester, Vermont on five-lane VT Route 15, the HAWK signal connects a hospital complex and some commercial destinations. Data suggests that driver yielding increased 18% after the installation of the HAWK and the number of vehicles slowing down as they approached within 300 feet of the crosswalk increased 83%.

Studying HAWK compliance statewide, researchers found that at crossing locations of roadways with 35 mph or 45 mph signed speed limits and five lanes in Utah, HAWK signals increased driver yielding compliance rates by 97%, overhead flashing beacons increased compliance by 77%, and RRFBs increased compliance by 57% (*68*). In Texas, HAWK signals were found to have compliance rates of 89% versus compliance rates of 98% for traditional traffic control signals and 86% for RRFBs (*69*).

HAWKs appear to significantly increase driver yielding at pedestrian crossings. But do they impact actual safety outcomes? An early analysis of twenty-one HAWK signals in Tucson, Arizona, found that HAWK installation resulted in a 29% reduction in total crashes (statistically significant), a 15% reduction in severe crashes (not statistically significant), and a 69% reduction in pedestrian crashes (statistically significant) (*70*). A later study in Arizona focusing on HAWK signals at locations with higher-operating-speed conditions (85th-percentile speeds ranging between 44 and 54 mph) found that HAWK signals resulted in significant crash reductions for serious injury crashes (25%), pedestrian crashes (46%), severe rear-end crashes (29%), and various other crash types (*71*).

4. METHODOLOGY

To improve pedestrian safety outcomes, traffic safety countermeasures aim to alter road users' behaviors. Primary methods of altering behavior to improve safety include lowering vehicle speeds, shifting people from unsafe personal automobiles into safer modes of transportation, and providing safe spaces for vulnerable road users to move laterally or cross a road. Different types of countermeasures are aimed at affecting different types of road user behaviors. We therefore first provide detailed descriptions of the countermeasures that we will be investigating (Section 4.2) and then discuss the types of analyses (Section 4.3.) For the discussion of analyses, we first discuss our behavioral analyses (Sections 4.3.1, 4.3.2, and 4.3.3) and finish with a discussion of our crash analyses (Section 4.3.4).

4.1. HISTORY OF CENTRAL AVENUE

Before we discuss the safety countermeasure changes to Central Avenue, it is worth providing some context and history of the roadway. While Central Avenue remains today an important east/west corridor through the city of Albuquerque, the road also holds significance to the identity and history of the city and, in a way, to the entire country.

The history of the Central Avenue corridor goes back to prehistoric times. The Sandia and Manzano mountain ranges stretch approximately 60 miles in the north/south direction in Central New Mexico, running parallel to the Rio Grande. Tijeras Pass is the only navigable pass within this stretch. Because the Central Avenue corridor traces more or less a straight line from Tijeras Pass to the river, the trail was in use by native people far before it could be considered a roadway.

When the railroad arrived in Albuquerque in the 1880's, city founders laid out the coinciding development around what was then called Railroad Avenue, which was renamed to Central Avenue in 1912 in an attempt to attract commercial development. When the decision was made in 1925 to integrate state highway systems into a single national highway system, Central Avenue was the logical choice for the primary east/west highway. By 1937, Central Avenue was also known as Route 66 and was a major paved thoroughfare passing through Tijeras Canyon and the center of Albuquerque. Route 66 became a national emblem of westward expansion.

By 1970, construction of Interstate 40 in Albuquerque was completed. Significant amounts of traffic diverted from Central Avenue onto the new interstate, leading to lower traffic volumes and a general decline along the Central Avenue corridor.

Despite declining traffic volumes over the preceding decades, the Central Avenue is still important today as it passes through downtown Albuquerque, Old Town, the University of New Mexico, and many commercial areas. However, with average daily traffic (ADT) in 2017 at about 25,000 to 30,000 vehicles per day and most of the corridor being five or seven lanes wide, today's Central Avenue is overbuilt, allowing for high motor vehicle speeds and long crossing distances for pedestrians.

4.2. COUNTERMEASURES

Because of varying goals for behavioral changes and varying dates of installation for the different countermeasures in this study, each countermeasure underwent different types of analyses. Each countermeasure investigated in this study is detailed below.

4.2.1. Albuquerque Rapid Transit

Major construction on Albuquerque Rapid Transit began in November 2016 and was completed in summer 2018. It is important to note that while major construction was completed in summer 2018, buses were not yet operating at that time. Electric buses that had originally been purchased to operate on the corridor had issues and needed to be replaced. The replacement diesel buses then began service on November 30, 2019.

At the time of the writing of this report, crash data through 2019 was available from NMDOT. For the sake of this report, the 'after' period therefore consists of the time after major infrastructure construction on the BRT corridor was completed but while buses were not yet operating (summer 2018 through December 2019). In addition to the crash analysis, we are also able to obtain motor vehicle volume and speed data for the corridor over this timeframe. We therefore completed vehicle volume, vehicle speed, and crash analyses for the BRT corridor using the same definition of the 'after' period (Table 1).

TABLE 1. Types of analyses performed by safety treatment type.

		Behavioral Analyses			Crash Analysis
		Vehicle Volumes	Vehicle Speeds	Pedestrian Behavior	
ART		X	X		X
HAWK	Central Ave.			X	
	Non-Central Ave.				X
Road Diet		X	X		

The entire Central Avenue corridor today stretches 16.0 miles across Albuquerque in the east/west direction. The physical infrastructure of the BRT system (i.e., dedicated bus lanes, a median-aligned busway, intersection treatments to prioritize bus operations, pre-board fare collection, and stations that are level with bus boarding areas) was implemented on 8.2 miles in the center of the Central Avenue corridor, excluding a 0.5 mile stretch through downtown Albuquerque (Figure 6).

FIGURE 6. Central Avenue corridor through Albuquerque and the extent of the ART infrastructure.

Before the ART system was built, there was both limited-stop express bus service called Rapid Ride and a traditional bus line called Route 66 serving Central Avenue. These were well-used transit services that provided a good foundation for ART. Before ART construction, each of the two Rapid Ride services saw about 1,000,000 riders per year and the Route 66 service saw about 2,500,000 riders per year.

Bus service for the ART lines extends beyond the extent of the physical BRT infrastructure that was detailed above. The ART system was implemented with two lines: the Green Line and the Red Line. The Green Line's western terminus is at Central Avenue & Unser Boulevard and eastern terminus is at Central Avenue & Tramway Boulevard. The Red Line's western terminus is at Central Avenue & Unser Boulevard and eastern terminus is at Uptown Transit Center. That means that both ART bus service lines extend about 0.7

miles to the west of the BRT infrastructure, the Green Line extends 4.0 miles east of the BRT infrastructure, and the Red Line extends about 1.9 miles to the north of the BRT infrastructure. For this study, we are strictly examining the 8.2 miles of Central Avenue that saw ART infrastructure changes, not the entire extents of ART bus service.

Physical changes to the BRT corridor primarily included changes to lane configurations (with the removal of car lanes and the addition of bus-only lanes), the installation of physical medians to prevent left turns, and the prohibition of left turns at signalized intersections (Tables 2-4). There was also a reduction of speed limit on one segment of the ART corridor (Table 2), although we hypothesize that vehicle operating speeds were reduced simply because of changes to the physical roadway even without changes to the posted speed limits. We performed analyses of crash outcomes according to the different infrastructure changes experienced along the corridor.

TABLE 2. ART corridor characteristics: speed limits and lane configurations.

Corridor	Distance (miles)	Before		After		
		Speed Limit (mph)	Car Lanes (ea. direct.)	Speed Limit (mph)	Car Lanes (ea. direct.)	BRT Lanes (total)
Coors to Yucca	0.69	40	2	40	2	2
Yucca to Atrisco	0.82	35	2	35	2	2
Atrisco to Tingley	0.49	35	3	35	2	2
Tingley to Lomas	0.80	35/30	3	35/30	2	2
Lomas to 10th	0.78	30	1	30	1	1
1st to Oak	0.68	30	2	25	1	1
Oak to University	0.73	30	2	30	1	2
University to Girard	0.77	30	2	30	2	1
Girard to Carlisle	0.50	30	2	30	1	2
Carlisle to Washington	0.52	35	2	35	1	2
Washington to San Mateo	0.52	35	3E/2W	35	1	2
San Mateo to San Pedro	0.50	35	3	35	2	2
San Pedro to Louisiana	0.51	35	3	35	2	2

TABLE 3. ART corridor characteristics: median permeability.

Corridor	Distance (miles)	Before		After		
		Median Openings	Median Openings per Mile	Median Openings	Median Openings per Mile	Median Openings Closed per Mile
Coors to Yucca	0.69	13	18.8	2	2.9	15.9
Yucca to Atrisco	0.82	11	13.4	3	3.6	9.8
Atrisco to Tingley	0.49	2	4.1	1	2.0	2.0
Tingley to Lomas	0.80	8	10.0	2	2.5	7.5
Lomas to 10th	0.78	∞	∞	-	-	-
1st to Oak	0.68	6	8.8	3	4.4	1.5
Oak to University	0.73	5	6.8	1	1.4	5.5
University to Girard	0.77	10	13.0	3	3.9	9.1
Girard to Carlisle	0.50	6	12.0	2	4.0	8.0
Carlisle to Washington	0.52	7	13.5	1	1.9	11.5
Washington to San Mateo	0.52	8	15.4	1	1.9	13.5
San Mateo to San Pedro	0.50	10	20.0	2	3.8	16.2
San Pedro to Louisiana	0.51	5	9.8	1	2.0	7.8

TABLE 4. Major intersections on the ART corridor.

Intersecting Road	Functional Classification	Permissive Left Turn Before	Permissive Left Turn After
Coors	Principal Arterial	Yes	No
Yucca	Minor Arterial	Yes	No
Atrisco	Major Collector	Yes	No
Sunset	Major Collector	Yes	No
Rio Grande	Minor Arterial	No	No
Lomas	Principal Arterial	N/A	N/A
10^{th}	Major Collector	Yes	No
1^{st}	Minor Arterial	Yes	No
Broadway	Principal Arterial	Yes	No
Locust/Oak	Major Collector	Yes	No
University	Minor Arterial	Yes	No
Yale	Minor Arterial	Yes	No
Girard	Major Collector	Yes	No
Carlisle	Minor Arterial	Yes	No
Washington	Major Collector	Yes	No
San Mateo	Principal Arterial	Yes	No
San Pedro	Minor Arterial	Yes	No
Louisiana	Principal Arterial	Yes	No

4.2.2. HAWK

We examined five HAWK signals in total (Table 5). Two of the signals were on Central Avenue and three of the signals were on other roads in the Albuquerque metro area.

TABLE 5. HAWK signal characteristics.

#	Primary Road					Secondary Road	Installation Month
	Name	ADT (2017)	Functional Classification	# Lanes	Speed Limit (mph)	Name	
1	Isleta Blvd.	19,000	Principal Arterial	3	40	Perry Rd.	Oct. 2014
2	Lomas Blvd.	25,800	Principal Arterial	7	40	Alvarado Dr.	Nov. 2015
3	Louisiana Blvd.	17,400	Minor Arterial	5	35	Natalie Ave.	Aug. 2018
4	Central Ave.	28,600	Principal Arterial	7	40	Conchas St.	Aug. 2022
5	Central Ave.	31,200	Principal Arterial	7	35	San Pablo St.	Aug. 2022

The HAWK on Isleta is located in South Valley, a town to the south of Albuquerque. It is a more suburban and lower density area than the other HAWK signals that are located in the city of Albuquerque. The HAWK on Louisiana was installed next to a middle school in response to two students being killed while walking to school. The HAWK at Central & Conchas is next to a bus stop that has substantial pedestrian activity. The HAWK at Central & San Pablo is next to the International District Library and is also in an area with substantial pedestrian activity.

The study HAWK signals that were installed on roadways other than Central Avenue were installed early enough that we were able to perform crash analyses. However, we did not perform vehicle volume, vehicle speed, or pedestrian behavior analyses on these HAWK signals because we were not able to obtain the necessary data on these other roadways.

The HAWK signals that were installed on Central Avenue were installed too recently to obtain crash data, vehicle volumes, or vehicle speeds. For that reason, we only performed pedestrian behavior analyses on the Central Avenue HAWK signals.

4.2.3. Road Diet

A road diet was implemented on the far eastern end of the Central Avenue corridor from Juan Tabo Boulevard to Tramway Boulevard. This was outside the extent of the ART infrastructure construction. The road diet saw Central Avenue go from seven lanes (three lanes in each direction with a center turn lane) to five lanes (two lanes in each direction with a center turn lane). The extra lanes in each direction that were removed were simply cross hatched. The curb was not moved.

The road diet is in a lower density area of Central Avenue relative to other sections of the corridor that are more central to downtown Albuquerque. The ADT is between 20,100 and 22,900 vehicles per day for this part of the corridor.

The road diet was completed in August of 2021. Therefore, we were not able to obtain adequate crash data to perform a proper before/after crash analysis. However, we were able to obtain vehicle volume data and vehicle speed data to perform those analyses.

4.3. TYPES OF ANALYSES

4.3.1. Vehicle Volume Analyses

Shifting road users out of personal automobiles can be an effective traffic safety countermeasure in and of itself, hence justifying independent vehicle volume analyses. We obtained vehicle volumes from StreetLight Data (SLD), a private company that provides cloud-based software delivering information on vehicle and person trips (e.g., annual average daily traffic (AADT) counts, average travel distances, top origins and destinations, and vehicle speeds) derived from locational big data. SLD's raw data comes from two types of location data sources: location-based services (LBS) data and navigation-Global Positioning System (GPS) data. Navigation-GPS data comes specifically from commercial trucks while LBS data is derived from smartphones and can be from any mode. While SLD's supplier data represents approximately 110 million devices in the U.S. and Canada, or about one-third of those countries' combined population, trip penetration rates for individual analyses can range from as small as 1% to as large as 35%. The 110 million devices provide about 50 billion monthly location data points and 1.5 billion trips monthly.

To determine the mode of the trips in the LBS dataset, SLD uses a multi-pass algorithm to identify each mode of travel (e.g., vehicle, bus, rail, bike, or walk trips) using a random forest model machine learning technique to assign mode probabilities to every ping. The model utilizes various sources of training data, including a combination of the National Renewable Energy Laboratory's (NREL) Transportation Secure Data Center, GPS data from transit agencies, data derived from bus lines in service, and vehicular data from navigation-GPS devices. Since this is a probabilistic approach, the result is not a single mode for every ping but instead a mode probability distribution (0–1).

After mode assignment, individual trips must be differentiated by looking for key patterns. For example, a series of data points whose first timestamp is early in the morning, travels at reasonable speeds for several minutes, and then stands still for several minutes could be grouped into a probable trip. When the mode probability changes for a series of pings, SLD ends the current trip and starts a new trip with the new mode. For example, if a string of ten pings that are high-probability vehicle pings is followed by a string of five high-probability bike pings, then two trips are created: a vehicle trip followed by a bike trip.

Once trips are defined, the trips must be linked with the physical transportation system. Since a device may only be pinging every ten seconds, pings will not necessarily lie on the road network. SLD therefore uses a process that they call Trip Locking to match their pings to the transportation network. For walk, vehicle, bike, bus, and rail trips, SLD utilizes network information from OpenStreetMap (OSM), including route types, speed limits, and directionality to lock the trip to the network.

Once all trips have been defined and locked to the transportation system, the data is normalized and expanded to derive a volume estimate, or a StreetLight Index value. Suppliers' data sample sizes fluctuate month over month, necessitating this normalization process so the data is comparable over time. For LBS trips tagged as vehicle, bike, and walk, the sample is expanded to estimate the actual flow of travel. This process involves implementing machine learning models and integrating data from the census and thousands of permanent counters to normalize the sample and represent the full population. Monthly trip estimates for each respective mode are produced for any given location.

Since their methodology is relatively new, SLD has sought to validate their product. SLD AADT metrics have been validated against 4,255 permanent counter data points across the U.S. with a Pearson correlation of 0.99 (p-value <0.001) (*72*). SLD information is becoming standard in the transportation industry and is being used in the 25 largest metropolitan statistical areas (MSAs) in the U.S. and the 15 largest MSAs in Canada.

Although use has become widespread, there are still limitations that have been identified. The AADT metric shows relatively large percentage errors for very low-volume roads (0- 499 AADT) due to small sample sizes. Issues have also been identified on international borders (*73*).

SLD has been used for exposure metrics in other peer-reviewed research exploring traffic safety (*74-77*). An analysis comparing non-motorized road user volume estimates from passively gathered crowdsourced data to counts found promising correlations (*78*).

4.3.2. Vehicle Speed Analyses

We utilized StreetLight Data to also obtain vehicle speeds. SLD uses the time and distance between pings to calculate vehicle speeds. SLD validated their vehicle speed data against speed reports from 202 sample locations provided by Washington State Department of Transportation (WSDOT) and data published for 71 sample locations by the California Department of Transportation's Performance Management System (PeMS) (*79*). Both state agencies used permanent loop counters to collect speed data. Permanent loop counters are prone to error because some counters detect only speeds within a certain range or estimate speeds in cases of single loop detectors. SLD speeds may be subject to error in scenarios where trip samples are limited or network configurations lead to trip-locking challenges.

When 85th percentile speed estimates from SLD were compared to WSDOT 85th percentile speeds at sampled locations, there was a strong correlation. Specifically, an R^2 value of 0.9159 was obtained between SLD and validation 85th percentile data points (Figure 7).

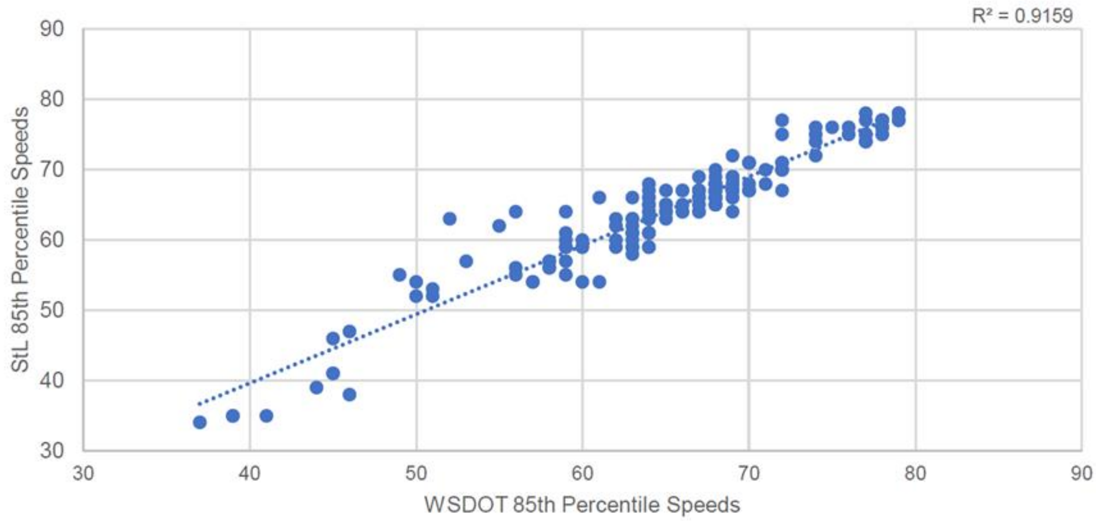

FIGURE 7. Correlation between WSDOT and StreetLight's 85th percentile speeds.

To get a better picture of SLD's speed data across the speed continuum, all vehicle speeds over an average day were broken into 5 mph intervals for both SLD data and WSDOT data (*79*). This process was completed across Washington and Highway 5 near Tacoma is shown below (Figure 8). In general, the speed distribution obtained from SLD estimates is similar to the WSDOT distribution. The SLD distribution is overrepresented at lower vehicle speeds, but only slightly so.

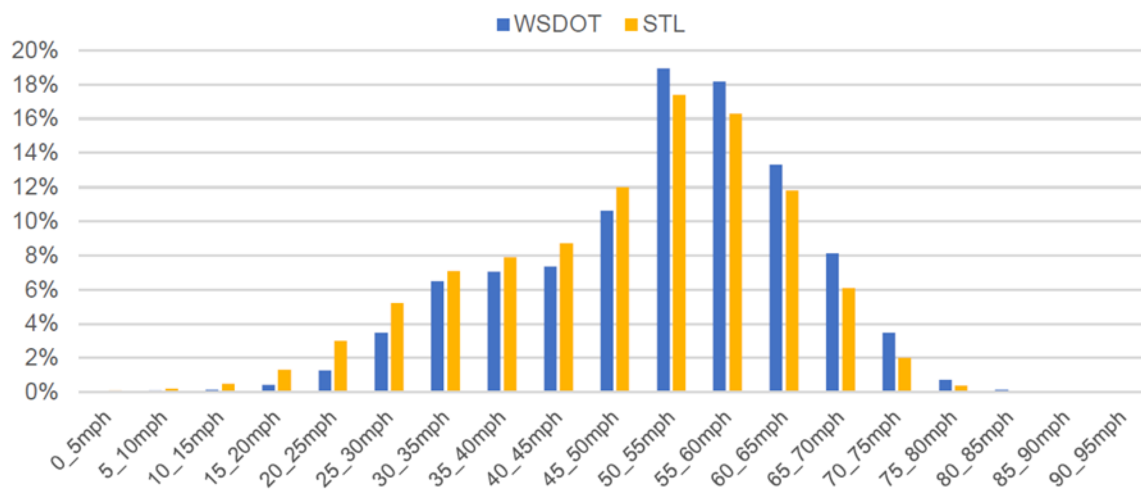

FIGURE 8. Speed distribution of WSDOT and StreetLight data for Highway 5 near Tacoma.

As a final validation, SLD compared the average vehicle speed for each hour of a typical weekday from PeMS data to their own estimates (*79*). The overall trends were similar with both sources showing slower speeds at the peak AM and PM hours and relatively consistent speeds otherwise (Figure 9). SLD appears to slightly (<10%) underestimate speeds during peak periods and overestimate (<5%) speeds at midday.

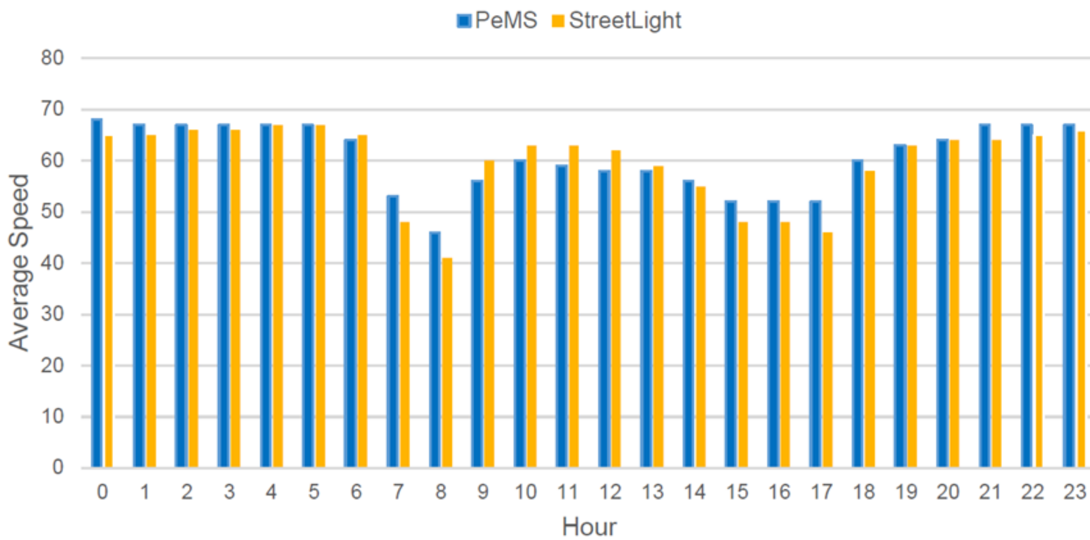

FIGURE 9. Average weekday hourly speed comparison for PeMS and StreetLight data on Costa Mesa Freeway.

We were not able to find any peer-reviewed journal papers that used StreetLight Data speed data. That may not be a reflection on the validity of the data source so much as the newness of the data source.

4.3.3. Pedestrian Behavioral Analyses

To understand if and how the HAWK signals influenced pedestrian behavior, we observed pedestrian routes at the Central Avenue HAWK signal sites both before and after installation. We collected before data on May 26, May 31, June 1, and June 6, 2022. We collected after data on March 13 and March 14, 2023. All data was collected on weekdays between 10:00 AM and 4:00 PM. All collection days had clear weather without precipitation. A single data collector was used to ensure consistent data collection methodologies. The data collector did not wear distinctive clothing and in general acted inconspicuously so as to not alter pedestrian behavior with their presence.

The data collector sat on a ledge at the location of the HAWK crossing. The study area was defined as the distance that a person could reasonably see in either direction, which given the setting was about 800 feet in either direction. When a pedestrian walked into the study area (either along Central Avenue or from a side street), their entrance location and time was noted. They were tracked, noting where they crossed Central and/or where they left the study area (either along Central or down a side street). A physical map was printed on a piece of paper and held with a clipboard and each pedestrian's route was noted with a pen. We also noted if the pedestrian got off or onto a bus. If there were more than three pedestrians at a time, we could not keep track of the increased activity and we therefore did not monitor anymore pedestrians until one left the study area.

After data collection in the field, we returned to the lab and entered the pedestrian routes into a geographic information system (GIS) as polyline shapefiles. The location of bus stops within the study areas were also noted as point shapefiles in GIS.

4.3.4. Crash Analyses

4.3.4.1. BRT Crash Analysis

For our crash analyses, we needed to count crash data within certain geographies related to the Central Avenue corridor. We also wanted to account for the level of exposure – or the relative level of risk experienced by different types of road users – for those geographies. The data needs for our crash analyses therefore fell into three categories: 1) crash data, 2) geographic boundaries, and 3) exposure data.

We obtained the crash data used in this study from NMDOT. The NMDOT crash database is compiled from crash data reported by police departments across New Mexico. Police officers responding to a reported motor vehicle crash complete a Uniform Crash Report (UCR), which is a standardized form used by agencies statewide. Reported motor vehicle crashes occurring on public roadways and involving one or more motor vehicles that resulted in death, personal injury, or at least $500 in property damage are entered into the NMDOT crash dataset. No account is kept of unreported crashes, and the database does not include crashes on private property. Once the UCRs are submitted to NMDOT from police agencies across New Mexico, the data is then cleaned and formatted by the Geospatial & Population Studies unit at the University of New Mexico and then returned to NMDOT.

It is important to note that injury severity is often misdiagnosed by responding police officers, and especially so for pedestrian crash victims (*80*). Furthermore, crash data only illuminates some pedestrian safety issues. Other pedestrian safety issues may be so dangerous that there is little pedestrian activity at those locations and therefore few crashes to investigate (*81-84*). The analysis in this work only investigates safety issues that precipitated into crashes. Future work might further benefit from analyses of near misses or subjective perceptions of safety.

City council district boundaries, municipal limits, and road centerlines were provided by the city of Albuquerque's Planning Department. The data is publicly available for download from the city of Albuquerque's website. All data was in the New Mexico State Plane-Central Zone, Feet (NAD 83) projection and can be downloaded in ESRI shapefile format.

Exposure is a measure of risk experienced in the roadway environment, typically quantified in either the number of persons, distance travelled, or time spent in the transportation system (*85*). Population-based exposure metrics allow road safety to be studied as a public health issue and are common in studies that consider socio-demographic and socio-economic factors (*86-90*). Outcomes based on population-based exposure reflect overall societal risk while those based on travel exposure (e.g., distance or time) reflect travel risk (*91, 92*).

While the focus of our study was pedestrian safety, we unfortunately did not have access to data pertaining to historical pedestrian volumes or activity. We did, however, have access to historic levels of motor vehicle volumes through StreetLight Data, as detailed in Section 4.3.1. Because of the data availability constraints, we ran our exposure analysis based on motor vehicle crashes per motor vehicle. We therefore completed both crash frequency analyses (the overall number of crashes) and crash rate analyses (the rate of crashes per motor vehicle).

To complete our analysis, we first divided the Central Avenue corridor into segments according to the land use and road design characteristics detailed in Section 4.2.1. Because crash characteristics typically vary between mid-block segments and intersections, we separately analyzed all major intersections where Central Avenue is intersected by roadways with a functional classification of major collector or greater. All these analysis intersections were signalized.

We also analyzed alternative routes for the motor vehicle collision analyses. These routes included Zuni Road, Lead Avenue, Coal Avenue, Lomas Boulevard, Dr. Martin Luther King Jr. Avenue, and Bridge Boulevard. All these roadways were collectors or arterials within a mile of Central Avenue and were roughly parallel. Given the construction of ART, it would be reasonable to expect that traffic might divert off Central Avenue and onto these alternative routes. We do not believe that pedestrians would have diverted far enough out of their path of travel to use these alternative routes during ART construction.

We drew a 100-foot buffer around the road centerlines for midblock segments and a 200-foot buffer around each analysis intersection. For the analysis intersections, we separately analyzed each approach to the intersection and the intersection itself. This methodology assumes that the GIS coordinates have been placed with a fair amount of accuracy to where the crashes occurred. Once the buffers were established around each analysis segment and intersection, we performed spatial joins to count the total number of reported motor vehicle collisions that occurred in each study polygon for each month of the analysis period.

The BRT construction began in November 2016 and was completed in summer 2018. We selected the period of analysis to account for before, during, and after the ART system's implementation. The "before" period was defined as November 2013 through October 2016, which was when major construction of the ART system began. The "during" period was defined as November 2016 through May 2018, which was when the major construction of the ART system occurred. The "after" period was defined as June 2018 through November 2019. It is important to note that there were no ART buses operating in the ART designated bus lanes during the "after" period because of operational issues with the buses. The "after" period is therefore when the major infrastructure was completed but there were no buses yet operating on the system. There were still buses operating on the Central Avenue corridor, but these were the traditional buses operating on the outside lanes of Central Avenue.

For the time frames specified above, we analyzed all reported motor vehicle crashes, all reported motor vehicle crashes resulting in a serious injury or fatality, all pedestrian crashes, and all crashes resulting in a serious or fatal pedestrian injury. We compared crash counts to see whether there were any significant changes in crash frequency before versus after implementation of the ART infrastructure. We coincided motor vehicle volume exposure metrics with these timeframes to derive crash rates. In this way, we analyzed both crash frequencies and crash rates for the ART system.

We used the NMDOT police-reported data to analyze contributing factors and analysis (which can also be thought of as crash type). For the contributing factor and crash type analyses, we combined several variables into broader categories.

For the contributing factor analysis, "Excessive Speed" consists of:

- Excessive Speed
- Speed Too Fast for Conditions

For the crash type analysis, "From Opposite Direction" consists of:

- Other Vehicle – From Opposite Direction

For the crash type analysis, "Left Turn" consists of:

- Other Vehicle - Both Turn Left/Entering At Angle
- Other Vehicle - From Opposite Direction/One Left Turn
- Other Vehicle - From Same Direction/Both Turn Left
- Other Vehicle - From Same Direction/One Left Turn
- Other Vehicle - One Left Turn/Entering At Angle
- Other Vehicle - One Vehicle/Making A U-Turn

For the crash type analysis, "Rear End" consists of:

- Other Vehicle - From Same Direction/Both Going Straight
- Other Vehicle - From Same Direction/Rear End Collision

For the crash type analysis, "Right Turn" consists of:

- Other Vehicle - Both Turn Right/Entering At Angle

- Other Vehicle - From Opposite Direction/One Right Turn
- Other Vehicle - From Same Direction/Both Turn Right
- Other Vehicle - From Same Direction/One Right Turn
- Other Vehicle - One Right Turn/Entering At Angle

For the crash type analysis, “Sideswipe” consists of:
- Other Vehicle - Both Going Straight/Entering At Angle
- Other Vehicle - From Opposite Direction/Sideswipe Collision
- Other Vehicle - From Same Direction/Sideswipe Collision

We created heat maps using the kernel density tool in ArcMap. We used an output cell size of 10 meters by 10 meters which provided us with a smoot output image. We used a search radius of 500 meters which allowed enough fidelity that we could observe crash concentrations at midblock locations and no major intersection would overlap with any other. We created a before and after map for each factor analyzed. For each factor, both the before and after maps were set to the same scale so they can be directly compared.

4.3.4.2 HAWK Signal Crash Analysis

We again obtained crash data from NMDOT and boundary data from the city of Albuquerque, as detailed in Section 4.3.4.1. We drew a 200-foot buffer around each HAWK signal that was being analyzed. We separately accounted for each approach to the HAWK signals. Spatial joins allowed us to obtain counts for each month in the analysis period. We analyzed the 24 months before installation and 24 months after installation for all reported motor vehicle crashes, all reported motor vehicle crashes resulting in a serious injury or fatality, all pedestrian crashes, and all crashes resulting in a serious or fatal pedestrian injury. We compared crash counts to see whether there were any significant changes in crash frequency before versus after implementation of the HAWK signals.

5. ANALYSIS AND FINDINGS

5.1 BRT

For the contributing factors analysis, we used 19 months before (4/2015-10/2016 inclusive) and 19 months after (6/2018-12/2019 inclusive).

5.1.1. BRT Crash Frequency Results

There were 18 major intersections along the BRT corridor in this analysis (counting the Locust/Oak interchange at I-25 as a single intersection) (see Table 4 for a list of major intersections). There were 22 other signalized intersections (not counting HAWK signals) along the BRT corridor. There were 70 unsignalized intersections along the BRT corridor. Much of the corridor consists of midblock segments.

5.1.1.1. All Motor Vehicle Crashes

There were significant improvements in traffic safety with the installation of the BRT system, especially in terms of serious and fatal injuries. While overall reported motor vehicle collisions decreased 15.3%, the number of people seriously or fatally injured on the BRT corridor decreased 60.0% (Table 6). The number of pedestrian collisions actually rose 3.4%, but the number of pedestrians seriously or fatally injured decreased 7.7%. Safety improvements appear to be consistent across smaller signalized intersections, unsignalized intersections, and midblock segments but major intersections either saw little progress or increasing numbers for pedestrians.

TABLE 6. ART corridor motor vehicle crash frequencies (results statistically significant at 95% confidence in bold).

Crash Type	Location	Before	After	Change	% Change	p-value
All Modes All Severities	Major Intersections	851	796	-55	-6.5%	0.079
	Other Signalized Intersections	**288**	**228**	**-60**	**-20.8%**	**0.015**
	Unsignalized Intersections	**369**	**282**	**-87**	**-23.6%**	**0.003**
	Midblock	**143**	**93**	**-50**	**-35.0%**	**0.007**
	TOTAL	**1,651**	**1,399**	**-252**	**-15.3%**	**0.001**
All Modes KA	**Major Intersections**	**25**	**11**	**-14**	**-56.0%**	**0.006**
	Other Signalized Intersections	**10**	**4**	**-6**	**-60.0%**	**0.022**
	Unsignalized Intersections	**16**	**5**	**-11**	**-68.8%**	**0.005**
	Midblock	4	2	-2	-50.0%	0.194
	TOTAL	**55**	**22**	**-33**	**-60.0%**	**<0.001**
Pedestrians All Severities	Major Intersections	28	40	12	42.8%	0.077
	Other Signalized Intersections	**10**	**4**	**-6**	**-60.0%**	**0.036**
	Unsignalized Intersections	15	12	-3	-20.0%	0.303
	Midblock	5	4	-1	-20.0%	0.373
	TOTAL	58	60	2	3.4%	0.430
Pedestrians KAB	Major Intersections	15	24	9	60.0%	0.094
	Other Signalized Intersections	**8**	**3**	**-5**	**-62.5%**	**0.039**
	Unsignalized Intersections	6	8	2	33.3%	0.308
	Midblock	4	3	-1	-25.0%	0.343
	TOTAL	33	38	5	15.2%	0.292

For overall motor vehicle collisions, major intersections had the most crashes (51.5% of all crashes in the before period) and saw the smallest decrease in crashes (56.9% of all crashes in the after period) (Table 6). The largest total decrease in crashes occurred at unsignalized intersections (a reduction of 87 crashes). The largest proportional decrease in crashes occurred on midblock segments (a 35.0% decrease in crashes), although relatively few crashes happened on midblock segments to begin with.

In terms of seriously and fatally injured road users, there was a 60.0% decrease in the after period, which is equal to a reduction of 1.7 serious or fatal injuries per month along the corridor (Table 6). While major intersections were once again the least safe location along the corridor (home to 45.4% of all serious and fatal injuries), major intersections promisingly saw the largest decrease in serious and fatal injuries. Another promising characteristic of the substantial decrease in serious and fatal injuries is that all location types saw substantial decreases. The smallest decrease was 50.0% for midblock locations and the largest decrease was 68.8% for unsignalized intersections. This suggests that the benefits in terms of reducing injuries and saving lives was spread relatively evenly across the entire corridor.

While there were promising and relatively consistent decreases in terms of overall motor vehicle collisions, pedestrian outcomes were more uncertain (Table 6). The increase in the total number of pedestrians being struck was a result of a 42.8% increase (12 additional pedestrians) being struck at major intersections. While the number of pedestrians seriously or fatally injured decreased overall, there was a 33.3% increase at major intersections. Promisingly, all other location types saw decreases in pedestrians struck and pedestrians seriously or fatally injured (other than the number of pedestrians seriously or fatally injured at midblock locations which stayed the same).

For the corridor analysis in Tables 7-10, the corridors are inclusive of their major intersections so the numbers should not be aggregated. The highlighted rows are to guide the reader by bringing attention to the largest decreases in crashes (in green) and largest increases (in red).

TABLE 7. ART corridor all motor vehicle crash frequency outcomes.

Corridor	All Modes All Severities						
	Before	After	Change	% Change	p-value	Before (per mile)	After (per mile)
98th to 86th	149	144	-5	-3.4%	0.400	201.4	194.6
86th to Unser	94	100	6	6.4%	0.354	229.3	243.9
Unser to Coors	236	225	-11	-4.7%	0.316	323.3	308.2
Coors to Yucca	**222**	**183**	**-39**	**-17.6%**	**0.050**	**321.7**	**265.2**
Yucca to Atrisco	**226**	**160**	**-66**	**-29.2%**	**0.004**	**275.6**	**195.1**
Atrisco to Tingley	136	128	-8	-5.9%	0.329	277.6	261.2
Tingley to Lomas	160	155	-5	-3.1%	0.430	200.0	193.8
Lomas to 10th	**53**	**34**	**-19**	**-35.8%**	**0.010**	**67.1**	**43.0**
10th to 1st	**113**	**81**	**-32**	**-28.3%**	**0.024**	**179.4**	**128.6**
1st to Oak	**152**	**95**	**-57**	**-37.5%**	**<0.001**	**223.5**	**139.7**
Oak to University	**172**	**128**	**-44**	**-25.6%**	**0.012**	**235.6**	**175.3**
University to Girard	220	197	-23	-10.5%	0.198	285.7	255.8
Girard to Carlisle	138	148	10	7.2%	0.307	276.0	296.0
Carlisle to Washington	72	66	-6	-8.3%	0.283	138.5	126.9
Washington to San Mateo	158	128	-30	-19.0%	0.056	303.8	246.2
San Mateo to San Pedro	175	164	-11	-6.3%	0.299	350.0	328.0
San Pedro to Louisiana	200	226	26	13.0%	0.141	392.2	443.1
Louisiana to Pennsylvania	194	198	4	2.1%	0.425	366.0	373.6
Pennsylvania to Wyoming	145	132	-13	-9.0%	0.242	290.0	264.0
Wyoming to Zuni	99	97	-2	-2.0%	0.442	291.2	285.3
Zuni to Eubank	152	161	9	5.9%	0.298	223.5	236.8
Eubank to Morris	115	116	1	0.9%	0.472	261.4	263.6
Morris to Juan Tabo	75	73	-2	-2.7%	0.447	136.4	132.7
Juan Tabo to Dorado	93	87	-6	-6.5%	0.349	138.8	129.9
Dorado to Tramway	81	81	0	0.0%	0.500	238.2	238.2
AVERAGE BRT				**-13.1%**	**0.004**	**253.3**	**226.9**
AVERAGE NON-BRT				-3.3%	0.254	239.9	233.3

In general, traffic safety was worst in the before period on the far west end and east end of the BRT corridor (Table 7). The most substantial decreases in total motor vehicle collisions occurred on the west half of the corridor (Figure 10). This included everything west of the river (the West Side of Albuquerque), the segments around downtown (Lomas to University), and just east of Nob Hill (Washington to San Mateo). Interestingly, four of these corridors were the six corridors that saw reductions to a single car lane in each direction. These corridors saw reductions from 2 lanes to 1 lane and the only speed limit reduction on the corridor (1st to Oak). Girard to Carlisle also saw a reduction to one car lane in each direction, but the major intersection with Girard got substantially worse (see major intersection outcomes below in Table 11). They also had the lowest speed limits at 30 mph.

FIGURE 10. Kernel density of all motor vehicle crashes of all severities on Central Avenue.

There was an interesting pattern that emerged on the eastern end of the corridor (Washington to Louisiana) where safety issues appear to have migrated further to the east (Table 7). While the three segments that comprise this corridor had the three highest crash rates per mile in the before period, the westernmost segment saw substantial improvement, the central segment saw moderate improvement, and the easternmost segment saw a degradation in safety. It appears that the safety issues present in the eastern part of the BRT corridor may have migrated further east. This may have been a result of differing road design changes (the Washington to San Mateo segment was reduced to one car lane in each direction while the other segments were reduced to two car lanes in each direction).

Results for serious and fatal injuries were similar to overall crash counts. The West Side (Coors to Atrisco) was least safe in the before period but saw a reduction of 15 serious and fatal crashes (Table 8). The corridor from Girard to San Pedro had the second worst safety outcomes in the before period and also saw substantial decreases in serious and fatal injuries to just one in the after period (Figure 11). It is promising that the worst segments saw the most impressive safety improvements.

TABLE 8. ART corridor killed and/or serious injury (KA) motor vehicle crash frequency outcomes.

Corridor	All Modes KA						
	Before	After	Change	% Change	p-value	Before (per mile)	After (per mile)
98th to 86th	**8**	**0**	**-8**	**-100.0%**	**0.006**	**10.8**	**0.0**
86th to Unser	1	3	2	200.0%	0.152	2.4	7.3
Unser to Coors	6	6	0	0.0%	0.500	8.2	8.2
Coors to Yucca	**12**	**4**	**-8**	**-66.7%**	**0.028**	**17.4**	**5.8**
Yucca to Atrisco	**11**	**3**	**-8**	**-72.7%**	**0.019**	**13.4**	**3.6**
Atrisco to Tingley	**5**	**0**	**-5**	**-100.0%**	**0.008**	**10.2**	**0.0**
Tingley to Lomas	5	6	1	20.0%	0.389	6.3	7.5
Lomas to 10th	1	0	-1	-100.0%	0.162	1.3	0.0
10th to 1st	3	5	2	66.7%	0.304	4.8	7.9
1st to Oak	5	2	-3	-60.0%	0.110	7.4	2.9
Oak to University	4	2	-2	-50.0%	0.232	5.5	2.7
University to Girard	4	2	-2	-50.0%	0.232	5.2	2.6
Girard to Carlisle	**5**	**1**	**-4**	**-80.0%**	**0.039**	**10.0**	**2.0**
Carlisle to Washington	1	0	-1	-100.0%	0.162	1.9	0.0
Washington to San Mateo	**6**	**0**	**-6**	**-100.0%**	**0.012**	**11.5**	**0.0**
San Mateo to San Pedro	**6**	**0**	**-6**	**-100.0%**	**0.003**	**12.0**	**0.0**
San Pedro to Louisiana	4	4	0	0.0%	0.500	7.8	7.8
Louisiana to Pennsylvania	9	10	1	11.1%	0.403	17.0	18.9
Pennsylvania to Wyoming	10	5	-5	-50.0%	0.070	20.0	10.0
Wyoming to Zuni	4	9	5	125.0%	0.100	11.8	26.5
Zuni to Eubank	**3**	**8**	**5**	**166.7%**	**0.039**	**4.4**	**11.8**
Eubank to Morris	3	2	-1	-33.3%	0.321	6.8	4.5
Morris to Juan Tabo	**9**	**2**	**-7**	**-77.8%**	**0.021**	**16.4**	**3.6**
Juan Tabo to Dorado	**10**	**3**	**-7**	**-70.0%**	**0.025**	**14.9**	**4.5**
Dorado to Tramway	4	4	0	0.0%	0.500	11.8	11.8
AVERAGE BRT				**-65.2%**	**<0.001**	**7.8**	**2.5**
AVERAGE NON-BRT				-18.6%	0.169	10.8	9.6

FIGURE 11. Kernel density of all motor vehicle crashes of killed and/or serious injury (KA) severities on Central Avenue.

5.1.1.2. Pedestrian Crashes

While the West Side had impressive improvements for all motor vehicle crashes, there were not similar results for pedestrians (Table 9). The best improvements were in the University of New Mexico (UNM) area and Washington to San Mateo. The San Pedro to Louisiana segment saw a 200.0% increase in pedestrian collisions (12 more in the after period), 6 of which occurred at the Louisiana intersection and 4 at the San Pedro intersection.

TABLE 9. ART corridor all pedestrian crash frequency outcomes.

Corridor	Pedestrian All Severities						
	Before	After	Change	% Change	p-value	Before (per mile)	After (per mile)
98th to 86th	2	1	-1	-50.0%	0.280	2.7	1.4
86th to Unser	1	2	1	100.0%	0.280	2.4	4.9
Unser to Coors	**5**	**13**	**8**	**160.0%**	**0.044**	**6.8**	**17.8**
Coors to Yucca	12	13	1	8.3%	0.426	17.4	18.8
Yucca to Atrisco	6	3	-3	-50.0%	0.225	7.3	3.6
Atrisco to Tingley	3	1	-2	-66.7%	0.205	6.1	2.0
Tingley to Lomas	4	3	-1	-25.0%	0.343	5.0	3.8
Lomas to 10th	1	0	-1	-100.0%	0.162	1.3	0.0
10th to 1st	7	7	0	0.0%	0.500	11.1	11.1
1st to Oak	**0**	**4**	**4**	**N/A**	**0.018**	**0.0**	**5.9**
Oak to University	2	4	2	100.0%	0.194	2.7	5.5
University to Girard	9	5	-4	-44.4%	0.138	11.7	6.5
Girard to Carlisle	3	4	1	33.3%	0.364	6.0	8.0
Carlisle to Washington	3	1	-2	-66.7%	0.152	5.8	1.9
Washington to San Mateo	11	7	-4	-36.4%	0.201	21.2	13.5
San Mateo to San Pedro	15	15	0	0.0%	0.500	30.0	30.0
San Pedro to Louisiana	**6**	**18**	**12**	**200.0%**	**0.013**	**11.8**	**35.3**
Louisiana to Pennsylvania	13	20	7	53.8%	0.091	24.5	37.7
Pennsylvania to Wyoming	14	15	1	7.1%	0.431	28.0	30.0
Wyoming to Zuni	6	11	5	83.3%	0.121	17.6	32.4
Zuni to Eubank	**3**	**10**	**7**	**233.3%**	**0.035**	**4.4**	**14.7**
Eubank to Morris	4	3	-1	-25.0%	0.343	9.1	6.8
Morris to Juan Tabo	4	1	-3	-75.0%	0.123	7.3	1.8
Juan Tabo to Dorado	7	7	0	0.0%	0.500	10.4	10.4
Dorado to Tramway	6	6	0	0.0%	0.500	17.6	17.6
AVERAGE BRT				4.0%	0.425	9.4	10.2
AVERAGE NON-BRT				**33.3%**	**0.027**	**11.8**	**15.6**

1st to Oak and Oak to University also had increases in pedestrians struck (Table 9 and Figure 12). This is interesting because these 1st to University segments had some of the largest reductions in overall motor vehicle collisions and had some of the lowest crash rates (per mile) along the entire BRT corridor. These segments were still relatively safe for pedestrians, but the increase could be because the lane and speed limit reductions led to more pedestrians crossing the street at unmarked crossings.

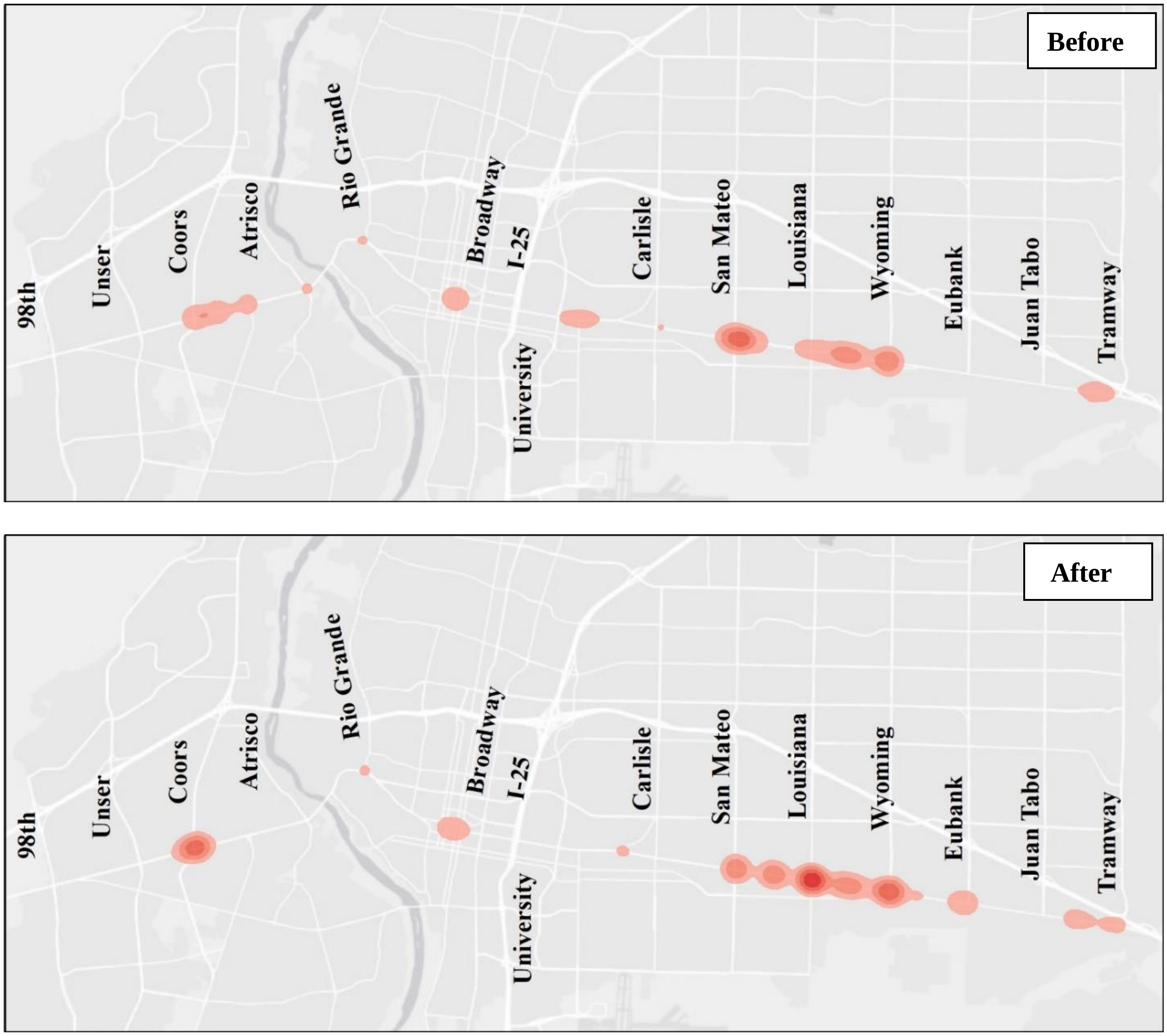

FIGURE 12. Kernel density of all pedestrian crashes of all severities on Central Avenue.

Seriously and fatally injured pedestrian counts were relatively low on the corridor level and there were few large changes in the after period (Table 10 and Figure 13). Most activity occurred on the east end of the corridor, which again exhibited the migration of safety issues further to the east. Washington to San Mateo and San Mateo to San Pedro were two of the least safe segments in the before period but they eliminated all serious and fatal pedestrian crashes in the after period. San Pedro to Louisiana had no serious or fatal pedestrian crashes in the before period but became by far the least safe corridor in the after period by adding three serious or fatal pedestrian crashes. Coors to Atrisco was unsafe in both the before and after periods although there was a slight improvement.

TABLE 10. ART corridor KA pedestrian crash frequency outcomes.

Corridor	Pedestrian KAB						
	Before	After	Change	% Change	p-value	Before (per mile)	After (per mile)
98th to 86th	1	1	0	0.0%	0.500	1.4	1.4
86th to Unser	1	2	1	100.0%	0.280	2.4	4.9
Unser to Coors	**3**	**10**	**7**	**233.3%**	**0.025**	**4.1**	**13.7**
Coors to Yucca	8	9	1	12.5%	0.403	11.6	13.0
Yucca to Atrisco	5	2	-3	-60.0%	0.197	6.1	2.4
Atrisco to Tingley	2	0	-2	-100.0%	0.162	4.1	0.0
Tingley to Lomas	3	2	-1	-33.3%	0.321	3.8	2.5
Lomas to 10th	0	0	0	0.0%	N/A	0.0	0.0
10th to 1st	3	6	3	100.0%	0.163	4.8	9.5
1st to Oak	0	1	1	N/A	0.162	0.0	1.5
Oak to University	**0**	**3**	**3**	**N/A**	**0.037**	**0.0**	**4.1**
University to Girard	3	3	0	0.0%	0.500	3.9	3.9
Girard to Carlisle	2	3	1	50.0%	0.350	4.0	6.0
Carlisle to Washington	1	1	0	0.0%	0.500	1.9	1.9
Washington to San Mateo	6	4	-2	-33.3%	0.311	11.5	7.7
San Mateo to San Pedro	8	9	1	12.5%	0.408	16.0	18.0
San Pedro to Louisiana	**4**	**13**	**9**	**225.0%**	**0.021**	**7.8**	**25.5**
Louisiana to Pennsylvania	8	14	6	75.0%	0.090	15.1	26.4
Pennsylvania to Wyoming	10	8	-2	-20.0%	0.299	20.0	16.0
Wyoming to Zuni	3	4	1	33.3%	0.343	8.8	11.8
Zuni to Eubank	**1**	**7**	**6**	**600.0%**	**0.032**	**1.5**	**10.3**
Eubank to Morris	2	2	0	0.0%	0.500	4.5	4.5
Morris to Juan Tabo	**4**	**0**	**-4**	**-100.0%**	**0.048**	**7.3**	**0.0**
Juan Tabo to Dorado	6	4	-2	-33.3%	0.263	9.0	6.0
Dorado to Tramway	2	4	2	100.0%	0.194	5.9	11.8
AVERAGE BRT				19.0%	0.267	5.4	6.6
AVERAGE NON-BRT				**40.9%**	**0.050**	**7.1**	**9.7**

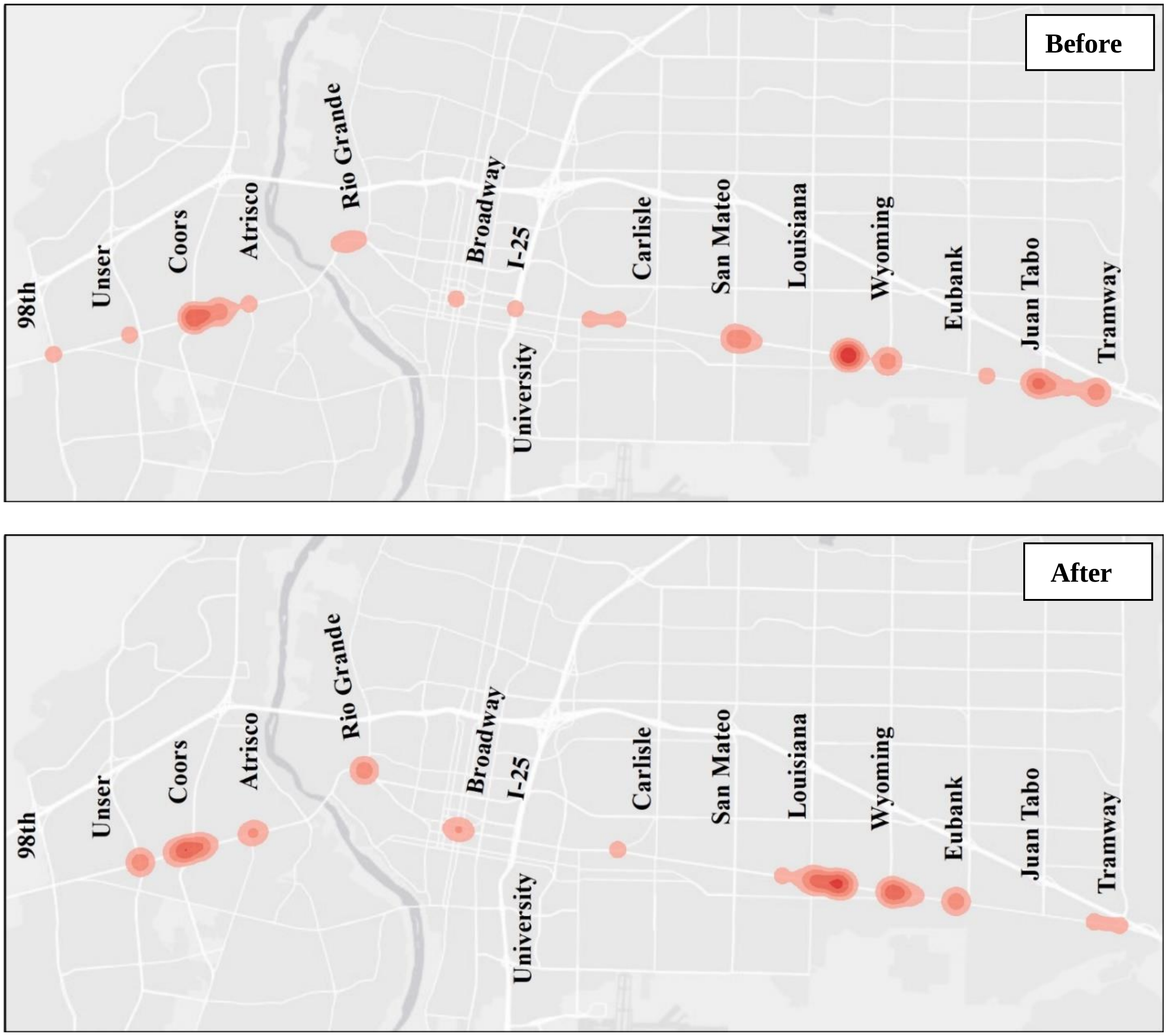

FIGURE 13. Kernel density of all pedestrian crashes of KA severities on Central Avenue.

Echoing the corridor level results, major intersections on the West Side saw substantial improvements (Table 11). The migration of safety concerns on the east end of the corridor was again present in that San Mateo saw a reduction in overall crashes and killed and/or serious injury (KA) crashes and San Pedro saw a reduction in KA crashes, but Louisiana saw an increase in overall crashes and no reduction in KA crashes. Interestingly, one of the best improvements occurred at the Locust/Oak interchange with I-25.

TABLE 11. Major intersection motor vehicle crash frequency outcomes.

Intersecting Road	All Modes All Severities					All Modes KA				
	Before	After	Change	% Change	p-value	Before	After	Change	% Change	p-value
98th	100	89	-11	-11.0%	0.253	**4**	**0**	**-4**	**-100.0%**	**0.018**
86th	12	8	-4	-33.3%	0.161	0	0	0	0.0%	N/A
Unser	77	86	9	11.7%	0.282	0	2	2	N/A	0.077
Airport	12	15	3	25.0%	0.291	0	2	2	N/A	0.077
Coors	137	110	-27	-19.7%	0.063	6	2	-4	-66.7%	0.059
Yucca	**9**	**19**	**10**	**111.1%**	**0.024**	2	1	-1	-50.0%	0.280
Atrisco	66	56	-10	-15.2%	0.209	**3**	**0**	**-3**	**-100.0%**	**0.037**
Sunset	29	29	0	0.0%	0.500	1	0	-1	-100.0%	0.162
Rio Grande	63	74	11	17.5%	0.084	1	4	3	300.0%	0.123
Lomas	1	2	1	100.0%	0.329	0	0	0	0.0%	N/A
10th	**13**	**3**	**-10**	**-76.9%**	**0.003**	0	0	0	0.0%	N/A
1st	15	9	-6	-40.0%	0.076	1	1	0	0.0%	0.500
Broadway	33	28	-5	-15.2%	0.274	1	0	-1	-100.0%	0.162
Locust/Oak	**72**	**32**	**-40**	**-55.6%**	**<0.001**	2	0	-2	-100.0%	0.077
University	50	51	1	2.0%	0.468	1	0	-1	-100.0%	0.162
Yale	33	27	-6	-18.2%	0.245	0	0	0	0.0%	N/A
Girard	**36**	**53**	**17**	**47.2%**	**0.024**	1	1	0	0.0%	0.500
Carlisle	25	24	-1	-4.0%	0.441	0	0	0	0.0%	N/A
Washington	17	15	-2	-11.8%	0.364	0	0	0	0.0%	N/A
San Mateo	83	75	-8	-9.6%	0.215	2	0	-2	-100.0%	0.077
San Pedro	42	57	15	35.7%	0.093	2	0	-2	-100.0%	0.077
Louisiana	127	132	5	3.9%	0.390	2	2	0	0.0%	0.500
Wyoming	57	66	9	15.8%	0.192	3	5	2	66.7%	0.251
Zuni	24	20	-4	-16.7%	0.256	1	3	2	200.0%	0.152
Eubank	95	100	5	5.3%	0.349	1	2	1	100.0%	0.280
Morris	16	13	-3	-18.8%	0.306	1	0	-1	-100.0%	0.162
Juan Tabo	53	52	-1	-1.9%	0.468	**7**	**1**	**-6**	**-85.7%**	**0.019**
Dorado	14	11	-3	-21.4%	0.305	2	2	0	0.0%	0.500
Tramway	61	65	4	6.6%	0.255	1	2	1	100.0%	0.280
TOTAL BRT	851	796	-55	-6.5%	0.079	**25**	**11**	**-14**	**-56.0%**	**0.006**
TOTAL NON-BRT	521	525	4	0.8%	0.462	20	19	-1	-5.0%	0.435

Some major intersections that deserve further analysis include Rio Grande, Girard, and Louisiana, all of which saw increases in either overall crashes and/or KA crashes (Table 11).

In terms of pedestrian crashes, the major safety issues are on the far west and east ends of the BRT corridor (Table 12). The major intersections on the West Side performed poorly in the before period and did not have a major change in the after period. The east end migration of safety issues was more prevalent. San Mateo saw significant improvement and Louisiana got significantly worse.

TABLE 12. Major intersection pedestrian crash frequency outcomes.

Intersecting Road	Pedestrian All Severities					Pedestrian KAB				
	Before	After	Change	% Change	p-value	Before	After	Change	% Change	p-value
98th	1	1	0	0.0%	0.500	1	1	0	0.0%	0.500
86th	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Unser	0	2	2	N/A	0.077	0	2	2	N/A	0.077
Airport	0	2	2	N/A	0.077	0	2	2	N/A	0.077
Coors	5	8	3	60.0%	0.250	3	5	2	66.7%	0.251
Yucca	0	1	1	N/A	0.162	0	1	1	N/A	0.162
Atrisco	3	1	-2	-66.7%	0.205	2	0	-2	-100.0%	0.162
Sunset	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Rio Grande	2	2	0	0.0%	0.500	1	1	0	0.0%	0.500
Lomas	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
10th	1	0	-1	-100.0%	0.162	0	0	0	0.0%	N/A
1st	0	2	2	N/A	0.077	0	1	1	N/A	0.162
Broadway	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Locust/Oak	0	1	1	N/A	0.162	0	0	0	0.0%	N/A
University	1	1	0	0.0%	0.500	0	1	1	N/A	0.162
Yale	1	1	0	0.0%	0.500	1	0	-1	-100.0%	0.162
Girard	1	1	0	0.0%	0.500	1	1	0	0.0%	0.500
Carlisle	1	1	0	0.0%	0.500	0	1	1	N/A	0.162
Washington	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
San Mateo	9	7	-2	-22.2%	0.321	5	4	-1	-20.0%	0.385
San Pedro	**1**	**5**	**4**	**400.0%**	**0.039**	**0**	**4**	**4**	**N/A**	**0.018**
Louisiana	**3**	**9**	**6**	**200.0%**	**0.045**	2	5	3	150.0%	0.110
Wyoming	6	8	2	33.3%	0.319	3	2	-1	-33.3%	0.321
Zuni	0	2	2	N/A	0.077	0	1	1	N/A	0.162
Eubank	2	3	1	50.0%	0.321	0	2	2	N/A	0.077
Morris	1	0	-1	-100.0%	0.162	1	0	-1	-100.0%	0.162
Juan Tabo	2	1	-1	-50.0%	0.280	2	0	-2	-100.0%	0.077
Dorado	2	2	0	0.0%	0.500	1	2	1	100.0%	0.280
Tramway	2	3	1	50.0%	0.350	0	1	1	N/A	0.162
TOTAL BRT	28	40	12	42.8%	0.077	15	24	9	60.0%	0.095
TOTAL NON-BRT	16	24	8	50.0%	0.153	8	13	5	62.5%	0.134

5.1.2. BRT Crash Frequency Outcomes by Road Design Characteristics

5.1.2.1. All Motor Vehicle Crashes

The largest reductions in all crashes and serious/fatal injury crashes were realized by the narrowest segment, even though it had a single lane in each direction during both the before and after periods (Table 13). The worst safety outcomes were seen in the segments that went from 3 lanes in each direction to 2 lanes, even though there was a reduction in lanes present. The segments that had 2 lanes in the before period (regardless of whether there was a reduction in the after period) experienced safety outcomes that fell in between the wider and narrower segments. These results suggest that the overall right-of-way of the road was more important than the change in lane configurations.

TABLE 13. ART corridor crash frequency outcomes by changes to lane configuration (number of general vehicle lanes in each direction).

		All All			All KA		
Lane Change	**n**	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**
3 to 2	4	671	673	0.3%	20	10	-50.0%
2 to 2	3	668	540	-19.2%	27	9	-66.7%
2 to 1	5	692	565	-18.4%	21	5	-76.2%
1 to 1	1	53	34	-35.8%	1	0	-100.0%

The only segment that experienced a decrease in posted speed limit also experienced the largest drop in overall crashes and a substantial drop in serious and fatal injury crashes (Table 14). Interestingly, the segments that had 35 mph speed limits in both the before and after periods did better than those that had 30 mph in both before and after, possibly because the higher speed roadways were worse to begin with and experienced more of a traffic calming effect. However, future research should examine the changes in operating speeds versus safety outcomes.

TABLE 14. ART corridor crash frequency outcomes by changes to posted speed limits.

		All All			All KA		
Speed Limit Change (mph)	**n**	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**
35 to 35	7	1,189	1,055	-11.3%	45	11	-75.6%
30 to 30	5	743	662	-10.9%	19	11	-42.1%
30 to 25	1	152	95	-37.5%	5	2	-60.0%

The segments with the most left-turn restrictions had the largest decrease in serious and fatal injury crashes and the second largest decrease in overall crashes (Table 15). Interestingly, the segments with the fewest closed median openings did relatively well, possibly because these segments were relatively calm to begin with (for instance, 1st to Oak and Oak to University).

TABLE 15. ART corridor crash frequency outcomes by changes to median permeability.

		All All			All KA		
Median Openings Closed per Mile	**n**	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**
0-5	3	460	351	-23.7%	14	4	-71.4%
6-10	5	944	886	-6.1%	29	16	-44.8%
10+	5	680	575	-15.4%	26	4	-84.6%

5.1.2.2. Pedestrian Crashes

While pedestrian crash outcomes were more variable, a relationship still emerged with infrastructure characteristics (Table 16). The narrowest road again performed well for pedestrian safety, even though low numbers in the before period precluded significant changes. The worst pedestrian safety outcomes were seen in the segments that went from 3 lanes in each direction to 2 lanes, even though there was a reduction in lanes present. The segments that had 2 lanes in the before period (regardless of whether there was a reduction in the after period) experienced pedestrian safety outcomes that fell in between the wider and narrower segments. These results again suggest that the overall right-of-way of the road was more important than the change in lane configurations.

TABLE 16. ART corridor pedestrian crash frequency outcomes by changes to lane configuration (number of general vehicle lanes in each direction).

		Pedestrian All			Pedestrian KAB		
Lane Change	**n**	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**
3 to 2	4	28	37	32.1%	17	24	41.2%
2 to 2	3	27	21	-22.2%	16	14	-12.5%
2 to 1	5	19	20	5.3%	9	12	33.3%
1 to 1	1	1	0	-100.0%	0	0	N/A

Interestingly, the only segment that had a reduction in posted speed limit (i.e., 1st to Oak) performed poorly in terms of pedestrian safety (Table 17). Pedestrian collision counts were clearly higher on the higher-speed segments, but there was little clear relationship between the changes.

TABLE 17. ART corridor pedestrian crash frequency outcomes by changes to speed limits.

		Pedestrian All			Pedestrian KAB		
Speed Limit Change (mph)	**n**	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**
35 to 35	7	56	58	3.6%	34	38	11.8%
30 to 30	5	19	16	-15.8%	8	11	37.5%
30 to 25	1	0	4	N/A	0	1	N/A

Results suggest that median permeability and access management had a significant impact on pedestrian safety since the segments with the most left-turn restrictions performed substantially better than other segments in terms of pedestrian crashes and injuries (Table 17). Left-turn restrictions through median closures also appeared to improve overall crash outcomes but had an even stronger impact on pedestrian safety.

TABLE 18. ART corridor pedestrian crash frequency outcomes by changes to median permeability.

		Pedestrian All			Pedestrian KAB		
Median Openings Closed per Mile	**n**	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**
0-5	3	5	9	80.0%	2	4	100.0%
6-10	5	28	33	17.9%	17	23	35.3%
10+	5	42	36	-14.3%	23	23	0.0%

5.1.3. BRT Contributing Factor Results

The above analysis defined the traffic safety issue and identified changes in safety outcomes along the BRT corridor. This section and the following section seek to understand the mechanisms behind those changes by exploring contributing factors and crash types.

It is worth noting the limitations of the police-reported crash data used for these analyses. Police are reliant on their observations after a crash occurs and what the involved persons tell them, which may lead to inaccuracies in identifying factors that led to the crash. Furthermore, only one contributing factor was reported for each crash in the dataset. Since it is possible that there was more than one contributing factor for a crash (both "Alcohol/Drug Involved" and "Excessive Speed", for example), this could lead to further inaccuracies.

Even if contributing factors were marked correctly for every crash, the existing categories may not be helpful to our understanding of the safety impacts of the BRT system. For example, the categories "Failed to Yield Right of Way" and "Other Improper Driving" were cited in significant numbers of crashes. Hypothetically, if we identify a reduction in "Failed to Yield Right of Way" at a particular intersection, that does not really inform us of what exactly caused the improvement.

While the below analyses are comprehensive, it is worthwhile to have two specific hypotheses in mind while going through the results. First, safety may have been improved on the BRT corridor (both reduced crash counts and especially reduced KA counts) if motor vehicle speeds were reduced throughout the corridor. Second, a major conflict point may have been eliminated if left turns were restricted. Given those two hypotheses, we will focus on the "Excessive Speed" and "Made Improper Turn" contributing factors.

5.1.3.1. All Motor Vehicle Crashes

The most frequently cited contributing factors in the before period for all reported motor vehicle crashes were "Driver Inattention" (29.5% of all crashes) and "Failed to Yield Right of Way" (15.0% of all crashes) (Table 19). The most frequently cited contributing factors in the before period for KA crashes were "Alcohol/Drug Involved" (17.6% of KA crashes) and "Excessive Speed" (17.6% of KA crashes).

The largest reductions in overall crashes came from "Failed to Yield Right of Way" (-43.5%), "Improper Lane Change" (-22.0%), "Alcohol/Drug Involved" (-20.3%), "Excessive Speed" (-19.1%), and "Driver Inattention" (-13.9%) (Table 19).

TABLE 19. Entire BRT corridor contributing factor frequencies for all modes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	All Modes All Severities					All Modes KA				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Alcohol/Drug Involved	74	59	-15	-20.3%	0.068	9	5	-4	-44.4%	0.156
Disregarded Traffic Signal	124	116	-8	-6.5%	0.335	4	3	-1	-25.0%	0.364
Driver Inattention	**425**	**366**	**-59**	**-13.9%**	**0.043**	**7**	**2**	**-5**	**-71.4%**	**0.049**
Excessive Speed*	94	76	-18	-19.1%	0.059	**9**	**0**	**-9**	**-100.0%**	**<0.001**
Failed to Yield Right of Way	**216**	**122**	**-94**	**-43.5%**	**<0.001**	**8**	**0**	**-8**	**-100.0%**	**0.018**
Following Too Closely	168	155	-13	-7.7%	0.218	1	3	2	200.0%	0.152
Improper Lane Change	41	32	-9	-22.0%	0.145	1	0	-1	-100.0%	0.162
Improper Overtaking	16	14	-2	-12.5%	0.386	1	0	-1	-100.0%	0.162
Made Improper Turn	49	45	-4	-8.2%	0.339	0	0	0	0.0%	N/A
None	**54**	**32**	**-22**	**-40.7%**	**0.009**	0	0	0	0.0%	N/A
Other Improper Driving	41	43	2	4.9%	0.406	3	1	-2	-66.7%	0.152
Pedestrian Error	28	29	1	3.6%	0.450	8	6	-2	-25.0%	0.318
Other	110	87	-23	-20.9%	0.085	0	1	1	N/A	0.162
TOTAL KNOWN	**1,440**	**1,176**	**-264**	**-18.3%**	**<0.001**	**51**	**21**	**-30**	**-58.8%**	**<0.001**
Missing Data	211	223	12	5.7%	0.366	4	1	-3	-75.0%	0.079

TABLE 20. Entire BRT corridor contributing factor proportions (for known crashes) for all modes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	All Modes All Severities			All Modes KA		
	Before	After	Change	Before	After	Change
Alcohol/Drug Involved	5.1%	5.0%	-0.1%	17.6%	23.8%	6.2%
Disregarded Traffic Signal	8.6%	9.9%	1.3%	7.8%	14.3%	6.4%
Driver Inattention	**29.5%**	**31.1%**	**1.6%**	**13.7%**	**9.5%**	**-4.2%**
Excessive Speed*	6.5%	6.5%	-0.1%	**17.6%**	**0.0%**	**-17.6%**
Failed to Yield Right of Way	**15.0%**	**10.4%**	**-4.6%**	**15.7%**	**0.0%**	**-15.7%**
Following Too Closely	11.7%	13.2%	1.5%	2.0%	14.3%	12.3%
Improper Lane Change	2.8%	2.7%	-0.1%	2.0%	0.0%	-2.0%
Improper Overtaking	1.1%	1.2%	0.1%	2.0%	0.0%	-2.0%
Made Improper Turn	3.4%	3.8%	0.4%	0.0%	0.0%	0.0%
None	**3.8%**	**2.7%**	**-1.0%**	0.0%	0.0%	0.0%
Other Improper Driving	2.8%	3.7%	0.8%	5.9%	4.8%	-1.1%
Pedestrian Error	1.9%	2.5%	0.5%	15.7%	28.6%	12.9%
Other	7.6%	7.4%	-0.2%	0.0%	4.8%	4.8%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

The only contributing factor that saw an increase in overall crashes was "Pedestrian Error" which saw an increase of one crash (Table 19). The only contributing factor that saw an increase in KA crashes was "Following Too Closely" which saw an increase of 2 KA crashes. "Disregarded Traffic Signal" also performed relatively poorly with only small decreases.

Based on the contributing factor analysis, there is evidence that excessive speeding was reduced on the BRT corridor. The total number of collisions attributed to “Excessive Speed” was reduced by 19.1%, which was slightly more than average. But more importantly, while “Excessive Speed” contributed to the most KA crashes in the before period at nine KA crashes, that number was reduced to zero in the after period. This reduction in “Excessive Speed” KA crashes represented 30.0% of the total reduction in KA crashes.

We are not confident in making any judgements on the role of turning restrictions based on the contributing factor data. “Made Improper Turn” was only 3.4% of total crashes and 0.0% of KA in the before period. We would assume that “Failed to Yield Right of Way”, which saw significant reductions in overall crashes and KA crashes, would consist of some turning crashes, but we will wait until the crash type analysis to make any conclusions on the turning movements.

Another important factor in improved safety was a reduction in “Alcohol/Drug Involved” crashes. There were substantial reductions in this category for both total crashes and KA crashes. It would be interesting to determine whether there were reduced levels of driving while intoxicated between the before and after periods (we would imagine that would not be the case, at least not 20.3% fewer driving while intoxicated cases), or whether this reduction represents intoxicated road users being less likely to get into a crash.

We identified substantial decreases in “Alcohol/Drug Involved”, “Excessive Speed”, and “Failed to Yield Right of Way” crashes across the entire BRT corridor. In which location types were these reductions most prevalent?

“Alcohol/Drug Involved” saw similar substantial reductions at major intersections (-22.7%), other signalized intersections (-33.3%), and midblock segments (-44.4%). Interestingly, “Alcohol/Drug Involved” increased at unsignalized intersections (+33.3%, although only an increase of 3 crashes) (Figure 14). “Driver Inattention” saw relatively consistent decreases across the corridor (Figure 15).

“Excessive Speed” crashes saw similar reductions at other signalized intersections (-31.3%) and unsignalized intersections (-28.6%) but smaller reductions at major intersections (-15.6%). There was an increase of “Excessive Speed” crashes on midblock segments (40.0%; although only an increase of 2 crashes). All “Excessive Speed” KA crashes were eliminated in the after period. These Excessive Speed” KA crashes most frequently occurred at unsignalized intersections (Figure 16).

“Failed to Yield Right of Way” saw similar reductions at other signalized intersections (-53.1%), unsignalized intersections (-64.2%), and midblock segments (-40.0%). There was again a smaller reduction at major intersections (-27.5%) (Figure 17).

While “Made Improper Turn” did not change substantially overall, there was an interesting dichotomy present. Improper turns decreased at major intersections (-28.6%) and on midblock segments (-60.0%) while increasing at other signalized intersections (+16.7%) and unsignalized intersections (+60.0%). But again, we want to wait until our crash type analysis to pass judgement on this turning movement hypothesis.

While “Disregarded Traffic Signal” did not experience a substantial change overall, there was a relatively large reduction at major intersections (-8.4%).

TABLE 21. Major intersections contributing factor frequencies for all modes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	All Modes All Severities					All Modes KA				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Alcohol/Drug Involved	44	34	-10	-22.7%	0.128	5	2	-3	-60.0%	0.146
Disregarded Traffic Signal	83	76	-7	-8.4%	0.312	3	1	-2	-66.7%	0.152
Driver Inattention	195	199	4	2.1%	0.411	2	2	0	0.0%	0.500
Excessive Speed*	45	38	-7	-15.6%	0.163	**3**	**0**	**-3**	**-100.0%**	**0.037**
Failed to Yield Right of Way	**102**	**74**	**-28**	**-27.5%**	**0.008**	**4**	**0**	**-4**	**-100.0%**	**0.048**
Following Too Closely	83	79	-4	-4.8%	0.362	0	0	0	0.0%	N/A
Improper Lane Change	20	19	-1	-5.0%	0.433	1	0	-1	-100.0%	0.162
Improper Overtaking	11	9	-2	-18.2%	0.365	1	0	-1	-100.0%	0.162
Made Improper Turn	28	20	-8	-28.6%	0.152	0	0	0	0.0%	N/A
None	31	23	-8	-25.8%	0.152	0	0	0	0.0%	N/A
Other Improper Driving	18	19	1	5.6%	0.429	0	1	1	N/A	0.162
Pedestrian Error	13	23	10	76.9%	0.055	3	4	1	33.3%	0.364
Other	51	44	-7	-13.7%	0.221	0	0	0	0.0%	N/A
TOTAL KNOWN	**724**	**657**	**-67**	**-9.3%**	**0.039**	**22**	**10**	**-12**	**-54.5%**	**0.019**
Missing Data	127	139	12	9.4%	0.311	3	1	-2	-66.7%	0.152

TABLE 22. Major intersections contributing factor proportions (for known crashes) for all modes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	All Modes All Severities			All Modes KA		
	Before	After	Change	Before	After	Change
Alcohol/Drug Involved	6.1%	5.2%	-0.9%	22.7%	20.0%	-2.7%
Disregarded Traffic Signal	11.5%	11.6%	0.1%	13.6%	10.0%	-3.6%
Driver Inattention	26.9%	30.3%	3.4%	9.1%	20.0%	10.9%
Excessive Speed*	6.2%	5.8%	-0.4%	**13.6%**	**0.0%**	**-13.6%**
Failed to Yield Right of Way	**14.1%**	**11.3%**	**-2.8%**	**18.2%**	**0.0%**	**-18.2%**
Following Too Closely	11.5%	12.0%	0.6%	0.0%	0.0%	0.0%
Improper Lane Change	2.8%	2.9%	0.1%	4.5%	0.0%	-4.5%
Improper Overtaking	1.5%	1.4%	-0.1%	4.5%	0.0%	-4.5%
Made Improper Turn	3.9%	3.0%	-0.8%	0.0%	0.0%	0.0%
None	4.3%	3.5%	-0.8%	0.0%	0.0%	0.0%
Other Improper Driving	2.5%	2.9%	0.4%	0.0%	10.0%	10.0%
Pedestrian Error	1.8%	3.5%	1.7%	13.6%	40.0%	26.4%
Other	7.0%	6.7%	-0.3%	0.0%	0.0%	0.0%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

TABLE 23. Other signalized intersections contributing factor frequencies for all modes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	All Modes All Severities					All Modes KA				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Alcohol/Drug Involved	12	8	-4	-33.3%	0.125	2	1	-1	-50.0%	0.280
Disregarded Traffic Signal	24	23	-1	-4.2%	0.449	0	1	1	N/A	0.162
Driver Inattention	79	61	-18	-22.8%	0.116	2	0	-2	-100.0%	0.077
Excessive Speed*	16	11	-5	-31.3%	0.137	1	0	-1	-100.0%	0.162
Failed to Yield Right of Way	**32**	**15**	**-17**	**-53.1%**	**0.003**	1	0	-1	-100.0%	0.162
Following Too Closely	35	32	-3	-8.6%	0.316	1	1	0	0.0%	0.500
Improper Lane Change	8	5	-3	-37.5%	0.205	0	0	0	0.0%	N/A
Improper Overtaking	2	1	-1	-50.0%	0.280	0	0	0	0.0%	N/A
Made Improper Turn	6	7	1	16.7%	0.400	0	0	0	0.0%	N/A
None	7	3	-4	-57.1%	0.074	0	0	0	0.0%	N/A
Other Improper Driving	5	9	4	80.0%	0.138	0	0	0	0.0%	N/A
Pedestrian Error	8	3	-5	-62.5%	0.058	3	1	-2	-66.7%	0.152
Other	26	18	-8	-30.8%	0.147	0	0	0	0.0%	N/A
TOTAL KNOWN	**260**	**196**	**-64**	**-24.6%**	**0.003**	**10**	**4**	**-6**	**-60.0%**	**0.022**
Missing Data	28	32	4	14.3%	0.318	0	0	0	0.0%	N/A

TABLE 24. Other signalized intersections contributing factor proportions (for known crashes) for all modes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	All Modes All Severities			All Modes KA		
	Before	After	Change	Before	After	Change
Alcohol/Drug Involved	4.6%	4.1%	-0.5%	20.0%	25.0%	5.0%
Disregarded Traffic Signal	9.2%	11.7%	2.5%	0.0%	25.0%	25.0%
Driver Inattention	30.4%	31.1%	0.7%	20.0%	0.0%	-20.0%
Excessive Speed*	6.2%	5.6%	-0.5%	10.0%	0.0%	-10.0%
Failed to Yield Right of Way	**12.3%**	**7.7%**	**-4.7%**	10.0%	0.0%	-10.0%
Following Too Closely	13.5%	16.3%	2.9%	10.0%	25.0%	15.0%
Improper Lane Change	3.1%	2.6%	-0.5%	0.0%	0.0%	0.0%
Improper Overtaking	0.8%	0.5%	-0.3%	0.0%	0.0%	0.0%
Made Improper Turn	2.3%	3.6%	1.3%	0.0%	0.0%	0.0%
None	2.7%	1.5%	-1.2%	0.0%	0.0%	0.0%
Other Improper Driving	1.9%	4.6%	2.7%	0.0%	0.0%	0.0%
Pedestrian Error	3.1%	1.5%	-1.5%	30.0%	25.0%	-5.0%
Other	10.0%	9.2%	-0.8%	0.0%	0.0%	0.0%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

TABLE 25. Unsignalized intersections contributing factor frequencies for all modes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	All Modes All Severities					All Modes KA				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Alcohol/Drug Involved	9	12	3	33.3%	0.296	1	2	1	100.0%	0.280
Disregarded Traffic Signal	9	8	-1	-11.1%	0.403	0	0	0	0.0%	N/A
Driver Inattention	**108**	**84**	**-24**	**-22.2%**	**0.022**	1	0	-1	-100.0%	0.162
Excessive Speed*	28	20	-8	-28.6%	0.138	**5**	**0**	**-5**	**-100.0%**	**0.008**
Failed to Yield Right of Way	**67**	**24**	**-43**	**-64.2%**	**<0.001**	**3**	**0**	**-3**	**-100.0%**	**0.037**
Following Too Closely	41	34	-7	-17.1%	0.188	0	2	2	N/A	0.077
Improper Lane Change	10	5	-5	-50.0%	0.132	0	0	0	0.0%	N/A
Improper Overtaking	3	2	-1	-33.3%	0.321	0	0	0	0.0%	N/A
Made Improper Turn	10	16	6	60.0%	0.126	0	0	0	0.0%	N/A
None	**14**	**5**	**-9**	**-64.3%**	**0.027**	0	0	0	0.0%	N/A
Other Improper Driving	11	11	0	0.0%	0.500	**3**	**0**	**-3**	**-100.0%**	**0.037**
Pedestrian Error	**7**	**1**	**-6**	**-85.7%**	**0.008**	2	0	-2	-100.0%	0.077
Other	22	23	1	4.5%	0.442	0	1	1	N/A	0.162
TOTAL KNOWN	**339**	**245**	**-94**	**-27.7%**	**<0.001**	**15**	**5**	**-10**	**-66.7%**	**0.006**
Missing Data	30	37	7	23.3%	0.213	1	0	-1	-100.0%	0.162

TABLE 26. Unsignalized intersections contributing factor proportions (for known crashes) for all modes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	All Modes All Severities			All Modes KA		
	Before	After	Change	Before	After	Change
Alcohol/Drug Involved	2.7%	4.9%	2.2%	6.7%	40.0%	33.3%
Disregarded Traffic Signal	2.7%	3.3%	0.6%	0.0%	0.0%	0.0%
Driver Inattention	**31.9%**	**34.3%**	**2.4%**	6.7%	0.0%	-6.7%
Excessive Speed*	8.3%	8.2%	-0.1%	**33.3%**	**0.0%**	**-33.3%**
Failed to Yield Right of Way	**19.8%**	**9.8%**	**-10.0%**	**20.0%**	**0.0%**	**-20.0%**
Following Too Closely	12.1%	13.9%	1.8%	0.0%	40.0%	40.0%
Improper Lane Change	2.9%	2.0%	-0.9%	0.0%	0.0%	0.0%
Improper Overtaking	0.9%	0.8%	-0.1%	0.0%	0.0%	0.0%
Made Improper Turn	2.9%	6.5%	3.6%	0.0%	0.0%	0.0%
None	**4.1%**	**2.0%**	**-2.1%**	0.0%	0.0%	0.0%
Other Improper Driving	3.2%	4.5%	1.2%	**20.0%**	**0.0%**	**-20.0%**
Pedestrian Error	**2.1%**	**0.4%**	**-1.7%**	13.3%	0.0%	-13.3%
Other	6.5%	9.4%	2.9%	0.0%	20.0%	20.0%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

TABLE 27. Midblock segments contributing factor frequencies for all modes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	All Modes All Severities					All Modes KA				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Alcohol/Drug Involved	9	5	-4	-44.4%	0.138	1	0	-1	-100.0%	0.162
Disregarded Traffic Signal	8	9	1	12.5%	0.408	1	1	0	0.0%	0.500
Driver Inattention	**43**	**22**	**-21**	**-48.8%**	**0.012**	2	0	-2	-100.0%	0.077
Excessive Speed*	5	7	2	40.0%	0.272	0	0	0	0.0%	N/A
Failed to Yield Right of Way	15	9	-6	-40.0%	0.088	0	0	0	0.0%	N/A
Following Too Closely	9	10	1	11.1%	0.413	0	0	0	0.0%	N/A
Improper Lane Change	3	3	0	0.0%	0.500	0	0	0	0.0%	N/A
Improper Overtaking	0	2	2	N/A	0.077	0	0	0	0.0%	N/A
Made Improper Turn	5	2	-3	-60.0%	0.110	0	0	0	0.0%	N/A
None	2	1	-1	-50.0%	0.280	0	0	0	0.0%	N/A
Other Improper Driving	7	4	-3	-42.9%	0.198	0	0	0	0.0%	N/A
Pedestrian Error	0	2	2	N/A	0.077	0	1	1	N/A	0.162
Other	**11**	**2**	**-9**	**-81.8%**	**0.002**	0	0	0	0.0%	N/A
TOTAL KNOWN	**117**	**78**	**-39**	**-33.3%**	**0.016**	4	2	-2	-50.0%	0.194
Missing Data	26	15	-11	-42.3%	0.065	0	0	0	0.0%	N/A

TABLE 28. Midblock segments contributing factor proportions (for known crashes) for all modes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	All Modes All Severities			All Modes KA		
	Before	After	Change	Before	After	Change
Alcohol/Drug Involved	7.7%	6.4%	-1.3%	25.0%	0.0%	-25.0%
Disregarded Traffic Signal	6.8%	11.5%	4.7%	25.0%	50.0%	25.0%
Driver Inattention	**36.8%**	**28.2%**	**-8.5%**	50.0%	0.0%	-50.0%
Excessive Speed*	4.3%	9.0%	4.7%	0.0%	0.0%	0.0%
Failed to Yield Right of Way	12.8%	11.5%	-1.3%	0.0%	0.0%	0.0%
Following Too Closely	7.7%	12.8%	5.1%	0.0%	0.0%	0.0%
Improper Lane Change	2.6%	3.8%	1.3%	0.0%	0.0%	0.0%
Improper Overtaking	0.0%	2.6%	2.6%	0.0%	0.0%	0.0%
Made Improper Turn	4.3%	2.6%	-1.7%	0.0%	0.0%	0.0%
None	1.7%	1.3%	-0.4%	0.0%	0.0%	0.0%
Other Improper Driving	6.0%	5.1%	-0.9%	0.0%	0.0%	0.0%
Pedestrian Error	0.0%	2.6%	2.6%	0.0%	50.0%	50.0%
Other	**9.4%**	**2.6%**	**-6.8%**	0.0%	0.0%	0.0%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

FIGURE 14. Kernel density of all "Alcohol/Drug Involved" crashes of all severities on Central Avenue.

FIGURE 15. Kernel density of all "Driver Inattention" motor vehicle crashes of all severities on Central Avenue.

FIGURE 16. Kernel density of all "Excessive Speed" crashes of all severities on Central Avenue.

FIGURE 17. Kernel density of all "Failed to Yield Right of Way" crashes of all severities on Central Avenue.

5.1.3.2. Pedestrian Crashes

Across the entire BRT corridor, most pedestrian collisions were attributed to "Pedestrian Error", which does not tell us much about the mechanisms of the crash (Table 29). "Pedestrian Error" crashes increased slightly (+8.7%), which follows the trend of increasing overall pedestrian collisions.

It is interesting to note that while "Alcohol/Drug Involved" and "Driver Inattention" are the two other contributing factors also cited in many pedestrian crashes, "Alcohol/Drug Involved" decreased substantially while "Driver Inattention" increased substantially (Table 29 and Figure 18). The decrease in "Alcohol/Drug Involved" follows overall crash trends while the increase in "Driver Inattention" is the opposite of the overall crash trend. Why driver inattention decreased overall but increased around pedestrians remains to be seen. It is also interesting that much of the improvement that was observed in terms of pedestrian safety was because of a reduction in "Alcohol/Drug Involved", which might be difficult to link directly to the BRT infrastructure changes.

"Excessive Speed" was less prevalent in pedestrian collisions in the after period, although it was rarely marked as a contributing factor. This again suggests that excessive vehicle speeds may have been reduced.

As with overall crashes, "Failed to Yield Right of Way" saw reductions in the after period. However, this category was less frequently used for pedestrians and this is not particularly informative regarding the mechanisms behind these crashes. "Other Improper Driving" also increased but is not informative either.

TABLE 29. Entire BRT corridor contributing factor frequencies for pedestrian crashes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	Pedestrians All Severities					Pedestrians KAB				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Alcohol/Drug Involved	18	12	-6	-33.3%	0.117	9	8	-1	-11.1%	0.403
Disregarded Traffic Signal	0	2	2	N/A	0.077	0	0	0	0.0%	N/A
Driver Inattention	8	12	4	50.0%	0.144	5	6	1	20.0%	0.365
Excessive Speed*	1	0	-1	-100.0%	0.162	1	0	-1	-100.0%	0.162
Failed to Yield Right of Way	4	2	-2	-50.0%	0.194	1	1	0	0.0%	0.500
Following Too Closely	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Improper Lane Change	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Improper Overtaking	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Made Improper Turn	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
None	3	1	-2	-66.7%	0.205	2	1	-1	-50.0%	0.329
Other Improper Driving	**0**	**3**	**3**	**N/A**	**0.037**	0	2	2	N/A	0.077
Pedestrian Error	23	25	2	8.7%	0.394	14	18	4	28.6%	0.243
Other	1	3	2	200.0%	0.152	1	2	1	100.0%	0.280
TOTAL KNOWN	58	60	2	3.4%	0.430	33	38	5	15.2%	0.292
Missing Data	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A

TABLE 30. Entire BRT corridor contributing factor proportions for pedestrian crashes (for known crashes) (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	Pedestrians All Severities			Pedestrians KAB		
	Before	After	Change	Before	After	Change
Alcohol/Drug Involved	31.0%	20.0%	-11.0%	27.3%	21.1%	-6.2%
Disregarded Traffic Signal	0.0%	3.3%	3.3%	0.0%	0.0%	0.0%
Driver Inattention	13.8%	20.0%	6.2%	15.2%	15.8%	0.6%
Excessive Speed*	1.7%	0.0%	-1.7%	3.0%	0.0%	-3.0%
Failed to Yield Right of Way	6.9%	3.3%	-3.6%	3.0%	2.6%	-0.4%
Following Too Closely	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Improper Lane Change	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Improper Overtaking	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Made Improper Turn	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
None	5.2%	1.7%	-3.5%	6.1%	2.6%	-3.4%
Other Improper Driving	**0.0%**	**5.0%**	**5.0%**	0.0%	5.3%	5.3%
Pedestrian Error	39.7%	41.7%	2.0%	42.4%	47.4%	4.9%
Other	1.7%	5.0%	3.3%	3.0%	5.3%	2.2%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

"Pedestrian Error" increased significantly at major intersections (+81.8%) and on midblock segments (N/A%) but decreased at other signalized intersections (-66.7%) and unsignalized intersections (-83.3%). This seems to follow the trend where major intersections got worse for pedestrians while other signalized intersections and unsignalized intersections improved.

TABLE 31. Major intersections contributing factor frequencies for pedestrian crashes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	Pedestrians All Severities					Pedestrians KAB				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Alcohol/Drug Involved	12	6	-6	-50.0%	0.067	5	5	0	0.0%	0.500
Disregarded Traffic Signal	0	2	2	N/A	0.077	0	0	0	0.0%	N/A
Driver Inattention	**1**	**5**	**4**	**400.0%**	**0.039**	1	2	1	100.0%	0.280
Excessive Speed*	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Failed to Yield Right of Way	2	1	-1	-50.0%	0.280	0	0	0	0.0%	N/A
Following Too Closely	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Improper Lane Change	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Improper Overtaking	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Made Improper Turn	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
None	1	1	0	0.0%	0.500	1	1	0	0.0%	N/A
Other Improper Driving	0	2	2	N/A	0.077	0	1	1	N/A	0.162
Pedestrian Error	11	20	9	81.8%	0.070	7	13	6	85.7%	0.092
Other	1	3	2	200.0%	0.152	1	2	1	100.0%	0.280
TOTAL KNOWN	28	40	12	42.9%	0.077	15	24	9	60.0%	0.095
Missing Data	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A

TABLE 32. Major intersections contributing factor proportions for pedestrian crashes (for known crashes) (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	Pedestrians All Severities			Pedestrians KAB		
	Before	After	Change	Before	After	Change
Alcohol/Drug Involved	42.9%	15.0%	-27.9%	33.3%	20.8%	-12.5%
Disregarded Traffic Signal	0.0%	5.0%	5.0%	0.0%	0.0%	0.0%
Driver Inattention	**3.6%**	**12.5%**	**8.9%**	6.7%	8.3%	1.7%
Excessive Speed*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Failed to Yield Right of Way	7.1%	2.5%	-4.6%	0.0%	0.0%	0.0%
Following Too Closely	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Improper Lane Change	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Improper Overtaking	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Made Improper Turn	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
None	3.6%	2.5%	-1.1%	6.7%	4.2%	-2.5%
Other Improper Driving	0.0%	5.0%	5.0%	0.0%	4.2%	4.2%
Pedestrian Error	39.3%	50.0%	10.7%	46.7%	54.2%	7.5%
Other	3.6%	7.5%	3.9%	6.7%	8.3%	1.7%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

TABLE 33. Other signalized intersections contributing factor frequencies for pedestrian crashes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	Pedestrians All Severities					Pedestrians KAB				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Alcohol/Drug Involved	1	2	1	100.0%	0.280	0	1	1	N/A	0.162
Disregarded Traffic Signal	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Driver Inattention	1	0	-1	-100.0%	0.162	1	0	-1	-100.0%	0.162
Excessive Speed*	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Failed to Yield Right of Way	1	0	-1	-100.0%	0.162	0	0	0	0.0%	N/A
Following Too Closely	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Improper Lane Change	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Improper Overtaking	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Made Improper Turn	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
None	1	0	-1	-100.0%	0.162	1	0	-1	-100.0%	0.162
Other Improper Driving	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Pedestrian Error	6	2	-4	-66.7%	0.059	6	2	-4	-66.7%	0.059
Other	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
TOTAL KNOWN	**10**	**4**	**-6**	**-60.0%**	**0.036**	**8**	**3**	**-5**	**-62.5%**	**0.039**
Missing Data	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A

TABLE 34. Other signalized intersections contributing factor proportions for pedestrian crashes (for known crashes) (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	Pedestrians All Severities			Pedestrians KAB		
	Before	After	Change	Before	After	Change
Alcohol/Drug Involved	10.0%	50.0%	40.0%	0.0%	33.3%	33.3%
Disregarded Traffic Signal	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Driver Inattention	10.0%	0.0%	-10.0%	12.5%	0.0%	-12.5%
Excessive Speed*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Failed to Yield Right of Way	10.0%	0.0%	-10.0%	0.0%	0.0%	0.0%
Following Too Closely	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Improper Lane Change	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Improper Overtaking	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Made Improper Turn	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
None	10.0%	0.0%	-10.0%	12.5%	0.0%	-12.5%
Other Improper Driving	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pedestrian Error	60.0%	50.0%	-10.0%	75.0%	66.7%	-8.3%
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

TABLE 35. Unsignalized intersections contributing factor frequencies for pedestrian crashes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	Pedestrians All Severities					Pedestrians KAB				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Alcohol/Drug Involved	2	3	1	50.0%	0.321	2	2	0	0.0%	0.500
Disregarded Traffic Signal	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Driver Inattention	4	6	2	50.0%	0.237	1	3	2	200.0%	0.152
Excessive Speed*	1	0	-1	-100.0%	0.162	1	0	-1	-100.0%	0.162
Failed to Yield Right of Way	1	1	0	0.0%	0.500	1	1	0	0.0%	0.500
Following Too Closely	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Improper Lane Change	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Improper Overtaking	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Made Improper Turn	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
None	1	0	-1	-100.0%	0.162	0	0	0	0.0%	N/A
Other Improper Driving	0	1	1	N/A	0.162	0	1	1	N/A	0.162
Pedestrian Error	**6**	**1**	**-5**	**-83.3%**	**0.019**	1	1	0	0.0%	0.500
Other	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
TOTAL KNOWN	15	12	-3	-20.0%	0.303	6	8	2	33.3%	0.308
Missing Data	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A

TABLE 36. Unsignalized intersections contributing factor proportions for pedestrian crashes (for Known Crashes) (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	Pedestrians All Severities			Pedestrians KAB		
	Before	After	Change	Before	After	Change
Alcohol/Drug Involved	13.3%	25.0%	11.7%	33.3%	25.0%	-8.3%
Disregarded Traffic Signal	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Driver Inattention	26.7%	50.0%	23.3%	16.7%	37.5%	20.8%
Excessive Speed*	6.7%	0.0%	-6.7%	16.7%	0.0%	-16.7%
Failed to Yield Right of Way	6.7%	8.3%	1.7%	16.7%	12.5%	-4.2%
Following Too Closely	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Improper Lane Change	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Improper Overtaking	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Made Improper Turn	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
None	6.7%	0.0%	-6.7%	0.0%	0.0%	0.0%
Other Improper Driving	0.0%	8.3%	8.3%	0.0%	12.5%	12.5%
Pedestrian Error	**40.0%**	**8.3%**	**-31.7%**	16.7%	12.5%	-4.2%
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

TABLE 37. Midblock segments contributing factor frequencies for pedestrian crashes (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	Pedestrians All Severities					Pedestrians KAB				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Alcohol/Drug Involved	3	1	-2	-66.7%	0.152	2	0	-2	-100.0%	0.077
Disregarded Traffic Signal	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Driver Inattention	2	1	-1	-50.0%	0.280	2	1	-1	-50.0%	0.280
Excessive Speed*	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Failed to Yield Right of Way	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Following Too Closely	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Improper Lane Change	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Improper Overtaking	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Made Improper Turn	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
None	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Other Improper Driving	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Pedestrian Error	0	2	2	N/A	0.077	0	2	2	N/A	0.077
Other	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
TOTAL KNOWN	5	4	-1	-20.0%	0.373	4	3	-1	-25.0%	0.343
Missing Data	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A

TABLE 38. Midblock segments contributing factor proportions for pedestrian crashes (for known crashes) (* Excessive Speed = Excessive Speed & Speed Too Fast for Conditions).

Contributing Factor	Pedestrians All Severities			Pedestrians KAB		
	Before	After	Change	Before	After	Change
Alcohol/Drug Involved	60.0%	25.0%	-35.0%	50.0%	0.0%	-50.0%
Disregarded Traffic Signal	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Driver Inattention	40.0%	25.0%	-15.0%	50.0%	33.3%	-16.7%
Excessive Speed*	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Failed to Yield Right of Way	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Following Too Closely	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Improper Lane Change	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Improper Overtaking	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Made Improper Turn	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
None	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Improper Driving	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pedestrian Error	0.0%	50.0%	50.0%	0.0%	66.7%	66.7%
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

FIGURE 18. Kernel density of pedestrian "Alcohol/Drug Involved" crashes of all severities on Central Avenue.

5.1.4. BRT Crash Type Results

5.1.4.1. All Motor Vehicle Crashes

This first thing to note is that there was a substantial increase in crash types coded as "Left Blank" in the after period (Table 39) along with a substantial decrease in "Invalid Code". These coding errors make interpretation of crash type results difficult. However, this is only the case for the analyses of all modes and all severities. For serious and fatal crashes, there were no "Invalid Code" or "Left Blank" values in either the before or after periods. For pedestrian crashes, there was only one such crash, which occurred in the before period (Table 39). Therefore, crash type results for all modes and all severities should be interpreted with caution but the issue does not extend to the serious/fatal injury analysis or the pedestrian analysis.

It is also important to note that there were several subcategories of the "Other Vehicle" classification: "From Opposite Direction", "Left Turn", "Rear End", "Right Turn", and "Sideswipe". The exact definition of all these categories can be found in the Methods section.

There is evidence supporting both of our original hypotheses: that vehicle speed reductions and turning conflict reductions resulted in improved safety outcomes. The largest decrease in serious/fatal injuries occurred with a decrease in “Left Turn” crashes (Table 39). “Left Turn” crashes resulted in 8 serious/fatal injury crashes in the before period, which was the highest category behind “Pedestrian”. This was reduced to just 1 serious/fatal “Left Turn” crash in the after period. This represented 21.2% of the total reduction in serious/fatal crashes.

There were substantial reductions in fixed object collisions and serious/fatal injuries, which would suggest that vehicle speeds – or at least excessive vehicle speeds – were reduced throughout the corridor (Table 39). The reduction in fixed object crashes resulting in serious/fatal injuries was the second largest decrease in serious/fatal injuries, representing 15.2% of the total reduction in serious/fatal crashes. In Table 40, you can also see that the largest proportional decreases in serious/fatal crashes occurred for “Left Turn” and “Fixed Object” crashes (-10.0% and -9.1%, respectively).

It was interesting that while there was a relatively small decrease in the total number of “Sideswipe” crashes and there was actually an increase in “Rear End” crashes, the number of serious/fatal injuries for these categories still saw significant decreases (50.0% and 57.1% decreases, respectively) (Table 39). This suggests that while the corridor may have gotten more complicated for drivers (resulting in more low-severity crashes), the safety of the corridor in terms of reducing injuries was improved, likely because of lowered vehicle speeds.

There was also a significant decrease in “Parked Vehicle” crashes (Table 39). Although this category did not represent a large proportion of total crashes or serious/fatal crashes, it is worth noting that the BRT implementation resulted in significant reductions for this crash type.

TABLE 39. Entire BRT corridor crash type frequencies for all modes (* Parked Vehicle = Parked Vehicle & Vehicle Parked; ** Pedalcyclist = Pedalcyclist & Vehicle Struck Pedalcyclist).

Crash Type	All Modes All Severities					All Modes KA				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Fixed Object	**68**	**39**	**-29**	**-42.6%**	**0.002**	**5**	**0**	**-5**	**-100.0%**	**0.008**
Other Vehicle	**1,257**	**794**	**-463**	**-36.8%**	**<0.001**	**27**	**8**	**-19**	**-70.4%**	**<0.001**
From Opp. Direct.	**288**	**46**	**-242**	**-84.0%**	**<0.001**	1	0	-1	-100.0%	0.162
Left Turn	**201**	**131**	**-70**	**-34.8%**	**<0.001**	**8**	**1**	**-7**	**-87.5%**	**0.009**
Rear End	349	350	1	0.3%	0.486	7	3	-4	-57.1%	0.074
Right Turn	**76**	**37**	**-39**	**-51.3%**	**0.002**	1	0	-1	-100.0%	0.162
Sideswipe	**202**	**163**	**-39**	**-19.3%**	**0.011**	8	4	-4	-50.0%	0.086
Parked Vehicle*	**46**	**6**	**-40**	**-87.0%**	**<0.001**	1	0	-1	-100.0%	0.162
Pedalcyclist**	30	29	-1	-3.3%	0.450	4	1	-3	-75.0%	0.123
Pedestrian	61	60	-1	-1.6%	0.465	16	12	-4	-25.0%	0.189
Other	10	16	6	60.0%	0.107	2	1	-1	-50.0%	0.280
TOTAL KNOWN	**1,472**	**944**	**-528**	**-35.9%**	**<0.001**	**55**	**22**	**-33**	**-60.0%**	**<0.001**
Invalid Code	**89**	**12**	**-77**	**-86.5%**	**<0.001**	0	0	0	0.0%	N/A
Left Blank	**90**	**443**	**353**	**392.2%**	**<0.001**	0	0	0	0.0%	N/A

TABLE 40. Entire BRT corridor crash type proportions (for known crashes) for all modes (* Parked Vehicle = Parked Vehicle & Vehicle Parked; ** Pedalcyclist = Pedalcyclist & Vehicle Struck Pedalcyclist).

Crash Type	All Modes All Severities			All Modes KA		
	Before	After	Change	Before	After	Change
Fixed Object	**4.6%**	**4.1%**	**-0.5%**	**9.1%**	**0.0%**	**-9.1%**
Other Vehicle	**85.4%**	**84.1%**	**-1.3%**	**49.1%**	**36.4%**	**-12.7%**
From Opp. Direct.	**19.6%**	**4.9%**	**-14.7%**	1.8%	0.0%	-1.8%
Left Turn	**13.7%**	**13.9%**	**0.2%**	**14.5%**	**4.5%**	**-10.0%**
Rear End	23.7%	37.1%	13.4%	12.7%	13.6%	0.9%
Right Turn	**5.2%**	**3.9%**	**-1.2%**	1.8%	0.0%	-1.8%
Sideswipe	**13.7%**	**17.3%**	**3.5%**	14.5%	18.2%	3.6%
Parked Vehicle*	**3.1%**	**0.6%**	**-2.5%**	1.8%	0.0%	-1.8%
Pedalcyclist**	2.0%	3.1%	1.0%	7.3%	4.5%	-2.7%
Pedestrian	4.1%	6.4%	2.2%	29.1%	54.5%	25.5%
Other	0.7%	1.7%	1.0%	3.6%	4.5%	0.9%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

Where were the primary changes in reduced “Left Turn” and “Fixed Object” crashes most prevalent? According to the GIS location of police-reported data, 50.0% of the reduction in “Left Turn” crashes and 85.7% of the reduction in serious/fatal “Left Turn” crashes happened at major intersections. Only 7.1% of the total reduction occurred on midblock segments (the lowest proportion), but the remaining 14.3% reduction in serious/fatal “Left Turn” crashes occurred on midblock segments.

The reduction in “Fixed Object” crashes was more evenly distributed among location types. 44.8% of the total reduction and 20.0% of the reduction in serious/fatal “Fixed Object” crashes occurred at major intersections while 80.0% of the reduction in serious/fatal “Fixed Object” crashes occurred at unsignalized intersections.

TABLE 41. Major intersections crash type frequencies for all modes (* Parked Vehicle = Parked Vehicle & Vehicle Parked; ** Pedalcyclist = Pedalcyclist & Vehicle Struck Pedalcyclist).

Crash Type	All Modes All Severities					All Modes KA				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Fixed Object	**29**	**16**	**-13**	**-44.8%**	**0.034**	1	0	-1	-100.0%	0.162
Other Vehicle	**662**	**430**	**-232**	**-35.0%**	**<0.001**	**14**	**1**	**-13**	**-92.9%**	**<0.001**
From Opp. Direct.	**192**	**28**	**-164**	**-85.4%**	**<0.001**	1	0	-1	-100.0%	0.162
Left Turn	**105**	**70**	**-35**	**-33.3%**	**0.001**	**6**	**0**	**-6**	**-100.0%**	**0.012**
Rear End	158	171	13	8.2%	0.278	1	0	-1	-100.0%	0.162
Right Turn	**40**	**20**	**-20**	**-50.0%**	**0.014**	1	0	-1	-100.0%	0.162
Sideswipe	100	103	3	3.0%	0.413	4	1	-3	-75.0%	0.079
Parked Vehicle*	**18**	**1**	**-17**	**-94.4%**	**0.001**	1	0	-1	-100.0%	0.162
Pedalcyclist**	7	12	5	71.4%	0.122	2	1	-1	-50.0%	0.280
Pedestrian	29	40	11	37.9%	0.095	6	8	2	33.3%	0.278
Other	5	9	4	80.0%	0.138	1	1	0	0.0%	0.500
TOTAL KNOWN	**750**	**508**	**-242**	**-32.3%**	**<0.001**	**25**	**11**	**-14**	**-56.0%**	**0.006**
Invalid Code	**52**	**7**	**-45**	**-86.5%**	**<0.001**	0	0	0	0.0%	N/A
Left Blank	**49**	**281**	**232**	**473.5%**	**<0.001**	0	0	0	0.0%	N/A

TABLE 42. Major intersections crash type proportions (for known crashes) for all modes (* Parked Vehicle = Parked Vehicle & Vehicle Parked; ** Pedalcyclist = Pedalcyclist & Vehicle Struck Pedalcyclist).

Crash Type	All Modes All Severities			All Modes KA		
	Before	After	Change	Before	After	Change
Fixed Object	**3.9%**	**3.1%**	**-0.7%**	4.0%	0.0%	-4.0%
Other Vehicle	**88.3%**	**84.6%**	**-3.6%**	**56.0%**	**9.1%**	**-46.9%**
From Opp. Direct.	**25.6%**	**5.5%**	**-20.1%**	4.0%	0.0%	-4.0%
Left Turn	**14.0%**	**13.8%**	**-0.2%**	**24.0%**	**0.0%**	**-24.0%**
Rear End	21.1%	33.7%	12.6%	4.0%	0.0%	-4.0%
Right Turn	**5.3%**	**3.9%**	**-1.4%**	4.0%	0.0%	-4.0%
Sideswipe	13.3%	20.3%	6.9%	16.0%	9.1%	-6.9%
Parked Vehicle*	**2.4%**	**0.2%**	**-2.2%**	4.0%	0.0%	-4.0%
Pedalcyclist**	0.9%	2.4%	1.4%	8.0%	9.1%	1.1%
Pedestrian	3.9%	7.9%	4.0%	24.0%	72.7%	48.7%
Other	0.7%	1.8%	1.1%	4.0%	9.1%	5.1%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

TABLE 43. Other signalized intersections crash type frequencies for all modes (* Parked Vehicle = Parked Vehicle & Vehicle Parked; ** Pedalcyclist = Pedalcyclist & Vehicle Struck Pedalcyclist).

Crash Type	All Modes All Severities					All Modes KA				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Fixed Object	**13**	**4**	**-9**	**-69.2%**	**0.011**	0	0	0	0.0%	N/A
Other Vehicle	**218**	**140**	**-78**	**-35.8%**	**<0.001**	4	2	-2	-50.0%	0.194
From Opp. Direct.	**33**	**7**	**-26**	**-78.8%**	**0.001**	0	0	0	0.0%	N/A
Left Turn	36	22	-14	-38.9%	0.056	0	0	0	0.0%	N/A
Rear End	77	71	-6	-7.8%	0.310	2	1	-1	-50.0%	0.280
Right Turn	**9**	**2**	**-7**	**-77.8%**	**0.031**	0	0	0	0.0%	N/A
Sideswipe	**41**	**25**	**-16**	**-39.0%**	**0.030**	2	1	-1	-50.0%	0.280
Parked Vehicle*	8	3	-5	-62.5%	0.077	0	0	0	0.0%	N/A
Pedalcyclist**	9	5	-4	-44.4%	0.118	1	0	-1	-100.0%	0.162
Pedestrian	**11**	**4**	**-7**	**-63.6%**	**0.027**	5	2	-3	-60.0%	0.110
Other	1	3	2	200.0%	0.152	0	0	0	0.0%	N/A
TOTAL KNOWN	**260**	**159**	**-101**	**-38.8%**	**<0.001**	**10**	**4**	**-6**	**-60.0%**	**0.022**
Invalid Code	**14**	**3**	**-11**	**-78.6%**	**0.006**	0	0	0	0.0%	N/A
Left Blank	**14**	**66**	**52**	**371.4%**	**<0.001**	0	0	0	0.0%	N/A

TABLE 44. Other signalized intersections crash type proportions (for known crashes) for all modes (* Parked Vehicle = Parked Vehicle & Vehicle Parked; ** Pedalcyclist = Pedalcyclist & Vehicle Struck Pedalcyclist).

Crash Type	All Modes All Severities			All Modes KA		
	Before	After	Change	Before	After	Change
Fixed Object	**5.0%**	**2.5%**	**-2.5%**	0.0%	0.0%	0.0%
Other Vehicle	**83.8%**	**88.1%**	**4.2%**	40.0%	50.0%	10.0%
From Opp. Direct.	**12.7%**	**4.4%**	**-8.3%**	0.0%	0.0%	0.0%
Left Turn	13.8%	13.8%	0.0%	0.0%	0.0%	0.0%
Rear End	29.6%	44.7%	15.0%	20.0%	25.0%	5.0%
Right Turn	**3.5%**	**1.3%**	**-2.2%**	0.0%	0.0%	0.0%
Sideswipe	**15.8%**	**15.7%**	**0.0%**	20.0%	25.0%	5.0%
Parked Vehicle*	3.1%	1.9%	-1.2%	0.0%	0.0%	0.0%
Pedalcyclist**	3.5%	3.1%	-0.3%	10.0%	0.0%	-10.0%
Pedestrian	**4.2%**	**2.5%**	**-1.7%**	50.0%	50.0%	0.0%
Other	0.4%	1.9%	1.5%	0.0%	0.0%	0.0%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

TABLE 45. Unsignalized intersections crash type frequencies for all modes (* Parked Vehicle = Parked Vehicle & Vehicle Parked; ** Pedalcyclist = Pedalcyclist & Vehicle Struck Pedalcyclist).

Crash Type	All Modes All Severities					All Modes KA				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Fixed Object	**19**	**9**	**-10**	**-52.6%**	**0.039**	**4**	**0**	**-4**	**-100.0%**	**0.018**
Other Vehicle	**276**	**179**	**-97**	**-35.1%**	**<0.001**	6	4	-2	-33.3%	0.237
From Opp. Direct.	**41**	**10**	**-31**	**-75.6%**	**<0.001**	0	0	0	0.0%	N/A
Left Turn	**46**	**30**	**-16**	**-34.8%**	**0.013**	1	1	0	0.0%	0.500
Rear End	82	89	7	8.5%	0.300	3	2	-1	-33.3%	0.321
Right Turn	11	13	2	18.2%	0.232	0	0	0	0.0%	N/A
Sideswipe	**46**	**27**	**-19**	**-41.3%**	**0.017**	1	1	0	0.0%	0.500
Parked Vehicle*	**14**	**2**	**-12**	**-85.7%**	**0.011**	0	0	0	0.0%	N/A
Pedalcyclist**	13	11	-2	-15.4%	0.343	1	0	-1	-100.0%	0.162
Pedestrian	16	12	-4	-25.0%	0.251	4	1	-3	-75.0%	0.079
Other	3	3	0	0.0%	0.500	1	0	-1	-100.0%	0.162
TOTAL KNOWN	**341**	**216**	**-125**	**-36.7%**	**<0.001**	**16**	**5**	**-11**	**-68.8%**	**0.006**
Invalid Code	**14**	**2**	**-12**	**-85.7%**	**0.003**	0	0	0	0.0%	N/A
Left Blank	**14**	**64**	**50**	**357.1%**	**<0.001**	0	0	0	0.0%	N/A

TABLE 46. Unsignalized intersections crash type proportions (for known crashes) for all modes (* Parked Vehicle = Parked Vehicle & Vehicle Parked; ** Pedalcyclist = Pedalcyclist & Vehicle Struck Pedalcyclist).

Crash Type	All Modes All Severities			All Modes KA		
	Before	After	Change	Before	After	Change
Fixed Object	**5.6%**	**4.2%**	**-1.4%**	**25.0%**	**0.0%**	**-25.0%**
Other Vehicle	**80.9%**	**82.9%**	**1.9%**	37.5%	80.0%	42.5%
From Opp. Direct.	**12.0%**	**4.6%**	**-7.4%**	0.0%	0.0%	0.0%
Left Turn	**13.5%**	**13.9%**	**0.4%**	6.3%	20.0%	13.8%
Rear End	24.0%	41.2%	17.2%	18.8%	40.0%	21.3%
Right Turn	3.2%	6.0%	2.8%	0.0%	0.0%	0.0%
Sideswipe	**13.5%**	**12.5%**	**-1.0%**	6.3%	20.0%	13.8%
Parked Vehicle*	**4.1%**	**0.9%**	**-3.2%**	0.0%	0.0%	0.0%
Pedalcyclist**	3.8%	5.1%	1.3%	6.3%	0.0%	-6.3%
Pedestrian	4.7%	5.6%	0.9%	25.0%	20.0%	-5.0%
Other	0.9%	1.4%	0.5%	6.3%	0.0%	-6.3%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

TABLE 47. Midblock segments crash type frequencies for all modes (* Parked Vehicle = Parked Vehicle & Vehicle Parked; ** Pedalcyclist = Pedalcyclist & Vehicle Struck Pedalcyclist).

Crash Type	All Modes All Severities					All Modes KA				
	Before	**After**	**Change**	**% Change**	**p**	**Before**	**After**	**Change**	**% Change**	**p**
Fixed Object	7	10	3	42.9%	0.229	0	0	0	0.0%	N/A
Other Vehicle	**101**	**45**	**-56**	**-55.4%**	**<0.001**	3	1	-2	-66.7%	0.152
From Opp. Direct.	**22**	**1**	**-21**	**-95.5%**	**<0.001**	0	0	0	0.0%	N/A
Left Turn	14	9	-5	-35.7%	0.192	1	0	-1	-100.0%	0.162
Rear End	**32**	**19**	**-13**	**-40.6%**	**0.047**	1	0	-1	-100.0%	0.162
Right Turn	**9**	**2**	**-7**	**-77.8%**	**0.006**	0	0	0	0.0%	N/A
Sideswipe	15	8	-7	-46.7%	0.102	1	1	0	0.0%	0.500
Parked Vehicle*	**6**	**0**	**-6**	**-100.0%**	**0.012**	0	0	0	0.0%	N/A
Pedalcyclist**	1	1	0	0.0%	0.500	0	0	0	0.0%	N/A
Pedestrian	5	4	-1	-20.0%	0.373	1	1	0	0.0%	0.500
Other	1	1	0	0.0%	0.500	0	0	0	0.0%	N/A
TOTAL KNOWN	**121**	**61**	**-60**	**-49.6%**	**<0.001**	4	2	-2	-50.0%	0.194
Invalid Code	**9**	**0**	**-9**	**-100.0%**	**<0.001**	0	0	0	0.0%	N/A
Left Blank	**13**	**32**	**19**	**146.2%**	**0.013**	0	0	0	0.0%	N/A

TABLE 48. Midblock segments crash type proportions (for known crashes) for all modes (* Parked Vehicle = Parked Vehicle & Vehicle Parked; ** Pedalcyclist = Pedalcyclist & Vehicle Struck Pedalcyclist).

Crash Type	All Modes All Severities			All Modes KA		
	Before	**After**	**Change**	**Before**	**After**	**Change**
Fixed Object	5.8%	16.4%	10.6%	0.0%	0.0%	0.0%
Other Vehicle	**83.5%**	**73.8%**	**-9.7%**	75.0%	50.0%	-25.0%
From Opp. Direct.	**18.2%**	**1.6%**	**-16.5%**	0.0%	0.0%	0.0%
Left Turn	11.6%	14.8%	3.2%	25.0%	0.0%	-25.0%
Rear End	**26.4%**	**31.1%**	**4.7%**	25.0%	0.0%	-25.0%
Right Turn	**7.4%**	**3.3%**	**-4.2%**	0.0%	0.0%	0.0%
Sideswipe	12.4%	13.1%	0.7%	25.0%	50.0%	25.0%
Parked Vehicle*	**5.0%**	**0.0%**	**-5.0%**	0.0%	0.0%	0.0%
Pedalcyclist**	0.8%	1.6%	0.8%	0.0%	0.0%	0.0%
Pedestrian	4.1%	6.6%	2.4%	25.0%	50.0%	25.0%
Other	0.8%	1.6%	0.8%	0.0%	0.0%	0.0%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

Most of the reduction in "Fixed Object" crashes occurred on the west side of Albuquerque, and specifically at the intersection with Coors (Figure 19). The intersection with Rio Grande got slightly worse, while there were other minor reductions along the rest of the corridor.

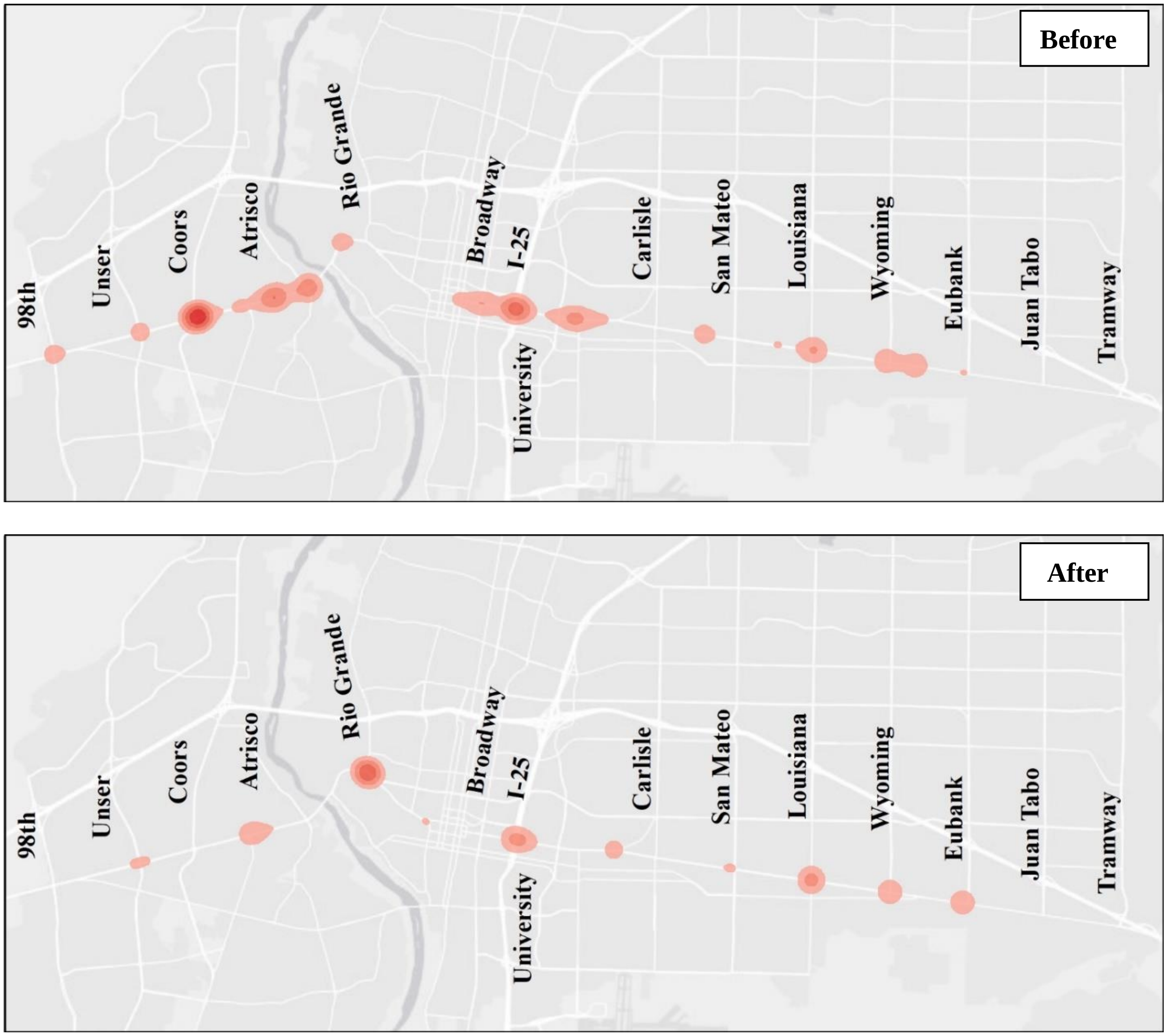

FIGURE 19. Kernel density of all "Fixed Object" crashes of all severities on Central Avenue.

The reduction in "Other Vehicle" crashes was relatively consistent across the entire BRT corridor (Figure 20-23). There were significant improvements at the I-25 interchange and at Coors. Louisiana continues to have issues with "Left Turn" crashes while Rio Grande – which got worse in some categories – actually improved in this category.

FIGURE 20. Kernel density of all "Other Vehicle-Left Turn" crashes of all severities on Central Avenue.

FIGURE 21. Kernel density of all "Other Vehicle-Rear End" crashes of all severities on Central Avenue.

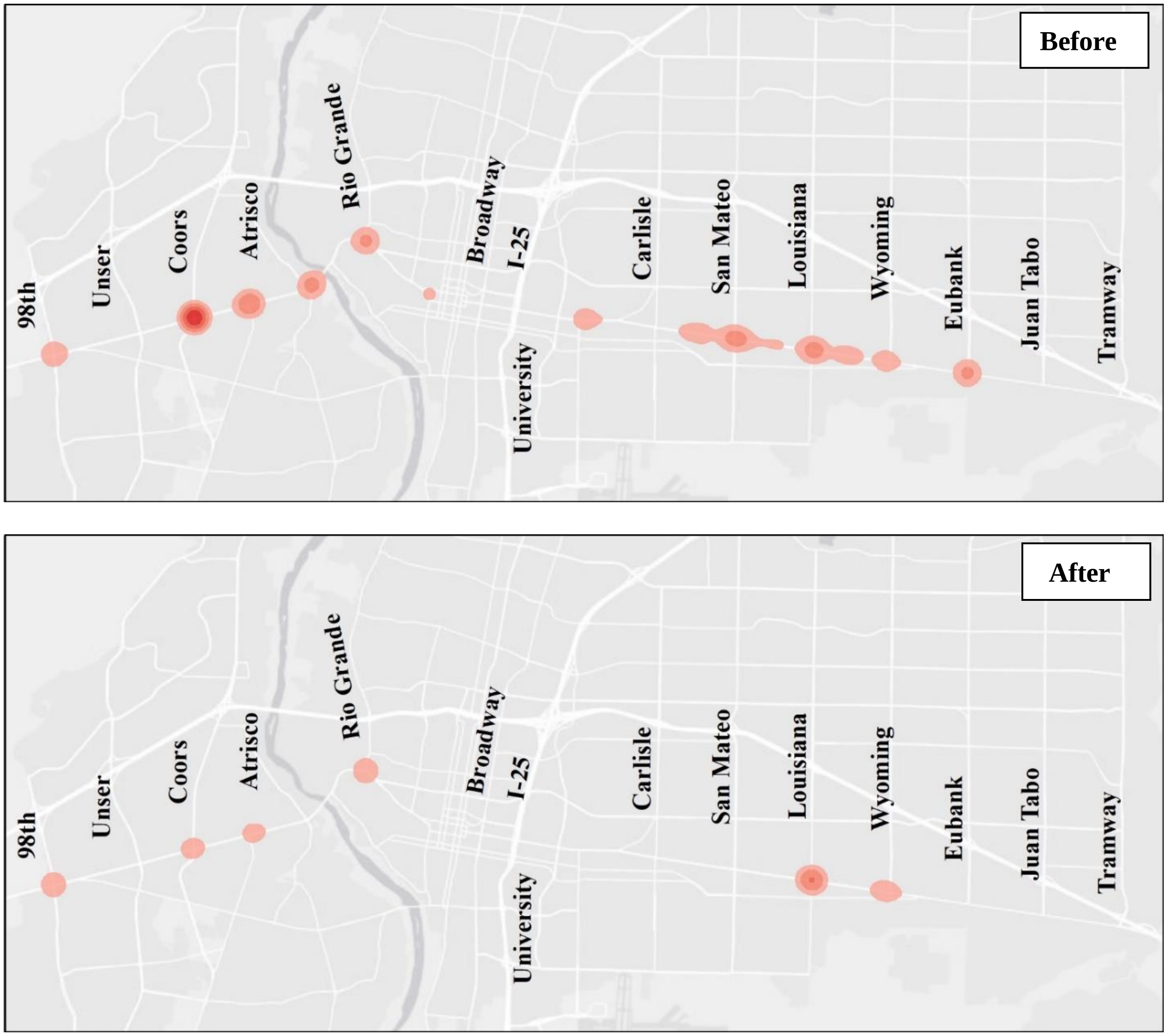

FIGURE 22. Kernel density of all "Other Vehicle-Right Turn" crashes of all severities on Central Avenue.

FIGURE 23. Kernel density of all "Other Vehicle-Sideswipe" crashes of all severities on Central Avenue.

5.1.4.2. Pedestrian Crashes

The majority of pedestrian collisions and nearly all serious/fatal pedestrian collisions consist of "Vehicle Going Straight" collisions (Table 49). Unfortunately, the number of pedestrians struck by vehicles going straight increased in the after period, and the number of pedestrians seriously or fatally injured by these collisions did not change. This may be a result of lane reductions and/or slower motor vehicles leading to more pedestrians risking a crossing when they are not protected by a signal.

Pedestrian collisions involving a moving vehicle decreased (Table 49). This echoes the results for all motor vehicles and suggests the importance of reduced turning conflicts in the BRT safety improvements. However, while pedestrian crashes involving turning motor vehicles decreased, these types of crashes represented a low proportion of the serious/fatal pedestrian crashes and therefore did not result in a large reduction of pedestrian injuries.

TABLE 49. Entire BRT corridor crash type frequencies for pedestrian crashes.

Crash Type	Pedestrians All Severities					Pedestrians KAB				
	Before	**After**	**Change**	**% Change**	**p**	**Before**	**After**	**Change**	**% Change**	**p**
Vehicle Backing	1	2	1	100.0%	0.280	1	2	1	100.0%	0.280
Vehicle Going Straight	36	41	5	13.9%	0.311	20	26	6	30.0%	0.206
Vehicle Turning Left	7	3	-4	-57.1%	0.101	5	1	-4	-80.0%	0.070
Vehicle Turning Right	12	9	-3	-25.0%	0.213	5	4	-1	-20.0%	0.373
TOTAL KNOWN	56	55	-1	-1.8%	0.430	31	33	2	6.5%	0.407
Pedestrian Collision-All Others and Not Known	**1**	**5**	**4**	**400.0%**	**0.039**	**1**	**5**	**4**	**400.0%**	**0.039**
Invalid Code	1	0	-1	-100.0%	0.162	1	0	-1	-100.0%	0.162
Left Blank	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A

TABLE 50. Entire BRT corridor crash type proportions (for known crashes) for pedestrian crashes.

Crash Type	Pedestrians All Severities			Pedestrians KAB		
	Before	**After**	**Change**	**Before**	**After**	**Change**
Vehicle Backing	1.8%	3.6%	1.9%	3.2%	6.1%	2.8%
Vehicle Going Straight	64.3%	74.5%	10.3%	64.5%	78.8%	14.3%
Vehicle Turning Left	12.5%	5.5%	-7.0%	16.1%	3.0%	-13.1%
Vehicle Turning Right	21.4%	16.4%	-5.1%	16.1%	12.1%	-4.0%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

Where did these changes in pedestrian safety outcomes occur? Pedestrian crashes involving "Vehicles Going Straight" increased significantly at major intersections (an increase of 9 crashes or 47.4%) and increased at midblock locations (an increase of 1 crash or 50.0%) but decreased substantially at unsignalized intersections (a decrease of 5 or -41.7%) (Table 51). Pedestrian crashes involving "Vehicle Turning Left" decreased consistently at every location type (except for non-major signalized intersections which did not have any crashes of this type). Pedestrian crashes involving "Vehicle Turning Right" decreased mostly at non-major signalized intersections (Figures 24-26).

TABLE 51. Major intersections crash type frequencies for pedestrian crashes.

Crash Type	Pedestrians All Severities					Pedestrians KAB				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Vehicle Backing	1	0	-1	-100.0%	0.162	1	0	-1	-100.0%	0.162
Vehicle Going Straight	19	28	9	47.4%	0.094	11	18	7	63.6%	0.101
Vehicle Turning Left	4	2	-2	-50.0%	0.194	2	1	-1	-50.0%	0.280
Vehicle Turning Right	4	6	2	50.0%	0.263	1	1	0	0.0%	0.500
TOTAL KNOWN	28	36	8	28.6%	0.154	15	20	5	33.3%	0.190
Pedestrian Collision-All Others and Not Known	**0**	**4**	**4**	**N/A**	**0.018**	**0**	**4**	**4**	**N/A**	**0.018**
Invalid Code	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Left Blank	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A

TABLE 52. Major intersections crash type proportions (for known crashes) for pedestrian crashes.

Crash Type	Pedestrians All Severities			Pedestrians KAB		
	Before	After	Change	Before	After	Change
Vehicle Backing	3.6%	0.0%	-3.6%	6.7%	0.0%	-6.7%
Vehicle Going Straight	67.9%	77.8%	9.9%	73.3%	90.0%	16.7%
Vehicle Turning Left	14.3%	5.6%	-8.7%	13.3%	5.0%	-8.3%
Vehicle Turning Right	14.3%	16.7%	2.4%	6.7%	5.0%	-1.7%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

TABLE 53. Other signalized intersections crash type frequencies for pedestrian crashes.

Crash Type	Pedestrians All Severities					Pedestrians KAB				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Vehicle Backing	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Vehicle Going Straight	4	4	0	0.0%	0.500	4	3	-1	-25.0%	0.343
Vehicle Turning Left	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Vehicle Turning Right	**5**	**0**	**-5**	**-100.0%**	**0.008**	**3**	**0**	**-3**	**-100.0%**	**0.037**
TOTAL KNOWN	9	4	-5	-55.6%	0.065	7	3	-4	-57.1%	0.074
Pedestrian Collision-All Others and Not Known	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Invalid Code	1	0	-1	-100.0%	0.162	1	0	-1	-100.0%	0.162
Left Blank	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A

TABLE 54. Other signalized intersections crash type proportions (for known crashes) for pedestrian crashes.

Crash Type	Pedestrians All Severities			Pedestrians KAB		
	Before	After	Change	Before	After	Change
Vehicle Backing	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Vehicle Going Straight	44.4%	100.0%	55.6%	57.1%	100.0%	42.9%
Vehicle Turning Left	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Vehicle Turning Right	**55.6%**	**0.0%**	**-55.6%**	**42.9%**	**0.0%**	**-42.9%**
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

TABLE 55. Unsignalized intersections crash type frequencies for pedestrian crashes.

Crash Type	Pedestrians All Severities					Pedestrians KAB				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Vehicle Backing	0	2	2	N/A	0.077	0	2	2	N/A	0.077
Vehicle Going Straight	12	7	-5	-41.7%	0.158	4	4	0	0.0%	0.500
Vehicle Turning Left	2	1	-1	-50.0%	0.280	2	0	-2	-100.0%	0.077
Vehicle Turning Right	1	2	1	100.0%	0.280	0	2	2	N/A	0.077
TOTAL KNOWN	15	12	-3	-20.0%	0.303	6	8	2	33.3%	0.308
Pedestrian Collision-All Others and Not Known	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Invalid Code	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Left Blank	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A

TABLE 56. Unsignalized intersections crash type proportions (for known crashes) for pedestrian crashes.

Crash Type	Pedestrians All Severities			Pedestrians KAB		
	Before	After	Change	Before	After	Change
Vehicle Backing	0.0%	16.7%	16.7%	0.0%	25.0%	25.0%
Vehicle Going Straight	80.0%	58.3%	-21.7%	66.7%	50.0%	-16.7%
Vehicle Turning Left	13.3%	8.3%	-5.0%	33.3%	0.0%	-33.3%
Vehicle Turning Right	6.7%	16.7%	10.0%	0.0%	25.0%	25.0%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

TABLE 57. Midblock segments crash type frequencies for pedestrian crashes.

Crash Type	Pedestrians All Severities					Pedestrians KAB				
	Before	After	Change	% Change	p	Before	After	Change	% Change	p
Vehicle Backing	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Vehicle Going Straight	1	2	1	100.0%	0.329	1	1	0	0.0%	0.500
Vehicle Turning Left	1	0	-1	-100.0%	0.162	1	0	-1	-100.0%	0.162
Vehicle Turning Right	2	1	-1	-50.0%	0.280	1	1	0	0.0%	0.500
TOTAL KNOWN	4	3	-1	-25.0%	0.364	3	2	-1	-33.3%	0.321
Pedestrian Collision-All Others and Not Known	1	1	0	0.0%	0.500	1	1	0	0.0%	0.500
Invalid Code	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A
Left Blank	0	0	0	0.0%	N/A	0	0	0	0.0%	N/A

TABLE 58. Midblock segments crash type proportions (for known crashes) for pedestrian crashes.

Crash Type	Pedestrians All Severities			Pedestrians KAB		
	Before	After	Change	Before	After	Change
Vehicle Backing	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Vehicle Going Straight	25.0%	66.7%	41.7%	33.3%	50.0%	16.7%
Vehicle Turning Left	25.0%	0.0%	-25.0%	33.3%	0.0%	-33.3%
Vehicle Turning Right	50.0%	33.3%	-16.7%	33.3%	50.0%	16.7%
TOTAL KNOWN	100.0%	100.0%	0.0%	100.0%	100.0%	0.0%

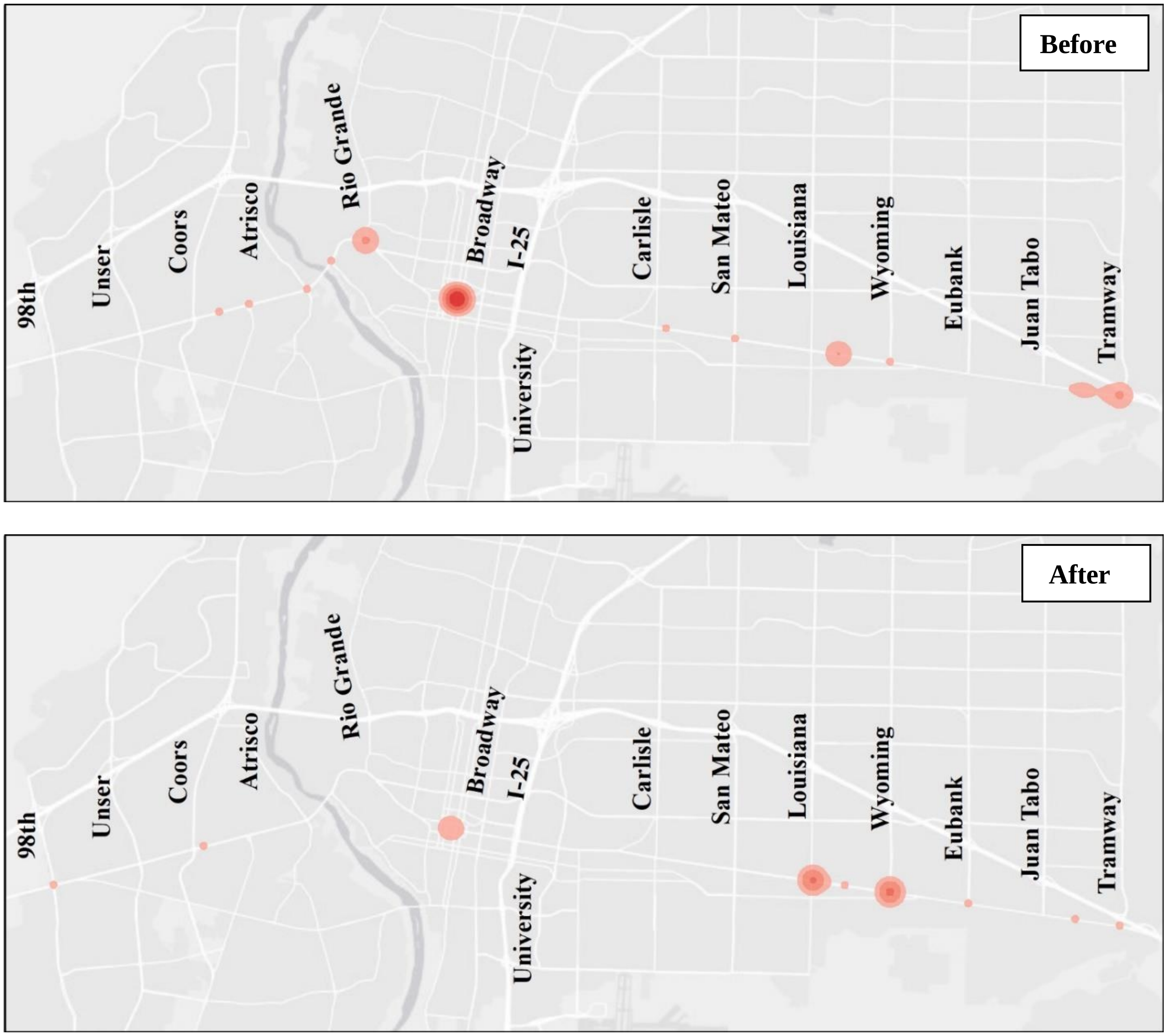

FIGURE 24. Kernel density of pedestrian "Left Turn" crashes of all severities on Central Avenue.

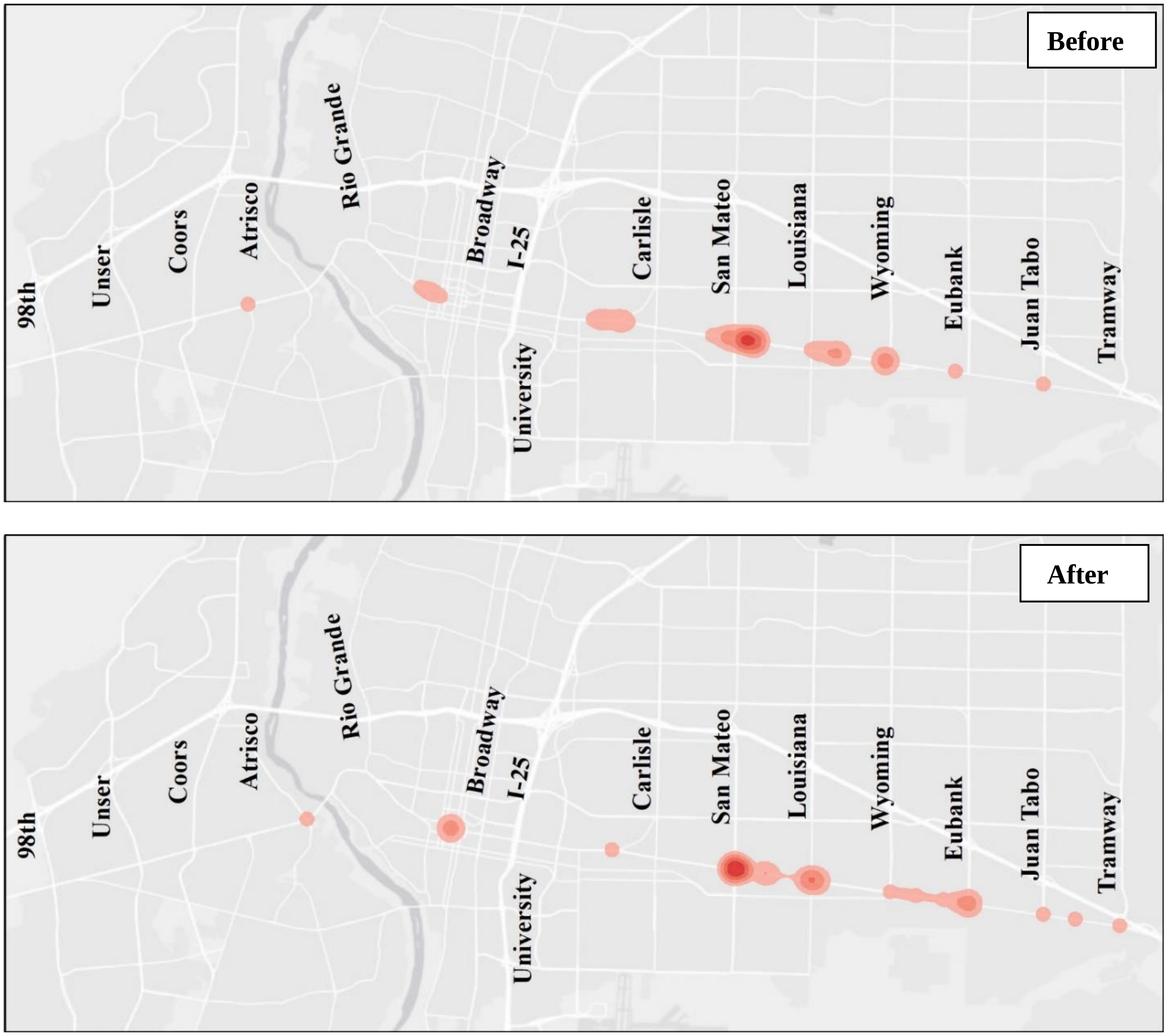

FIGURE 25. Kernel density of pedestrian "Right Turn" crashes of all severities on Central Avenue.

FIGURE 26. Kernel density of pedestrian "Straight" crashes of all severities on Central Avenue.

5.1.5. BRT Speed Results

A possible mechanism behind the safety improvements on the ART corridor identified above is a reduction in motor vehicle operating speeds, which were detected across the Central Avenue corridor and especially on the segments that saw ART construction. These motor vehicle speed reductions suggest that the ART project functioned as a traffic calming project as well as a transit project.

Across all 94 sites on the corridor that experienced ART construction, average vehicle speeds dropped 13.6% and 85th percentile speeds dropped 11.5% (Table 59). Those ART decreases were significantly higher than the reductions of 10.6% in average speeds and 5.8% in 85th percentile speeds experienced on the control segments of Central Avenue.

TABLE 59. Changes in motor vehicle speeds on Central Avenue corridor relative to BRT.

			Average Speed (mph)				85th Percentile Speed (mph)			
		n	Before	After	Change	% Change	Before	After	Change	% Change
ART	All	94	23.5	20.3	-3.2	-13.6%	32.3	28.6	-3.7	-11.5%
	Intersections	38	23.1	19.9	-3.2	-13.9%	31.7	27.6	-4.1	-12.9%
	Midblock	56	23.8	20.6	-3.2	-13.4%	32.6	29.3	-3.3	-10.1%
Control	All	70	27.3	24.4	-2.9	-10.6%	38.0	35.8	-2.2	-5.8%
	Intersections	22	28.6	24.9	-3.7	-12.9%	39.8	36.8	-3.0	-7.5%
	Midblock	48	26.8	24.2	-2.6	-9.7%	37.3	35.4	-1.9	-5.1%

The risk of serious injury for a pedestrian that is struck by a motor vehicle is 50% at 31 mph and 25% at 23 mph (*93*). The 85th percentile speed through intersections that experienced ART construction decreased from 31.7 mph to 27.6 mph (Table 59). In other words, the range of speeds experienced on the Central Avenue corridor and the reduction in speeds is a critical point for which we might expect to be avoiding injuries. If we had a 13% reduction in speeds on an interstate highway, the risk of serious and/or fatal injury would still be near 100%. However, we would expect a significant reduction in the risk of serious and/or fatal injury given the operating speeds on Central Avenue.

Both on the ART segments and on the control segments, intersections (as opposed to mid-block) saw the largest reductions in vehicle operating speeds. However, speeds through intersections were actually higher on control segments, while mid-block areas were faster than intersections on the ART segments.

There was spatial nuance in the vehicle operating speed reductions. The largest reductions in vehicle operating speeds were experienced in the UNM, Nob Hill, and Fairground segments of Central Avenue (Table 60). These were also the parts of the ART corridor that saw the largest drops in serious and/or fatal injuries (Table 8). This suggests a link between speeds and safety, which was leveraged by the ART project's ability to act as traffic calming.

TABLE 60. Changes in motor vehicle speeds on Central Avenue corridor by neighborhood relative to BRT.

		Average Speed (mph)				85th Percentile Speed (mph)			
	n	Before	After	Change	% Change	Before	After	Change	% Change
Westside (Control)	20	32.1	27.9	-4.2	-13.1%	44.3	40.4	-3.9	-8.8%
Westside	20	25.7	23.1	-2.6	-10.1%	34.7	33.1	-1.6	-4.6%
Old Town	10	29.0	24.7	-4.3	-14.8%	39.6	34.9	-4.7	-11.9%
West Downtown	8	20.5	18.3	-2.2	-10.7%	27.3	25.2	-2.1	-7.7%
Downtown (Control)	4	14.5	12.5	-2.0	-13.8%	20.3	18.5	-1.8	-8.9%
East Downtown	16	20.5	17.6	-2.9	-14.1%	27.3	24.6	-2.7	-9.8%
UNM	10	21.3	18.6	-2.7	-12.7%	29.5	24.5	-5.0	-16.9%
Nob Hill	12	22.5	18.4	-4.1	-18.2%	31.8	25.8	-6.0	-18.9%
Fairground	18	23.7	20.2	-3.5	-14.8%	33.6	29.2	-4.4	-13.1%
Eastside (Control)	46	26.5	24.0	-2.5	-9.4%	37.0	35.4	-1.6	-4.3%

The far eastside of Central Avenue (the control segment east of Louisiana) experienced the smallest decreases in vehicle operating speeds with only a 4.3% reduction in 85th percentile speeds (Table 60). This was also the segment that saw the worst safety outcomes (Table 8), further suggesting a link between speed and safety.

The only exception to the link between speed and safety was on the ART segments of the Westside. These segments saw a modest decrease of 4.6% in 85th percentile speeds but also saw strong decreases in serious/fatal injuries. This might suggest that there were other mechanisms at play in this area.

5.2 ROAD DIET

The road diet implemented between Juan Tabo and Tramway also correlated with reduced vehicle operating speeds, as opposed to increases at control segments between Eubank and Juan Tabo that did not experience the treatment. Average vehicle operating speeds through road diet intersections decreased by 7.0% in the short-term and remained 5.8% below their historic levels even 1.5 years after implementation (Table 61). This was compared to 10.2% increases in vehicle speeds on control intersections.

TABLE 61. Changes in average motor vehicle speeds for road diet.

		n	Before	Short-Term After	Change	% Change	Long-Term After	Change	% Change
Midblock	Road Diet	8	27.6	29.9	2.3	8.3%	30.4	2.8	10.1%
	Control	8	28.5	32.4	3.9	13.7%	33.1	4.6	16.1%
Intersections	Road Diet	2	25.8	24.0	-1.8	-7.0%	24.3	-1.5	-5.8%
	Control	4	24.5	27.0	2.5	10.2%	27.0	2.5	10.2%

On the other hand, average vehicle operating speeds increased 8.3% in the short-term and 10.1% in the long-term on road diet segments (Table 61). However, these road diet increases were significantly smaller than the increases on the control segments (13.7% in the short-term and 16.1% in the long-term).

The above findings were mirrored with the 85th percentile vehicle speed findings. Namely, intersections that were adjacent to the road diet saw decreases in 85th percentile vehicle speeds in both the short-term and long-term and midblock segments that underwent the road diet saw a reduction of 2.4% in 85th percentile vehicle operating speeds (Table 62). All the control intersections and midblock segments saw increases in 85th percentile vehicle operating speeds in both the short-term and long-term.

TABLE 62. Changes in 85th percentile motor vehicle speeds for road diet.

		n	Before	Short-Term After	Change	% Change	Long-Term After	Change	% Change
Midblock	Road Diet	8	42.4	42.8	0.4	0.9%	42.3	-0.1	-0.2%
	Control	8	43.1	44.8	1.6	3.7%	44.4	1.3	3.0%
Intersections	Road Diet	2	39.8	37.8	-2.0	-5.0%	38.0	-1.8	-4.5%
	Control	4	37.5	42.5	5.0	13.3%	42.0	4.5	12.0%

There were no strong differences when examining the eastbound versus the westbound directions. Eastbound traffic saw a short-term increase in average speed of 2.3 mph and westbound saw an increase of 2.0 mph. Both the eastbound and westbound 85th percentile speeds increased 0.8 mph.

5.3 HAWK SIGNALS

5.3.1. HAWK Signal Crash Analysis Results

5.3.1.1. All Motor Vehicle Crashes

There was limited evidence of an impact on motor vehicle crash outcomes for HAWK signal installations. For overall crashes, the HAWK signals on Isleta Boulevard and Louisiana Boulevard experienced no significant changes in crash outcomes relative to the respective signal installations. The HAWK signal located on Isleta Boulevard had seven reported motor vehicle crashes in the 24-month before period and nine crashes in the 24-month after period. The HAWK signal on Louisiana Boulevard had five reported motor vehicle crashes in both the before and after periods.

TABLE 63. HAWK signal crash analysis outcomes.

		Isleta Boulevard	Lomas Boulevard	Louisiana Boulevard
All Modes (All Severities)	Before	7	1	5
	After	9	5	5
All Modes (KA)	Before	1	0	1
	After	0	0	0
Pedestrian (All Severities)	Before	0	0	1
	After	0	0	0
Pedestrian (KA)	Before	0	0	1
	After	0	0	0

The most noticeable change in the HAWK signal crash analysis was for overall crashes at the HAWK signal on Lomas Boulevard. There was one reported motor vehicle crash in the 24-month before period and five crashes in the 24-month after period. Even given that increase, the change was not found to be statistically significant at 95% confidence when comparing the means (p-value of 0.085). It is also important to note that these crashes at the Lomas Boulevard HAWK signal mostly resulted in low injury severities. As can be seen below, the Lomas intersection had no serious or fatal crashes and no pedestrian crashes in either the before or after periods.

In terms of serious and fatal injuries, sample sizes were too low to draw any meaningful conclusions. The HAWK signal on Lomas Boulevard did not experience any serious or fatal crashes in either the 24 months before period or the 24-month after period. The HAWK signals on Isleta Boulevard and Louisiana Boulevard each experienced one serious or fatal crash in the before period and none in the after period. While this appears to be a promising downward trend, it is statistically unrealistic to give credit to the HAWK signal installations.

5.3.1.2. Pedestrian Crashes

There were not enough pedestrian crashes at the non-Central Avenue HAWK signals to draw any meaningful conclusions in terms of pedestrian safety outcomes. The HAWK signals on Isleta Boulevard and Lomas Boulevard experienced no pedestrian collisions either in the 24 months before installation or the 24 months after installation. The HAWK signal on Louisiana Boulevard saw one pedestrian collision before installation and no pedestrian collisions after installation. The pedestrian collision in the before period for the Louisiana Boulevard HAWK signal resulted in the death of a student at the middle school in front of which the HAWK signal is now located. While a similar tragedy was not experienced in the 24 months after installation, crash sample sizes are too low to establish the impact on pedestrian safety from the HAWK signal.

5.3.2. HAWK Signal Pedestrian Behavior Analysis Results

The purpose of this pedestrian behavior analysis was to determine whether pedestrians were willing to utilize the HAWK signals or were willing to go out of their way to use the HAWK signals. There were two types of crossing behaviors at the HAWK signals that we were interested in: 1) pedestrians that utilized the HAWK signals without deviating from their route (dashed line in Figure 27) and 2) pedestrians that utilized the HAWK signals while deviating from their route (solid line in Figure 27).

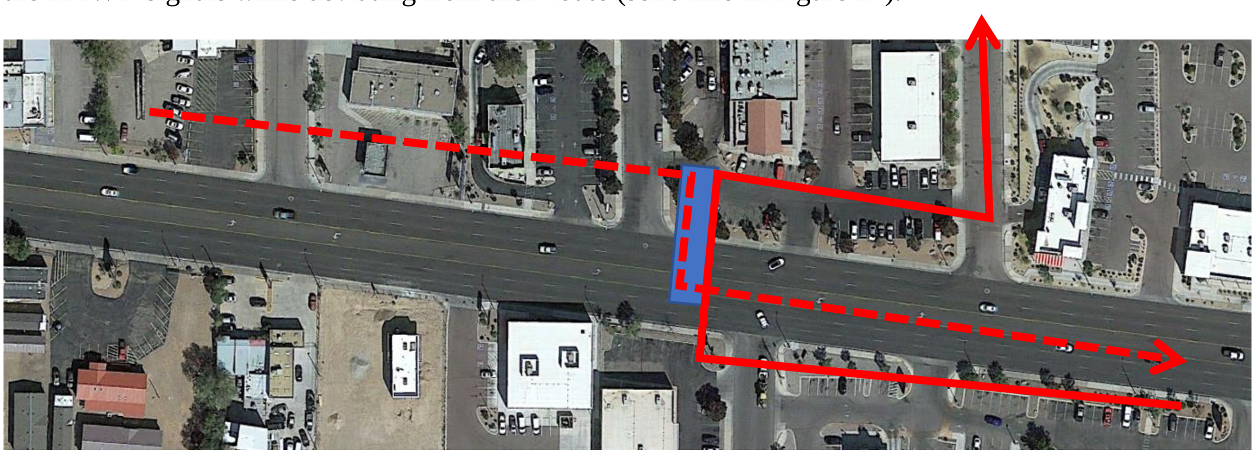

FIGURE 27. Types of pedestrian crossings utilizing the HAWK crossing locations: pedestrians not deviating from their route (dashed line) and pedestrians deviating from their route (solid line).

We were also interested in two types of non-compliant pedestrian crossings: 1) pedestrians that crossed Central Avenue away from any controlled crossing after the HAWK signal (dashed line in Figure 28) and 2) pedestrians that crossed Central Avenue away from any controlled crossing before the HAWK signal (solid line in Figure 28). It could be argued that the former non-compliant crossing is more egregious since, because the pedestrian has already walked past the HAWK crossing, they almost certainly knew of its presence, whereas the same might not be said for a pedestrian that crosses before the HAWK signal.

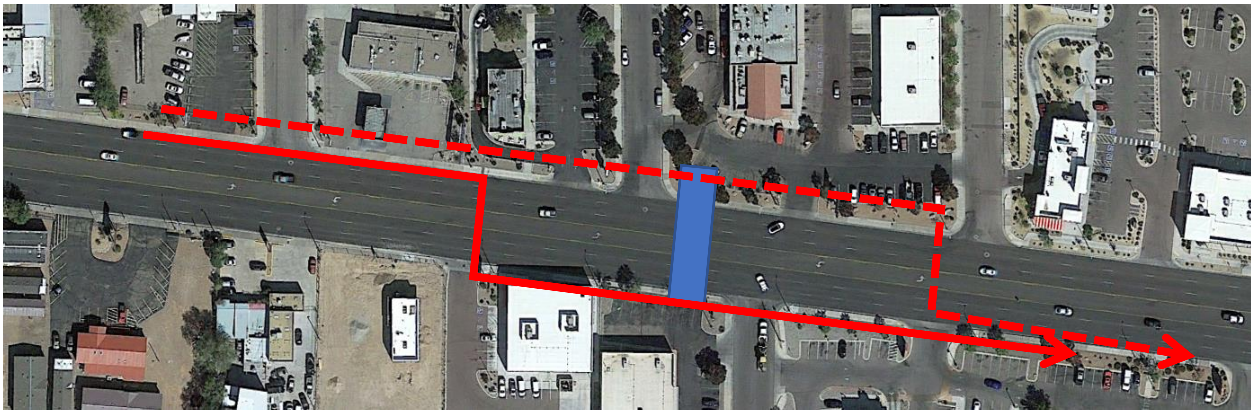

FIGURE 28. Types of pedestrian crossings not utilizing the HAWK crossing locations: pedestrians crossing after the HAWK crossing (dashed line) and pedestrians crossing before the HAWK crossing (solid line).

While the HAWK crossings did appear to have some attractive force for pedestrians, there were no instances of the HAWK signals being properly used. In fact, while there were 27 pedestrians that used the HAWK crossing in the after period (compared to 15 pedestrians that used the same location prior to the HAWK installation), none of those after-period pedestrians properly engaged the HAWK signals. Two people activated the western HAWK signal but crossed while the HAWK signal was still yellow. One person activated the western HAWK signal but then never crossed. The other 24 pedestrians that crossed at the HAWK crossing in the after period never engaged the signal.

In addition to the lack of proper signal usage, there were no instances of pedestrians going out of their way to utilize the HAWK crossings (i.e., the solid line in Figure 27). All the 27 pedestrian crossings at the HAWK locations were directly along the route of the pedestrians (i.e., the dashed line in Figure 27).

First examining the western HAWK signal located on Central Avenue between San Pablo Street NE and Grove Street NE, 60.0% of the pedestrians observed within 1,000 feet of the HAWK crossing crossed Central Avenue in the before period and a relatively consistent 52.8% crossed Central Avenue in the after period (Table 64).

TABLE 64. Western HAWK signal pedestrian behaviors.

	Before	After
Total Pedestrians Observed	200	210
Crossed Central Avenue	120	111
Crossed at HAWK	4	12
Utilized the HAWK	N/A	0
Did not utilize the HAWK	4	12
Crossed Central Before-Walked Past HAWK	16	21
<200 ft	6	12
200-500 ft	9	9
>500 ft	1	0
Walked Past HAWK-Crossed Central After	15	24
<200 ft	7	8
200-500 ft	8	14
>500 ft	0	2

The HAWK crossing appeared to have some attractive power for pedestrians; while only 3.3% of pedestrians who crossed Central Avenue in the before period crossed at the HAWK location, 10.8% of pedestrians who crossed Central Avenue in the after period crossed at the HAWK location. However, again none of the pedestrians used the crossing signal correctly.

24 pedestrians in the after period walked past the HAWK signal and then crossed Central Avenue at an uncontrolled location. Eight of those pedestrians crossed Central within 200 feet of the HAWK crossing, which is a higher proportion than in the before period. This again suggests that the HAWK signal may have had some attractive force for pedestrians, but the pedestrians were not willing to actually use the HAWK signal properly. An additional 21 pedestrians crossed Central Avenue at an uncontrolled location before walking past the HAWK signal. Nine of those pedestrians crossed within 200 feet of the HAWK.

Next examining the eastern HAWK signal located on Central Avenue at Conchas Street NE, 52.7% of pedestrians observed within 1,000 feet of the HAWK crossing crossed Central Avenue in the before period and 40.6% crossed in the after period (Table 65). The reason for this decrease in the proportion of pedestrians crossing Central Avenue is unknown.

TABLE 65. Eastern HAWK signal pedestrian behaviors.

	Before	After
Total Pedestrians Observed	201	192
Crossed Central Avenue	106	78
Crossed at HAWK	11	15
Utilized the HAWK	N/A	0
Did not utilize the HAWK	11	15
Crossed Central Before-Walked Past HAWK	8	3
<200 ft	2	0
200-500 ft	3	3
>500 ft	3	0
Walked Past HAWK-Crossed Central After	6	9
<200 ft	1	3
200-500 ft	4	6
>500 ft	1	0

The HAWK crossing again appeared to have some attractive force for pedestrians. While only 10.4% of pedestrians crossing Central Avenue in the before period crossed at the HAWK location, that proportion rose to 19.2% in the after period. However, none of the pedestrians activated the HAWK signal.

Nine pedestrians in the after period walked past the HAWK signal and then crossed Central Avenue at an uncontrolled location. Three of those pedestrians crossed Central within 200 feet of the HAWK crossing. An additional three pedestrians crossed Central at an uncontrolled location and subsequently walked past the HAWK crossing. All three of those pedestrians crossed Central within 500 feet of the HAWK crossing, where it would have been visible to them.

In addition to the pedestrians mentioned above that walked past the HAWK signal without utilizing it, another ten pedestrians crossed Central Avenue at uncontrolled locations but within 200 feet of one of the HAWK signals, although they did not walk past the HAWK. None of those ten pedestrians went out of their way to utilize the HAWK crossing.

Overall, the HAWK crossings appear to have some minimal attractive force for pedestrians but there was no proper utilization of the signals. An anecdotal observation was that pedestrians appeared to be more cavalier when crossing at the HAWK crossings relative to other uncontrolled locations, even though none of the pedestrians were properly utilizing the HAWK signal to control the motor vehicle traffic. In this way, future research might explore whether the HAWK signals actually provide a false sense of security to pedestrians who do not activate the signal (and therefore might not have any impact on motor vehicle driver behavior) by providing a marked crosswalk but without any traffic control. On the other hand, drivers may be more cautious around a HAWK signal even if the signal has not been activated. This dynamic can likely be explored in a few years when crash data is available.

6. CONCLUSIONS

This work analyzed the pedestrian safety and overall traffic safety impacts – in terms of both motor vehicle speeds and crash outcomes – of several countermeasures applied to the Central Avenue arterial corridor in Albuquerque, New Mexico. Countermeasures included a bus rapid transit (BRT) system, a road diet, and High-Intensity Activated Crosswalk (HAWK) signals. Vehicle speed data was collected from StreetLight Data and crash data was provided by New Mexico Department of Transportation (NMDOT).

Findings suggest that the infrastructure changes associated with the BRT system improved traffic safety by reducing vehicle operating speeds. Motor vehicle 85th percentile speeds were reduced by 11.5% on BRT segments (compared to a 5.8% decrease on non-BRT control segments) and average motor vehicle speeds were reduced by 13.6% on BRT segments (compared to a 10.6% reduction on non-BRT control segments). Serious and fatal injuries were reduced by 65.2% on BRT segments (compared to a reduction of 18.6% on non-BRT control segments). These serious and fatal injury reductions were consistent across signalized intersections, unsignalized intersections, and midblock locations.

Pedestrian safety outcomes were more variable for the BRT. Serious and fatal pedestrian injuries increased 19.0% on the BRT corridor. However, that was relatively positive compared to the 40.9% increase experienced on non-BRT control segments.

The mechanism behind the overall reduction in serious and fatal injuries was traffic calming through the BRT's road diet (as evidenced by the reductions in motor vehicle operating speeds) and left turn restrictions from both raised medians and signalization control. For example, the contributing factor in serious and fatal injury crashes that experienced the largest reduction with BRT implementation was "excessive speed", which went from 9 instances before BRT construction (the most frequent contributing factor) to 0 instances after BRT construction. The crash type in serious and fatal injury crashes that experienced the largest reduction with BRT implementation was "left turn", which went from 8 instances before BRT construction (the 2nd most frequent) to 1 instance after BRT construction. There was also a significant reduction in left-turn crashes resulting in a pedestrian injury (from 5 instances before the BRT to 1 instance after), but no significant reduction in any pedestrian injury contributing factor.

A painted road diet on another section of Central Avenue was also found to reduce vehicle speeds but not to the same level as the BRT. On the road diet section of Central Avenue, 85th percentile vehicle speeds dropped by 1.6% after road diet implementation compared to a 4.5% increase on non-road diet sections.

HAWK signals installed on Central Avenue and other arterial roads around the Albuquerque metro area showed no significant improvements for either crash outcomes or pedestrian behavior. However, crash outcomes did not see significant improvements at the HAWK locations largely because crash counts were low in the before period and remained low in the after period. While the HAWK signals did have some attractive power and pedestrians were more likely to cross Central Avenue at the HAWK locations after installation, the HAWK signals were not properly activated or utilized. However, the HAWK signals were installed on roadways with 5 or 7 lanes with 85th percentile motor vehicle speeds in the 35-45 mph range. The lack of proper use of the HAWK signals may be a result of the wide and fast characteristics of the roadway. More research is needed to better understand utilization of HAWK signals on narrower and slower roadways.

Overall, findings suggest that physical changes to traffic calm and reduce conflicts along the entire length of arterial corridors are superior to providing spot treatments such as controlled crossings when trying to improve traffic safety outcomes for both pedestrians and motor vehicle occupants alike. It is interesting to note that the BRT analysis is strictly analyzing the physical changes to the roadway as the BRT buses were not yet operating in the after period of our analyses. This suggests that it was not so much transit operations that improved safety along the corridor as it was the traffic calming aspects of the physical roadway design changes. This is further evidence that making unsafe arterial corridors more multimodal can improve traffic operations and safety not only for road users outside of cars, but such multimodal changes can actually improve traffic safety for all road users.

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