Qualitative and Quantitative Methods for Assessing Urban Walkability At City-Wide and Intersection-Level Scales

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by

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DEDICATION

I dedicate this work to my brother, father, and mother. They supported me during my academic pursuits, at the height of the pandemic, and throughout the process of preparing this research. I am very grateful for their unconditional love through the best and worst of times.

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ABSTRACT

QUALITATIVE AND QUANTITATIVE METHODS FOR ASSESSING URBAN WALKABILITY AT CITY-WIDE AND INTERSECTION-LEVEL SCALES

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Cities are opting to pursue various smart growth strategies which include the process of integrating more walkable environments. WalkScore.com offers users the ability to measure the alleged level of walkability at a given location. The problem with the website’s tool is that while it does consider nearby amenities for its calculation of walkability, it does not consider other equally important factors. In his book, city planner Jeff Speck presents the case that to be walkable an urban environment must be safe, useful, comfortable, and interesting for pedestrians. This thesis explores these four walkable categories with qualitative and quantitative approaches. The scale of the analysis is set to a macro city-wide analysis which uses collected GIS data from online sources, as well as manually digitized data. There is also a micro intersection-focused analysis that utilizes a direct observation method of collecting and operationalizing data.

1. INTRODUCTION

As cities gradually implement sustainable solutions toward smarter urban development, there are aspects to this process that can be overlooked. When most think of “smart cities”, they imagine compactness, mixed-use spaces, greenery, and energy-efficient buildings. There is also a push for enticing citizens to decrease the use of private vehicles since pollutants, traffic congestion, and lack of active transportation can lead to health concerns. One of the most influential components to a pedestrian-friendly city is its level of walkability. In his book, *Walkable City*, Jeff Speck (2012) makes the case that, “Walkability is both an end and a means, as well as a measure” (p. 4). The book explores the various components to what makes a streetscape walkable. Walkability itself is a simple concept to understand at the surface level, but its implementation can be difficult.

Walkability involves an environment that prioritizes pedestrian travel. It does so not at the expense of automotive travel but works in conjunction with pedestrian networks. Intersections with crosswalks could be considered walkable, but questions are raised based on how much time pedestrians get to utilize the crosswalks. An intersection may have signage indicating when to cross, but they may not be accessible for all pedestrians, such as people with visual impairments. The intersection may have several amenities, but these services may not be used much.

There is a convenient website that uses an algorithm to determine the level of walkability in an area. Walk Score (WS) enables users to see how convenient an area is for pedestrians by utilizing a score-based approach. An area is given a score on a scale of 0 to a maximum value of 100. Areas with a higher score are more “walkable” and areas with lower scores are less “walkable”. As stated on WalkScore.com, WS uses distance to different amenities that are generally considered important to people. With a distance decay function, points are rewarded to areas that are closer, and fewer points are rewarded if they are farther away. No points are rewarded, however, once a certain threshold is passed. The algorithm also considers population density as well as block length (Walk Score Methodology, n.d.). Overall, it appears as a viable tool to use for assessing convenient areas for pedestrians. The algorithm is available to use for cities all over the United States.

Fairfax City is a prime example of an urban environment connected by a multimodal transportation network. The city has roads for motorists, lanes for bicyclists, and sidewalks for pedestrians. Different transportation methods within a network offers options for residents and visitors alike. Figure 1 displays the city boundaries and noteworthy streets. WS assess some parts of Fairfax as highly walkable due to the compactness and amounts of amenities. But according to a recent publication of the 2022 City of Fairfax Factbook, there are quite a few gaps within the sidewalk network. These places are generally concentrated in the northwest and southeast parts of the city (p. 79). Therefore, is distance with a few other metrics enough for the city to facilitate a truly walkable environment?

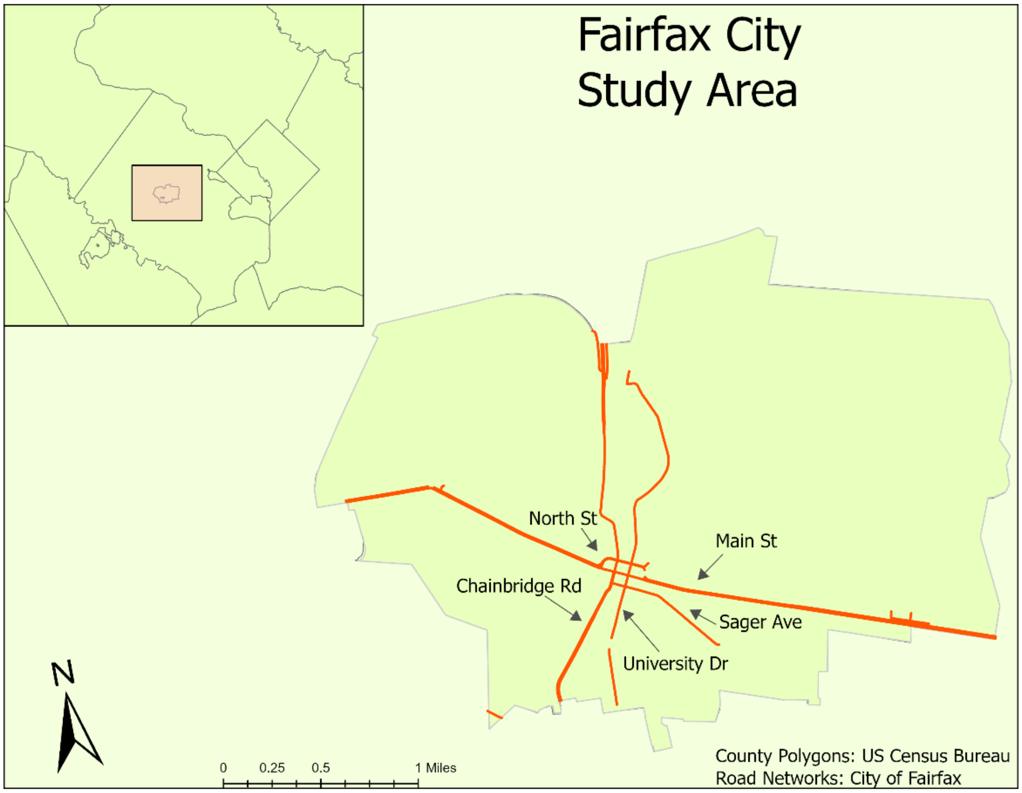


Figure 1: Overview of the selected study area

Historically, Fairfax City has seen several instances of pedestrian injuries and fatalities. A recent report published by FFXnow, a Fairfax County local news website, finds that there is an increase in pedestrian fatalities due to motor vehicle strikes (Miles 2023). Such occurrences are usually caused by the mixed-use methods the city attempts to implement. While diverse transportation is key to a thriving community, the dangers need to be highlighted. Walkability is not simply a matter of what interesting places are nearby, but it also requires that the methods to reach said destinations must be accessible for pedestrians. The formula for a walkable streetscape is not simple and can vary depending on a variety of factors. There have been, however, attempts by researchers and planners to simplify the equation.

Fairfax City has an overall Walk Score value of 54/100 according to WalkScore.com. There are several activity centers that score generally high on the website, some reaching scores of 90-95. Despite this, pedestrian and motorist incidents happen fairly frequently. A traffic safety advocacy group known as Fairfax Families for Safe Streets published a report in 2023 that claims drivers failing to yield causes more near miss incidents to occur than infrastructural or environmental factors. The cause was found by survey responses collected by the advocacy group (Fairfax FSS, 2023). Even when an urban environment has a decent walk score, it could still be prone to accidents due to reckless behaviors. An environment that is considered “walkable” according to WalkScore.com could still contain problems.

Due to the varied nature of the urban streetscape, the WS from WalksScore.com has its limitations. The overarching issue with WS is that it may not fully grasp what it takes for an environment to be truly walkable. Restaurants, cafes, and retail stores are attractive amenities that can be bring people on foot to a given environment. There are, however, more aspects of walkability that WS does not completely integrate. The distance between interesting attractions fails to include contextual features of the urban environment. It is possible that just because a nearby café is only fifty meters away, getting there may be a difficult process. The process only becomes more difficult depending on the infrastructure available for all pedestrians.

With walkable features and infrastructure comes the question of accessibility. Not all pedestrians walk at the average speed which can be due to age or disability. Some pedestrians have visual impairments, including blindness and low vison, which require additional features to properly utilize the streetscape. When attempting to increase a space's walkability, it must be accessible for everyone. Said space cannot simply have interesting things to do, even if that is the initial draw for people to visit. As such, there must be more aspects to walkability that makes the streetscape more accessible.

Speck (2012) mentions the General Theory of Walkability which comprises of four main focuses. To win the favor of pedestrians, a walkable area must be safe, useful, comfortable, and interesting (p. 12). He elaborates that while crosswalks, streetlights, and sidewalks are important for enticing people to walk, it is equally imperative to think about convincing people to walk. WS may be a useful universal method of assessing walkability, but there are unique features and site-specific factors to consider that may contradict the algorithm's results. In other words, even though interesting places could be nearby, the means to reach these areas could be hindered by infrastructure not friendly for pedestrians.

Fairfax City can be analyzed following the four focuses discussed by Speck. For safety, pedestrians need to be able to confidently walk around the streetscape without the risk of injury from motor vehicles. Regarding usefulness, pedestrian infrastructure should enable people to get from point A to point B with ease. The environment must also be comfortable, in that pedestrians will feel calm through their environmental perceptions. Lastly, there is still a need for interesting places that pedestrians would want to visit. The

WS algorithm does not consider most of these focuses and could prove to be misleading for Fairfax City.

Due to the growing desire for more accessible places for pedestrians, the WS methodology can be improved upon. Given the unique variety of streetscapes and urban areas, more variables must be considered to ascertain whether an area is truly walkable. Therefore, the research aims to answer the following question: Is Fairfax City as walkable as its WS suggests and what walkable aspects are missing or need improvement? The question focuses whether the WS algorithm is misleading, as it could be missing key variables as to what makes a streetscape walkable. The research question is accompanied by sub questions which address the differing aspects of walkability in more detail.

The data collection and analysis will be divided into two main focuses being a "macro" city-wide approach and a "micro" intersection-focused approach. With these approaches, one question asks what are some features of the streetscape that are considered walkable? The question is largely addressed in the "Literature Review" section as prior studies will share various walkable features. With the first approach, another question asks where do areas within the city with high walk scores overlap with walkable streetscape features, and where do they not overlap? The macro methodology addresses this question, showing areas of high and low WS values and what features are present there. The micro approach asks the question of are the selected intersections highly walkable as the WS website suggests and do these intersections provide the necessary features to be safe, useful, comfortable, and interesting?

To understand the potential methods, data, and variables for the research, a reading of relevant literature is required. Several researchers have addressed the lack of walkability in urban places. Features considered to increase an area's walkability have been studied using public surveys to collect feedback from pedestrians. The shortcomings of WS have also been discussed in prior research. Previous studies have utilized both quantitative and qualitative solutions with the use of GIS to assess the current conditions of pedestrian travel in cities.

2. LITERATURE REVIEW

2.1 WALKABILITY AS A BENEFIT

Walkable environments offer several benefits for the pedestrians that utilize them. Perhaps what is one of the more obvious traits of a pedestrian-friendly streetscape is the level of fitness it can provide. McCormack et al. (2020) ask participants through surveys to see the effects of the built environment and how that matches with perceived health-related fitness (p. 3). Another study by Jensen et al. (2017) explored pedestrian use by observing the streetscape equity between genders. A couple factors included how many observed pedestrians utilized different streetscapes after renovation and how many males and females utilized these environments. Proportionally, females tended to use non-walkable environments less than males (p. 85). The study focused primarily on interesting walkable features such as the presence of grocery stores. It is possible that the perception of these amenities influenced the behavior of the pedestrians.

A more walkable streetscape also enables greater accessibility for pedestrians with disabilities. When the streetscape's infrastructure is more accessible, more pedestrians are enticed to utilize the space. Gamache et al. (2020) reviewed relevant literature and conducted a series of interviews with a wide range of individuals. People with disabilities, clinicians, and walkability experts were invited to the study to weigh in on what can increase accessibility. Curb ramps that allowed for a smoother transition from the sidewalk to the crosswalk was favorable (p. 98). A walkable feature like this can increase the streetscape's walkability since all pedestrians can move around without obstacles. As such, allowing for more visitors to utilize the streetscape is a great benefit to any city.

2.2 ENHANCING WALK SCORE

Walk Score is a popular measure for assessing walkability within urban areas. Duncan et al. (2013) studied how effectively it can be used in a small area analysis. The Walk Score algorithm utilizes publicly available data from OpenStreetMap as well as Google Maps and calculates score values based on walking distance to various amenities (p. 410). The researchers also note that the Walk Score is a composite measure and can reduce the significance of any walkable feature (p. 414). The findings from the study indicate that there are in fact limitations to the WS methodology. Such limitations must be reviewed and analyzed as missing variables can lead to a misunderstanding of what makes the streetscape truly walkable.

The Walk Score algorithm fails to incorporate many other variables that are part of the urban streetscape. One study by Zhang et al. (2022) notes that Walk Score misses the specific context of a particular region. A more site-specific approach to assessing a walkable environment is necessary, as a broad overview of an urban environment tends to miss important details. They also state that it fails to consider the feelings of pedestrians, which impacts their willingness to walk through an area (p. 1400).

Another study regarding the assessment of walkability by Wei et al. (2021) asserted that the Walk Score algorithm does not consider individual walking choices (p. 122). The context surrounding the streetscape and the decisions made by motorists and pedestrians within that environment is crucial to understanding walkability. These behaviors allow for the assessment of how visitors utilize the walkable features and infrastructure, or if they are using such resources at all. It is one thing for the streetscape to contain interesting amenities, but pedestrians must want to visit and use these places. The decisions made by people shows how behaviors are shaped by the urban environment. As such, these environments must facilitate the features and infrastructure necessary for people to make these decisions.

There are certain aspects that make an area with high walkability “walkable” for pedestrians. D’Orso and Migliore (2020) observe characteristics of walkable places from relevant literature. Table 1 shows a list of walkability indicators provided by D’Orso and Migliore (2020). Their research focuses on pedestrian networks near railway stations and GIS is used to aid with the analysis (p. 4). Measures of walkability often correlate to pedestrian happiness, with variation based on features of the walking landscape. Kim et al.’s (2019) research also improves upon Walk Score. The researchers divided their study area into 100 x 100 grid points and their own methodology led to a walkability score which was calculated for each point (p. 6). A newer walkability methodology, derived either from missing variables from Walk Score’s algorithm or relevant literature, can enhance the assessment of a streetscape’s walkability.

Table 1: Walkability indicator table from the study conducted by D'Orso and Migliore (2020)

Factors	Weight	Indicators	Points	Description
Practicability	0.3	Sidewalk Slope	0	Steep slope for elderly people and wheelchair users (> 5%).
			1	Manageable slop (<5%).
		Pedestrian LOS	0	High pedestrian flows, small pavement width, obstacles (LOS D, E, F).
			1	Low pedestrian flows, adequate sidewalk width or absence of obstacles (LOS A, B, C).
		Surface degradation	0	Presence of holes or dips, degraded sidewalk.
			1	Absence of holes or dips, pavement in a good state.
Pleasantness	0.3	Street furniture	0	Absence of baskets, benches, and other elements of street furniture
			1	Presence of baskets, benches, and other elements of street furniture
		Shelter for rain and sun	0	No shelter from sun or rain
			1	Presence of shelters from sun or rain
		Green spaces	0	Absence of flower beds or green areas
			1	Presence of flower beds or green areas
		Shops	0	Absence of shops
			1	Presence of shop windows
		Building context, land use mix, and urban design	0	Degraded urban landscape (presence of damage to urban furniture, lack of cleanliness, presence of graffiti and abusive posters in buildings, presence of buildings with a degraded facade, presence of industrial buildings)
			1	Nice urban landscape (perfect functionality of urban furniture, adequate cleaning, presence of well-maintained buildings)
Safety	0.4	Streetlights	0	Poor lighting according to the Uni standard (UNI 11248) or lack of streetlights
			1	Proper and efficient streetlights according to the Uni standard (UNI 11248)
		Traffic Volume and vehicle speed	0	High traffic volumes (> 1000 vph) or high speed (> 50 km/h)
			1	In other cases
			2	Free flow (< 300 vph) and low speed (< 30 km/h)
		Barriers for pedestrian protection from vehicles	0	Absence of protection elements
			1	Presence of barriers for pedestrian protection from vehicles
		Traffic control signal at intersections	0	Absence of traffic control signal at the intersection
			1	Traffic control signal at the intersection but presence of conflicts between different traffic components
			2	Traffic control signal that eliminates conflict points between vehicles and pedestrians
		Driveways	0	Absence of driveways along the way
			1	Presence of one or more driveways

Hall and Ram (2019) note in their study about tourist attractions how complex assessing the walkable variables in the streetscape is. They place two distinct categories, one for measuring walkability and the other for assessing walking accessibility (p. 226). The researchers noted various methods through different studies that have been used for walkability studies. Fonseca et al. (2022) describe the built environment and how pedestrians are impacted by it. From their research, they found that land use density, land use diversity, accessibility, street network connectivity, pedestrian facility/comfort, safety, and streetscape design as being imperative components of a walkable environment as indicated in Figure 2 (p. 4). These aspects of the built environment relate to how D’Orso and Migliore (2020) place features into categories as noted by Jeff Speck. Distance is not the only factor to consider when assessing walkability, as safety, comfort, and accessibility were considered in the study. Perhaps then a similar method of categorizing walkable features can be replicated for other study areas as well.

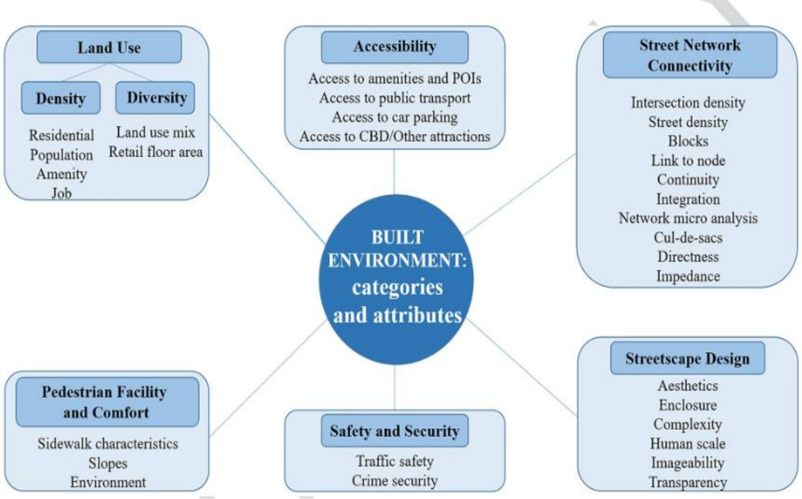


Figure 2: Summary of the built environment from the study conducted by Fonseca et al. (2022)

While sites such as Walk Score look at the neighborhood broadly, Koo et al. (2022) make the case in their study that assessing walkability is best conducted at the street-level. At a macroscale, which in their study is considered the neighborhood level, they used GIS data such as population density while the mesoscale involved the street-level variables such as sidewalk width (p.220). Arellana et al. 2020) conducted a review of relevant literature on walkability and found that mesoscale is a common scale of measurement for various studies on the topic but disagree with the terminology that Koo et al. (2022) stated. Instead, they use the term "microscale" to classify the streetscape and its built environment conditions (p. 187). Regardless of the term used, studies appear to agree that street-level is the most useful scale when assessing the walkable environment. While a more macro scale analysis of walkability can be insightful, a more focused microscale approach offers a more detailed overview. Pedestrians utilize the built environment on a day-to-day basis, and the scale used for analysis should reflect that.

In addition to relevant spatial scales, Rice et al. (2013) emphasize the temporal scales at which walkability and accessibility should be measured. A challenge in any built environment is assessing the impacts of change. When those changes are significant, but transitory, they are hard to measure a use in any walkability analysis. The crowdsourcing approaches by Rice et al. maybe a useful way to augment the approaches used by Arellana et al. and others.

2.3 DIRECT OBSERVATION

Due to a lack of quantitative data that many cities provide, researchers have utilized the process of obtaining qualitative data to provide additional context. The behavior of how people interact with the surrounding streetscape was observed in Anderson et al.'s (2019) study. Motor vehicles, pedestrians, and bicyclists were observed by how they utilize and react to safety features, specifically flashing beacons. Some observations included pedestrians that did not consider the traffic conditions, or they began to cross but returned to their starting point upon realizing they were unable to cross safely (p. 4). Another study by Ehrenfeucht (2017) observed pedestrian behavior regarding their maneuverability around food trucks. The food trucks were to become potential obstacles for pedestrians as customers lined up (p. 279). Behavior can also be observed by multiple parties, as is the case with a study conducted by Roberts et al. (2019) regarding pedestrian park usage. These observers would assign parks a quality score, and then the highest score for a park was used for the study (p.7).

The procedures around direct observation may initially appear to be a violation of privacy, but Kim (2015) argues for their research this was not the case. To understand pedestrian walk patterns, Kim observed their activities and behaviors. The individuals were in public areas where there is no expectation of privacy as they were not identifiable within the research (p. 147). Therefore, there is no ethics violation with collecting this type of qualitative data. An approach to measuring walkability through direct observation is feasible as the real-world impacts of the streetscape can be recorded and operationalized.

Motorist behavior can also be assessed more closely in a walkable environment through direct observation. As mentioned in the Introduction section, drivers failing to yield to pedestrians is one of the leading causes of near-misses and accidents between pedestrians and motor vehicles. Shaaban (2019) reached a similar conclusion in his study observing the behaviors of drivers yielding to pedestrians using crosswalks and adhering to traffic signs. He does note that the process of keeping track of traffic is labor intensive but that it provides a useful sample of what happens at a selected study site (p. 6). The streetscape could contain many features that are generally considered walkable, but there is also the question of whether those using the urban environment abide by traffic laws. Motorists are especially susceptible to committing traffic violations which could be at the expense of pedestrians walking around.

2.4 THE SAFE WALK

Buffers between the street and sidewalk can provide a physical barrier between vehicles and pedestrians. Kweon et al. (2021) share the sentiment that these buffers do not have to be complicated, as on-street parking and grass strips are viable options (p. 2). Speck (2012) in his *Walkable City* book agrees with the assertion that on-street parking provides a sense of safety for pedestrians and entices motorists to stay clear of the sidewalks. While cars will more than likely not always be parked in the streetscape at all times, even the extra spacing alone provides a buffer. With the vehicles parked in between the sidewalk and road, drivers are enticed to slow down, and pedestrians have a barrier to protect them.

The built environment also plays a role in safety analysis in other ways, as Zhao et al. (2022) discovered in their study. Distance from a starting point to the end point can either strengthen or hinder accessibility for pedestrians, or in the case of this study, school children. The conflict of people and motor vehicles was also a primary deterrent to safety (p. 8). Here both behavior of vehicles and the environment can cause issues when pedestrians attempt to utilize their traveling network.

2.5 THE USEFUL WALK

Features such as crosswalks are supposed to provide a useful means of traveling around the streetscape. Kadali and Vedagiri (2015) explore how an increase in vehicle traffic within intersections can decrease the pedestrian's level of safety (p. 121). A vehicle which attempts to beat the red light or tries to get a head start can block the pedestrian crosswalk. As noted in Kadali and Vedagiri's (2015) study, however, there are times when motorist traffic is so intense that lines of cars can get backed up, covering the crosswalk. Another study by Jensen et al. (2017) also discusses the importance of crosswalks as a useful feature of the streetscape. They investigated how residents perceive zebra-striped crosswalks as accessible features, which can help with busy intersections. The researchers noted that while crosswalks were present in active areas, there were seemingly lacking in suburban areas with less vehicle traffic (p. 14).

Crosswalks and curb ramps are also explored in Majumdar et al.'s (2021) study by looking into the perceived usefulness and how much they contribute to overall walkability. Attributes that the researchers noted to be useful for these walkable features included time to use crosswalks as well as the quality of raised curbs (p. 6). Another study collected their own crosswalk data to be used for their own research. Moran (2022) used high-resolution satellite imagery to digitize intersections containing marked crosswalks. The researchers used this method since there was no available data at the city level that included locations of crosswalks (p. 2251). Features that are not available through conventional means can still be integrated into the research through a method that allows for the creation of said data. Since crosswalk locations are not publicly available, the method of digitizing appears to be feasible.

2.6 THE COMFORTABLE WALK

Greenness can provide ample comfort for pedestrians as they move from place to place. Kasraian et al.'s (2021) study seeks to understand what pedestrians want from the streetscape through participant surveys in Toronto, Canada. It was found through their research that respondents would be willing to sacrifice more sidewalk width for the addition of trees (p. 1800). Tree canopy is a comforting feature to add to any urban environment. Heuwinkel et al. (2019) developed canopy-weighting factors for accessible pedestrian and wheel-chair routing, noting that body thermoregulation was reported by interview subjects to be a major factor in their route choice. A comfortable walk, and a comfortable wheel-chair trip both benefit from an overhead tree canopy that reduces the nearby air and surface temperatures.

The addition of greenness must be carefully implemented as Shuvo et al. (2021) investigated the spatial relationship between areas of high/low walkability and "greenness". Normalized Difference Vegetation Index (NDVI) data as well as publicly greenspace data and walk scores were used to determine if places with ample greenness and high walkability experienced many pedestrians walking. Multivariate clustering by the K Means algorithm showed that areas with large amounts of green negatively correlated to high walkability. Due to a lack of amenities and pedestrian infrastructure, they found that a significant amount of greenspace can lower an area's walkability. (p.

10). From the study, areas with much greenness were very car-dependent and did not offer opportunities for pedestrians to walk to their destinations. This presents an interesting challenge from a planning perspective, especially with initiatives being pushed for more green spaces to be added in urban areas.

A pedestrian's sense of comfort can also be impacted by the streetscape's ability to facilitate proper features during both day and night. Rahm et al. (2021) note how street lighting entices pedestrians to walk during nighttime hours. They found that many pedestrians who were interviewed avoided areas that they perceived as being too dark (p. 46). These people did not feel comfortable using a route that did not have adequate lighting. Brookfield and Tilley (2016) also found that street lighting plays a role in a streetscape providing a sense of comfort. Here they found that pedestrian age had an impact in that individuals 65 and older preferred areas that were well-lit (p. 6). Walking at night in an urban environment can be intimidating, and these studies provide insight into the fact that pedestrians want the streetscape to be more visible.

Unwin and Fotios (2011) explored the impact that street lighting has on pedestrian reassurance. The researchers spent most of the study analyzing the findings of prior literature and conducted their own study through interviews. By presenting the respondents with images of nighttime streetlighting, each with varying levels of luminescence. The interviewees would indicate whether they would be happy to walk the various routes, and it was found that they preferred the images with more visibility (p. 12).

2.7 THE INTERESTING WALK

Walk Score primarily utilizes the distance to amenities, and while this is not the only aspect of walkability to consider, it is still important. Pedestrians must want to use the walkable environment to decide to walk in the first place. Moldavanova et al. (2022)'s study reveals that an uneven distribution of such interesting places can cause problems. By using walking distance for some of their indicators, they produced maps which showcased how accessible certain cultural amenities (such as libraries and historical organizations) are (p. 631). While the study is primarily focused on a more macroscale approach, it does highlight different amenity types that differ from what the Walk Score algorithm uses. There could be more interesting places beyond a restaurant or grocery store.

A careful examination as to why people prefer more walkable spaces with interesting things to do is crucial for understanding why pedestrians travel to places on foot. People's preferences shape how willing they will be to visit a place with amenities. These preferences change across demographics regarding age, education income, and number of household members as Brookfield (2017) finds. Some people prefer to live away from amenities due to the noise, lack of privacy, and can find it more convenient to just take a car and drive to where they need to be (p. 51). Others may prefer to have such interesting places close by and are not bothered by the noise concerns, showing the stark contrast in preferences across demographics. As such, the preferences across an urban environment vary, and the transition to a more walkable streetscape is not always desirable to some.

2.8 GIS ANALYSIS

Utilizing Walk Score can become more complex when the different types of transportation networks are considered. Zhao et al. (2021) compare a pedestrian network walkability score and a road network walkability score within a high-density area. By cleaning the data, the researchers removed certain amenities that pedestrians would not require day-to-day (p. 2423). Not surprisingly, they found many areas in their study areas where simply using the road network underestimated the walkability of those places. There were also areas of overestimation of walkability using road networks which was found in suburbs. These results were not random, as they did find trends in older towns expressing higher walkability scores than newer towns (p. 2431). GIS is a useful tool for compiling spatial data and performing analysis. The study also provides insight into how unreliable road networks can be when assessing walk score given the lack of pedestrian features.

One study did use pedestrian sidewalk networks collected from open-source data. Telega et al.'s (2021) research focuses on measuring walkability and comparing two different regions of the city: the "built-up" areas closer to the core, and the places on the periphery. Measuring depends on the study area, and whether it is at a micro (a single street) or macro (district level) (p. 5). As with other literature, kernel density is used for estimating walkability. Using OpenStreetMap data, the researchers overlayed attractive amenity locations over pedestrian networks, and generated maps showing the areas that are more walkable and areas that are less walkable. As with Zhao et al.'s (2021) study, walkability is not just a matter of distance to attractions for pedestrians, but the quality and options matter too, as GIS can highlight visually. Qin et al. (2015) looked closely at pedestrian networks, and the impediments for use by wheel-chair users and visually impaired pedestrians. Using GIS-based routing algorithms, they demonstrated the remarkable differences in route length for members of the public requiring an ADA compliant, walkable pedestrian network.

Various analytical tools and procedures can be implemented through GIS, Vector data is oftentimes used for spatial analysis, but raster data offers insights as well. There are tools within GIS software that can convert vector data into raster data, as Abastante et al. (2020) note in their research utilizing the software called QGIS. In their study, they created buffers of adequate lighting in an urban environment, and the buffers were converted into raster data (p. 13). Raster data allows for understanding the distribution of a certain phenomenon.

To assess where there are safety issues for pedestrians in a city, an analysis of incidents can be used. A trend with analyzing bicycle safety is to first figure out where the collisions are happening and what factors lead to those areas being high risk hotspots. Wang et al. (2019) collected many different contributing factors to collisions through reading relevant literature. With census, traffic, and infrastructure data the researchers used kernel density to assess the spatial density of collisions and suitable risk model for the temporal analysis, along with a Poisson regression (p. 96). It is found in the case of their study area that the most collisions occur in urban bridges. While the research does not include an assessment of bicycle-friendly environments, the approach of using historical incidents can be used for pedestrian infrastructure.

3. METHODOLOGY

3.1 MACRO CITY-WIDE METHODOLOGY

The methodology of this research aims to answer the research question which is divided into four sub-questions. Since the research is divided into macro and micro approaches, the data gathering and analyzing will encompass the macro city-wide approach first. The macro city-wide approach uses publicly available GIS data. The collected data includes points, lines, polygons, and raster outputs of walkable features. Each of these different features were matched to one of Speck's walkable categories. Raster data was then created through different geoprocessing tools, and these outputs are displayed in the Results section of the research. Table 2 shows the data used for the Macro City-wide approach and the sources.

Table 2: Summary of the downloaded data types.

Data Type	Source	Walkable Category
City Boundary	www.fairfaxva.gov	N/A
Sidewalk Polylines	FairfaxCounty.gov	Safety
Crosswalk Location Points (Imagery)	FairfaxCounty.gov	Usefulness
Tree Canopy Raster	mrlc.gov	Comfort
Building Polygons	FairfaxCounty.gov	Interesting
Incident Points	treds.virginia.gov	N/A

The research aims to explore walkable features at a city-wide scale which uses Speck's four walkable components to guide the approach. For Safety, an analysis of sidewalk density will highlight what areas within the city offer safe passages for pedestrians. For the Usefulness category, since there is no data on crosswalk locations, each crosswalk in the city will be digitized manually. Comfort will involve tree canopies around the city, as pedestrians find the presence of trees pleasing in an otherwise urban environment. The data for this will be in raster format. Regarding the Interesting category, building polygons of commercial and retail businesses will be used to assess how much of these amenities exist in the city.

3.1.1 Sidewalk Density

Sidewalk density offers a sense of safety to pedestrians as it separates the modes of transportation. It allows pedestrians to not be forced to share the infrastructure designed for vehicles. A shapefile of sidewalks was downloaded from the Fairfax County Open Geospatial Data website. The shapefile contains the county's records of sidewalks that reside within the entire county. In ArcGIS Pro, the sidewalk lines were loaded onto a map display. A shapefile of the boundary of Fairfax city was downloaded from the City of Fairfax GeoHub website. The Fairfax City boundary fill color was removed, and the outline was enhanced to show the overall extent of the city. Once the sidewalk shapefile and the city's boundary were displayed in ArcGIS Pro, the geoprocessing tool Clip was used. Only the sidewalk lines that fell within or intersected with the city boundary shapefile were used. Once the clipped sidewalks were created, the Line Density tool was used. The Population Field was set to the default, which is NONE. The Output Cell Size was set to 30 Meters and the Search Radius was set to 500 Meters with the Area Units set to Square Kilometers. The tool was run, and the output appeared on the display.

3.1.2 Crosswalk Point Density

For the “Useful” category, crosswalks were chosen as a useful means for pedestrians to cross from one side of the street to another. Since there is no publicly available crosswalk data, the data had to be manually generated. Using Fairfax’s 3-inch 2022 Areal Imagery in ArcGIS Pro, the Create Feature Tool was used to manually place a point in the center of a crosswalk. As seen in Figure 3, the imagery provides a way for crosswalks to be identified throughout the city. The Walk Score intersection points, which will be discussed later, are used as a reference for cycling through intersections across the city and placing new crosswalk points. After the points were created, the Point Density tool was used. For the parameters, the population field was set to NONE and the Output Cell size was set to 30 Meters. The Neighborhood, which dictates the shape of the area around each cell used to calculate the density value, is changed to “Circle”. The radius is set to 500 Meters and the Units type is left on the Cell value. Area Units is set to Square Kilometers.

Figure 3: Image of crosswalk locations being digitized.

3.1.3 Canopy Raster Data

As discussed in Kasraian et al.’s (2021) study, a sense of nature brings comfort to those visiting an otherwise heavily urban environment. Trees are usually among the first things people think of when they consider what invokes a pleasant environment. As such, tree canopy data was downloaded from the Multi-Resolution Land Characteristics Consortium (MLRC) website. The data came from the website’s National Land Cover Database (NLCD) Tree Canopy dataset folder, and the file is the 2016 Continental United States (CONUS) Tree Canopy. Figure 4 displays the MLRC’s website interface, and an area of interest was drawn to select the extent of the canopy data to be downloaded. The resolution is 30x30 pixels, and since the area of interest boundary stretched well beyond Fairfax City’s boundary, the data was loaded into ArcGIS Pro to be clipped.

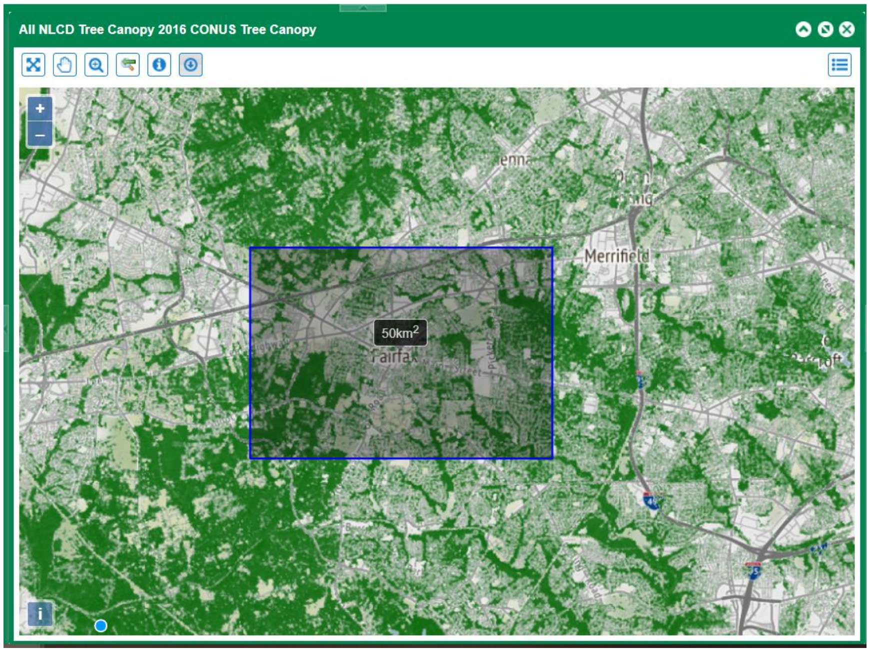


Figure 4: Image showcasing the website's interface for selecting a region of interest.

Figure 5 displays the canopy data once opened in ArcGIS Pro overlayed with the boundary of Fairfax City. The Clip Raster Geoprocessing Tool is used to trim down the extent of the canopy raster data. The tree canopy data was the input data, and the Fairfax City boundary data collected from the City's geospatial portal is used as the Output Extent. The tree canopy data represents the percentage of canopy cover for each 30-meter pixel within the city.

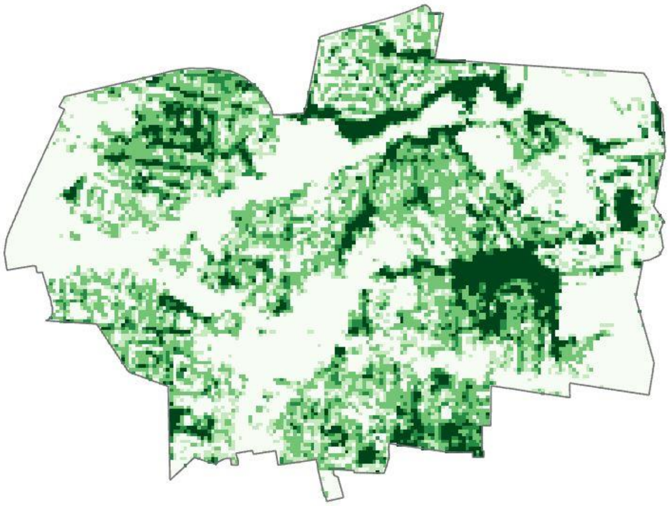


Figure 5: Raster clip displaying canopy amounts in Fairfax City

3.1.4 Commercial and Retail Buildings

The building polygon data that is downloaded from the Fairfax County Geospatial data website is reduced to only the buildings that fall within the City's boundary. The polygons include commercial or retail buildings and were then rasterized using most of the default parameters except for the value that was to be carried over to the raster file and the cell size, which was changed to 30. This value carried over is the shape area value. Once the raster file was generated, the Reclassify Tool is used. The "Reclass" field was automatically set to "Value" and could not be changed. It was classified as Quantile, which generated the output that is used for the Focal Stats Tool. The tool calculates for each input cell location a statistic of the values within a specified neighborhood around it. The neighborhood is changed to “Circle”, the radius to 900, and the unit type is changed to "Map" with the units being meters. The statistic type is changed to "Sum". The tool draws from the shape area value and each cell that is retail space represents 900 Square Meters of retail by 30x30 Meter pixels.

3.1.5 Walk Score Points

For this research, Walk Score data could not be requested in bulk as a shapefile from WalkScore.com. A significant fee would be required to request this data, so an alternative method of generating Walk Score data was developed to gather a granular dispersion of Walk Scores throughout the city while not having to pay a fee. To generate the Walk Score points, multiple tools from ArcGIS Pro are utilized. The Streets Polyline Data is used as the input data for the Unsplit Line Tool. No parameters were altered, but the map layout’s coordinate system was selected for the output to keep consistency. The output from the Unsplit Line tool was used for the Intersection Tool, which creates points at any line intersection. Roughly 2,400 points were generated from this tool. Three new columns were added to the point data’s attribute table. These are Latitude, Longitude, and WS value. The “Calculate Geometry” function on ArcGIS Pro was used to generate the latitude and longitude values of each of the points. Upon further inspection of the data, however, there were many duplicate points.

One over top of the other, many points had been made. The solution here was to use the Delete Identical Tool which used the identical latitude and longitude values and deleted any instance where there were extra identical records. After the tool was run, only 734 points remained. From these points, the latitude and longitude coordinates were copied over and pasted into Google Maps. Once entered, Google Maps displayed the address (or nearest address) to that intersection. Sometimes the map marker would not fall directly into an address, so a residence would have to be manually selected. Once the address was copied, it was pasted into WalkScore.com. After selecting the Search button, the website would give the associated WS value. The value was copied into the attribute table for that address' respective point. Figure 6 displays the simplified workflow for this process.

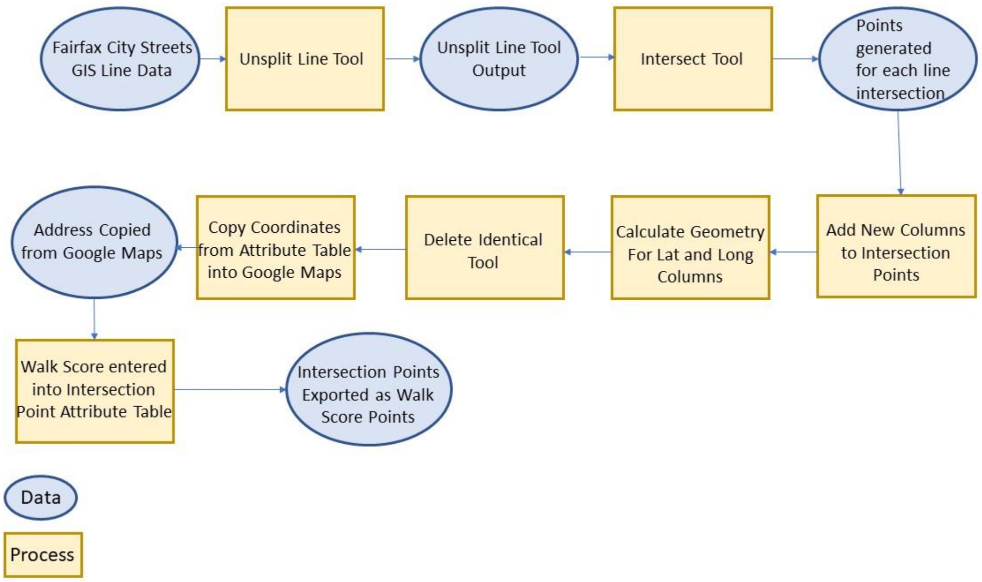


Figure 6: Flow Chart showing the process of creating WS points.

Upon further review, it was decided to also include WS points that resided in cul-de-sacs and street dead ends. To do this, the Features Vertices to Points tool was used. The tool creates points wherever there are vertices in polyline data, and it can be specified if these are to be start or end vertices. Both were used, and the output was used for the "select by location" method. It is specified here in the parameters to only select the WS points which are within 150-meters. The Invert Spatial Relationship check box was selected so that this would select points that were outside of that distance, as opposed to within. After this, 24 points were selected and saved as a separate feature layer. The Edit tool was then used to create new WS points over this new selected layer, which added an additional 24 points to the WS point layer, totaling 258 WS points. The same procedure for compiling the WS values was used for these new points. Figure 7 displays the total number of WS points that were generated for the city of Fairfax.

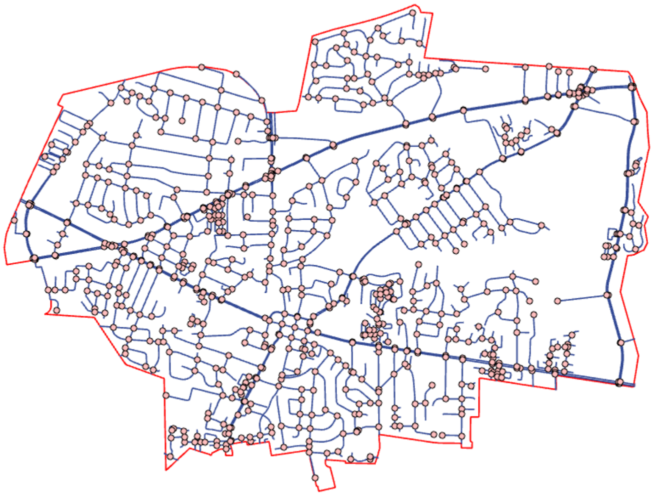


Figure 7: Map of finished WS point locations.

With the Walk Score point data generated, a geostatistical procedure takes place. Inverse weighted distance takes the average cell values and the closer a point is to the center of the cell, the more weight it has in the averaging procedure. Further points hold less weight, and the tool was utilized with most of the defaults. The Z Value parameter was changed to the Walk Score point value, and the Output Cell Size was set to 30 Meters, just like the other city data output raster data. The result shows a classified raster map of areas with high and low walk score values based on the points created from the scores collected from WalkScore.com.

3.1.6 Combining the Walkable Layers

To combine each of the four walkable layers into a single data output, they each first needed to be reclassified. Each of the layers represents ¼ of the total walkability score. So, when the overall walkability is in a 0-100 scale, each individual layer is set to represent 0-25. The highest values are 25, while 0 indicates “No Data”, and every other value falls within 1-25. The Reclassify geoprocessing tool was used to create these classes. Once the layers were reclassified, they were combined through the Raster Calculator geoprocessing tool.

3.1.7 Finding the difference between WS and the Walkability Layer

With the combined Walkability data output, it could then be subtracted from the WS layer. The Raster Calculator geoprocessing tool was again used to make this difference. The Walkability layer was subtracted from the WS layer, and a series of values ranging from negatives and positives were created. For the visualization of this data output, it was decided that it should have a more neutral color showing where WS and Walkability agreed, and extreme colors where they disagreed. To explore a more quantitative analysis, the output was converted into points using the Raster to Point geoprocessing tool. It was found that while WS and Walkability are both scaled to 100, WS has a bias toward higher scores. The solution to provide a more accurate representation of the data is to use an ordinal approach.

3.1.8 Creating Ordinal Data

The Walkability values differ from WS in that there is allegedly less walkability. There are significant differences between the distributional characteristics of the two scores. Therefore, the data was converted into ranks to gain a better understanding of these differences. The attribute table of over 18,000 points from the WS and Walkability difference layer was exported into Excel. The "rank.eq" function was used to determine where each value in the table is ranked at. A WS rank, walkability rank, and difference rank column were added to the table for the computed outputs. The Excel table was then exported as a .csv file and joined back with the attribute table of the WS and Walkability difference shapefile in ArcGIS Pro. With the ordinal data, it can now be determined where areas that are ranked high and low for both scores are located.

3.1.9 Managing the Ordinal WS and Walkability Difference Data

Using the "Select by Attribute" function in ArcGIS Pro, the points in the top 5% were selected for both WS and Walkability. The points selected show where the ranked data is highest for both scores. To find the value for the selection, the total number of points was multiplied by 5%. 909 points were calculated, and within the select by attribute window a query for WS Rank <= 909 and a query for Walkability Rank <= 909 was entered. For the low ranks, the total number of points is subtracted by 909 to find the lowest 5% of values. 18,264 – 909 is equal to 17,255, so WS Rank >= 17,255 and Walkability Rank >= 17, 255 were entered into the select by attribute field.

3.2 MICRO INTERSECTION-FOCUSED METHODOLOGY

3.2.1 Site Selection

The micro approach starts with a study area selection process which first involves a quantitative approach and uses publicly available city data. Because the research uses a micro approach to analyze walkability in an urban environment, it was necessary to pick ideal sites that exhibit a potential need for more walkable features. In addition, areas that are popular for pedestrians had to be considered as well. These micro areas are best understood as intersections, as those are where the transportation infrastructures (roads, sidewalks, crosswalks, etc.) tend to intersect. “Old Town” areas are a favorite for pedestrians across all ages, and the Old Town area in Fairfax City is no exception.

The justification for selecting a particular intersection starts with where the need for greater walkability is required. Historical data of previous incidents such as accidents causing injuries or fatalities are used. The Virginia Department of Motor Vehicles operates a website that facilitates the Traffic Records Electronic Data System (TREDS). The system collects and displays traffic incidents across the state. By using the filters, a user can set the incidents to include only incidents between motorists and pedestrians and can also set the timescale. All recorded incidents have latitude and longitude values and can be downloaded as a CSV file.

The CSV file containing the TREDS website incident locations is downloaded and opened in ArcGIS Pro where the coordinates are converted into GIS vector points through the XY Table to Point Geoprocessing tool. A vector polygon of the City's boundaries was downloaded from the City's Open Data Portal. A Spatial Clip was used to select only the points which fell within Fairfax City's boundaries. The symbology of the points was changed to a heat map, to summarize the extent of the points better visually. The result was a map displaying the areas where clusters of historical incident points were "hottest". Past incidents were not the only variable that aided in finding suitable sites for the research.

Areas that already experience high levels of pedestrian foot traffic were also considered by looking at sidewalk data. Fairfax County's Open Geospatial Data Portal publishes and updates sidewalk information for the entire county. The sidewalk density raster that was used previously for the macro analysis was used for this case. The density data allowed for a visualization of the specific intersections that appeared to have the most sidewalks present. To no surprise, the areas within the city's center, including Old Town, had the highest density of sidewalks.

After these data variables were displayed on a map, subjective reasoning was used to select the intersections with the highest amounts of incidents as well as the most sidewalks. Figure 8 showcases the data with the hot spots of incidents and the density of the sidewalks. As anticipated, Old Town contains an extensive sidewalk network suitable for pedestrian use but also contains some of the highest amounts of pedestrian incidents in the entire city according to the TREDS website.

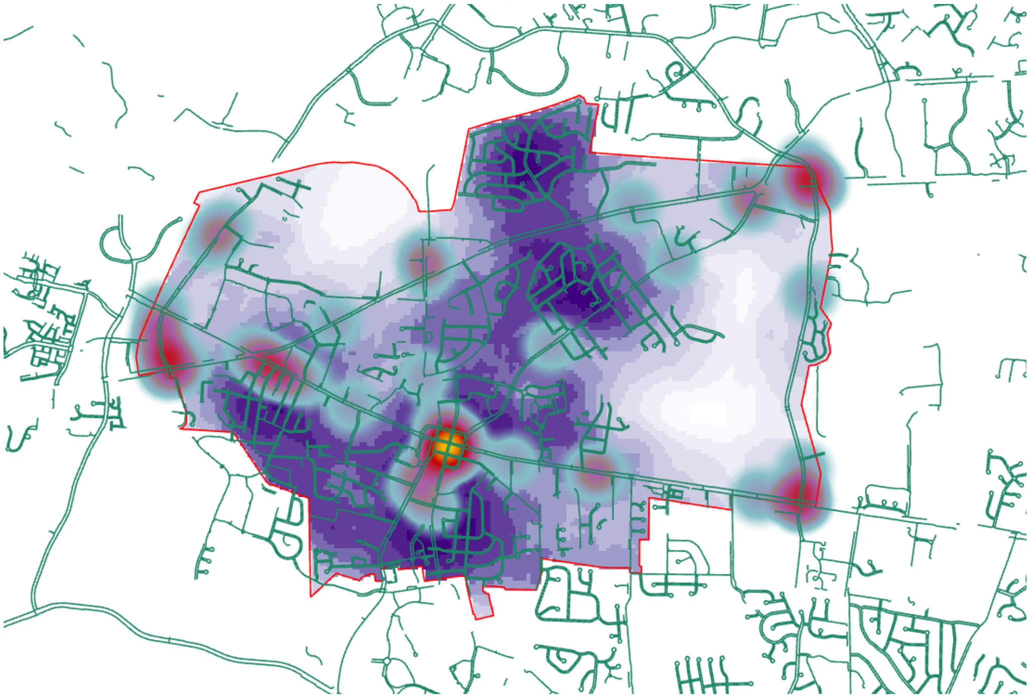


Figure 8: Map showing the overlap between sidewalk density and pedestrian/motorist incident hotspots.

3.2.2 Intersection Buffers

The three intersections chosen for the research are Sager Ave and University Dr, University Dr and Main St, and Chain Bridge Rd and North St. Because amenities tend to be a little further from the intersection, a quantitative approach for creating the extent of each study site is used. With ArcGIS Pro, a buffer was created to encompass surrounding amenities. There was a restriction to the extent of the buffer, however, as two of the three intersections, Sager Ave and University Dr and University Dr and Main St are next to each other. Therefore, the buffer's boundaries reached to the midway point of both intersections. This was standardized and used for the extent of the third intersection

Chain Bridge and North St as well. The radius of the buffer is 48 meters, or 157 feet and Figure 9 showcases where these buffers are located within Old Town Fairfax City.

Figure 9: Buffers for intersections that are observed.

3.2.3 Overview of Direct Observation Data Collection

The data collection process for assessing the walkability of the intersections involves two different methods: Feature Observations and Behavioral Observations. Feature Observations involve the researcher visiting each study site, note the walkable features present, and assign a score based on whether such features are missing. These observations can be made at any time, as the walkable features are static and do not depend on the presence of traffic or pedestrians. Behavioral Observations involve the researcher visiting each study site and, within an hour, noting what occurs based on the behavior of either motorists or pedestrians. The process is much more varied than the feature observation process. It is also restrained to certain hours of the day, with the standard being anytime from 9:00AM to 4:00PM.

Each site is observed for one hour to gather data, and all three intersections are observed for each behavioral observation. The observations take place within the created buffer, and ArcGIS Field Maps is used to ensure only the features and behaviors which take place within the buffer zone. All observations, whether involving features or behaviors, are categorized into Speck's Four Walkable Components. Through a subjective procedure, each observation was placed in either the safety, comfort, useful, or interesting category. While some walkable observations could have overlap within multiple categories, for the purposes of the research each observation was assigned to a single category. Table 3 shows the features and behaviors along with their respective walkable categories.

Table 3: Summary of walkable features and behavioral observation categories.

Safety	Usefulness	Comfort	Interesting
Presence of Barriers	Time To Use Crosswalk	Presence of Trees	Presence of Amenities
Crosswalk Audio	Presence of Truncated Dome Surfaces on Curb Ramps	Presence of Street Lighting Fixtures	Presence of Historical Markers
(Behavioral) Motorists Turning Right on Red	(Behavioral) Crosswalk Usage	(Behavioral) Curb Usage	(Behavioral) Amenity Usage

3.2.4 Feature Observation Data Collection

For features which are categorized into the Safety category, researchers found that having some type of barrier between pedestrians and motorists created a safer route. Speck agrees, in that the barriers such as cars parked along the sidewalk provides safety for pedestrians walking on the sidewalk. As such, the features including street parking, concrete barriers, trees, or fencing are observed. There is another safety feature that is observed which enables greater accessibility. Crosswalk audio devices attached to the traffic light poles add additional levels of safety for pedestrians. Figure 10 shows what the audio device looks like in Fairfax City.

Figure 10: A crosswalk audio device present at the Chain Bridge Rd./North St. intersection

Specifically, these allow pedestrians who are visually impaired to know when it is time to cross and when to wait. Without these audio cues, pedestrians may not know when it is safe to cross. The crosswalk audio device feature was chosen because of how much it can impact the safety of someone when trying to cross through an intersection. This adds greater accessibility for pedestrians and is a safety feature that lowers the risk of pedestrian and motorist incidents. Therefore, it is appropriate for the Safety category in that it enables all pedestrians to navigate the streetscape.

Another category is Comfort, which involves the pedestrian’s perception of what eases them while crossing through the streetscape. The Literature Review mentions studies involving trees, so these are features that are considered to grant a sense of comfort. They can provide a feeling of nature in an otherwise heavily urban environment. The other feature is impactful during nighttime walks through intersections. Street lighting fixtures allow pedestrians to perceive the environment more easily at night and can provide a sense of comfort since they are able to see what lies around or ahead of them. Some street light fixtures are managed by private companies for providing lighting for buildings, so for the purposes of this research, only lighting that is managed by the city will be considered. These will include more decorative fixtures with gas lamps and brighter traffic lights that overlook an intersection.

The Usefulness category involves the crosswalk lengths, and how much time is allowed for pedestrians to cross given a certain walk speed. The three selected intersections have differing crosswalk designs. For example, Sager Ave./University Dr. contains a “zebra” pattern for its crosswalks, but that will not be considered for this research. This feature observation will differ from many others in that it will be carried out through ArcGIS Pro. The measurements of the crosswalks in the intersection will be taken and an average walk speed will be used to calculate how far a pedestrian would make it through the crosswalk. The observation is the different times in seconds which are collected from each crosswalk sign in each intersection. The other feature observation for Usefulness looks at the truncated dome surfaces which are placed on curb ramps, as seen in Figure 11, usually between the sidewalks and crosswalks at an intersection. The observation is to see if these curb ramps with truncated dome surfaces are present at every curb within the intersection.

Figure 11: A truncated dome surface present at the Sager Ave./University Dr. intersection

The Interesting Category involves what nearby amenities are present for pedestrians to travel to. Dining, cafes, grocery stores, banks, and retail options are interesting in that pedestrians either need these places or enjoy visiting them. Within the intersection boundary, amenities are observed and recorded. Another observed feature for this category includes historical markers. Because of Fairfax City's historical significance, as well as justification from sources in the Literature Review, these markers are observed and recorded within each intersection buffer. The city contains these plaques and signs wherever there is a historic building or other structure type, and they provide details about the significance of these places.

3.2.5 Behavioral Observation Data Collection

For the Behavioral Observations, four different behaviors were identified from the relevant literature as well as what is observed in the study area. Each behavioral observation is recorded during a certain time of day, either in the morning or the afternoon. The observations were alternated to consider the differences the time of day has on pedestrian and motorist traffic. For example, the observation for Safety was first recorded during 9:00AM in the morning, and then sometime later was observed at 1:00PM in the afternoon. All observations were compiled in Google Sheets with the columns representing times and the rows representing each light cycle. The light cycle is dictated by the traffic lights which are usually automatic except for the Sager Ave/University Dr intersection. Table 4 displays an example of the raw data collected from a day of observing. The intersections were color coded to assist with visuals while entering the values out in the field.

Table 4: An example of the raw data collected from the safety behavioral observation

9:00AM-10:00AM	**9:00AM-10:00AM**	**10:05AM-11:05AM**	**10:05AM-11:05AM**	**11:09AM-12:09PM**	**11:09AM-12:09PM**
Sager Ave	**University Dr**	**University Dr**	**Main St**	**Chain Bridge Rd**	**North St**
Total # in right lane 1 # infringing on crosswalk 0 # turned right on red 0 # who turned right without stopping 0	Total # in right lane 0 # infringing on crosswalk # turned right on red # who turned right without stopping	Total # in right lane 2 # infringing on crosswalk # turned right on red 0 # who turned right without stopping	Total # in right lane 0 # infringing on crosswalk # turned right on red # who turned right without stopping	Total # in right lane 2 # infringing on crosswalk 1 # turned right on red # who turned right	Total # in right lane 0 # infringing on crosswalk # turned right on red # who turned right
Total # in right lane 1 # infringing on crosswalk 0 # turned right on red 0 # who turned right without stopping 0	Total # in right lane 0 # infringing on crosswalk # turned right on red # who turned right without stopping	Total # in right lane 2 # infringing on crosswalk # turned right on red 0 # who turned right without stopping	Total # in right lane 3 # infringing on crosswalk # turned right on red 0 # who turned right without stopping	Total # in right lane 2 # infringing on crosswalk # turned right on red # who turned right	Total # in right lane 1 (1 wanted to turn) # infringing on crosswalk # turned right on red # who turned right
Total # in right lane 1 # infringing on crosswalk 0 # turned right on red 0 # who turned right without stopping 0	Total # in right lane 0 # infringing on crosswalk # turned right on red # who turned right without stopping	Total # in right lane 0 # infringing on crosswalk # turned right on red # who turned right without stopping	Total # in right lane 2 # infringing on crosswalk # turned right on red 0 # who turned right without stopping	Total # in right lane 2 # infringing on crosswalk # turned right on red # who turned right	Total # in right lane 0 # infringing on crosswalk # turned right on red # who turned right

Each observation for each category takes place over an hour. An ideal location within the intersection is selected upon arriving at the intersection to collect the field data. It will typically be a spot where all corners of the intersection are in view, and where the roads on all sides can be seen reaching to the border of the assigned buffers. Every observation takes place when there is no rain or snow present, as these factors may impact a visitor’s decision to visit the study areas. Additionally, days where there are major events for holidays are also avoided, as this may increase pedestrian and motorist volume beyond what is normal. The behavioral observations fall into one of the walkable categories which were placed through a subjective assessment. Depending on what the observation involves, it was placed into what was deemed the appropriate category.

The first observation involves motor vehicles and how they turn right during a red light. Specifically, these observations investigate whether motorists come to a complete stop or not. The observation is placed in the Safety walkable category, as there are a couple major safety concerns with those who do not stop completely. Firstly, there is a risk of them colliding with another motorist driving down the street through a green light. Because the research is focused on pedestrian safety, there is also a concern for when a pedestrian is moving across the crosswalk in front of the vehicle. If the motorist does not stop, then an accident may occur, resulting in injury or death of the pedestrian. Two of the three observed intersections have signs for all four corners stating that no motorist is allowed to turn right on a red light. The sign reads “No Turn on Red” as shown in Figure 13. For these two intersections, University Dr/Main St, and Chain Bridge Rd/North St, it will be observed whether the motorist disregards the sign and turns anyway on a red light.

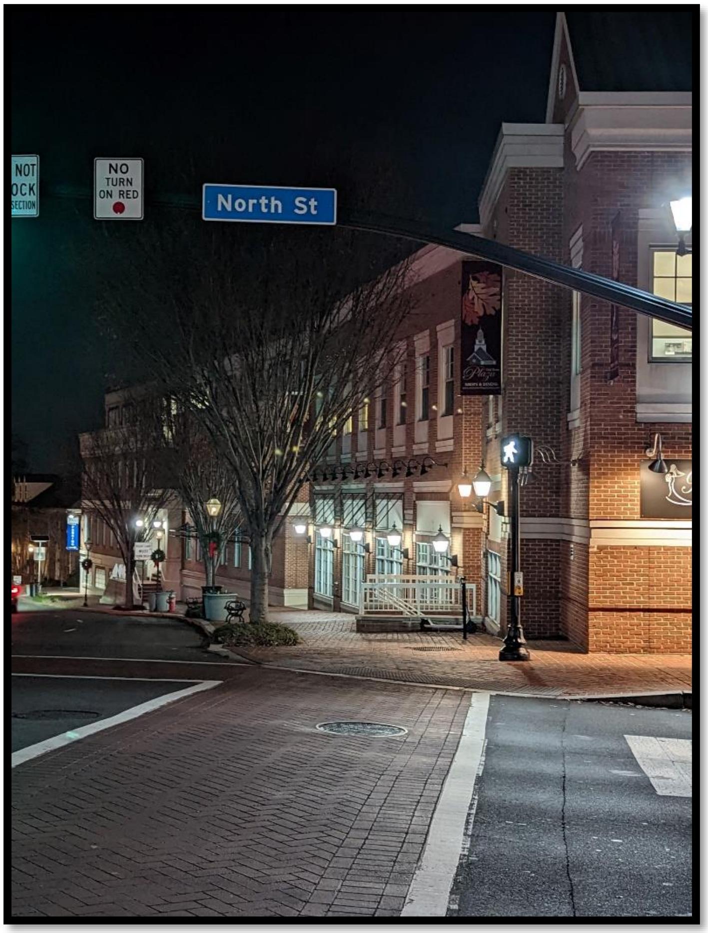


Figure 12: No Turn on Red sign present at the Chain Bridge Rd./North St. intersection

The next behavioral observation is for the Usefulness category. This observation involves the pedestrian crosswalks, and whether pedestrians are utilizing them. With the entirety of the intersection in view, following the traffic light cycles, pedestrians are recorded who walk through the designated crosswalk areas. The total number of pedestrians are recorded within a light cycle, and the total number who veer off or do not use the crosswalk at all are also recorded. The pedestrians that fail to utilize the crosswalk are also considered when they walk across the road far away from the intersection. If the pedestrians are within the buffer, they are considered when crossing. Pedestrians that do not end up crossing during the light cycle are not counted. This would usually occur when pedestrians that would wait for their crosswalk signal were also not counted, and only if they crossed would they be recorded for that light cycle. Pedestrians walking along the sidewalk to only use a curb to get to their destination were also not recorded, but the next observation addresses curb usage.

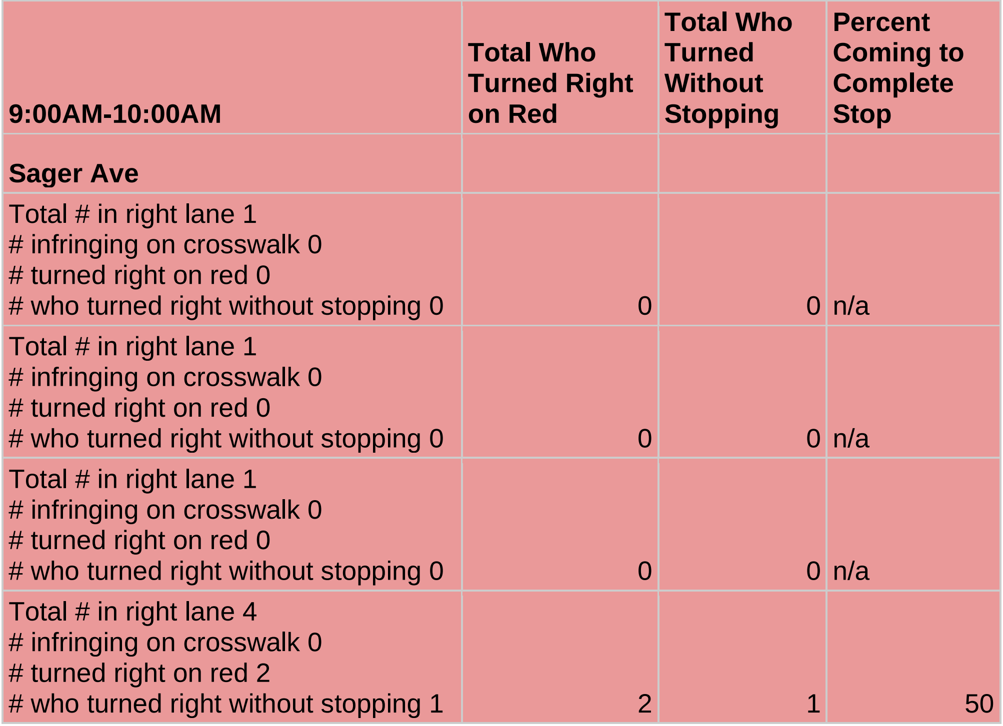
Comfort is analyzed through the third behavioral observation which focuses on the pedestrian use of curbs. Due to tight spacing and large volumes of foot traffic, curbs can either be a convenience or a hinderance when navigating the streetscape. Similar to the crosswalk observation, only pedestrians who use the curbs are recorded in the Google Sheets table. As pedestrians are walking around the curbs in the intersection, any pedestrian that had to step off the curb, even briefly, were counted. The number of pedestrians who veered off the curb were recorded in order to see how they utilize the infrastructure. The perception that a curb may be too narrow causes pedestrians to risk stepping onto the road. The feeling of having to step into the road does not bring a sense of comfort and can disrupt the ease of travel.

Lastly, for the Interesting category, the behavioral observation records what pedestrians are doing within the intersection buffer. Specifically, they are observed when they utilize the surrounding amenities. These amenities offer interesting things to do, which can be perceived as interesting to a pedestrian. When pedestrians are present in the intersection, the total number is counted then recorded. Then, within that same light cycle, the pedestrians that enter shops, banks, cafes, or retail stores are also counted and recorded. Within the hour, this observation shows whether visitors are using any of the interesting amenities. The observation builds on one of the other Interesting category's feature observation, which counts the number of amenities within the intersection.

3.2.6 Behavioral Observation Data Calculation

Once all the behavioral observations were recorded in Google Sheets, the values were then calculated to find the percentages for each intersection based on each walkable category. The percentage value is the final data output for the Behavioral Observations to be used for the analysis in that scores will be assigned depending on the percentage value.

Table 5: An example of the percentages calculated for a behavioral observation



9:00AM-10:00AM	**Total Who Turned Right on Red**	**Total Who Turned Without Stopping**	**Percent Coming to Complete Stop**
Sager Ave			
Total # in right lane 1 # infringing on crosswalk 0 # turned right on red 0 # who turned right without stopping 0	0	0	n/a
Total # in right lane 1 # infringing on crosswalk 0 # turned right on red 0 # who turned right without stopping 0	0	0	n/a
Total # in right lane 1 # infringing on crosswalk 0 # turned right on red 0 # who turned right without stopping 0	0	0	n/a
Total # in right lane 4 # infringing on crosswalk 0 # turned right on red 2 # who turned right without stopping 1	2	1	50

For Safety, the total number of vehicles that did not stop when turning right on a red light were divided by the total number of vehicles turning right at the red light. Columns were added to the Google Sheets table and a sample is shown in Table 5 with the last column of an intersection containing the percentages, if applicable. If no data was observed during a light cycle, then the cell is entered as “n/a”. Only one of the three intersections lacked a “No Turn on Red” sign, so this observation was handled a little differently for the other two intersections. For Main St./University Dr and Chain Bridge Rd/North St., it was observed whether drivers would turn on red at all. The fact that there is a sign dictating for motorists would in theory deter drivers from doing so.

Regarding the Usefulness category, the crosswalk behavioral observations were divided by total number of pedestrians staying within the crosswalk boundaries over the total number of pedestrians crossing. For the Comfort category, the curb ramp usage is recorded in a similar manner to the crosswalk observation. The total number of pedestrians using the curbs were divided by the total number of pedestrians who stayed on the curb. The percentages show how sometimes pedestrians would veer off the curbs, possibly due to there not being enough space when pedestrian traffic is high. Lastly, for the Interesting category, the total pedestrians present within the intersection buffer were divided by the number of pedestrians entering any amenities. There may have been several people within the intersection during a given light cycle, but only a few would enter the surrounding shops, cafes, etc.

The total average for each street was calculated from the total number of observed cycles where the specific observed phenomenon took place. For example, with the

“Interesting” category, if there were sixty light cycles within the observed hour, and only twenty-six cycles for a street had pedestrians present in the intersection, then only those twenty-six light cycles would be considered. The percentages calculated from the number of pedestrians who were present and those who used the amenities would be added and divided by the number of observed light cycles (being twenty-six). It would be for one street, and then the same procedure occurs for the other street. The two percentages that are calculated from both streets are then averaged, resulting in the average percentage of that intersection.

Once the percentages were calculated for each category regarding each intersection, the scores were assigned. The Walkability scores are placed on a scale and depending on how high or low the percentages are will place that intersection into that score. Each intersection receives a score for each category, and for the behavioral observation, will receive a score for the morning observation and the afternoon observation.

4. RESULTS

4.1 MACRO CITY-WIDE RESULTS

The data outputs generated from the geoprocessing tools are visually displayed to show the spatial phenomena across Fairfax City. A comparison between each individual walkable layer is shown alongside the WS interpolation layer. Another figure displays the combined walkability layer generated from the four layers. Finally, the combined walkable layer and WS interpolation layer are compared with scatter plots showcasing the minimum and maximum values between the data outputs. The data showcases areas around the city that have low and high WS values, as well as low and high walkability values. The purpose is to compare the locations where WS scored high and walkability scored lower, and to then point out the phenomenon that occurs at that place to explain the discrepancies of the two layers.

The chapter also provides a more in depth look at the differences between WS and the generated walkability layer at different activity centers. An ordinal ranking between the two separate scores is also highlighted. The Old Town area where the micro intersection-focused approach will also be investigated.

4.1.1 Comparison of Layer outputs to WS

Once the raster data outputs for the walk score and four walkable categories were generated, a map layout is created. Figure 15 shows the Walk Score interpolation along with the densities of sidewalks and crosswalks. Five classes using the quantile method in the data are displayed for the sidewalk density and crosswalk density.

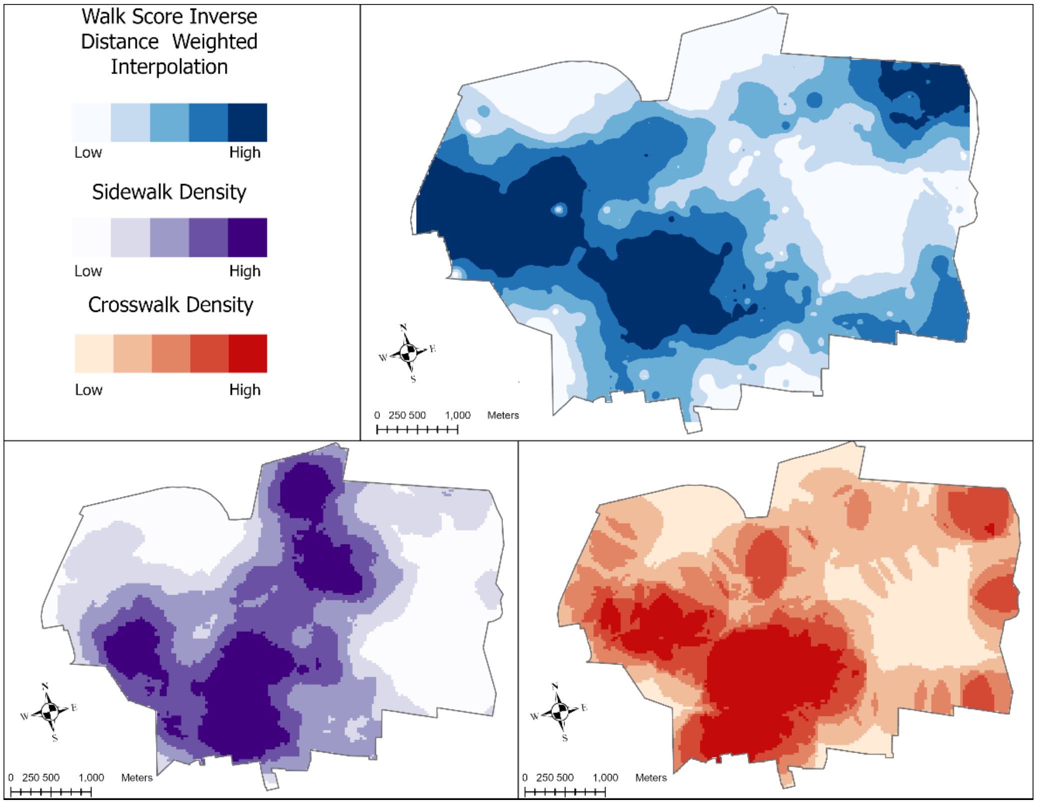


Figure 13: A map displaying the sidewalk and crosswalk densities compared to WS in Fairfax City

Figure 16 displays tree canopy amounts and commercial/retail amounts that are compared to the Walk Score Interpolation. These are also five classes with natural breaks in the data to showcase the areas with high and low amounts of comfortable features (trees) and interesting things to do. The high and low values for the commercial and retail buildings indicate the lengths of such structures and highlight how much space they take up.

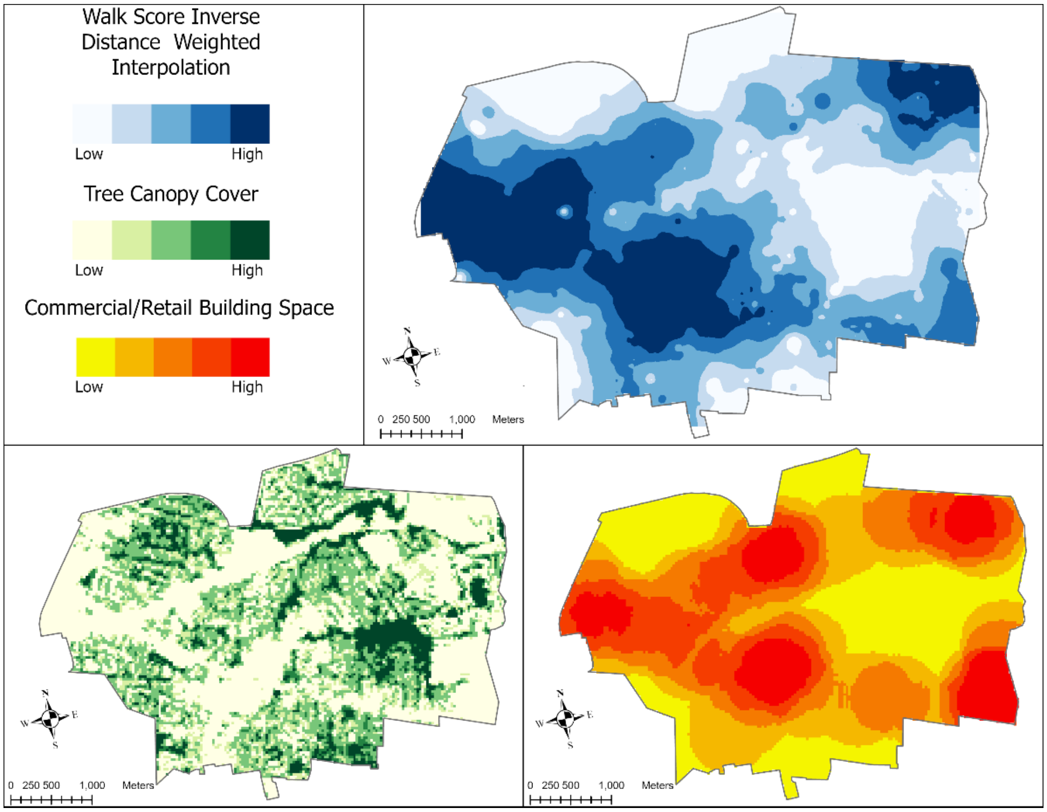
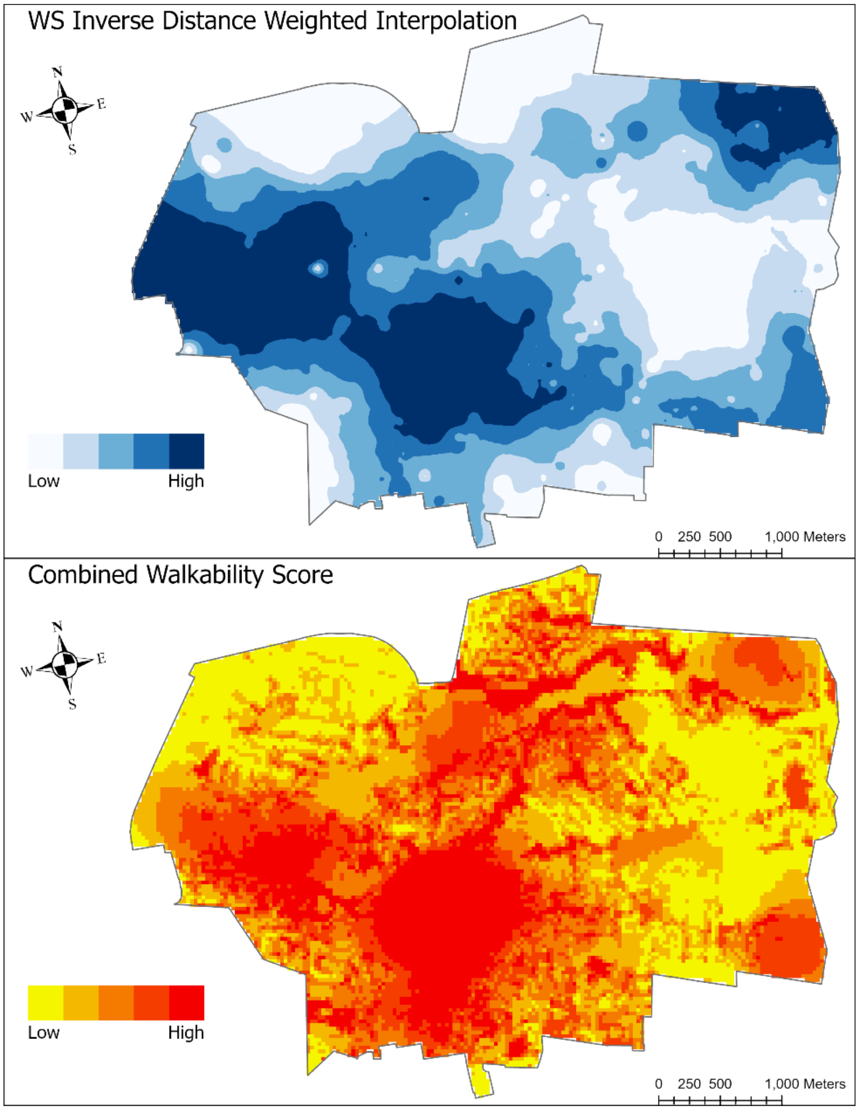


Figure 14: A map displaying the canopy and commercial/retail presence compared to WS in Fairfax City

4.1.2 Walkability Layer

The four aspects of walkability are represented in this research via four different data outputs. The combined sidewalk, canopy, crosswalk, and building data creates a walkability layer to be compared with the WS data. After reclassifying each of the four layers and adding them together through the raster calculator geoprocessing tool, a final Walkability layer is produced. Figure 17 displays a comparison between the WS data and the combined Walkability layer. The map showcases, visually, where WS and the

Walkability data report high and low values. The highlights from the data, however, can be further emphasized by subtracting these values from the two different scores.



WS Inverse Distance Weighted Interpolation

Combined Walkability Score

Figure 15: Comparison between WS and the combined walkability data

4.1.3 WS and Walkability Data Difference Layer

Based on the layer created by the differences between WS and Walkability, there are certain areas within Fairfax City that experience extremes from both scores. Figure 18 displays the variations and highlights key places where the scores are extreme, and where they agree. The first location shows high WS values but lower Walkability values. The area in question contains many amenities but hardly any canopies, and not much sidewalk infrastructure. Jermantown Center is present and much of the area also incorporates what is now the Kamp Washington Small Area Plan and includes residential areas of the Mosby Woods neighborhood and important sections of the Accotink Creek and the George Snyder Trail. While trails were not specifically targeted in the walkability analysis, the presence of tree canopy is a factor.

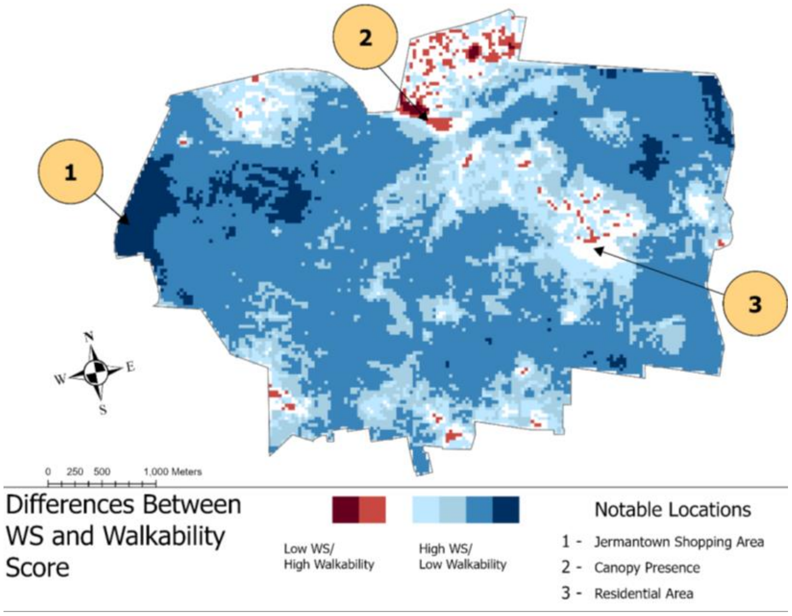


Figure 16:Map of the differences between WS and the Walkability score

The next location differs from the previous in that it contains low WS values and high Walkability scores. Based on the map visuals, there appears to be ample canopy here at the expense of amenity presence. The WS finds that there are not many interesting things to do, so the score is much lower. The area is situated roughly north of the Northfax Small Area Plan.

Situated between two parks, the last location on the WS and Walkability difference map differs from the previously mentioned locations. A key variable here is that both scores appear to agree in that there is not much variation between the two scores. The location lacks amenities, and while canopy is present it is missing crosswalks. A residential area which, while lacking sufficient walkable features, does provide insight into how complex the urban environment can be.

The raster displaying the WS and Walkability Scores were converted into point shapefile format. Over 18,000 points were generated, and a scatter plot was created to show the relationship between the two variables. Figure 19 displays the points and where their values for WS and Walkability fall into.

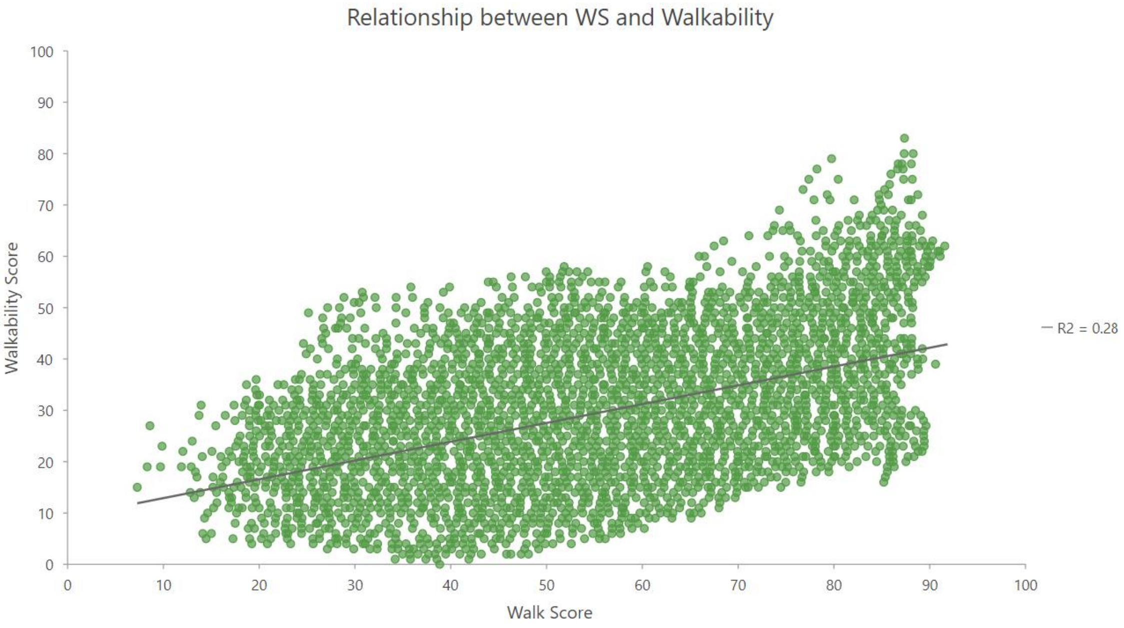


Figure 17: Scatterplot showing the total number of WS and Walkability points

4.1.4 Ordinal Ranking

The WS and Walkability scores are scaled to the same start and end values, but the Walkability score in an aggregate sense tends to be lower than WS. To implement a fair comparison, an ordinal ranking approach is used. Once the points were joined with the csv file containing the ranked WS and Walkability values, a scatter plot was created. Figure 20 shows the points that are in the top 5% for both WS and Walkability. Figure 21 displays the bottom 5% for both scores. Figure 22 shows where the top 5% of points for both scores aggregated within Fairfax City. A polygon was digitized around the cluster of points for the visualization. It should be noted that the points overlap with the three observed intersections, indicating that both WS and the Walkability data agree that those places are very walkable.

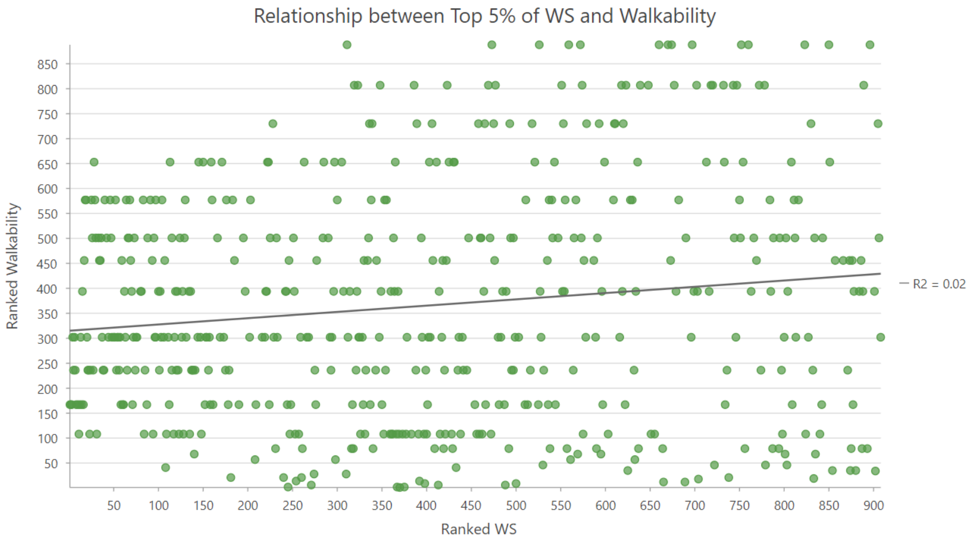
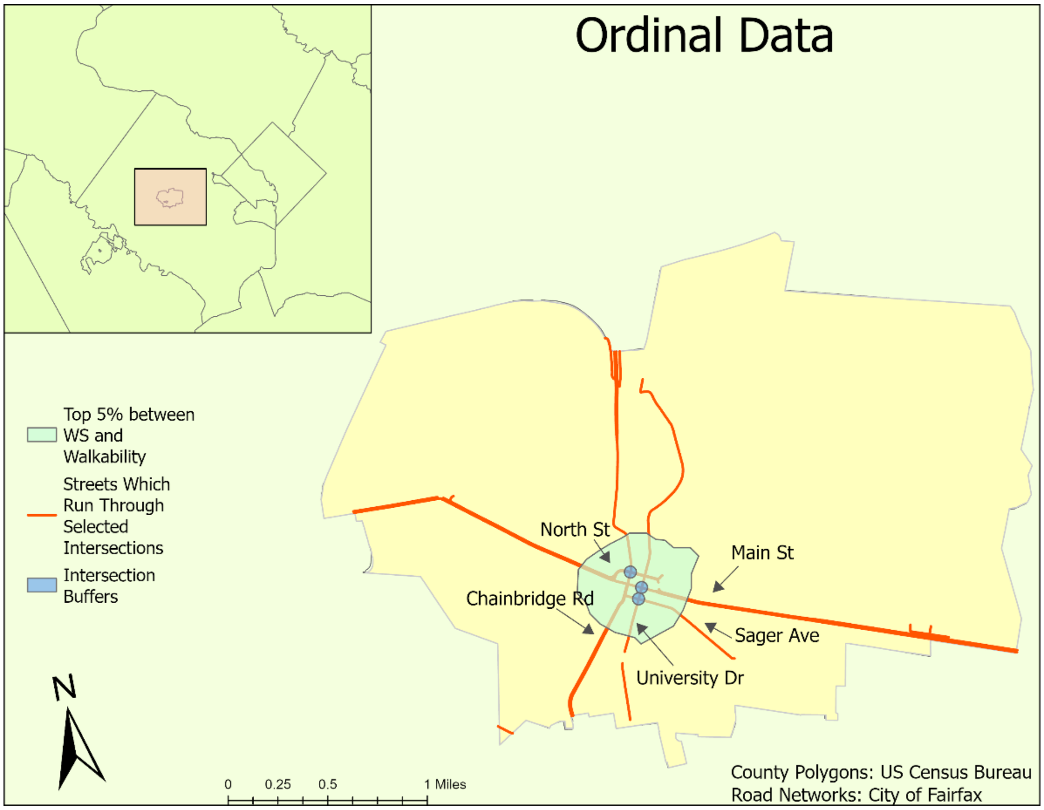


Figure 18: Scatterplot showing the Top 5% of points and their WS and Walkability values

Figure 19: Scatterplot showing the Bottom 5% of points and their WS and Walkability values



County Polygons: US Census Bureau
Road Networks: City of Fairfax

Figure 20: A map showing where the top 5% of points fell within Fairfax City

4.2 MICRO INTERSECTION-FOCUSED RESULTS OVERVIEW

To complement the city-wide comparison to WS, the micro intersection-focused approach looks at the three selected intersections within Fairfax City. The results differ in one major way. Unlike the macro approach, where data is either collected from online sources or manually digitized with GIS software, the data is collected directly from the field. The direct observation method is utilized for the intersections of Sager Ave./University Dr., University Dr./Main St., and Chain Bridge Rd./North St.

4.3 DIRECT OBSERVATION FEATURE RESULTS

For the direct observation feature results, each walkable category will be highlighted as a question. The scoring will be displayed to show how points were given to each intersection based on the presence or absence of walkable features. Each walkable category has two feature observations, each having an equal scale of 1-5. With all the scores compiled from the feature observations, Table 6 shows the total number of points attributed to each intersection. Figure 23 displays the data in a visual manner.

4.3.1 Safety

- Is there a presence of barriers including on street parking, concrete, or fencing?

1 - No present barriers between sidewalks and road on intersection
2 - One sidewalk corridor contains a type of barrier
3 - Two sidewalk corridors contain a type of barrier
4 - Three sidewalk corridors contain a type of barrier
5 - Four sidewalk corridors contain a type of barrier

Sager Ave/University Dr. receives a score of 1 since has no barriers of any kind between the sidewalk infrastructure and the road. University Dr./Main St. has three sidewalks with on-street parking next to them, giving this intersection a score of 4. Chain Bridge Rd./North St. receives a score of 4 because it utilizes trees, street parking, and even a concrete wall to act as barriers.

- Is there a presence of traffic light audio devices?

1 - No audio features present when pedestrians cross

2 - A single stoplight provides audio when it's time for pedestrians to cross

3 - Two stoplights provide audio when it's time for pedestrians to cross

4 - Three stoplights provide audio when it's time for pedestrians to cross

5 - Four stoplights provide audio and at least one provides street information

Sager Ave/University Dr. does not have audio features implemented into the crosswalks and receives a score of 1. University Dr./Main St. also does not incorporate audio cues for pedestrians using the crosswalks, so it receives a score of 1. Chain Bridge Rd./North St. receives a score of 5 since all four crosswalks have audio devices which signal pedestrians to use the crosswalk safely.

4.3.2 Usefulness

- Is there sufficient time to cross the crosswalks going 0.94m/s?

1 - No crosswalks offer enough time to cross

2 - One crosswalk offers enough time to cross

3 - Two crosswalks offer enough time to cross

4 - Three crosswalks offer enough time to cross

5 - All four crosswalks offer enough time to cross

As mentioned in the "Introduction" section, the research will be focusing on the average walk speed of pedestrians 65 and over from Alves et al. (2020) findings. Sager Ave's two crosswalks in the Sager Ave/University Dr. intersection have a length of 12.9 meters and 16 meters. Both crosswalks give the pedestrians 16 seconds to cross. With a walk speed 0.94 m/s, 12.9 meters divided by 0.94 m/s is 13.7 seconds, and 16 meters divided by 0.94 m/s is 17.02 seconds. At that speed, a pedestrian walking 0.94 m/s will make it across one of the crosswalks, but not the longer one. The two crosswalks which lie within University Dr. have a length of 14.8 meters and 16.5 meters. These give pedestrians 20 seconds to cross. With a walk speed 0.94 m/s, 14.8 meters divided by 0.94 m/s is 15.7 seconds, and 16.5 meters divided by 0.94 m/s is 17.6 seconds. At that speed, a pedestrian walking that speed has time to cross completely both crosswalks. Since the intersection has three crosswalks which enable elderly pedestrians to cross within the allotted time, it receives a score of 4.

University Dr.'s two crosswalks in the University Dr./Main St. intersection have a length of 12 meters and 10.5 meters. Both crosswalks give pedestrians 18 seconds to cross. With a walk speed 0.94 m/s, 12 meters divided by 0.94 m/s is 12.8 seconds, and 10.5 meters divided by 0.94 m/s is 11.2 seconds. As such, both crosswalks give enough time to cross. Main St.'s two crosswalks are both 11 meters in length and they give pedestrians 16 seconds to cross. 11 meters divided by 0.94 m/s is 11.7 seconds. Therefore, both crosswalks offer pedestrians walking at that speed time to cross. The intersection receives a score of 5.

Chain Bridge Rd has two crosswalks in the Chain Bridge Rd/North St. intersection with lengths of 19.2 meters and 14.8 meters. Each crosswalk gives pedestrians 26 seconds to cross. With a walk speed of 0.94 m/s, 19.2 meters divided by 0.94 m/s is 20.4 seconds, and 14.8 meters divided by 0.94 m/s is 15.8 seconds. Therefore, both crosswalks give pedestrians walking at that speed time to cross. As for North St, the crosswalks are 16 meters and 16.7 meters in length and offer pedestrians 24 seconds to cross. 16 meters divided by 0.94 m/s is 17.02 seconds and 16.7 divided by 0.94 m/s is 17.8 seconds. Both crosswalks can be crossed in the allotted time, and the intersection receives a score of 5.

- Do curb ramps in the intersection include truncated dome surfaces?

1 - No corners contain curb ramps with truncated dome surfaces
2 - One corner contains curb ramps with truncated dome surfaces
3 - Two corners contain curb ramps with truncated dome surfaces
4 - Three corners contain curb ramps with truncated dome surfaces
5 - All corners contain curb ramps with truncated dome surfaces

Sager Ave./University Dr. has only three curb ramps with truncated dome surfaces which give it a score of 4. Both University Dr./Main St. and Chain Bridge Rd./North St. intersections have truncated dome surfaces in all four curb ramps which gives them a score of 5.

4.3.3 Comfort

- Is there a presence of trees?

1 - No trees present at intersection
2 - One to Two Trees are present
3 - Three to Four trees are present
4 - Five to Six trees are present
5 - Over Six trees are present

University Dr./Main St. have three trees present in the intersection buffer area which gives the intersection a score of 4. Sager Ave./University Dr. and Chain Bridge Rd./North St both contain over six trees, so they receive a score of 5.

- Are there street lighting fixtures present?

1 - No street lighting fixtures are present
2 - At least 4 street lighting fixtures are present
3 - At least 6 street lighting fixtures are present
4 - At least 8 street lighting fixtures are present
5 - 10 or more street lighting fixtures are present

University Dr./Main St., Sager Ave./University Dr., and Chain Bridge Rd./North St all have over ten street lighting fixtures present. Each intersection receives 5 points. The types of fixtures varied between decorative lamps, utility pole fixtures, and lighting attached to traffic lights. Figure () demonstrates the variability in the lighting for University Dr./Main St.

4.3.4 Interesting

- Are amenities including dining options, cafes, banks, and retail options present?

1 - Neither of these amenities are present
2 - One to Two amenities are present
3 - Three to Four amenities are present
4 - Five to Six amenities are present
5 - Over six amenities are present

Sager Ave./University Dr. only has one amenity within the buffer, which happens to be a bank with a twenty-four-hour ATM machine. The intersection receives a score of 2. University Dr./Main St. and Chain Bridge Rd./North St. both contain over six amenities ranging from cafes, laundry mats, and restaurants, giving these intersections a score of 5.

- Are historical markers including signs and plaques present?

1 - No markers are present
2 - One marker is present
3 - Two markers are present
4 - Three markers are present
5 - At least four markers are present

Sager Ave/University Dr. had no historical plaques present which gives the intersection a score of 1. University Dr./Main St. contains one plaque for the Fairfax Old Town Hall building so it receives a score of 2. Chain Bridge Rd./North St. contains three historical plaques which gives the intersection a score of 4.

Table 6: A summary of the total scores added from each walkable category for each intersection

Intersection	Safety	Usefulness	Comfort	Interesting
Sager Ave/University Dr.	2	8	10	3
University Dr./Main St.	5	10	8	7
Chain Bridge Rd./North St.	9	10	10	9

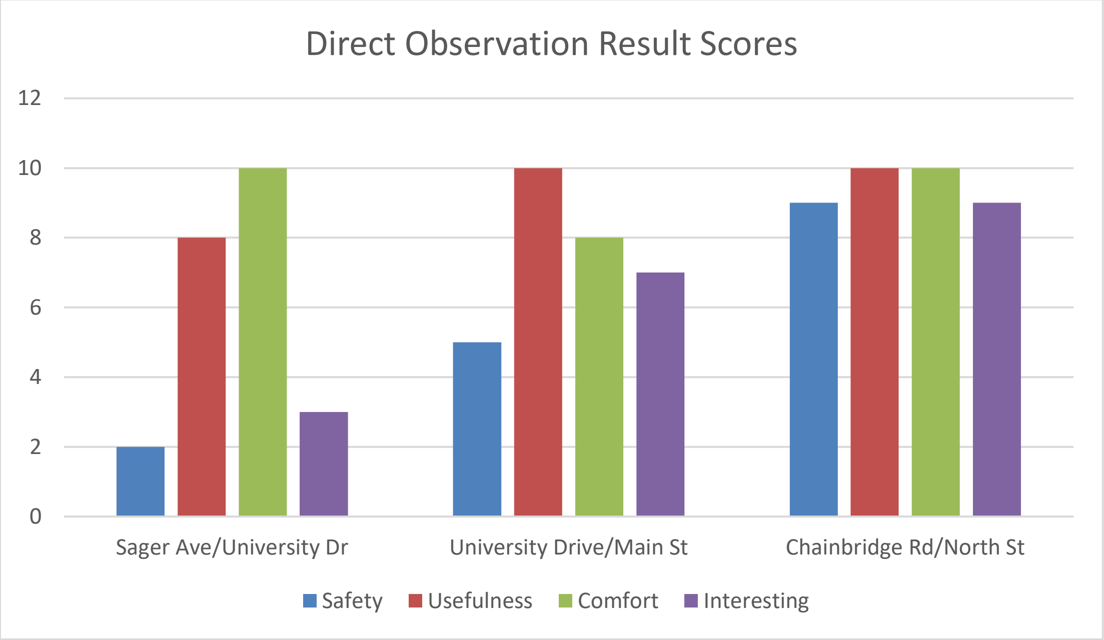


Figure 21: Bar chart displaying the direct observation scores for each intersection

4.4 BEHAVIORAL OBSERVATION SCORES

The following results provide how many light cycles each street for each intersection experienced and what percentage of the behavioral phenomena occurred during those cycles. A light cycle is defined as when a street experiences a red light. The counts of an occurrence were recorded within that timeframe, and then the other street was observed when the red light changed. It is important to note that pedestrians and motorists were not present for every light cycle. The total number of light cycles is still provided, but the light cycle number where observed phenomena took place is what is considered for the calculation. Table 7 shows each average percentage and assigned score each intersection receives for the morning observation. Table 8 shows each average percentage and assigned score each intersection receives for the afternoon observation. Lastly, Table 9 shows the combined percentages and scores for each intersection and Figure 24 provides a visual of the data.

4.4.1 Safety Behavioral Observation (Sager Ave/University Dr Morning Observation)

- Do drivers come to complete stops when turning right on red?

1 - 0% - 20% Do come to a complete stop

2 - 21% - 40% Do come to a complete stop

3 - 41% - 60% Do come to a complete stop

4 - 61% - 80% Do come to a complete stop

5 - 81% - 100% Do come to a complete stop

Sager Ave/University Dr Morning Observations

After sixty-two light cycles, Sager Ave had sixteen cycles experienced phenomena that will be used for the calculation. Sager Ave saw a total of twenty-five drivers turning right on a red light where 34.4% stopped when that street experienced a red light. Only one light cycle was experienced for University Dr. due to traffic flow and only one driver turned right on red. 100% of vehicles came to a complete stop when University Dr. had the red light. Therefore, the average percentage for this intersection is 38.3%, giving the intersection a score of 2 points.

Sager Ave/University Dr Afternoon Observations

After ninety total intersection light cycles, Sager Ave had eighteen light cycles where phenomena took place and thirty-one total drivers turned right on red. Of those observations, 37.4% of vehicles came to a complete stop. University Dr. experienced four light cycles where a vehicle approached the red light and four drivers in total making a right turn on red. Of these cycles, 75% of vehicles came to a complete stop before turning right on red. With that, 44.3% of vehicles came to a complete stop. The intersection receives a score of 3.

Sager Ave/University Dr. Observations Combined Score

For Sager Ave, the morning and afternoon observations resulted in 34 total light cycles where the phenomenon was observed where 36% of drivers came to a complete stop. Regarding University Dr. and its combined observations, it had a total of 5 light cycles with 5 total drivers that turned right on red and 80% of these drivers came to a complete stop at this street before doing so. Therefore, the average percentage for this intersection is 41.6% giving the intersection a score of 3.

4.4.2 Safety Behavioral Observation (For University Dr./Main St. and Chain Bridge Rd/North St.)

- Do drivers turn right on red when they are not supposed to?

1 - 0% - 20% Did not turn right on red

2 - 21% - 40% Did not turn right on red

3 - 41% - 60% Did not turn right on red

4 - 61% - 80% Did not turn right on red

5 - 81% - 100% Did not turn right on red

University Dr./Main St. Morning Observation

University Dr./Main St. experienced sixty-two light cycles and no observed cycles involved a motorist turning right on red. Most light cycles did experience motorists in the right lane, but there was never an instance where a driver turned right on Red. University Dr. receives 100% percentage since no one turned right on red. Main St. is the same in that during the hour observation no driver turned right on red, giving it a 100% percentage. As such, the intersection receives a score of 5.

University Dr./Main St. Afternoon Observation

The University Dr./Main St. Intersection experienced sixty-four light cycles in an hour of observation. Similarly to the morning observation, University Dr. did not experience any drivers turning right on red, giving the street a 100% percentage. However, there was a light cycle for Main St. where a single driver did turn right on red. Therefore, the street receives a percentage of 96.9%. The entire intersection for the afternoon observation has an average percentage of 98.5% giving it a score of 5.

University Dr./Main St. Observations Combined Score

With University Dr., 100% of drivers in the right lane did not turn right at the red light during the morning and afternoon observations. For Main St. and its combined observations, 100% of drivers did not turn right on red in the morning, but since there was one that did in the afternoon, the street saw 98.5% stay in the lane and not turn right.

The overall intersection across both times receives a score of 5 due to the percentage being 99.3%.

Chain Bridge Rd/North St. Morning Observation

The Chain Bridge Rd/North St intersection experienced sixty-two light cycles where no observed cycles involved a motorist turning right on red. Most light cycles did experience motorists in the right lane, but there was never an instance where a driver turned right on Red. Chain Bridge Rd receives a percentage of 100% since no driver turned right on red. North St. is the same in that during the observation no driver turned right on red, giving it a 100% percentage. Therefore, the intersection receives a score of 5.

Chain Bridge Rd/North St. Afternoon Observation

The Chain Bridge Rd/North St. intersection experienced sixty light cycles in an hour of observation. Similarly, to the morning observation, Chain Bridge Rd. did not experience any drivers turning right on red, giving the street a 100% percentage of driver's not turning at the red light. However, there was a light cycle for North St. where one of the drivers in the right lane did turn right on red. Therefore, the street receives a percentage of 98.4%. Overall, the intersections total percentage averages to 99.2% giving the intersection a score of 5.

Chain Bridge Rd/North St. Observations Combined Score

With Chain Bridge Rd., 100% of drivers in the right lane did not turn right at the red light during the morning and afternoon observations. For North St. and its combined observations, 100% of drivers did not turn right on red in the morning, but there was one that did in the afternoon. The street receives a percentage of 99.23%. Combined, the intersection has an overall percentage of 99.6% giving it a score of 5.

4.4.3 Usefulness Behavioral Observation

- Do pedestrians use the crosswalks?

1 - 0% - 20% Utilize the crosswalks

2 - 21% - 40% Utilize the crosswalks

3 - 41% - 60% Utilize the crosswalks

4 - 61% - 80% Utilize the crosswalks

5 - 81% - 100% Utilize the crosswalks

Sager Ave/University Dr. Intersection Morning Observation

The intersection experienced seventy-four light cycles and Sager Ave. saw ten light cycles where the observed phenomena occurred. For this street, there were seventeen total pedestrians crossing over, and 90.6% of these properly used the crosswalks. For University Dr., two light cycles were observed with two total pedestrians where 100% of pedestrians used the crosswalks. Therefore, the total percentage of pedestrians properly using the crosswalks is 92.1%, giving it a score of 5.

Sager Ave/University Dr. Intersection Afternoon Observation

For the afternoon observation, one hundred light cycles passed within the observed hour. For Sager Ave, twelve of these cycles had twenty-two total pedestrians using the crosswalks where 83.33% of pedestrians stayed on the crosswalks when using them. University Dr. had four observed light cycles with seven total pedestrians and 75% of these properly used the crosswalks. In total, 81.2% of pedestrians used the crosswalks when walking to the other side of the intersection. The intersection therefore receives a score of 5.

Sager Ave/University Dr. Intersection Observations Combined Score

For Sager Ave., there were 22 total observed cycles where 54.8% of pedestrians between the morning and afternoon stayed on the crosswalks. Regarding University Dr. with its 6 total observation cycles, 83.33% of pedestrians stayed on the crosswalks. Once combined, the intersection has an overall percentage of 61% giving it a score of 4.

University Dr./Main St. Morning Observation

Sixty light cycles were observed in the span of an hour for University Dr./Main St. University Dr. had nine cycles where sixteen total pedestrians utilized the crosswalks, and 77.8% of pedestrians stayed on the crosswalks. Main St. experienced twenty cycles where forty-three pedestrians used the crosswalks, wherein 82.1% of pedestrians properly used the crosswalks. Therefore, the intersection had an average percentage of 80.8% giving the intersection a score of 4.

University Dr./Main St. Afternoon Observation

University Dr./Main St. experienced slightly more light cycles during the afternoon, at seventy. University Dr. experienced thirty-three cycles where one hundred fifty-five pedestrians were crossing. 80.6% of pedestrians used the crosswalks properly when this street had a red light. Main St. had twenty-nine light cycles where two hundred ten pedestrians used the crosswalks. 85.2% of pedestrians used the crosswalks properly, and that brings the average percentage of the intersection to 82.8%. The intersection earns a score of 5.

University Dr./Main St. Observations Combined Score

For University Dr., there were 42 total observed cycles where 80% of pedestrians between the morning and afternoon stayed on the crosswalks. Regarding Main St. with its 49 total observation cycles, 82.9% of pedestrians stayed on the crosswalks. Once combined, the intersection has an overall percentage of 81.6% giving it a score of 5.

Chain Bridge Rd/North St. Morning Observation

During the observed hour, sixty light cycles took place in the morning for the Chain Bridge Rd/North St. intersection. Chain Bridge Rd. experienced the observed phenomenon for two light cycles and a total of two pedestrians crossed where 100% of pedestrians stayed on the crosswalks. North St. had eight light cycles of pedestrians crossing over, in which 97.5% of fourteen total pedestrians properly used the crosswalks. The average percentage of the whole intersection is 98% giving it a score of 5.

Chain Bridge Rd/North St. Afternoon Observation

Sixty light cycles took place in the afternoon for the Chain Bridge Rd/North St. intersection. Chain Bridge Rd. experienced the observed phenomenon for thirteen light cycles and 84.6% of twenty-six total pedestrians properly used the crosswalks when crossing over. North St. experienced 17 cycles in which pedestrians attempted to cross, and 91.2% of forty-seven total pedestrians used the crosswalks properly. Overall, the intersection has an average percentage of 88.3% giving it a score of 5.

Chain Bridge Rd/North St Observations Combined Score

With Chain Bridge Rd, there were 15 total observed cycles where 86.7% of pedestrians between the morning and afternoon stayed on the crosswalks. Regarding North St. with its 25 total observation cycles, 93.2% of pedestrians stayed on the crosswalks. Once combined, the intersection has an overall percentage of 90.8% giving it a score of 5.

4.4.4 Comfort Behavioral Observation

- Do pedestrians stay on the curb when walking around corners?

1 - 0% - 20% Did stay on the curb

2 - 21% - 40% Did stay on the curb

3 - 41% - 60% Did stay on the curb

4 - 61% - 80% Did stay on the curb

5 - 81% - 100% Did stay on the curb

Sager Ave/University Dr. Intersection Morning Observation

The intersection experienced fifty-eight light cycles in the morning. Sager Ave. had seven light cycles where pedestrians used the curbs. Out of these, there were a total of thirteen pedestrians where 78.6% of pedestrians stayed on the curb when walking around corners. For University Dr. which had two light cycles, there were only two pedestrians, and each stayed on the curbs, which equates to 100%. The average percentage for the intersection is therefore 83.3% giving it a score of 5.

Sager Ave/University Dr. Intersection Afternoon Observation

During the afternoon observation, the intersection experienced a total of ninety-eight light cycles. A total of thirty-three pedestrians walked around the curbs when Sager Ave. experienced the red light for fourteen light cycles. Sager Ave. had 96.4% of pedestrians stayed on the curbs. University Dr. had a total of three pedestrians and two observed light cycles. 100% of pedestrians used the curbs properly. Therefore, 96.9% of pedestrians stayed on the curbs when walking around the corners, giving the intersection a score of 5.

Sager Ave/University Dr. Observations Combined Score

For Sager Ave, there were 21 total observed cycles where 90.5% of pedestrians between the morning and afternoon stayed on the curbs. Regarding University Dr. with its 4 total observation cycles, 100% of pedestrians stayed on the crosswalks for both times of day. Once combined, the intersection has an overall percentage of 92.02% giving it a score of 5.

University Dr./Main St. Morning Observation

The intersection experiences a total of sixty light cycles, where the observed phenomenon took place during sixteen cycles for University Dr. With a total of thirty-six pedestrians, 93.8% used the curbs properly. Main St. also had sixteen light cycles, with thirty-seven pedestrians walking around the corners. 90.6% of these pedestrians effectively used the curbs. Overall, the morning observation percentage for the intersection is 92.2% giving the intersection a score of 5.

University Dr./Main St. Afternoon Observation

In the afternoon observation, the intersection had sixty light cycles overall. University Dr. experienced twenty-one cycles where the observed phenomenon took place, with one hundred thirteen pedestrians total 70.2% of pedestrians were able to use the curbs properly. Main St. had twenty-one light cycles where a total of one hundred thirty-three pedestrians walked around corners. Of this, 84.8% of pedestrians properly used the curbs. Therefore, 77.5% of pedestrians stayed on the curbs when walking around the corners of the intersection which give it a score of 4. Significantly narrow sidewalk widths and an obstructing lamppost at the corner cause significant problems for staying completely on the curb when pedestrian traffic is heavy.

University Dr./Main St. Observations Combined Score

With University Dr., there were 37 total observed cycles where 80.4% of pedestrians between the morning and afternoon stayed on the curbs. For Main St. with its 37 total observation cycles, 87.3% of pedestrians stayed on the crosswalks for both times of day. Once combined, the intersection has an overall percentage of 83.85% giving it a score of 5.

Chain Bridge Rd/North St. Morning Observation

The intersection in the morning had a total of sixty light cycles within the observed hour. Chain Bridge Rd. experienced sixteen light cycles where thirty-eight pedestrians were walking around corners. 97.9% of pedestrians properly used the curbs. North St. saw fifteen light cycles and sixty-four pedestrians in total. 93.3% of pedestrians used the curbs properly. The average percentage for the intersection is 95.7 which gives it a score of 5.

Chain Bridge Rd/North St. Afternoon Observation

During the afternoon observation, the intersection had a total of sixty-two light cycles. Chain Bridge Rd. had twenty-five light cycles where seventy-five pedestrians attempted to walk around the corners. 96% of pedestrians properly utilized the curbs when this street had the red light. North St. had twenty-three light cycles and eighty total pedestrians. 99.5% of pedestrians used the curbs properly. The total average is 97.7%, giving this intersection a score of 5.

Chain Bridge Rd/North St. Observations Combined Score

For Chain Bridge Rd., there were 41 total observed cycles where 96.7% of pedestrians between the morning and afternoon stayed on the curbs. For North St. with its 38 total observation cycles, 97.1% of pedestrians stayed on the crosswalks for both times of day. Once combined, the intersection has an overall percentage of 96.9% giving it a score of 5.

4.4.5 Interesting Behavioral Observation

- Do Pedestrians Utilize the Surrounding Amenities?

1 - 0% - 20% of Pedestrians enter amenities

2 - 21% -40% of Pedestrians enter amenities

3 - 41% – 60% of Pedestrians enter amenities

4 - 61% - 80% of Pedestrians enter amenities

5 - 81% - 100% of Pedestrians enter amenities

Sager Ave/University Dr. Intersection Morning Observation

For the morning observation, the Sager Ave./University Dr. intersection had seventy-four total light cycles. For Sager Ave., ten total light cycles were observed having thirteen total pedestrians present at the intersection. 10% of pedestrians used the surrounding amenities. Regarding University Dr., there were two observed light cycles with three pedestrians and none of these pedestrians used any amenity, making this 0%. Therefore, the average percentage for the intersection is 8.3% earing the intersection a score of 1.

Sager Ave/University Dr. Intersection Afternoon Observation

During the afternoon, the intersection had one hundred twelve total light cycles. Sager Ave. experienced thirty-two light cycles where the observed phenomenon occurred.

There were eighty-five total pedestrians, and 0.6% of these utilized the amenities. University Dr. had twenty-two light cycles and fifty-six total pedestrians. 4.5% of pedestrians used the amenities, which brings the average overall percentage to 2.1% for the intersection. The score is 1.

Sager Ave/University Dr. Observations Combined Score

For Sager Ave., there were 42 total observed cycles where 2.9% of pedestrians between the morning and afternoon utilized the amenities. For University Dr., with its 24 total observation cycles, 4.2% of pedestrians used the surrounding amenities. Once combined, the intersection has an overall percentage of 3.4% giving it an overall score of 1.

University Dr./Main St. Morning Observation

The morning observation for University Dr./Main St. had a total of sixty light cycles. There were thirty-two observed cycles for University Dr. where one hundred forty-eight pedestrians were present in the intersection. 27.5% of pedestrians used the surrounding amenities. Main St. used twenty-seven light cycles where there were one hundred ten total pedestrians. 26.6% of pedestrians used the surrounding amenities. Therefore, the average percentage of the intersection is 27.1% making the intersection receive a score of 2.

University Dr./Main St. Afternoon Observation

For the afternoon observation, the intersection experienced a total of sixty light cycles. University Dr. had thirty light cycles, meaning there was a pedestrian present every time University Dr. had a red light. Two hundred sixty-three total pedestrians were present in the intersection, and 15.9% of them utilized the amenities. For Main St., there were also thirty light cycles where pedestrians were present. Two hundred fifty-one pedestrians were present, and 14.8% of them used the amenities. The intersection has an average percentage of 15.4% which received a score of 1.

University Dr./Main St. Observations Combined Score

With University Dr., there were 62 total observed cycles where 21.8% of pedestrians between the morning and afternoon utilized the amenities. For University Dr., with its 57 total observation cycles, 20.4% of pedestrians used the surrounding amenities. Once combined, the intersection has an overall percentage of 21.1% giving it an overall score of 2.

Chain Bridge Rd/North St. Morning Observation

The morning observation of the Chain Bridge Rd/North St. intersection had sixty light cycles. Chain Bridge Rd. had a total of twenty-seven light cycles where a total of seventy-four pedestrians were present. 3.4% of pedestrians entered the surrounding amenities. North St. had twenty-six light cycles where a total of seventy-six pedestrians were present. 41.9% of pedestrians utilized the amenities. Therefore, the entire intersection has am average percentage of 22.3% and receives a score of 2.

Chain Bridge Rd/North St. Afternoon Observation

For the afternoon observation, the intersection had sixty light cycles. Chain Bridge Rd. had a total of twenty-seven light cycles where one hundred thirty four pedestrians were present. 17.8% of pedestrians entered amenities when this street had the red light. North St. had twenty-four light cycles where ninety-seven pedestrians were present. 16.1% of pedestrians used the surrounding amenities. As such, the average percentage for this intersection is 17% giving it the score of 1.

Chain Bridge Rd/North St. Observations Combined Score

With Chain Bridge Rd., there were 54 total observed cycles where 17.7% of pedestrians between the morning and afternoon utilized the amenities. For North St., with its 50 total observation cycles, 29.5% of pedestrians used the surrounding amenities. Once combined, the intersection has an overall percentage of 23.4% giving it an overall score of 2.

4.4.6 Tables of Behavioral Observation Percentages and Scores

Table 7: A summary of the total average percentages and summed scores for the morning behavioral observations

Intersection (Morning)	Safety	Usefulness	Comfort	Interesting
Sager Ave/ University Dr.	38.3% Score: 2	92.1% Score: 5	83.3% Score: 5	8.3% Score: 1
University Dr./Main St.	100% Score: 5	80.8% Score: 4	92.2% Score: 5	27.1% Score: 2
Chain Bridge Rd./North St.	100% Score: 5	98% Score: 5	95.7% Score: 5	22.3% Score 2

Table 8: A summary of the total average percentages and summed scores for the afternoon behavioral observations

Intersection (Afternoon)	Safety	Usefulness	Comfort	Interesting
Sager Ave/University Dr.	44.3% Score: 3	81.2% Score: 5	96.9% Score: 5	2.1% Score: 1
University Dr./Main St.	98.5% Score: 5	82.8% Score: 5	77.5% Score: 4	15.4% Score: 1
Chain Bridge Rd./North St.	99.2% Score: 5	88.3% Score: 5	97.7% Score: 5	17% Score: 1

Table 9: A summary of the total average percentages and summed scores for the combined morning and afternoon observations

Intersection (Combined)	Safety	Usefulness	Comfort	Interesting
Sager Ave/University Dr.	41.6% Score: 3	61% Score: 4	92.02% Score: 5	3.4% Score: 1
University Dr./Main St.	99.3% Score: 5	81.6% Score: 5	83.85% Score: 5	21.1% Score: 2
Chain Bridge Rd./North St.	99.6% Score: 5	90.8% Score: 5	96.9% Score: 5	23.4% Score: 2

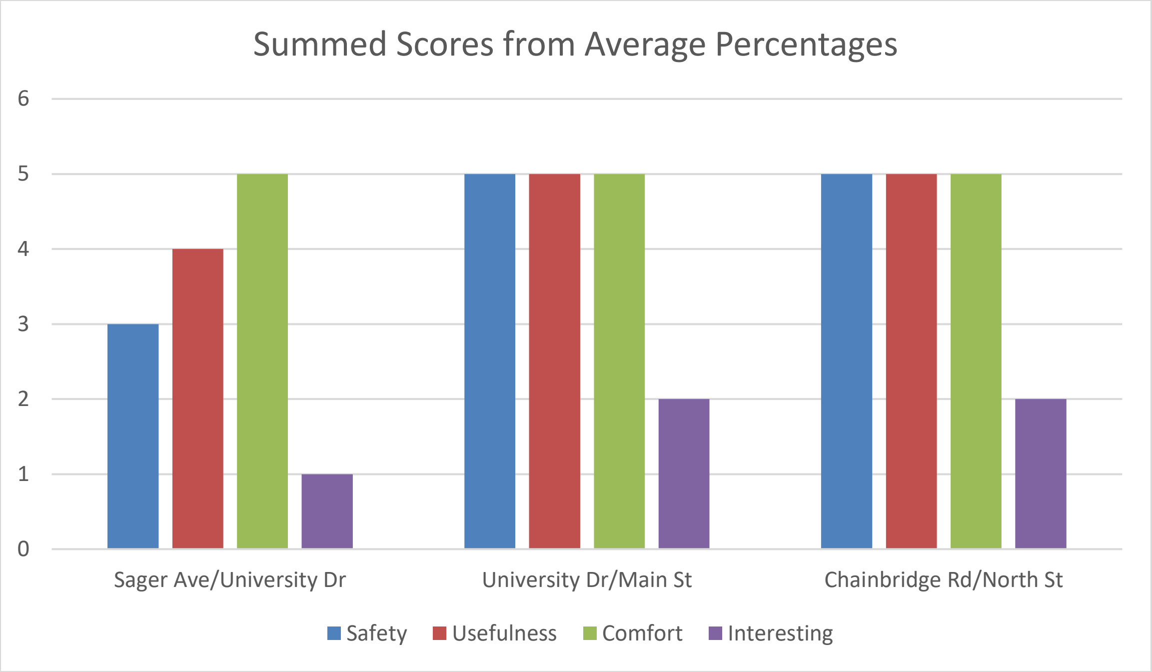


Figure 22: Bar chart showing the total scores from the average percentages

4.5 TOTAL SCORES FROM FEATURE AND BEHAVIORAL OBSERVATIONS

With the total scores assigned from both the Feature Observations and Behavioral Observations, they can be added up to show the total walkability score for each intersection. An intersection could score a maximum of 15 points for each category and could earn a maximum score of 60 points. Table 10 displays the total intersection scores from the Feature Observations summed with the morning and afternoon Behavioral Observations. Figure 25 shows a bar chart to visualize the data totals.

Table 10: A summary of the final scores given to each intersection

Intersection	Safety	Usefulness	Comfort	Interesting
Sager Ave/ University Dr.	5	12	15	4
University Dr./Main St.	10	15	13	9
Chain Bridge Rd./North St.	14	15	15	11

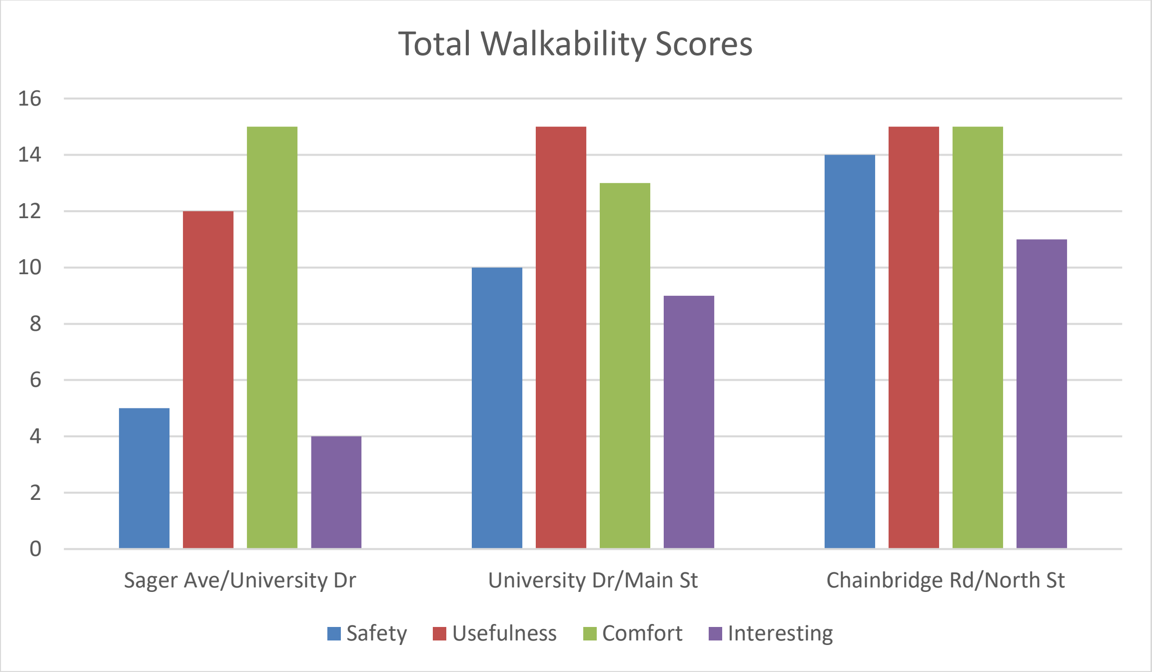


Figure 23: Bar chart showing the total scores summed from the direct and behavioral observations

- Total Walkability Score Scale

0 – 20 = Not walkable

21 – 30 = Somewhat walkable

31 – 40 = Walkable

41 – 50 = Very Walkable

51 – 60 = Extremely Walkable

Sager Ave/University Dr.

5 + 12 + 15 + 4 = 36

University Dr./Main St.

10 + 15 + 13 + 9 = 47

Chain Bridge Rd./North St.

14 + 15 + 15 + 11 = 55

5. CONCLUSIONS

5.1 MACRO CITY-WIDE RESULTS

5.1.1 Safety: Sidewalk Presence

Based on the maps produced in the “Results” section, there are notable similarities and differences between areas with high WS values and walkable feature densities. Sidewalk amounts tend to aggregate within the center of the city, encompassing Old Town. Toward the east of this area, there is a significant gap in sidewalk infrastructure which also correlates with a decrease in WS values. The area appears to be largely residential with a park. Major differences between the maps include the area to the north of the city where high amounts of sidewalks are reported, but the WS values remain low. The phenomenon is because there is a high residential presence in the city toward the north, but there are not many interesting things to do there. Additionally, there are high WS values in the northeast of the city, but there are hardly any sidewalks. The amounts of amenities are high there, with many restaurant options, but the map indicates that WalkScore.com is failing to incorporate safe infrastructure for travelling to said amenities on foot.

5.1.2 Usefulness: Crosswalk Presence

The amounts of crosswalks in the city appear to follow a similar pattern with the sidewalks in that there are many crosswalks within the city’s center. The WS values here are high and it is possible that because of the presence of sidewalks and amenities, the need for more crosswalks was addressed thoroughly here. There is also a gap east of the city’s center which also reports low WS values. However, unlike with the sidewalks, this is the only area where there are high amounts of crosswalks, as even toward the western part of the city these features are not as common. The western side of the city appears to be lacking crosswalk infrastructure, which can hinder a pedestrian’s ability to traverse the streetscape.

5.1.3 Comfort: Tree Presence

Unlike the previous data outputs with sidewalks and crosswalks, tree canopies appear to be missing in the city’s center. WS values are reported there as being very high, but the sense of comfort appears to be missing. There is a high number of trees east of the city’s center, where other walkable features are missing. The largest amount of low WS values aggregates in this spot, while tree presence appears to flourish. The phenomenon visualized there could be what Shuvo et al. (2021) mentioned in their study in that too much greenspace may lessen an area’s walkability. These areas are comfortable but lack useful and safe infrastructure, and judging by the WS values, are not very interesting.

With the commercial and retail buildings, there appears to be a direct contrast for where trees are located and where these buildings reside. The city has placed a cost on facilitating interesting amenities at the expense of comfort. Similarly with sidewalks and crosswalks, there is an aggregation of such buildings in the city’s center. As expected, the WS values tend to yield higher scores where commercial and retail buildings congregate. WalkScore.com uses nearby amenities as its only aspect of walkability, so these data outputs overlap.

5.1.4 Interesting: Retail and Commercial Presence

The interesting building map differs from the other map outputs in that the data is concentrated places and is not as dispersed. At the center of the city, where cafes, restaurants, grocery stores, and other amenities appear, there are more square meters of interesting places than along important road networks. Lee Highway, Main St., and Fairfax Boulevard are a few of these roads. It seems that the goal is to facilitate as many amenities as possible where the most drivers are. The incentive enables many retail and commercial options, but at the expense of comfort and usefulness where tree canopies and even crosswalks are not as common.

5.1.6 Discussion

As noted, there are areas which contain walkable features and infrastructure with high WS values. There are also areas with high WS values but with little to no walkable features present. The question of Fairfax City being as walkable as its WS suggests requires an answer that may be too broad for a city-wide approach to tackle. The statement is not meant to dissuade from using GIS analysis to assess the walkability of an urban environment. It does however point out the fact that such a large area contains a degree of variability, and the concept of walkability itself is highly variable. Overall, the city yields a “Somewhat Walkable” WS of 54, but as the maps show there are areas with much higher scores than that. There are also areas with much lower scores. A pedestrian using the streetscape in the center of the city in the Old Town area will have a different experience of one navigating around east of the center. Even within Old Town itself, walkability varies.

As such, the micro-intersection approach is not to replace the macro city-wide methodology but is rather meant to compliment it. City-wide trends, notable correlations, and comparisons of data all yield invaluable insights. Once can collect WS data and visualize how misleading it can be when compared to features that pedestrians need to navigate a given urban place. The micro-intersection approach further enhances this as a more detailed assessment. The walkable features can be recorded and observations of how pedestrians and motorists alike use the streetscape can be collected and operationalized. The smaller study areas also provide a more thorough glimpse into what the pedestrians experience. Therefore, the Walkability Index derived from the research applies a more specific understanding of that the conditions are like for selected intersections.

Based on the city-wide analysis, one can assume that the Old Town area is reasonably walkable given the fact that both WS and the Walkability data agree. It should be noted that the walkability data only takes a few aspects into consideration, and that there may be more details that are missing from the approach. An additional weakness involves the boundary of the city shapefile itself. Data such as the canopy had to be clipped around the border, and it is possible that the values derived from areas along the edge of the city are not entirely accurate.

5.2 MICRO INTERSECTION-FOCUSED RESULTS

5.2.1 Morning Observation

With the Feature and Behavioral observations added together, a walkability index is applied to the three observed intersections. In the morning, Sager Ave/University Dr.

received a score of 36, which assigns it to the category of “Walkable”. University Dr./Main St. and Chain Bridge Rd./North St. received scores of 46 and 55 respectively, placing the former in the “Very Walkable” category, and the latter in the “Extremely Walkable” category. While all three intersections fall into at least a walkable category, there were noticeable reasons as to why they did not score higher. Particularly, Sager Ave/University Dr. contains noteworthy reasons why it did not score as high as the other two observed intersections.

Sager Ave/University Dr. earned a higher number of points from the Usefulness and Comfort categories. The intersection offers enough time for even older pedestrians to walk across. Assuming the walk speed is constant, pedestrians should have no trouble walking across in the allotted time. Most of the curb ramps do contain truncated dome surfaces. As observed in the behavioral observation, pedestrians do appear to utilize the crosswalks effectively. Perhaps due to the amount of space and relatively less foot traffic compared to the other intersections in Old Town Fairfax, there is a greater desire to stay within the crosswalks. Trees are plentiful and as is lighting at night. Similarly, to the crosswalks, the curb ramps appear to be utilized effectively as well.

Sager Ave/University Dr. did lose points due to the lack of features within the Safety and Interesting categories. The intersection lacks any barriers between the road and the sidewalk. The intersection is also not very safe for pedestrians who are visually impaired, as there are no audio cues when crossing a street. Additionally, motorists do not tend to come to a complete stop when turning right on a red light, increasing the risk of pedestrian-motorist incidents. There are also not many interesting things to do or learn within the intersection. The only real amenity happens to be a bank with a 24 hour ATM, and there are no historical plaques. As such, pedestrians were not frequently visiting the single amenity.

University Dr./Main St. did receive a high number of points due to the Usefulness and Comfort categories. The intersection allows enough time for pedestrians to walk across the crosswalks, which is perhaps mainly because the width of the streets is not as wide as other intersections. All curb ramps contain truncated dome surfaces. During the Behavioral Observation, pedestrians did for the most part utilize the crosswalks. Those that did not were typically farther away from the intersection, or were outside the observed buffer and simply did not bother to walk all the way to intersection to cross. For Comfort, while the intersection is lacking trees, it made up for this with its lighting. Additionally, most pedestrians did use the curbs when walking around corners, with a slight decrease during the afternoon observation.

University Dr./Main St. did score slightly lower for the Safety and Interesting categories. While the intersection does contain a type of barrier between the sidewalk and the road for the most part, it lost points due to the lack of audio devices for the crosswalks. Since there is a sign that tells drivers to not turn right on a redlight, there were hardly any instances recorded where a driver did so. For the Interesting category, despite the number of amenities present, it lacks historical plaques. During the behavioral observation, there also were not as many pedestrians actually using the surrounding amenities, with the score being higher in the morning than in the afternoon. A possible theory here is that the intersection houses amenities that are best experienced in the morning and evening. For example, a café is present, which is more popular for its breakfast and coffee selection. Additionally, there are a handful of restaurants that are more suited for dinner, thus not being very attractive in the morning or early afternoon.

Chain Bridge Rd./North St. scored the highest out of all three intersections, with only the Interesting category lacking higher points. For Safety, the intersection score high for the presence of on street parking as barriers, and it being the only observed intersection with crosswalk audio cues. Much like University Dr./Main St., the intersection includes signage which tells driver to not turn right on red. Regarding Usefulness, despite the distance a pedestrian must walk, the intersection appears to accommodate the extra distance with enough time to cross. Truncated dome surfaces are present for all curb ramps. Pedestrians appear to mostly utilize the crosswalks without stepping out into the road. For Comfort, trees and streetlights are plentiful and there is usually enough space for pedestrians to walk around curbs without stepping onto the street.

For the Interesting Category, the intersection scored like Main St./University Dr with how many amenities are offered. The intersection also scored the highest in historical plaque presence. The behavioral observation for the Interesting category is where points decreased, as pedestrians were not visiting the surrounding amenities as much. One restaurant appears to be popular spot for lunch, but it has a parking lot, so it appears the preference for visiting there is to drive, not walk. There might need to be greater incentive for pedestrians visiting Old Town to walk to the restaurant as opposed to driving. The other restaurants may be better suited for dinner, so an evening observation may yield different results with amenity use.

5.2.2 Afternoon Observation

In the afternoon, Sager Ave/University Dr. received a score of 37, which once again assigns it to the category of “Walkable”. University Dr./Main St. and Chain Bridge Rd./North St. received scores of 45 and 53 respectively, placing them again in the “Very Walkable” category. While the scores did change in the afternoon observations, these decreases were not significant enough to cause any of the intersections’ scores to drop to a lower or higher walkability threshold. The possibility of why the intersection did score slightly lower is due to the higher volume of pedestrian and motorist traffic. People start to become hastier when space is limited. Crosswalks become more crowded, people using curbs lose freedom of movement, and lines of stopped vehicles become backed up, infringing on crosswalks. The ever-changing nature of the urban environment is shown through direct observation.

The morning and afternoon Behavioral Observations display the fact that the streetscape is not immutable. There can be static features and infrastructure that can award an intersection a high score of walkability, but there needs to be an observation to see if these features are being properly used, if at all. Even though the change between the observation times was not necessarily significant, there is still variation. The score values still decrease during the afternoon. WS does not consider the micro-focused, changing methodology of this research. To better understand the differences between the WS and the Walkability Scores of this research, a comparison needs to take place.

5.2.3 WalkScore.com Comparison

The Walkability Scores from the research are to be placed in a calculation out of 100, like the WS values from WalkScore.com's WS. Because WS involves whole numbers, the scores will be rounded up once they are standardized to be out of 100. Table 11 displays the WS values from WalkScore.com for the observed intersections and is compared with the Walkability Scores derived from the research after they were standardized. Based on WalkScore.com's scale, each of the three intersections are considered a "Walker's Paradise" as they each receive a score above 90.

Table 11: Total Walkability Score for each intersection standardized with WS

Intersection	WalkScore.com WS	Walkability Score
Sager Ave/University Dr.	92	60
University Dr./Main St.	92	78
Chain Bridge Rd./North St.	91	92

Looking at the scores, is clear that the research does not agree with WalkScore.com regarding the Sager Ave./University Dr. and University Dr./Main St. intersections. Sager Ave./University Dr. scored rather poorly around Safety because of its lack of accessible features and motorist behaviors. It can be misleading to assume that the intersection is a “walker’s paradise” when it may not be the safest place for a pedestrian to access. The intersection also lacks interesting things to do, which contradicts its WS value. WalkScore.com uses a much wider radius than the research. Maximum points are rewarded to a point for having amenities within a .25-mile (roughly 402-meter) distance, while the research used 48-meter buffers. It is therefore understandable why the website would consider the intersection to have interesting things to do because of the wider scale. The research has argued that a smaller, more micro-focused approach provides a more accurate assessment of a streetscape’s true level of walkability.

WalkScore.com and the Walkability Score do relatively agree with the walkability of the Chain Bridge Rd./North St. intersection. It is a safe, comfortable, and usefulness intersection for pedestrians. There are interesting things to do, which is the sole walkable aspect WalkScore.com considers. The research does note, however, that the actual utilization of the interesting amenities varies, and the area may not be as popular as its WS would suggest. The comparison displays the complexity of what makes a space walkable. Speck’s four walkable aspects provide an appropriate foundation for what can improve the walkability of the streetscape.

There is never a one size fits all solution to making a given urban environment more walkable. The micro intersection-focused results seem agree with the macro analysis, but the closer look reveals just how many layers there are to the streetscape. WalkScore.com fails to truly encapsulate the definition of walkability and all of its variables. The methodology described in the research of data collecting, recording, calculating, and analyzing is not meant to be followed precisely. For example, the Safety category does not have to include the features and behavior that were recorded. The purpose is to showcase the fact that the streetscape and all its features, infrastructure, and amenities varies. GIS is an excellent tool for displaying city-wide walk score values and evaluating areas that need more walkable features. However, a more accurate assessment must take place at the street level, and the research emphasizes the importance of this approach. Without the micro intersection-focused methodology, it would be impossible to know what intersections lack audio devices, whether or not the crosswalks offer enough time to cross, or if the area is well-lit at night. Additionally, the utilization of such features can only be observed and recorded at the micro-intersection focused level. As such, the areas of improvement are site-specific for the study areas used for the research.

Based on the findings, the need for greater accessibility regarding all pedestrians is a must for the streetscape. Most intersections scored poorly in the Safety category because of the lack of audio cues for crosswalks. For an intersection as busy as University Dr./Main St., there is not a great sense of comfort due to the lack of trees. Because of certain missing variables, the overall research question can be answered. The city is not in fact as walkable as its WS implies, but that answer is complicated. The city-wide data compared to WS may imply that the score of 54 is fairly accurate, in that overall, the city is lacking walkable features. From this macro-approach, it may lead one to assume that WalkScore.com has an accurate assessment, which could be true at that scale and only when amenities are considered. The micro-intersection focused approach changes this, as intersections that WalkScore.com deems as a walker’s paradise are not necessarily ideal for pedestrians.

6. OPPORTUNITIES FOR FUTURE RESEARCH

6.1 PARTICIPANT SURVEYS

One methodology mentioned frequently in the “Literature Review” section used the dispersion and collection of participant surveys. McCormack et al. (2020) and Kasraian et al.’s (2021) gathered their data by creating surveys and asking people within the study area to answer the questions. The recorded answers were then operationalized and was used for the analysis. A process of creating surveys would involve a thorough overview of the site-specific streetscape environment. It is possible that the features gathered from the “Literature Review” section would also be used for the survey. The questions would ask about topics related to what pedestrians consider to be important for walkability. A scale of 1 to 5, like the micro-intersection focused observations, could be used to indicate what the respondent considers to be more or less important for a given feature.

The idea behind using surveys in a local area involves the assessment of how perceptions of the urban environment changes depending on the respondents. Additional parameters may include demographics such as age, race, gender, as well as income level. The results of this approach would be used for prioritizing which walkable features are preferred by the very people who utilize the streetscape. Afterwards, the same procedure of direct observation can be used for assessing the behaviors of motorists and pedestrians.

6.2 WEIGHTS

While gathering methods and procedures from relevant literature, a trend in the use of weights was noticed. A weight applied to a statistic adds more value to a given variable over others. For example, in the study conducted by D'Orso and Migliore (2020), there were weights applied to each walkable indicator. A higher weight was applied to the Safety category because after a review of relevant literature, it was determined that the Safety category is the most important. The conclusion of Safety being a priority was made from sources that used participant surveys to find what pedestrians felt were the most important aspects of a walkable environment.

The use of weights would be beneficial, especially if the use of surveys was used. Once the features would be ranked as being most and least important to respondents, different weights could be applied to the various walkable categories. The category that is deemed most important would hold the most value for the analysis. Weights would add more complexity to the research and further provide support for the notion that enhancing walkability is a very site-specific process. Some features are prized over others, and certain features that are preferred by pedestrians for one area may differ from another.

6.3 IMPROVING THE CITY-WIDE APPROACH

The current research compared three intersections that were selected based on historical pedestrian-motorist incidents and sidewalk infrastructure. While this micro intersection-focused approach displayed the variations at the street level, strengthening the macro city-wide approach would further enhance efforts to assess walkability. More data variables could be categorized into the walkable aspects and displayed onto maps. In a similar manner to how the research displayed the results, these maps would highlight areas that are missing walkable features. Multiple features for each walkable category would further the assessment. For example, with the Safety category, in addition to sidewalk infrastructure the map could also include GIS data for areas with barriers between the sidewalk and road. The method of compiling this data would be similar to how the crosswalk and WS data was manually digitized. Aerial and street view imagery would be used to digitize streets that contain some form of barrier such as on-street parking. Sidewalk width could also be a useful variable to consider.

Another example of data for the Safety category would involve a process of compiling locations where there is a “No right turn on Red” sign at intersections. There are many possibilities of what could be generated at the macro city-level, and more data for the map outputs would serve to further compliment the intersection-focused approach. The solution of the lack of available walkable feature data for the City of Fairfax is the process of digitizing. The research explored this method, but it could be taken further to incorporate more walkable features to compare to the WS point locations. More data for walkable features would also play a role in the micro intersection-focused process of selecting sites to observe.

6.4 IMPROVING THE INTERSECTION-FOCUSED APPROACH

The site selection process for determining which intersection to observe involved accident data. The data was limited, and only encapsulates incidents that were reported. It would be beneficial to compile additional data of near miss incidents which, according to sources mentioned in the Introduction section, are on the rise. It may be difficult to find a source on near miss data but perhaps police reports could be collected and converted into spatial data to aid in the site selection process.

While the Behavioral Observations incorporated two different times of day for each category with the three intersections, a third time of day would also be useful. As noted previously, amenity use will vary depending on whether it is the morning, afternoon, or evening. In the case of University Dr./Main St for example, many of the amenities are either suited for the morning or the evening. The addition of an evening observation would shed light on how motorists behave when visibility is lower. The evening observation would also provide insight into how pedestrians navigate the streetscape with lower visibility as well. The streetlight feature observation resulted in the intersections receiving high points for Comfort, but the question remains as to if these lights help people. A behavioral observation across the four categories for each intersection at night could yield very different results from the morning and afternoon observations.

Amenity use would more than likely see the most significant change. It is also possible that due to higher motorist and pedestrian traffic, the other categories would be impacted as well. With lower visibility, pedestrians may not utilize the crosswalks or curbs as effectively. Drivers may be less inclined to come to a complete stop, or worse may ignore the “No Turn on Red” sign. With the added observation time, the argument that streetscape walkability not being static would be further supported. Greater variations across three different times of day would be highlighted to show just how variable behaviors of motorists and pedestrians can be.

When it comes to the Safety category, it is a complex topic that involves multiple variables spanning from the design of the environment to human behavior. The research focuses on designated safety elements found from relevant literature. These elements, however, are not the only factors to consider. Other aspects of safety could include drivers yielding when turning on a green light, drivers blocking crosswalks when stopped at a light, as well as those who run red lights. Additionally, the features observed can also involve tripping hazards through the sidewalk network. As such, future studies can expand on what the walkable aspect of Safety entails, which may also change depending on the selected site. It is also possible that the observed behaviors of one intersection vary drastically from others nearby, supporting the idea that the streetscape is constantly fluctuating in its infrastructure over very little distance.

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