Transportation Consortium of South-Central States

Tran-SET

Solving Emerging Transportation Resiliency, Sustainability, and Economic Challenges through the Use of Innovative Materials and Construction Methods: From Research to Implementation

ABQ Streets Project: Creating Alternative Residential Street Designs

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16. Abstract

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AAA	All Ages & Abilities
ABQ	Albuquerque
ACS	American Community Survey
CMF	Crash Modification Factor
CPTED	Crime Prevention Through Environmental Design
FHWA	Federal Highway Administration
GIS	Geographic Information System
HAWK	High-Intensity Activated Crosswalk
MUTCD	Manual on Uniform Traffic Control Devices
NACTO	National Association of City Transportation Officials
NHTS	National Household Travel Survey
NHTSA	National Highway Traffic Safety Administration
NMDOT	New Mexico Department of Transportation
NSF	National Science Foundation
SRTS	Safe Routes to School
UNM	University of New Mexico

EXECUTIVE SUMMARY

This research evaluates opportunities for retrofitting residential streets with alterative designs with the overall goal of improving their function, reducing their negative impacts and reducing maintenance costs. This is accomplished through three main research tasks. First, we conduct a comprehensive review of the street design literature with a focus on studies that report how alterative or unique designs that are relevant to the residential street context affect travel behavior, traffic flow, safety, crime and environmental impacts. We then survey residential streets in several study neighborhoods to measure typical design features and cross sections. With this information we then evaluate which alterative street designs could be used to retrofit typical Albuquerque residential streets within currently used right of way. For this subset of alternatives, we estimate the expected benefits and construction and maintenance costs using information from our literature review and the city's unit construction cost data.

Findings suggest that street lighting may provide significant benefits in terms of both traffic safety and crime reduction, while design alternatives using curb can realize considerable traffic safety benefits while keeping annual costs low. The complex woonerf design that combined multiple alternatives had the highest benefit-to-cost ratio. Pavement treatments including permeable asphalt and white asphalt sealant had costs that outweighed direct environmental benefits.

1. INTRODUCTION

The residential or local street is a ubiquitous feature of communities small and large (Figure 1). The streets at the end of our driveways or out our front doors are arguably the most essential piece of public infrastructure. Without a street, we would be trapped in our homes or climbing over our neighbors' fences to get anywhere. While residential streets are clearly important for providing access and mobility, how their design affects these functions and the sustainability, security and health of our communities needs to be better understood *(1)*. Most roadway-related transportation research focuses on more heavily trafficked and congested roadways rather than low-volume residential streets. However, residential streets make up the bulk of the transportation network. In Albuquerque, New Mexico there are approximately 1,800 miles of low-volume residential streets, making up about 75 percent of the roadway network. Understanding how this vast infrastructure affects communities and the environment and opportunities to reduce construction and maintenance costs is therefore important.

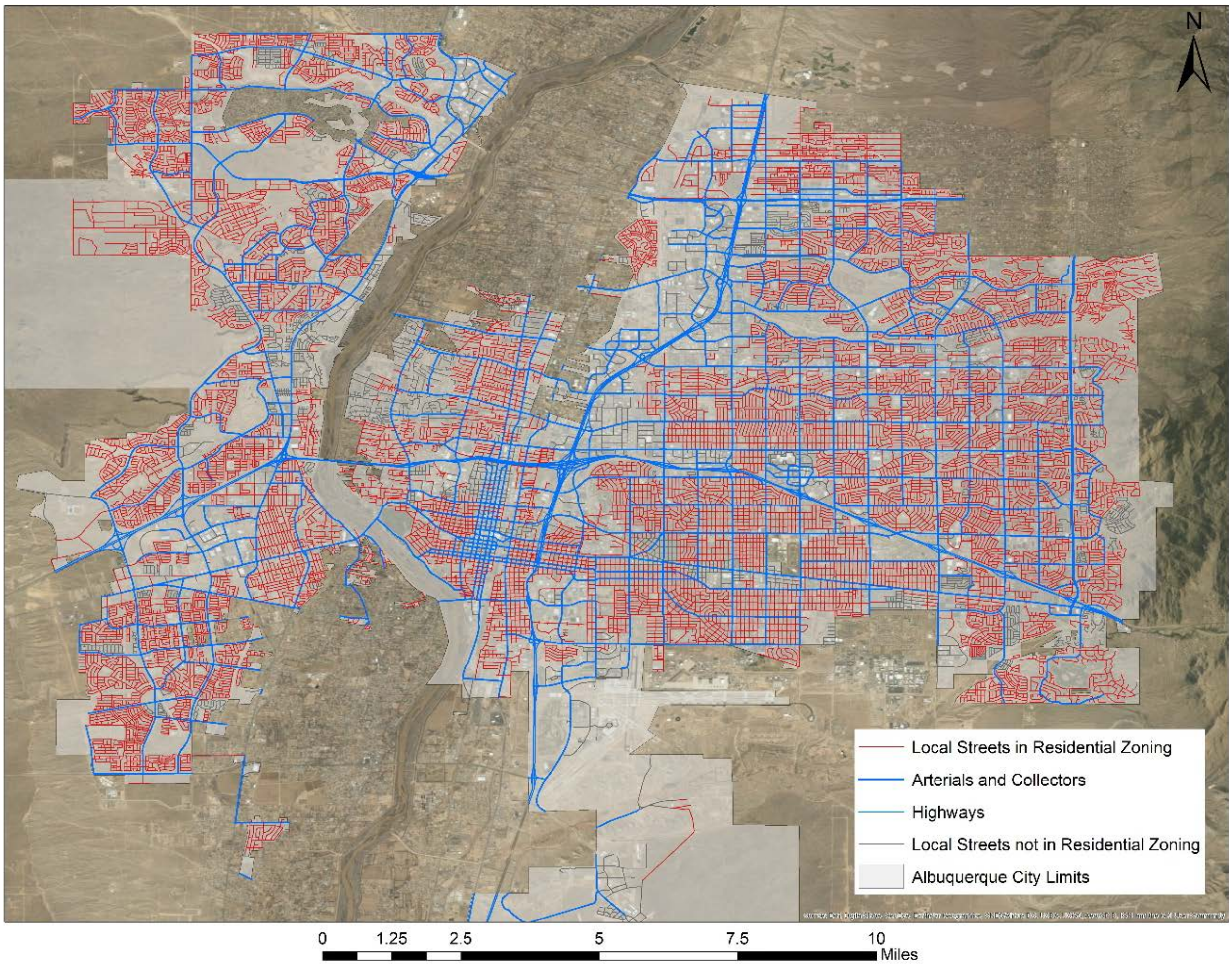

Figure 1. Map of Albuquerque street network.

The streets in our neighborhoods can affect how we travel *(2)*. Streets can be designed to prioritize high speed vehicular traffic or to keep traffic moving slowly. They can also be designed to prioritize transit, walking or biking or travel by all means (e.g., complete streets). Many residential streets built during the mid to late 20th century, including many of Albuquerque's and those in other Region 6 cities, were designed principally to accommodate vehicle traffic. Streets from this period in Albuquerque often have narrow, difficult to use, sidewalks; intersections with large turning radii and wide widths that encourage high speed travel; little street lighting; and lack street trees or other amenities that may enhance the street environment. A 2012 analysis by the U.S. Census Bureau reports that only 2% of commute trips in Albuquerque occurred by walking and 1% by bicycling. The research team's own analysis of more recent local survey data suggest that these rates have not changed much.

Residential streets also affect our environment, security, and safety. Air quality and climate change concerns stemming from vehicle exhaust emissions are perhaps the most well-known environmental impacts of our transportation system; however, streets pose other environmental challenges too. Urban heat and runoff are two of the most significant. Residential streets cover a large portion of most cities with asphalt and concrete pavements that absorb and retain a large amount of heat from solar *(3, 4)*. This contributes substantially to urban heat islands – the widely observed phenomena that cities tend to be warmer than surrounding less-developed land. Some studies indicate that Albuquerque has one of the largest urban heat islands in the United States, with daytime temperatures elevated by up to 6 degrees Fahrenheit during the day and 10 degrees Fahrenheit at night *(5)*. These elevated temperatures not only cause additional discomfort during hot summer days but they have been shown to increase energy consumption for air conditioning (and likely water consumption too when evaporative coolers are used) which increases costs for homeowners and businesses. The low efficiency of air conditioners also produces additional heat and the energy they consume can indirectly cause additional warming through the production of greenhouse gas emissions that contribute to global warming *(6)*. Since many pavements used for streets, sidewalks and parking lots are also impervious to water, they contribute to a large amount of urban runoff which can be difficult and costly to control and can have environmental impacts too. Many communities in Albuquerque have experienced flooding caused when heavy rains produce runoff that exceeds the capacity of old and undersized stormwater drainage systems and detention ponds. Urban runoff can also carry toxic pollutants from the roadway in rivers and it can be warmed to relatively high temperatures as it flows over hot pavements.

Residential street designs that prioritize vehicular travel and encourage high speed travel (or fail to discourage it), provide inadequate pedestrian facilities, and that have poor lighting can also contribute to excessive traffic fatalities and injuries *(7)*. Albuquerque is consistently one of the most dangerous places to walk or travel by any means in the United States. Albuquerque had the 2nd highest pedestrian fatality rate among large U.S. cities in 2016 (the latest available year of data from the NHTSA) and in 2012 it was 3rd. Overall, Albuquerque had the 4th highest traffic fatality rate among large U.S. cities in 2016, a rate that has steadily increased since at least 2010. While these statistics are not entirely due to street design, improved designs could help.

While crime and security are not often thought of when discussing street design, there is a connection. Well-lighted streets have been shown to discourage some crime and can decrease the perception of crime too *(8)*. Less street crime, and a greater sense of security can lead to greater amounts of active travel and transit use, which can itself have a reinforcing effect on actual and perceived security *(9)*. Other street design features and maintenance that reinforce the street as an inviting and vibrant public space can help in this regard. Albuquerque has very little street lighting, low shares of pedestrian, transit, and bicycle travel and one of the highest property and violent crime rates in the country. While street design is not likely to be the main cause of these challenges, they can be part of a solution.

2. OBJECTIVES

This project is part of a larger research project that we refer to as the Albuquerque Streets Project (ABQ Streets), which aims to understand the multiple ways in which improvements to residential streets can affect the wellbeing of communities in Albuquerque. The ABQ Streets project will use several neighborhoods in the Albuquerque metropolitan area as natural laboratories where interdisciplinary teams of researchers can measure how changes to residential streets affect a wide range of outcomes including travel behavior, energy and water use, urban heat, runoff, crime, traffic safety and overall wellbeing. We also aim to find designs that would cost less to build and maintain – addressing the critical challenge that many cities face of funding routine street maintenance and rehabilitation.

What's unique about the ABQ Streets project is that it employs a research design to the urban street environment that up until now has been mostly used in ecological studies of the natural environment. The research team is working with the City of Albuquerque to identify a set of neighborhoods to test innovative street designs and a set of neighborhoods to act as controls. Through a coordinated effort with the city and its residents, the research team plans to collect an extensive amount of baseline data that can then be compared with data collected after alternative street designs are implemented by the city.

Few prior transportation studies have used a similar design owing to the difficulty of coordinating public works projects with research project funding. Studies that have collected before and after data, while controlling for exogenous changes, have been limited to individual transportation projects and have focused on a single outcome such as a change in mode share *(10, 11)* or have focused on larger facilities where traffic volume and speed were the focus (*12-14*). A vast majority of transportation studies with similar objectives to ours have used less robust research designs that leave many questions not fully answered about how transportation infrastructure can affect many dimensions of life in our cities and towns. For example, it has been very difficult to conduct research to determine if infrastructure design affects mode choice *(15-17)*.

The current TranSET project contributes to the ABQ Streets project by developing a set of alternative street designs that can be considered by the City of Albuquerque and its residents for implementation. The alterative designs will be informed with input from an interdisciplinary team of researchers with interests in different aspects of residential streets such as travel behavior (the focus of our Year 2 TranSET project), runoff, heat, crime, public health, and traffic safety. These designs would also be shared with communities where they might be implemented and with the city's public works and planning departments to gather additional perspectives and suggestions that will be used to develop a refined (or potentially new) set of designs. The development of innovative, feasible (financially and physically), and publicly-supported alternative street designs will be a critical piece of the overall ABQ Streets project.

The ABQ Streets project currently has funding for three related sub-projects from the City of Albuquerque, the National Science Foundation (NSF), and TranSET that support two graduate students in the Department of Civil, Construction and Environmental Engineering who are collecting important baseline community data. These sub-projects are collecting data on urban heat and runoff (funding from NSF through the Department's Center for Water and Environment), travel behavior (funding from our current, year 2, TranSET project) and current state of sidewalk quality (City of Albuquerque and year 1 TranSET project). The research team has also begun working with faculty in the Sociology Department to collect baseline data on crime and understand its potential relation to street design. Furthermore, UNM already collects traffic crash data for the New Mexico Department of Transportation (NMDOT) that can be used in this project. We use these baseline data and alternative designs and a partnership with the City of Albuquerque to answer our research questions.

Ultimately, it will be the community's and the city's decision whether to move forward with any of our designs and complete more detailed engineering and design work. The goal of this project is to complete the background research on alternatives, estimate the potential community benefits and costs, complete preliminary design work, and facilitate early community and city participation in this process. By completing these objectives, our aim is to remove some of the barriers to trying something new and ensuring a plan is in place to know if it eventually works. We know that the city and its residents are looking for ways to make the city's streets safer, provide transportation alternatives, reduce crime, and improve the overall street environment and so we believe there is a real opportunity for this project's findings to contribute to those goals.

These objectives are broken into three tasks. In Task 1, we complete a comprehensive literature review of prior studies that have investigated how street design elements affect the range of outcomes we are interested in including, urban heat, runoff, traffic safety, active travel, and crime. Street design elements include geometric design, materials, traffic controls, lighting, parking, and amenities such as street trees. We search for studies published in peer-reviewed journals and as theses and dissertations. We also consider reports and studies created by government agencies and their consultants that discuss benefits of various street designs (such as the Federal Highway Administration's "Proven Safety Countermeasures") or that describe the outcomes of street improvement projects.

Task 1 has two main products. The first is a comprehensive written report that summarizes the street design literature. The literature review identifies what is currently known about designs and design elements and what is less known. The literature review also discusses how prior studies evaluated street design and design elements, identifying the strengths and weaknesses of prior research methods. The second product is a table that summarizes the literature review. The table contains residential street design elements with corresponding information on their potential effect on each outcome (quantitative if possible, otherwise a qualitative indicator), a qualitative metric of the weight of evidence supporting the effect, and a qualitative assessment of relative cost.

In Task 2 the research team evaluates which street design changes could feasibly be implemented in the neighborhoods that we focus on for this research. For example, which designs will work within available street right of way, city budgets, local climate and geography and concerns and preferences of current residents. We focus on neighborhoods that have been identified as needing maintenance, are politically ready for change, and where the public has been receptive to change. Focusing on these neighborhoods provides the greatest potential to cost effectively implement new designs or design elements.

This task will include some basic surveying work to understand the width of existing right of way and drainage considerations for typical residential streets in our study neighborhoods. While some data and maps exist that describe the public right of way along Albuquerque's streets, in many cases these data are either inaccurate or developers and homeowners have built on the right of way. In our project we will focus on the right of way currently occupied by the existing street and sidewalk surfaces. Our conversations with planners and engineers in Albuquerque indicate that any construction beyond what is currently built, even if it is on public right of way, would be politically and legally difficult to complete.

Our year 2 TranSET project collected travel behavior data on residential streets and stated preference data about residential street infrastructure. These data were used to select designs that are likely to meet the needs of residents in the study neighborhoods and face less resistance.

The main products of Task 2 are a series of feasible alternative residential street design concepts. Design concepts will include drawings of typical street cross sections, describe materials used, and identify other significant design elements.

In Task 3 we estimate the expected annualized benefits (including, the reduction in urban heat, runoff, traffic crashes and crime and increase in active travel and related public health benefits) and costs (e.g., construction and maintenance) of the conceptual designs identified in Task 2. Benefits are estimated based on the information gathered in Task 1 and the use of the City of Albuquerque's City Engineer's Estimated Unit Prices document (contains unit prices for various street construction activities and materials). To the extent possible, benefits are also monetized to facilitate a rough cost benefit analysis. Not all benefits can be easily monetized such as a reduction in crime. Benefits that cannot be monetized are presented in their original quantities. Even a partial accounting of monetized benefits can be useful; for example, by showing that a subset of benefits alone could exceed the project's costs.

The main product of Task 3 is a table that can be used to compare the benefits and costs each alterative design. We will then use these findings to garner public and government input.

3. LITERATURE REVIEW

For Task 1, we have completed a comprehensive literature review of prior studies that have investigated how street design elements affect the range of outcomes we are interested in. These outcomes include active travel, personal safety and crime, traffic safety, runoff and urban heat. 130 pieces of research and design guides were referenced to understand the latest design approaches. We investigated innovative residential design alternatives from across the country and around the world. We considered practicality in terms of both new construction and redevelopment. The focus was primarily on studies published in peer-reviewed journals and as theses and dissertations. Consideration was taken for reports and studies created by government agencies and their consultants that discuss benefits of various street designs or that described the outcomes of street improvement projects. The following two products were produced:

- Product 1: A comprehensive written review of the street design literature. The literature review identifies what is currently known about designs and design elements and what is less known. The literature review also discusses how prior studies evaluated street design and design elements, identifying the strengths and weaknesses of prior research methods.
- Product 2: A table that summarizes the literature review. The table contains residential street design elements with corresponding information on their potential effect on each outcome (quantitative if possible, otherwise a qualitative indicator), a qualitative metric of the weight of evidence supporting the effect, and a qualitative assessment of relative cost.

3.1. Street Design Outcomes

Residential streets must accommodate the needs of all users: pedestrians, bicyclists, transit riders and motorists. The way a street is designed can result in numerous benefits for these users such as increased active travel, improved sense of community, enhanced pedestrian and cyclist safety, and reduced environmental impacts. This section will establish the importance of five street design outcomes that should be taken into consideration when retrofitting an existing neighborhood or creating a new one.

3.1.1. Active Travel and Transit

According to the U.S. Department of Transportation, about one in every four adults in the United States report that they do not engage in any physical activity outside their jobs *(18)*. Likewise, two of every three adults in the United States are overweight or obese *(18)*. Transportation engineers can create opportunities for people to be active, whether it is for recreation or utilitarian purposes. Active travel can be encouraged by reducing distances between desirable destinations and providing suitable bicycle and pedestrian facilities *(17, 19)*. Active travel facilities and public transit access are especially important in low-income neighborhoods because people living in these communities are less likely to own a vehicle and unsafe streets might deter pedestrians from active travel *(20, 21)*.

Another form of active travel that has recently gained popularity is shared micromobility, which consists of station-based bike share, dockless bike share and scooter share. According to the National Association of City Transportation Officials (NACTO), people took 84 million trips on shared micromobility in the United States in 2018 which was more than double the number of trips taken in 2017 *(22)*. While mass public transit remains the most efficient choice for long distance travel, transporting people to and from transit stations remains a common difficulty. This is typically referred to as the first-mile/last-mile challenge *(23)*. People are more likely to opt into public transit if there is a convenient and affordable way to get there. Micromobility provides environmental, social and economic benefits for a community and might be an answer to the first-mile/last-mile challenge *(24)*.

A key component for active travel is providing adequate infrastructure to support multimodality on our streets. Building bicycle infrastructure that meets specific criteria is important to improve user safety, reduce congestion, improve public health, and provide equitable access to jobs and opportunities *(25)*. In 2017, NACTO created *Designing for All Ages*, a guide for high-comfort bicycle facilities that considers factors such as vehicular speeds and volumes, operational uses, and observed sources and solutions for bicycling stress. In this urban bikeway design guide, planners and engineers collaborate on traffic calming techniques as well as roadway design changes such as buffered bike lanes or parking-protected bike lanes. Their All Ages & Abilities (AAA) bike facilities promote safe, comfortable and equitable designs for the entire city's bicycle network.

Travel can be subdivided into three linked components: the person, the vehicle and the built environment *(26)*. Travel is only successful if these three links are effectively joined. Mobility-impaired people typically have a barrier between themselves and their built environment. An interdisciplinary approach is the only way to break down those barriers and increase mobility for all users. Accessible busses are increasing the travel availability for the elderly and other mobility-impaired community members. Sun Van, ABQ RIDE's paratransit service provides accessible transportation to persons residing in or visiting the metro area whose impairment makes it impossible to ride the fixed route service *(27)*. When designing a functional residential street, transit and paratransit routes must be incorporated into the design process.

There are numerous ways to quantify levels of active travel and transit usage within residential streets. The percent of people walking or biking to work, the percent of children walking or bike to school and the number of recreational walks or bike rides could be measured. This data could be collected through a neighborhood survey or travel diary. Residents would be asked how they travel to work and how their children travel to school. Residents would recall their trips with the survey or record them in real-time with a diary. We might also ask how active the residents think they are and what design considerations would need to change for them to increase activity even more. One issue with this approach is difficulty in recalling time/distance/frequency of trips accurately, especially for recreational trips, active travel trips, and children's trips *(28)*.

Other data sources include the American Community Survey (ACS) and the National Household Travel Survey (NHTS). The ACS is an annual survey administered to a representative sample of Americans and reports commute mode share down to the block group level. The NHTS has been administered every five to eight years since 1969 and provides estimates of trip frequency and distance for a variety of modes. However, precaution should be taken when using NHTS data longitudinally – especially for active travel trips – because of several methodological changes that have occurred throughout the life of the survey *(29)*. Children's trips to school may also be gleaned from Safe Routes to School (SRTS) surveys. These surveys were widely administered while SRTS had earmarked funding in the federal transportation budget from 2005-2012. Several schools in the study area have data available in the SRTS National Data Collection System.

3.1.2. Personal Safety and Crime

Research has shown that changes to local streets can impact both perceptions of crime and objective crime outcomes. Specifically, studies have shown that improved street lighting can lead to improved perceptions of crime and lower crime rates, although results are mixed *(30, 31)*. A systematic review of pertinent literature found four American studies that saw decreases in crime after street lighting improvements and four studies that did not experience decreases in crime *(31)*. Five more recent British studies all showed decreases in crime. The overall reduction in crime for the thirteen studies was estimated at 20% compared to control areas *(31)*. Targeted lighting improvements were found to decrease crime occurrences while general lighting improvements were able to improve perceptions of crime *(30)*. Interestingly, lighting improvements have been found to improve crime both at night and in the daytime *(30, 31)*.

A research study was conducted by Cambridge University to determine the influence of street lighting improvements on crime, fear, and pedestrian street use, after dark *(32)*. Street lighting was upgraded in three urban streets and a pedestrian footpath, in the north, east and west areas of London. Attitudinal and behavioral measures were assessed by a before and after survey of pedestrians. Pedestrians were asked about their experience of crime in the area within the previous 12 months. The number of pedestrians were counted and on-site incidents of crime and disorder were noted. The after surveys showed that incidents of crime and disorder were significantly reduced in two of the three study streets. There was also data to support a significant drop in crime and disorder occurring in adjacent streets. This suggests that lighting has a positive impact on the area as a whole. The study area also saw an overall increase in pedestrian use after dark.

Several studies have found a significant negative relationship between urban street trees and crime *(33-35)*. Troy, Grove, & O'Neil-Dunne estimated that a 10% increase in tree canopy was associated with a 12% reduction in crime *(34)*. Smaller, view-obstructing trees were found to have a positive relationship with crime while mature street trees had a negative relationship *(33)*. While mechanisms have not been proven, the researchers hypothesize that neighborhoods and houses with more trees appear better cared for and therefore subject to more authority than houses on streets without trees present *(33)*.

A school of thought that says that proper design of the built environment can lower crime and improve perceptions of crime is known as Crime Prevention Through Environmental Design (CPTED) *(36)*. Such approaches have been shown to reduce crime *(37)*. The principles of CPTED include natural surveillance, which would be induced by street designs encouraging more street activity *(38)*. Cozens, Saville, and Hillier found that some CPTED approaches are dependent upon social conditions *(39)*. Similarly, past research has found that through-streets are safer than cul-de-sacs because of greater visibility from surrounding homes and more eyes on the street *(40)*. A difficulty in evaluating this relationship is the endogeneity implicit within. In other words, while crime may impact levels of street activity, levels of street activity (and their associated land uses) may impact crime, and so on *(41)*.

Personal safety and crime of a neighborhood can be quantified by gathering crime data from the local police department. Geographic Information System (GIS) data repositories occasionally provide crime data as a shapefile layer to be analyzed spatially. Knowing the number and location of crimes along residential streets can aid in mitigating perceived safety and crime. As previously mentioned, a neighborhood survey could be conducted throughout neighborhoods with potential safety and crime risks. Surveys are good initial indicators as to how people perceive safety and the level of concern throughout specific areas. The residents could rate their comfort walking down their street during the day, as well as at night. The survey would allow community members to voice their concerns, bringing into view possible design alternatives that had not been considered before. The survey can be conducted during the public meeting phase of the project.

3.1.3. Traffic Safety

According to NMDOT crash database, there were a total of 18,035 crashes in Albuquerque in 2017. About 10% of those crashes happened on local roads. 20% of those local road crashes resulted in an injury or fatality. Local roads are probably overrepresented in these statistics considering the fact that local roads have low vehicle volumes. There were 69 people killed on Albuquerque streets in 2018: 17 automobile drivers or passengers, 35 pedestrians, 13 motorcyclists, and 4 bicyclists. On a national scale, 36,560 lives were lost on U.S. roads in 2018. Of those fatalities, 6,283 pedestrians and 857 bicyclists were killed in traffic crashes *(42)*.

One way in which transportation engineers around the world are working towards safer roads is the implementation of Vision Zero. Vision Zero is a commitment to create safer streets for all people whether they are walking, biking, driving or taking transit, regardless of age or ability *(43)*. Vision Zero plans to eliminate all traffic fatalities and severe injuries, while increasing safe, healthy, equitable mobility for all. In May 2019, Albuquerque's Mayor Tim Keller signed an executive order committing the city to Vision Zero. The administration is currently forming an action plan to eliminate all traffic fatalities and injuries in the city. The Albuquerque city council unanimously passed a Complete Streets Ordinance in August 2019 giving the Vision Zero pledge some legislative backing and specific design criteria. Improving traffic safety for all road users is currently an important policy priority in Albuquerque and across the country.

Travel speed is an important component in residential traffic safety that can be influenced through design. Speed increases the possibility of a crash by impacting braking distance. Speed also increases the severity of crashes. According to the Federal Highway Administration, about half of speeding-related fatalities occur on lower speed collector and local roads *(18)*. Setting appropriate speed limits and providing designs that enforce them are key for the safety of all roadway users.

Both residents and road safety professionals advocate that residential speed limits should not exceed 30 mph considering the frequent human interaction with traffic *(44, 45)*. The most economical solution to manage speed is reducing the posted speed limit *(46)* which can improve with effectiveness over time *(44)*. However, the most efficient way to reduce speed through a neighborhood is reducing the speed limit in conjunction with physical design changes such as road width, bike lane, chicanes, mini roundabouts, etc.

A few miles per hour can make a difference between life and death of a pedestrian or cyclist. Danny Dorling, a Professor of Geography at the University of Oxford, suggests the implementation of 20 mph speed limits in residential areas. Dorling explains that introducing 20 mph zones would save lives, prevent injuries and reduce health inequalities in the process. Slowing down cars would reduce inequalities within cities because it tends to be in the poorer parts of cities that people are most at risk of being hurt or killed by cars *(47)*. From the years 2005-2007, Sheffield, UK experienced a noteworthy contrast of child deaths under the age of 10 in two constituencies with different socio-economics, indicating equity issues *(48)*. The risk of pedestrian fatality was calculated in the UK by Danny Dorling in 2014. The results indicated that there is a 50% chance of a fatality when hit by a vehicle traveling 40 mph *(47)*. As speed increases, so does risk. 20 mph should be the speed limit in residential streets in order to best protect the most vulnerable street users.

Changing the speed limit however, does not always result in drivers abiding by the rules and driving slower. Other than better signage, alterations in the street geometry and intersection design can help to further reduce speed and mitigate crash severity *(49-51)*. Figure 2 displays a chart from NACTO's *Urban Street Design Guide (52)*. As lane width increases, traffic speed also increases. For every 3.3 ft of additional lane width, vehicles were found to travel 9.4 mph faster. This traffic safety design consideration would be effective in residential neighborhoods due to the limitations of street space. A smaller street width would also help pedestrians and cyclists cross the street faster. If the existing street is currently too wide, solutions such as road diets – which typically replace a travel lane with a buffered bike lane – could also be implemented as a way to force low speed driving.

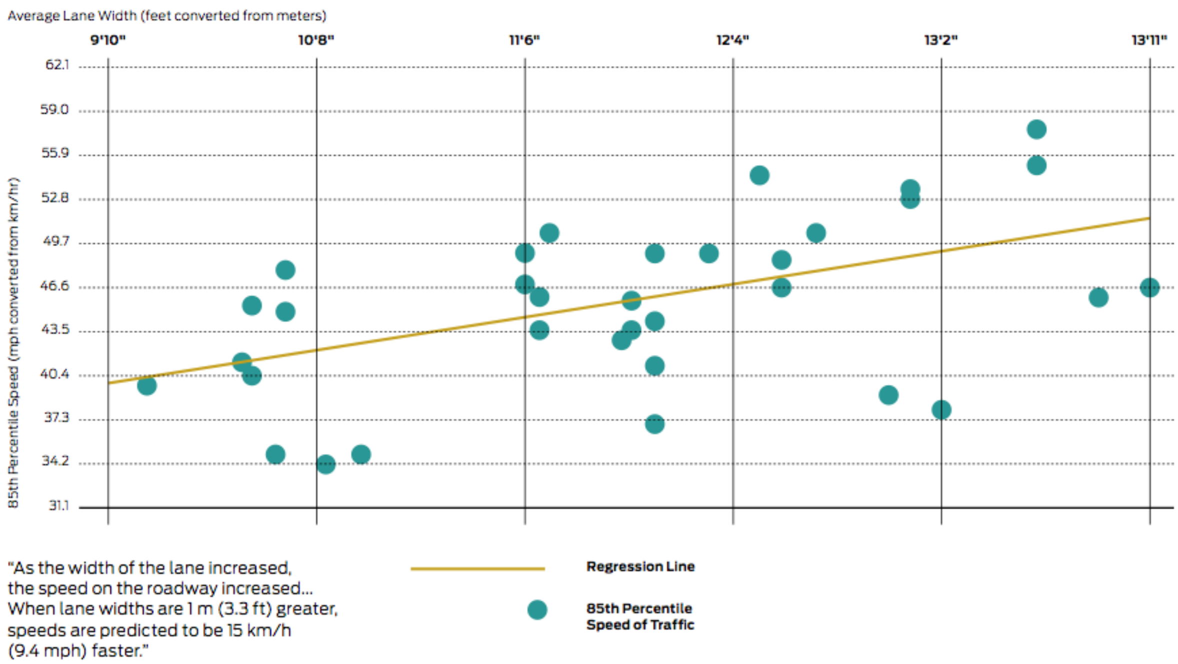

Figure 2. Wider travel lanes are correlated with higher vehicle speed. ***(52)***

In addition to altering driver behavior – primarily through decreased speeds or raised awareness – we can improve traffic safety by providing safe facilities for pedestrians and bicyclists *(53)*. Bicycle lanes provide greater separation between cyclists and vehicular traffic, reducing crash risk as well as perceived safety *(54, 55)*. A bicyclists level of comfort is directly related to proximity to motorized traffic *(56, 57)*. Bicycle encouragement stems from the desire to improve physical health, reduce automobile pollution and increase mobility and access. People's perceived safety and risk of bicycling near traffic, especially near intersections, remains a significant barrier to widespread cycling *(58)*.

We anticipate the procurement of traffic safety data from NMDOT. There is a statewide crash database that specifies user demographics and mode, vehicles involved, and roadway conditions that will inform us of safety outcomes for our study area. Understanding near-misses is a complex, expensive, and time-intensive exercise and is therefore outside the scope of this project. Traffic safety perceptions can be obtained from surveys during the public meeting phase of the project.

3.1.4. Water Runoff

When rain falls, there are two ways the water may travel. Option one is to seep into the ground, refilling the groundwater table. Option two is to become surface runoff. Physical characteristics that affect runoff are land use, vegetation, soil type, drainage area, elevation, slope, topography and drainage network patterns *(59)*. Common runoff destinations include rivers, oceans, ponds, lakes, reservoirs and sinks. When watersheds are urbanized, vegetation is replaced with impervious surfaces. Impervious surfaces significantly alter the natural hydrologic cycle by reducing infiltration of rainfall and increasing stormwater runoff *(60)*. To reduce flooding downstream, stormwater runoff must be retained. City streets are also required to have proper drainage to mitigate street flooding which can increase the chance of a car crash. Ponding at lows points in a street or parking lot can lead to premature deterioration of pavement. Runoff can be harmful due to its potential pollution accumulation as it travels over roofs, roads, agriculture land, near construction sites, etc. Stormwater typically picks up pollutants such as sediment, nutrients, bacteria, pesticides, metals and petroleum-by-products *(61)*. For all these reasons, incorporating more porous surfaces into street design such as permeable pavement may be an effect way to mitigate excess runoff *(62)* and preserve the biotic integrity of an aquatic ecosystem *(63, 64)*.

Brattebo and Booth examined the long-term effectiveness of permeable pavement as an alternative to traditional impervious asphalt pavement in Seattle, Washington *(65)*. After evaluating the performance of four permeable pavement systems overall a span of six years, almost all rainwater was captured by the pavement. The infiltrated water had low levels of copper and zinc and no motor oil was detected. This site in Washington State had favorable soil conditions and no sub-freezing weather indicating that further investigation is necessary for alternative climate zones. The cost of installing permeable pavement should be compared with the cost savings from reduced stormwater management. Permeable pavement has potential for long-term suitability as long as the limitations are properly considered. Porous pavements are most effective during small storms or early in larger events *(62)*.

3.1.5. Urban Heat Island Effect

As a city becomes more urban, buildings and roads replace open land and vegetation which results in an increase of impermeable surfaces. This forms an “island” of higher temperatures within the urban region *(66)*. Urban heat islands are important to minimize because they increase energy consumption, elevate emissions of air pollutants and greenhouse gases, compromise human health and comfort and impair water quality. Warmer outside temperatures prompt people to turn on their air conditioners, resulting in the burning of fossil fuels by electricity companies. Air pollution and increased daytime temperatures are harmful to human health by creating discomfort, respiratory issues, heat exhaustion and possibly heat strokes *(67)*. High pavement and rooftop surface temperature can heat stormwater runoff. Hot stormwater runs into streams, rivers and ponds and can negatively affect the aquatic life metabolism and reproduction *(68)*. Urban heat islands are not only impactful during the day, after sunset, temperatures can rise up to 22˚F warmer than the air in more rural neighboring regions *(69)*.

As previously mentioned, urban heat island effect causes increasing energy consumption for building cooling *(70)*. Tongji University in Shanghai, China, the University of California in Davis, CA, and Assiut University in Assiut, Egypt, investigated the optical and thermal properties of cool pavement nano-coatings for urban heat island mitigation. The study conducted by these three universities included the collection of ten non-white samples to evaluate the performance of pigments and coatings. The dominant factors to influence thermal performance was the visible and short wave near-infrared reflectance (400 nm-1100 nm). Based on this 2018 study, there is evidence that reflective cool pavement coating and non-glare colored coatings have potential to mitigate urban heat effect. Other strategies for urban cooling are the implementation of green spaces, trees, albedo, pavement surfaces, and vegetation *(71-73)*.

3.2. Street Design Elements

Street design elements have a significant impact on how residential streets function. Network connectivity dictates the access and mobility of a neighborhood. Barriers create roadblocks for this connectivity. Geometric design, green space, parking, sidewalks, and traffic control can positively or negatively affect traffic safety and overall livability. Alternative street materials can help mitigate environmental impacts. This section will detail each street design element in order to determine what components may be included in a successful neighborhood design.

3.2.1. Network Connectivity

A key design element that impacts roadway operation is street connectivity. Street connectivity can lead to better distribution of traffic flows, improve accessibility, lead to more use of amenities such as parks, and encourage the use of non-motorized modes of transportation *(74-76)*. The livability of a community is improved when a street network is adequately connected *(77)*. Motorists are not the only ones who benefit from a connected system. Pedestrians and bicyclists are more likely to travel for recreation and utilitarian reasons if streets are well connected *(78, 79)*. A well-connected street network typically takes the form of a traditional grid pattern *(80)*. Common characteristics of street network connectivity are short block lengths, numerous intersections, and minimal dead ends or cul-de-sacs *(77)*.

Marshall and Garrick investigated whether a relationship existed between street network characteristics and the transportation modes selected within a residential area *(81)*. The results concluded that street connectivity, street network density and street patterns were all significant in affecting mode of choice such as walk, bike, transit or drive *(78, 79, 81)*. Marshall and Garrick emphasized that the relationship between the built environment and mode choice should be accounted for in planning and design of our transportation system as the U.S. works towards reducing carbon emissions and energy use *(81)*.

Urban planners have recently debated whether the cul-de-sac street form should be removed from residential street design *(76, 82, 83)*. A few negatives resulting from closed-off streets are the following: automobile dependency, reducing communal interaction, difficult for emergency vehicles to navigate, added environmental impacts, and a decline in active transport to school *(84)*. Despite the negative aspects, people are drawn to cult-de-sacs due to their perceived privacy, quietness, and safety for children. Hochschild utilized a quasi-experimental design to assess differences in social cohesion for residents of “bulb” cul-de-sacs, “dead-end” cul-de-sacs and through streets *(82)*. Hochschild’s data revealed that bulb residents experience the highest levels of attitudinal and behavioral cohesion, followed by dead-end, then through streets. Although social behaviors are typically not the first area of concern for a transportation engineer, the relationship between street design and neighborly bonds should be considered *(82)*. The solution for making cult-de-sacs effective is connecting them to minor and major collector roads as well as minor arterials *(82)*. This allows for the benefits of cult-de-sacs while still providing access and mobility to higher volume streets.

3.2.2. Barriers

Neighborhood barriers come in many shapes and forms whether they are physical, environmental, or social barriers *(85-88)*. A river might run through a city, providing green space but also dividing neighborhoods and limiting access. Major arterials and highways present challenges as well as benefits when they are located near residential areas. People desire the mobility provided but dislike the nuisance of highway congestion, pollution, and noise *(85)*. Highways, arterials, and even collector roads can act as barriers for different road users *(89, 90)*.

Survey data was performed in the Netherlands to study residential satisfaction and highway nuisance perceptions *(91)*. The survey was collected from 1220 respondents living within 1000 m of a highway. The results showed that perceived highway nuisance was associated with increased intentions to move. When highway nuisance and intentions to move were low on the survey, residents expressed satisfaction with highway accessibility, buildings, traffic safety and amount of greenery. A more extensive study should be conducted to investigate whether the highway presents more positives than negatives for the neighborhood communities.

Analysists and researchers typically use crash data to determine if an area is unsafe for pedestrian or bicyclist activity and acting as a barrier *(92, 93)*. This can be problematic because areas of high concern might experience limited activity due to undesirable features such as poor lighting, inadequate sidewalks, or lack of bicycle facilities. Limited activity impacts crash data which in return affects the perception of safety. A proactive approach would identify and examine areas where pedestrian and bicyclist activity is being suppressed due to safety concerns *(90)*. A study was completed in Denver, Colorado to compare results from a reactive analysis looking at crash data to a proactive analysis examining parental perceptions. The study recommends that reactive and proactive safety approaches should be used in conjunction to obtain a more thorough investigation of traffic safety barriers.

Providing appropriate barrier crossings can have an influence on travel behavior and mode choice *(89, 94, 95)*. Roadway barrier crossings can include traffic control devices such as rectangular rapid flash beacons or HAWK signals, crosswalks, and traffic calming and speed management techniques that allow for safe crossings. Physical barriers such as major highways or rivers include pedestrian and bicyclist bridges. Being aware of barriers and integrating appropriate crossings when necessary will be an important aspect of this project.

3.2.3. Geometric Design

The geometric design of a roadway consists of three major elements: vertical alignment, horizontal alignment and cross section *(96)*. A roadway's cross section is an important roadway configuration that affects safety as well as traffic operations. Cross-section elements consist of the travel lanes, shoulders, medians, roadside barriers, curbs, gutters, and sidewalks *(96)*. Many of these elements have traditionally not been used on residential streets, such as shoulders, medians, and roadside barriers. More lanes have been shown to be associated with more traffic crashes and fatalities *(97, 98)*. Decreased lane width is associated with decreased fatalities *(98, 99)* or no increase *(100)*. However, much of this work was performed on highways and arterials. Increased number of lanes and lane width would also lead to more impermeable surface area, likely having negative impacts on urban heat and stormwater management. More lanes and vehicle volumes can also negatively impact interaction between neighbors and social cohesion *(101)*.

3.2.4. Traffic Calming

As volumes on a local street increase, so does the need for traffic calming devices *(102)* such as speed humps, speed tables, raised crosswalks, raised intersections, textured pavements, traffic circles, roundabouts, chicanes, neckdowns, center-island narrowing and chokers *(96)*. There are numerous reasons for implementing residential traffic calming techniques such as reducing crime *(103, 104)*, eliminate through traffic, improve pedestrian safety, beautification, strengthen businesses *(105)*, and improve public health *(106)*.

Traffic calming devices are generally divided into three categories: horizontal deflection, vertical deflection, and other. Horizontal deflection includes treatments that narrow a street or cause vehicles to move laterally. An example is the mini-roundabout, which is a solution to managing traffic at intersections where volumes do not warrant a signal. They are successful in reducing crash conflict points at the intersection of two local streets, as shown in Figure 3. Shared lane markings or intersection crossing markings can be provided to guide bicyclists through the intersection. Fifteen feet of clearance should be provided from the corner to the widest point of the circle *(52)*. The turn-radii must be kept tight to avoid high speed vehicles, which would compromise pedestrian and bicyclist safety. To accommodate larger motor vehicles, a mountable curb should be provided. Landscaping adds aesthetic appeal but should not block sight distance. The cost for a landscaped traffic circle on an asphalt street is about $6,000 and range from $8,000-$12,000 for a landscaped mini circle on a concrete street *(107)*. Other examples include curb extensions, chokers, and chicanes. Such horizontal deflection treatments are often the most expensive of the traffic calming options as they involve curb realignment.

Figure 3. Mini roundabout. ***(52)***

Vertical displacement treatments include speed humps, speed tables, and raised crosswalks. These treatments are generally cheaper than horizontal displacement. However, they can alter stormwater and snow management strategies and they can also be noisy and unpopular with residents living on the street. They may also disrupt the routes of emergency responders. Spacing of vertical displacement treatments is generally between 250-600 feet between treatments. Raised tables and intersections can also be used to accommodate pedestrians (Figure 4).

Figure 4. Raised crosswalk.

The other category includes treatments such as pavement markings, bollards, and street trees (Figure 5). These can be the most affordable options, although drivers do not physically interact with them so their effectiveness may be reduced.

Figure 5. Traffic calming pavement markings.

While traffic calming is a solution that takes an unsafe roadway configuration and improves performance, there are other design techniques that integrate safety and livability directly into the roadway configuration. An example of this design mindset is the woonerf (Figure 6). Woonerfs integrate different modes into a common space, allowing all road users of all ages to use the road *(108)*. They are typically narrow roads with unique paving materials and lateral offsets throughout to slow vehicles. Research has shown that woonerfs are correlated with considerable reductions in traffic crashes, increased social interaction and play, and a high degree of satisfaction by the residents *(108)*. The design is flexible and can integrate other design elements.

Figure 6. Woonerf.

3.2.5. Green Space

Local streets are commonly underutilized as public space. Overly wide or undifferentiated lanes enable speeding and cut-through traffic. Stormwater and green space projects streetscapes, rain gardens, and bioswales can reinvigorate streets and residential neighborhoods. Due to low traffic volumes and low sediment and debris, neighborhood streets are ideal sites for bioretention facilities and permeable pavements *(52)*. Planting strips create opportunities for large infiltrating surface areas (Figure 7). A curb extension planter at the downstream end of the block serves as a partial closure to manage vehicle volume and enforce low speed turns and through movements. Bioretention planters can be sited at curb extensions with low shrubs that maximize visibility. Researchers have found that – while context-sensitive – street trees provide benefits in terms of livability, health, and well-being for humans in addition to environmental benefits in terms of climate change, air quality, and cultural ecosystem services *(109)*. Greener neighborhoods have been shown to be correlated with better public health outcomes and lower obesity *(110, 111)*.

Figure 7. Planter strip. ***(52)***

3.2.6. Parking

There are several parking configurations possible on local streets. Parking may be predominately garage parking fed by either curb cuts along the local street or by alleys between local streets. Alternatively, parking may be found on-street.

One effective design element for reducing vehicle speed in residential neighborhoods is a narrow two-lane road with on-street parking which requires oncoming traffic to yield to one another *(112)*. These yield streets (also known as skinny streets or queuing streets) require one direction of traffic to yield to the other before executing their path through the street *(113, 114)*. According to NACTO's *Urban Street Design Guide*, two-way yield streets function most effectively at a street width of 24-28 feet when there is parking on both sides and a minimum of 16 feet when there is parking on only one side *(52)*. Yield streets are effective in mitigating the effects of driveway conflicts, reducing cut-through traffic, and maintaining low speeds *(52)*. Furthermore, yield streets have environmental benefits in terms of stormwater management because of less impermeable surface area *(115)*. Motorists should be able to use the street intuitively without the danger of head-on collision.

Another design option for the effective utilization of parking in residential neighborhoods is back alley parking (Figure 8). Back-alley parking is a design alternative that should be considered for new residential developments. There are certain disadvantages of back-alley parking such as addition pavement needed, add area of police patrol and appropriate amount of lighting. However, back alleys have gained some renewed popularity among neo-traditional and transit-oriented development *(116)*. Benefits include more design flexibility, more accessibility (less curb cuts), and greater community social life *(117, 118)*. Garages and driveways can be viewed as hazards in areas where walking is to be encouraged. Alleys provide the opportunity to park cars behind the home, reserving the front of the house for recreation and socialization with neighbors. Many alleys in modern cities are underutilized and could be converted to "green infrastructure" that promote walkability and mobility, play space and green cover, biodiversity conservation, and urban runoff infiltration *(119)*.

Figure 8. Back alley parking. ***(120)***

3.2.7. Sidewalks

Sidewalks provide comfort, safety and accessibility to pedestrians along city streets. According to the FHWA, roadways without sidewalks are more than twice as likely to have pedestrian crashes than sites with sidewalks on both sides *(120)*. Providing walkways separated from travel lanes can help to prevent up to 88% of "walking along crashes" *(121)*. Sidewalks dramatically increase perceived safety from pedestrians, encouraging more people to use them frequently. Paved shoulders also provide perceived and actual safety for pedestrian, bicyclists and motorists and are approved by New York State Department of Transportation and Oregon Department of Transportation on streets where sidewalks may be impractical *(122)*. They are a stable surface for people to walking on when a sidewalk is not provided, they improve roadway drainage and increase turning radii capacity at intersections. Paved shoulders also reduce shoulder maintenance, provide emergency stopping space, snow storage space, and message board space. The concept of not providing sidewalks on a residential street resonates with the woonerf concept above, where a street is so calm that segregated facilities for different modes are not necessary.

Like roadways, sidewalks should be designed for all users. A range of abilities for pedestrians can include children, elderly, parents with strollers, pedestrians with vision impairment and people with wheelchairs or other assistive devices. Parents have reported that sidewalks are the most important factor when determining whether to allow their child to walk to school *(90)*. Sidewalk design and operation must comply with the accessibility standards in the Architectural Barriers Act (ACA) of 1968, the Rehabilitation Act of 1973 (Section 504) and the Americans with Disabilities Act (ADA) of 1990 *(123)*. The sidewalk, also known as the pedestrian access route (PAR), must be a minimum of four feet wide per AASHTO standards with a 5x5 feet passing space every 200 feet *(124)*. However, the Federal Highway Administration (FHWA) recommends a minimum width of five feet when setback from the curb and six feet if at the curb face *(125)*.

3.2.8. Traffic Control

Determining what traffic control tools to implement at residential intersections can be a controversial topic. Some researchers advocate for two-way stops, others say four-way stops are superior, and some say residential streets do not need to be controlled at all *(126)*. Researchers compared operational issues for three intersections that were converted from two-way stop sign control to four-way stop control *(127)*. The study collected traffic volume, delay, and vehicle speed. They found that the four-way stop control caused unnecessary motorist delay and road user costs. The use of a four-way stop was 2.6 times less efficient than the use of the two-way stop. Mean midblock vehicle speeds were not affected by the difference of intersection control. However, 85th percentile speeds decreased by 2.3 mph after installing the four-way stop control. In addition, the stop sign violation rate increased by 11% after installing the four-way stop. Other research found that any increase in the level of control from stop to yield control tended to cause more vehicle crashes and fewer pedestrian crashes, although most of the changes were statistically insignificant *(128)*. Traffic circles, as discussed in the traffic calming section, can also serve as traffic control devices at low-volume intersections.

The Washington and Old Dominion (W&OD) Trail is a 45-mile multiuse trail in Virginia that connects the counties of Fairfax and Loudoun *(129)*. More than seventy highway crossings of the trail create potential crash spots for vehicles and pedestrians/bicyclists. In 2010, the Virginia Department of Transportation decided to implement zig-zag pavement markings at two of the crossings to test their safety effectiveness. Effectiveness was defined by VDOT as motorist awareness, a positive change in motorist attitudes and an understanding of the markings by people who were completely unaware of the study. Awareness was assessed by before and after speed studies. Attitudinal changes were assessed through surveys posted on government office websites and electronic newsletters. Understanding was assessed by handing out surveys in other regions to motorists that were unfamiliar with the zig-zag marking installation.

The results showed that the zig-zag markings did heighten the awareness of motorists. This conclusion was supported by reduced vehicle mean speeds within the marking zones. Survey responders indicated an increased awareness, a change in behavior and a higher tendency to yield than without the markings. This study recommends that the Federal Highway Administration should include zig-zag pavement markings in the Manual on Uniform Traffic Control Devices (MUTCD). They also recommend that the two test locations remain painted with zig-zag markings for continued driver improvement at crossings. The cost of installing zig-zag pavement markings was less than other safety countermeasures such as advance flashing beacons and overhead flashing beacons.

Less restrictive traffic control countermeasures are typically preferred however, sometimes a highly restrictive one is necessary. A diverter is an island built at a residential street intersection to prevent a combination of through and or turning movements (Figure 9) *(107)*. Diverters are effective countermeasures in mitigating reckless through traffic. Full street and partial street closures are two other examples of restrictive traffic control countermeasures *(107)*. These vehicle restrictive streets should still be fully accessible for bicyclists and pedestrians.

Figure 9. Street diverter. ***(107)***

3.2.9. Materials

One example of using a material alternative in residential street design is the use of pervious pavement *(130)*. Pervious pavement effectively treats, detains, and infiltrates stormwater runoff where landscape options are restricted or undesired *(52)*. Pervious pavement can be a solution for roadways, sidewalks, street furniture zones, parking lots or gutter strips. According to NACTO's *Urban Street Design Guide*, it is critical to design pervious pavement according to the native subsoil infiltration rate and void space. A geotechnical report is helpful to determine the permeability, water table and depth of the bedrock. The variation of pavement, such as permeable pavers, permeable concrete, permeable asphalt or others, should be selected based on geotechnical constraints and overall street context. When applied appropriately, pervious pavement is an effective alternative to stormwater management.

A second example of a material alternative is the implementation of white asphalt or reflective pavements to prevent urban heat *(131, 132)*. Reflective materials on urban structures such as roads and pavements aim to reduce the surface and ambient temperature as much as possible. An implementation project of cool asphalt and cool concrete pavements was conducted in a major traffic axis of Western Athens covering a 37,000m^2 area *(133)*. Extended monitoring occurred during the summer while a Computational Fluid Dynamics (CFD) simulation was used to estimate the thermal impact. The experimentalists concluded that cool non-aged asphalt can reduce ambient temperature by up to 1.5˚C (34.7˚F) and the maximum surface temperature reduction could be 11.5˚C (52.7˚F). This study supports the use of reflective pavement as a reasonable alternative for minimizing urban heat.

3.3. Summary

This comprehensive literature review summarizes prior studies that investigated how street design elements affect a range of outcomes including active travel, personal safety and crime, traffic safety, runoff, and urban heat. Active travel is convenient when the distance between desirable locations is reduced and efforts should be made to avoid barriers to network connectivity. Street network connectivity can also help reduce traffic volume and vehicle delay within a community. Traffic safety is important in local roads due to the high activity of pedestrians and bicyclists. 20 mph speed limits within residential areas can help to maximize the safety of all roadway users. Geometric design plays a key role in controlling vehicle speed. Micromobility is on the rise in our transportation systems and we must ensure that proper infrastructure is provided for these new modes. Vegetation can improve aesthetics but can also lower perceived safety if used improperly. Quality lighting in residential streets can increase personal safety and reduce the risk of crime. Stormwater runoff can be appropriately managed through alternative stormwater designs such as permeable pavement, bioretention cells and planting strips, thereby reducing the cost of capital investment in stormwater management infrastructure and reducing maintenance costs. Urban heat can be minimized through techniques such as reflective sealants for pavements. Green space can improve aesthetics of a roadway (thereby influencing travel behavior) and can also assist in improving environmental outcomes. Innovative parking configurations can either help to calm traffic on the street or – by back-loading parking – can avoid roadway clutter and provide more space for multimodal elements.

These findings are summarized in Table 1 which contains residential street design elements with corresponding information on their potential effect on each outcome (quantitative if possible, otherwise a qualitative indicator), a qualitative metric of the weight of evidence supporting the effect, and a qualitative assessment of relative cost.

Table 1. Literature review summary.

Design Elements	Weight of Evidence	Effectiveness (1-10)	Approximate Cost
Bicycle Facilities			
Bike Lane (Standard)	High	7	$1,000-11,000/mile
Shared Lane Markings	Low	1	
Buffered Bike Lanes	Medium	8	$1,000-11,000/mile
Protected Bike Lanes	Medium	8	$1,000-11,000/mile
Road Diet and Bike Lane (Re-striping)	High	7	$5,000-50,000/mile
Personal Safety and Crime			
Street Lighting	High	9	$300-1,400/light pole
Street Furniture	Low	5	
Street Trees	Medium	7	$430/tree
Barriers			
Pedestrian/Bicycle Bridge Overpass	Low	7	$150-250/square foot
Traffic Calming			
Rectangular Rapid Flashing Beacons	Medium	8	$4,500-52,000
PHB or HAWK Signal	High	8	$21,000-128,000
In-Street Pedestrian Crossing Sign	Medium	7	$240/sign
Striped Crosswalk	High	6	$8.51/linear foot
Raised Crosswalk	High	8	$7,000-30,000
Raised Intersection	High	7	$25,000-100,000
Speed Humps	High	7	$1,000-6,900
Speed Tables	High	8	$2,000-20,000
Traffic Circle or Mini Roundabout	High	9	$5,000-15,000
Roundabout (Concrete or Asphalt)	High	9	$25,000-100,000
Intersection Median Barriers	Medium	7	$15,000-20,000
Raised Median	Medium	7	$2,000-40,000
Chicanes	High	8	$2,000-16,000
Curb Extensions	High	9	$2,000-25,000
Green Space			
Rain Garden and Bioswale	Medium	8	$5-20/square foot
Bioretention Basins	High	8	$0.69-2.30/square foot
Curb Extension Planter	Medium	6	$2,000-20,000
Parking			
Yield Streets	Medium	7	Initial Construction Cost
Back Alley Parking	Low	5	Initial Construction Cost
Sidewalks			
Concrete Sidewalk	High	8	$32/linear foot
Sidewalk Separation	Low	6	
Alternative Material Sidewalks	Low	5	
No Sidewalks	Low	5	$0
Traffic Control			
Two-Way Stop	High	7	$200-500/sign
All-Way Stop	Medium	6	$200-500/sign
Pedestrian Traffic Signal	High	8	$8,000-150,000
Island Diverter	Low	7	$5,000-85,000
Full and Half Street Closure	Low	7	$500-120,000
Zig-Zag Pavement Markings	Low	5	$2,850
Materials			
Porous Pavement	Medium	7	$1.66-9.98/square foot
White Asphalt	Low	6	$26/gallon
Geometric Design			
Narrow lanes			
Tight turning radii	High	9	

4. METHODOLOGY

After compiling information on design elements and their associated outcomes, our next step was to use these design elements in residential street alternatives. The alternatives were applied to an existing neighborhood in Albuquerque to understand their feasibility. We selected the Fair West neighborhood of Albuquerque as our test neighborhood. This neighborhood was selected because of political willingness for change in the street design and interest expressed from the local neighborhood association. In addition, this neighborhood is representative of other neighborhoods throughout Albuquerque, hopefully providing the opportunity for widespread applicability.

Figure 10. Fair West neighborhood in Albuquerque.

We determined street widths and number of intersections using Google Maps. Street widths throughout the neighborhood were 40’ wide from outside of sidewalk to outside of sidewalk. Sidewalks were 5’ on either side of the roadway resulting in 30’ of asphalt width. There were 49,598.94 feet (9.39 miles) of local streets in the residential zone. This resulted in 1,487,968.20 square feet of asphalt in the neighborhood. There are 64 intersections throughout the neighborhood.

All streets within the neighborhood are considered local streets. We only examine local streets inside the neighborhoods, not the collectors or arterials that surround it. The neighborhood is bounded by Lomas Boulevard NE on the north, San Pedro Drive NE on the east, Central Avenue NE on the south, and San Mateo Boulevard NE on the west. There are a few streets that connect the neighborhood to other neighborhoods across the surrounding collectors or arterials. While Alvarado Drive NE continues through Central Avenue NE on the south side, all other north/south local roads are internal to neighborhood. Alvarado Drive NE also connects to the north across Lomas Boulevard NE for pedestrians and bicyclists but not for motor vehicles. There are no other inter-neighborhood north/south connections. In terms of east/west connections, Copper Avenue NE has traffic signals on San Mateo Boulevard NE and San Pedro Drive NE. Copper Avenue NE continues into the neighborhood to the west. The New Mexico State Fairgrounds are to the east, so there is no through connection to the east. While Grand Avenue NE and Marquette Avenue NE connect to the neighborhood to the west, the roads dissipate into the western neighborhood and do not provide true connectivity or through movements.

The typical street design in the Fair West neighborhood allows for on-street parking on both sides of the local streets. There are approximately 8-10 curb cuts per block allowing for driveway access. All streets throughout the neighborhood have a similar design except for Copper Avenue NE which already has some traffic calming treatments in the form of traffic circles, double yellow striping, and shared lane markings.

Figure 11. Typical street design in Fair West neighborhood.

We organized the alternatives generally in order of cost and complexity. The first alternative consists of only pavement markings including demarcating the lanes with double yellow striping, single white striping for the parking lanes, crosswalk and stop bars at the intersections, and six zig-zag pavement markings throughout the neighborhood. This alternative will primarily act as traffic calming by better defining space and will not have significant impacts on environmental factors, travel behavior, or crime.

The second alternative uses traffic circles to further calm traffic. To coincide with traffic calming spacing guidance from the literature review, we select eight intersections on which we install traffic circles. This further has a further impact on traffic safety, but is still not expected to have a significant impact on environmental outcomes, travel behavior, or crime.

The third alternative is to add street lighting. Because the north/south blocks are longer than the east/west blocks, we have specified two street lights on each north/south block (78 blocks total) and one street light on each east/west block (68 blocks total). This results in a total of 224 street lights throughout the neighborhood. We specify steel light poles and LED lights. We assume that this treatment will have an impact on traffic safety at night as well as impact crime.

The fourth alternative is to add street trees. While street trees have been shown to have a traffic calming effect, this treatment also begins to accrue environmental benefits. Because there is no separation between existing pavement and sidewalk and we do not want to disturb private property, we use curb extensions to create a place for street trees. We assume eight-foot-tall deciduous trees that are suitable to Albuquerque's climate. We assume that each tree will need 100 gallons of irrigation per week according to Albuquerque and Bernalillo County Water Utility Authority guidance.

The fifth and sixth alternatives are focused on pavements and materials. Permeable asphalt is used to control stormwater and white asphalt sealant is used to reduce urban heat. We assume that all existing asphalt will undergo these treatments. Since we are assuming that traditional asphalt would be laid anyway, we determine the added cost for the permeable pavement. Because asphalt sealants are traditionally not used on roadways, we assume that the white asphalt sealant is a new cost.

The seventh alternative is more radical. Alternative seven is a woonerf that combines curb extensions, bollards, street trees, lighting, and street furniture.

We estimate the costs and benefits for each alternative. We attempt to account for materials, labor, installation, operations, and maintenance when compiling costs. We annualize all the costs using capital recovery equations. We assume an inflation rate of 1.0% to annualize costs.

Motor vehicle collision data was gathered from NMDOT. The collision data is cleaned by the University of New Mexico's Geospatial & Population Studies unit and is provided in GIS format. There was an average of 17 reported motor vehicle crashes per year over the three most recent years for which data were available (2015-2017). Five of these seventeen motor vehicle collisions occurred in the dark and fourteen of them occurred at intersections. There were and average of eight injury collisions per year (C on the KABCO scale) and the rest were property damage only (PDO). Two bicyclists were struck over the three years and no pedestrians. We used these averages for analysis when determining the possible reduction in motor vehicle collisions.

To monetize the crash data, we used the *FHWA Highway Safety BCA Guide and Tool (134)*. This guidance assumes a cost of $11,900 for the average PDO collision and $125,600 for the average c-injury collision nationwide. There was an adjustment factor of 0.78286 for New Mexico, meaning that the average PDO collision was $9,316.03 and the C-injury collision was $98,327.22 in New Mexico. This results in a total annual traffic safety cost within the Fair West neighborhood of $786,618 for injury collisions and $83,844 for PDO, or $870,462 total annually.

Crime data was gathered from June 1, 2020 until September 30, 2020, representing one-quarter of a year. We would have preferred to use historical data as crime may have changed during the COVID-19 pandemic, but such data was not available. We only recorded nighttime crimes because lighting was the only treatment we anticipated would significantly impact crime. The data is compiled, cleaned, and reported by the Albuquerque Police Department. This information is pulled from daily calls for service, which reflect all calls made to APD's 911 Emergency Communications Center. It does not reflect all crimes that police investigate, nor the final outcome of crimes investigated. Furthermore, it may not reflect the true location of all crimes as they may have occurred at a different location from which they are reported.

There was a total of 14 assaults, two burglaries, two motor vehicle thefts, and two theft/larcenies at night that were reported to police in the Fair West neighborhood within the three-month study period. There were also numerous incidences of disturbing the peace, but those were not accounted for in the analysis. Although disturbing the peace incidences may have an impact on property values and other qualitative measures, it is difficult to quantify the impacts of such minor events.

Using values provided by past research for the cost of different types of crime *(135)*, assaults were assumed to cost $107,020 each, motor vehicle thefts $10,772, burglary $5,480, and theft/larceny $3,532. The total cost of nighttime crime (excluding disturbing the peace) was $1,537,848 for the quarter, or $6,151,392 per year within the Fair West neighborhood.

5. ANALYSIS AND FINDINGS

5.1. Alternative 1: Pavement Markings

The simplest alternative was adding pavement markings to the roadways. The pavement markings included double yellow centerlines, single white lines to designate parking lanes, crosswalks, stop bars, and zig-zag pavement markings (Figures 12 & 13). All roads will have double-yellow centerlines and parking lanes added to their entire extents. Every intersection will have a crosswalk for each approach. Every stop-controlled approach will have a stop bar installed. We include zig-zag pavement markings to slow traffic at locations with long stretches lacking stop control.

Figure 12. Pavement markings midblock (before and after).

Figure 13. Pavement markings at an intersection (before and after).

Copper Avenue already has double yellow striping, so the length of double yellow striping is lower than the parking lane striping length. The total length of roadway is multiplied by two for each of the striping types because every linear foot will have two yellow stripes and two white stripes. Total capital costs were estimated to be $402,526 (Table 2). A lifespan of three years was assumed for all pavement markings. Annualizing over the lifespan of the treatments, the annual cost comes to $136,868 annually. Because these prices were provided by the city for construction estimates, we assume that these costs account for materials and labor.

Table 2. Pavement marking costs.

Item	Count	Unit	Unit Cost ($)	Capital Cost ($)	Lifespan (yrs)	Annual Cost ($)
Double Yellow	93,966	ft	0.95	89,268	3	30,353
Parking Lane	99,198	ft	0.95	94,238	3	32,043
Crosswalk	256	ea	770.00	197,120	3	67,025
Stop Bar	1,920	ft	2.50	17,100	3	5,814
Zig-Zag Marking	6	ea	2,850.00	4,800	3	1,632
Total				**402,526**		**136,868**

In terms of the traffic safety benefits, fourteen of the seventeen annual motor vehicle collisions occurred at intersections while three occurred midblock. Eight of the seventeen crashes resulted in an injury. We applied a crash modification factor (CMF) of 0.85 for edgeline pavement markings to the midblock collisions and a CMF of 0.81 for high-visibility crosswalks to the intersection collisions. The CMF for edgeline pavement markings was specifically for rural roads, but we used this one because there was no similar CMF for urban roads. The fourteen intersection collisions would be reduced by 2.66 collisions and the three midblock collisions would be reduced by 0.45 collisions. Assuming the injuries are evenly distributed between the location types, we would see a reduction of $143,905 in injuries and $15,339 in PDO.

Gross benefits were estimated to be $159,244 annually. Therefore, the pavement marking alternative would provide $22,376 in net benefits after the annual costs are subtracted. The only quantifiable benefits came from reduced motor vehicle collisions. We suspect that the traffic calming effects of the pavement markings may increase walking and biking activity and therefore have some indirect environmental and health benefits, but any quantification of this would be uncertain. We do not foresee any benefits in terms of crime, urban heat, or stormwater management.

5.2. Alternative 2: Traffic Circles

The next alternative was to add traffic circles to intersections throughout the neighborhood (Figures 14 & 15). Traffic circles already existed at four intersections along Copper Avenue. We therefore added traffic circles throughout the rest of the neighborhood. We preserved appropriate spacing to ensure that the treatments were effective. We distributed the traffic circles throughout north/south and east/west corridors.

Figure 14. Traffic circle placement (existing in orange, proposed in blue).

Figure 15. Traffic circle (before and after).

Total capital costs were estimated to be $80,000 (Table 3). Since traffic circles would be constructed with concrete curbing, a lifespan of 25 years was assumed. Annualizing over the lifespan of the treatments, the annual cost comes to $3,633 annually.

Table 3. Traffic circle costs.

Item	Count	Unit	Unit Cost ($)	Capital Cost ($)	Lifespan (yrs)	Annual Cost ($)
Traffic Circle	8	ea	10,000.00	80,000	25	3,633
Total				**80,000**		**3,633**

The only quantifiable benefits came from reduced motor vehicle collisions. We suspect that the traffic calming effects of the traffic circles may increase walking and biking and therefore have some indirect environmental and health benefits, but any quantification of this would be uncertain. We do not foresee any benefits in terms of crime, urban heat, or stormwater management.

In terms of the traffic safety benefits, fourteen of the seventeen annual motor vehicle collisions occurred at intersections. Eight of the seventeen crashes resulted in an injury. We applied a CMF of 0.22 for injury collisions and a CMF of 0.61 for PDO collisions. These CMFs were for roundabouts as the FHWA did not provide CMFs for traffic circles. Injury collisions would be reduced by 5.14 collisions and PDO would be reduced by 2.89 collisions. We therefore expect to see a reduction of $504,402 in injuries and $26,923 in PDO. Because we added eight traffic circles to the total of 64 intersections, we divided these total possible benefits by a factor of eight. The resulting benefits were therefore $63,175 for injuries and $3,365 for PDO.

Gross benefits were estimated to be $66,540 annually. Therefore, the traffic circle alternative would provide $62,907 in net benefits after the annual costs are subtracted.

5.3. Alternative 3: Lighting

The next alternative was to add street lighting (Figure 16). Lighting already existed at the intersections within the neighborhood. However, lighting was absent from the long north/south blocks to which the houses in the neighborhood face and the east/west blocks. We therefore added two lights to each north/south block and one light to each east/west block in the neighborhood. There were 78 north/south blocks and 68 east/west blocks throughout the neighborhood, resulting in a total of 224 lighting installations.

Figure 16. Lighting (before and after).

Total capital costs were estimated to be $1,102,080 (Table 4). Lifespans of 75 years for the light poles and 10 years for the LED lights were assumed. Annualizing over the lifespan of the treatments, the annual cost for the treatments themselves comes to $21,733 annually. We also accounted for energy usage for the lights. We assumed 90 Watts and 32 kWh per month at a rate of $0.12/kWh for each of the 224 lights. This comes to an annual total of $10,322 for energy usage. The total annual costs are therefore $32,055.

Table 4. Lighting costs.

Item	**Count**	**Unit**	**Unit Cost ($)**	**Capital Cost ($)**	**Lifespan (yrs)**	**Annual Cost ($)**
Light Pole	224	ea	4,880.00	1,093,120	75	20,787
LED Light	224	ea	40.00	8,960	10	946
Energy						10,322
Total				**1,102,080**		**32,055**

Quantifiable benefits came from reduced motor vehicle collisions and reduced crime. We suspect that enhanced lighting may increase walking and biking and therefore have some indirect environmental and health benefits, but any quantification of this would be uncertain. We do not foresee any benefits in terms of urban heat or stormwater management.

In terms of the traffic safety benefits, five of the seventeen annual motor vehicle collisions occurred at night. We assumed that three of the crashes are PDO and two are injury, which aligns with the injury severity distribution for the neighborhood. We applied a CMF of 0.69 for injury collisions and a CMF of 0.84 for PDO collisions as provided by FHWA for illumination. Injury collisions would be reduced by 0.62 collisions and PDO would be reduced by 0.48 collisions. We therefore expect to see a reduction of $60,963 in injuries and $4,472 in PDO.

We also expect some improvement in crime. Based on past research detailed in the literature review, we assume that there would be a 20% reduction in crime. The total cost of nighttime crime (excluding disturbing the peace) was $1,537,848 for the study quarter, or $6,151,392 per year for the Fair West neighborhood. We estimate that 75% of this crime occurred indoors and would therefore not be impacted by street lighting enhancements. The annual costs of nighttime, outdoor crime would therefore be $1,537,848. Reducing this crime by 20% would result in $307,570 in annual benefits.

Gross benefits were estimated to be $373,005 annually. Therefore, the street lighting alternative would provide $340,950 in net benefits after the annual costs are subtracted.

5.4. Alternative 4: Street Trees

The next alternative was to add street trees throughout the neighborhood (Figure 17). There is no existing tree lawn present on the streets in Fair West. We therefore proposed the installation of curb extensions that would then house the street trees and other native plantings. These planted areas could function as rain gardens to manage stormwater on site. We proposed two such planted areas on each north/south block throughout the neighborhood, resulting in a total of 156 street tree extensions.

Figure 17. Street trees (before and after).

Total capital costs were estimated to be $2,077,502 (Table 5). Since the planted areas would be constructed with concrete curbing, a lifespan of 25 years was assumed. A lifespan of 25 years was also assumed for the street trees. We assumed that the trees and other plantings would need 100 gallons of irrigation per week. At the current Albuquerque and Bernalillo County Water Utility Authority rate of $1.63 per unit (a unit is equivalent to 748 gallons), we assumed an annual cost of $1,768 for irrigation. Annualizing over the lifespan of the treatment, the annual cost comes to $96,100 annually.

Table 5. Street trees costs.

Item	**Count**	**Unit**	**Unit Cost ($)**	**Capital Cost ($)**	**Lifespan (yrs)**	**Annual Cost ($)**
Street Tree	156	ea	317.32	49,502	25	2,248
Curb Extension	156	ea	13,000.00	2,028,000	25	92,085
Irrigation						1,768
Total				**2,077,502**		**96,100**

We expect street trees to have a variety of benefits across several categories. However, many of those benefits are difficult to quantify. We expect the general beautification to increase walking and biking activity and to therefore have some indirect effect on health and reduced air pollution. Quantifying that change would be imprecise. We also expect that beautification of the neighborhood may have a positive impact on crime, but that has not been proven with past research and estimating for our case would be difficult.

In terms of environmental impacts, we anticipate that stormwater would be able to be managed on site and that the street trees would have a cooling effect. The average annual benefits per street tree are estimated to be $56/tree for stormwater, carbon dioxide, energy use, stormwater, and aesthetic benefits *(136)*. The average annual cost is estimated to be $29/tree for administration, inspection, and pruning. The net benefit is therefore $27/tree for our 156 trees, or a total annual benefit of $4,212.

In terms of the traffic safety benefits, we anticipate that the street trees would have a traffic calming effect, but FHWA does not provide specific CMFs for street trees or for curb extensions. We therefore used general CMFs for area-wide traffic calming of 0.89 for injuries and 0.95 for PDO. Injury collisions would be reduced by 0.88 collisions and PDO would be reduced by 0.45 collisions. We therefore expect to see a reduction of $87,511 in injuries and $8,850 in PDO.

Gross benefits were estimated to be $100,573 annually. Therefore, the street tree alternative would provide $4,473 in net benefits after the annual costs are subtracted.

5.5. Alternative 5: Permeable Asphalt

The next alternative was to pave the neighborhood with permeable asphalt (Figure 18). Doing so is expected to allow for stormwater to be managed on site. Since the roadways would typically be repaved periodically, we only account for the additional cost of the new material above and beyond the current standard of practice. We assume that permeable asphalt is 50% more expensive than traditional asphalt *(137)*. Assuming traditional asphalt is $12.95 per square yard per the Albuquerque City Engineer's Estimated Unit Price, permeable asphalt will be $19.43 per square yard, or $6.48 more expensive per square yard than a traditional asphalt. At 165,330 square yards of pavement throughout the Fair West neighborhood, the permeable asphalt would be $1,071,338 more expensive.

Figure 18. Permeable asphalt.

Total additional capital costs were estimated to be $1,071,338 (Table 6). Lifespan is assumed to be 15 years. Annualizing over the lifespan of the pavement, the annual additional cost comes to $77,269 annually.

Table 6. Permeable asphalt costs.

Item	Count	Unit	Unit Cost ($)	Capital Cost ($)	Lifespan (yrs)	Annual Cost ($)
Perm. Asphalt	165,330	SY	6.48	1,071,338	15	77,269
Total				**1,071,338**		**77,269**

The only quantifiable benefits came from reduced investment in stormwater management infrastructure. Although stormwater management infrastructure is already in place, there has been a need identified to improve the infrastructure. We assume that this treatment will prevent the need to upgrade the existing stormwater management infrastructure, thereby saving costs. Of course, if other surrounding neighborhoods are still having issues, the infrastructure may still need to be constructed. We use the Marble-Arno Stormwater Pump Station and Detention Pond, a $17 million project in Albuquerque, as an example. This project will serve the neighborhoods of Barelas, Martineztown, and Santa Barbara in Albuquerque. Since Fair West is a smaller neighborhood, we assume that our proposed treatment would save 15% of this cost over a 150-year lifespan. We would therefore avoid $32,895 in annualized capital costs for such upgrades. We could also expect to avoid some annual maintenance costs for the stormwater management infrastructure that we have evaded, but this would most likely be offset by additional maintenance costs for the permeable asphalt itself.

Gross benefits were estimated to be $32,895 annually. Therefore, the permeable asphalt alternative would actually result in $44,374 of additional annual costs after accounting for the stormwater management benefits.

5.6. Alternative 6: White Asphalt

The next alternative was to seal the asphalt with a white sealant to reflect sunlight and avoid urban heat (Figure 19). Since normal streets are not sealed, this will be treated as an additional cost. According to a sales quote from US Specialty Coatings out of Alpharetta, GA, Save The Planet (STP) Asphalt Sealer in color white costs $19 per gallon. Average coverage is 250 square feet per gallon per coat and two coats are required. Therefore, the cost of the white asphalt sealant is $1.37 per square yard (Table 7). At 165,330 square yards of pavement throughout the neighborhood, the permeable asphalt would be $226,502. Although there would be varying equipment, mobilization, and preparation costs for individual cases, we assume an extra cost of $2.70 per square yard or a total of $446,391 for installation *(138)*. This brings the total for materials and labor to $672,893. Assuming a five-year lifespan, this is $138,642 annually.

Figure 19. White asphalt sealant installation.

Figure 20. White asphalt sealant (before and after).

Table 7. White asphalt costs.

Item	Count	Unit	Unit Cost ($)	Capital Cost ($)	Lifespan (yrs)	Annual Cost ($)
White Sealant	165,330	SY	1.37	226,502	5	46,668
Installation Labor	165,330	SY	2.70	446,391	5	91,974
Total				**672,893**		**138,642**

The only quantifiable benefits came from reduced urban heat and corresponding reductions in energy use. The only research that we found quantifying the benefits of reduced urban heat were from a study of Los Angeles in 1997 *(139)*. The researchers estimate that the kWh savings from converting the streets of Los Angeles to high albedo pavements would be $15,000,000 per year. Converting this to 2020 dollars and using the same per capita energy savings applied to the Fair West neighborhood, this would result in $11,875 of reduced energy consumption per year.

Gross benefits were estimated to be only $11,875 annually. Therefore, the white asphalt sealant would cost an additional $126,767 per year.

5.7. Alternative 7: Woonerf

A woonerf is a design concept that combines many treatments together into what the Dutch call a ‘living street’. To conceptualize this design in an American context, we combine many of the former alternatives (Figure 21). We avoided any pavement material changes as that would have greatly increased the cost with minimal benefits. Our woonerf design includes all pavement markings from Alternative 1, eight traffic circles as detailed in Alternative 2, lighting as detailed in Alternative 3, and street trees housed in curb extensions as detailed in Alternative 4. We also included street furniture, adding one bench for each curb extension throughout the neighborhood. We also added two woonerf signs per block to make drivers aware of the radical design present.

Figure 21. Woonerf (before and after).

Total capital costs were estimated to be significantly higher than any of the other alternatives at $3,847,016 (Table 8). Annualizing over the lifespan of the treatments, the annual cost comes to $277,341 annually, which is approximately double the next most expensive alternative.

Table 8. Woonerf costs.

Item	Count	Unit	Unit Cost ($)	Capital Cost ($)	Lifespan (yrs)	Annual Cost ($)
Double Yellow	93,966	ft	0.95	89,268	3	30,353
Parking Lane	99,198	ft	0.95	94,238	3	32,043
Crosswalk	256	ea	770.00	197,120	3	67,025
Stop Bar	1,920	ft	2.50	17,100	3	5,814
Zig-Zag Marking	6	ea	2,850.00	4,800	3	1,632
Traffic Circle	8	ea	10,000.00	80,000	25	3,633
Light Pole	224	ea	4,880.00	1,093,120	75	20,787
LED Light	224	ea	40.00	8,960	10	946
Energy						10,322
Street Tree	156	ea	317.32	49,502	25	2,248
Curb Extension	156	ea	13,000.00	2,028,000	25	92,085
Irrigation						1,768
Street Furniture	156	ea	1,000.00	156,000	25	7,083
Woonerf Sign	292	ea	99.00	28,908	20	1,602
Total				**3,847,016**		**277,341**

We anticipate that there will be quantifiable benefits in terms of traffic safety, crime, and environmental considerations. In terms of traffic safety, we need to apply CMFs in a sequential order. We therefore disaggregated the motor vehicle collisions by intersection location, injury severity, and lighting condition and applied the CMFs mentioned in the preceding alternatives. It is estimated that 3.13 injury collisions and 2.61 PDO collisions avoided resulting in total annual benefits of $332,379.

In terms of crime, benefits would be accrued from the street lighting. Based on past research detailed in the literature review, we assume that there would be a 20% reduction in crime. The total cost of nighttime crime (excluding disturbing the peace) was $1,537,848 for the study quarter, or $6,151,392 per year for the Fair West neighborhood. We estimate that 75% of this crime occurred indoors and would therefore not be impacted by street lighting enhancements. The annual costs of nighttime, outdoor crime would therefore be $1,537,848. Reducing this crime by 20% would result in $307,570 in annual benefits.

The street trees may provide environmental benefits. We anticipate that stormwater would be able to be managed on site and that the street trees would have a cooling effect. The average annual benefits per street tree are estimated to be $56/tree for stormwater, carbon dioxide, energy use, stormwater, and aesthetic benefits *(136)*. The average annual cost is estimated to be $29/tree for administration, inspection, and pruning. The net benefit is therefore $27/tree for our 156 trees, or a total annual benefit of $4,212.

Gross benefits were estimated to be $644,161 annually. Therefore, the woonerf alternative would provide $366,820 in net benefits after the annual costs are subtracted.

We anticipate that there are also qualitative benefits to the woonerf alternative as the neighborhood begins to have a unique sense of identity. It may help the neighborhood become a special destination, with benefits to wellbeing and pride and engagement in the neighborhood. Property values may rise, which may be both positive and negative due to gentrification concerns.

5.8. Summary

The highest net benefits were accrued by the woonerf alternative (Table 9). Although costs were high, we predict that the woonerf alternative will see significant benefits in terms of traffic safety and crime reduction, additional benefits in terms of the environment, and qualitative quality of life benefits, in addition to providing the greatest aesthetic and sense of place benefits as well. The second highest net benefits were accrued by the street lighting alternative. This was driven primarily by the fact that we assumed that the lighting alternative would decrease crime and improve traffic safety, the only other alternative to accrue quantifiable benefits in both categories. The next most beneficial alternative was traffic circles. We expected traffic circles to result in traffic safety improvements while the long lifespan of the treatments resulted in relatively low annual costs. The pavement markings had significant traffic calming benefits, but the short lifespan and the extensive roadway network resulted in high costs, making the pavement marking alternative fourth. The street tree alternative was fifth. Although the trees themselves would have had significantly higher benefits, the fact that curb extensions would need to be provided resulted in high annual costs. The costs of both material treatments outweighed their respective benefits. Both had relatively low benefits and relatively high costs thanks to the shear amount of roadway that needed to be treated (9.4 miles in length by 30 feet in width).

Table 9. Alternative cost/benefit summary.

Alternative	Capital Cost ($)	Annual Cost ($)	Gross Annual Benefit ($)	Net Annual Benefit ($)
1: Pavement Marking	402,256	136,868	153,244	22,376
2: Traffic Circles	80,000	3,633	66,540	62,907
3: Lighting	1,102,080	32,055	373,005	340,950
4: Street Trees	2,077,502	96,100	100,573	4,473
5: Permeable Asphalt	1,071,338	77,269	32,895	(44,374)
6: White Asphalt	672,893	138,642	11,875	(126,767)
7: Woonerf	3,847,016	277,341	644,161	366,820

6. CONCLUSIONS

Local streets are ambiguous throughout our cities. Several of the problems that plague the neighborhoods in our cities may be remediated by rethinking standard designs of the local streets that comprise them.

While the issue is less concentrated than larger arterial roadways, traffic safety still presents a serious problem in many neighborhoods. For instance, there was an estimated annual cost of $870,462 for the 17 motor vehicle collisions per year in the Fair West neighborhood. After a cursory analysis of Albuquerque, this quantity seems to be a typical number that other neighborhoods also experience. Street design can effectively work toward a solution to this problem.

Street designs can also work toward deterring crime, especially with enhanced nighttime street lighting. This is important as there was an estimated annual cost of $6,151,392 for nighttime crime in the Fair West neighborhood. Crime was relatively high in this neighborhood, and especially so for assaults that have a particularly high estimated cost. The benefits of crime reduction for our analysis were therefore elevated. Other neighborhoods that experience less crime may not experience the same benefits. Future work may examine the impact of other treatments on crime. If a design alternative results in more residents walking and biking through their community, such changes may further reduce crime rates.

Environmental benefits were more difficult to justify in direct monetary terms. The permeable asphalt was estimated to be 50% more expensive than the traditional procedure and the white asphalt sealant introduced a new and costly procedure. Extrapolating these treatments to nearly ten miles of roadways resulted in high costs. However, benefits (at least in direct monetary terms) were minimal. Partially avoiding stormwater upgrades over long lifespans resulted in low annual cost savings. While decreasing ambient temperatures by a few degrees would result in reduced air conditioning use in the summer, benefits would be minimal during the other three months of the year while the sealant continued to degrade. However, that is not to say that environmental benefits and dealing with externalities is not important. Especially for the white asphalt sealant, we would be interested to pursue future research that performs a cost/benefit analysis once the treatment has been scaled up. We imagine that if the sealant becomes a standard procedure, materials and labor costs would decrease. As a majority of the city undergoes the treatment, energy usage reductions may be large enough that we could begin to consider changes to energy production and transfer. However, this type of analysis was not appropriate for a single neighborhood. While we anticipate that many of these environmental alternatives would also improve general wellbeing and lead to increases in walking and biking and the health benefits of those activities, we cannot be sure at this time.

In terms of costs, the most extensive treatments generally had the shortest lifespans. For example, the pavement markings, permeable asphalt, and white asphalt sealant all consisted of large quantities and extents but short life spans, leading to high annual costs. The traffic circle and street lighting alternatives had longer lifespans and resulted in much lower annual costs. The street tree alternative was somewhere in the middle with a long lifespan but significant upfront costs because of the extensive curb extensions that would be required.

Interestingly, the woonerf alternative that combines many of the proposed treatments performed the best. While costs were significantly higher than the other alternatives because of the quantity of treatments required, significant benefits were predicted in terms of traffic safety and crime while additional minor environmental benefits were expected. Further research might explore this complex alternative to better understand how to optimize the configuration of treatments and how the costs and benefits would develop as such designs were increased in scale. We might also expect additional qualitative benefits as Fair West develops a unique sense of place and becomes a destination.

A primary limitation of the current work lies in the estimation of our benefits. Although we used CMFs from the FHWA, those CMFs have been developed at a diverse set of locations over decades. Many of the CMFs may also have been performed on larger collector or arterial roadways. Our neighborhood in Albuquerque may see varying results. Crime reduction estimation was also a possible limitation. Crime rates may have been impacted by COVID-19 and more crimes than we predicted may have occurred inside and therefore not been impacted by the design of the street. While we took a conservative estimate examining only nighttime crimes, benefits may be lower than expected. However, while a sense of place develops in Fair West and more residents walk and bike through the neighborhood, we may also expect crime to reduce further. All of this is speculation at this point and would warrant further exploration.

In terms of costs, while we used authoritative costs, there may be additional costs associated with the implementation of new procedures. Such costs would further lower the net benefits seen by the treatments. Another consideration is that we are trying to retrofit an existing roadway. Future research might examine the possibility of building an enhanced alternative from new construction. Doing so may allow for more design flexibility and further cut costs. Also, the idea of scaling up these alternatives from the neighborhood level to the city level may result in lower costs as the procedures become standard practice.

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