Walking After Dark: A Sidewalk Illumination Case Study in Cedar City, UT

*Sabrina Waite *[a], Ian Nelson [b], & Jamie Spinney [b]*

[a] *Department of Humanities and Social Sciences, Southern Utah University, Cedar City, UT*
[b] *Department of Geosciences, Southern Utah University, Cedar City, UT*

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Students: sabrinawaite123@gmail.com, ian.andrew@comcast.net*
Mentor: jamie.spinney@suu.edu

ABSTRACT
Sidewalks are an important part of public space, but they are becoming increasingly dangerous, especially at night. Therefore, it is important that sidewalks are adequately illuminated to meet the safety, comfort, and accessibility needs (*i.e.*, provide high levels of pedestrian reassurance) to sidewalk users. The objective of this case study was to quantitatively measure and subsequently explore the spatial and statistical distributions of light intensities along the sidewalks that surround Southern Utah University in Cedar City, Utah. A secondary objective was to develop a set of "adequate lighting" guidelines (*i.e.,* 5 to 10 lux) to help identify areas that could benefit from sidewalks lighting enhancements. A digital light meter was used to measure horizontal light intensity, in lux, at a systematic sample of 208 points along the sidewalks within the study area. Geographic coordinates were also collected for each sample observation to enable mapping and spatial analysis of the light intensity data. Results indicate 61% of the observations have lux values equal to zero (complete darkness), 13.4% met or exceeded the minimum guidelines, while 4.3% fell within the "adequate lighting" guidelines adopted by this case study. These results suggest that sidewalks are too dark in too many places to provide reassurance to sidewalk users in the study area. The mapping and spatial analysis results from this case study also provide information to support targeted visibility enhancements of sidewalks within the study area.

KEY WORDS
Lighting; Optimum Illuminance; Luminometer; Sidewalks; Pedestrians; Safety; Security; Reassurance

INTRODUCTION

Sidewalks are an important component of public space because they enable personal mobility and provide public access to goods and services that are required to meet one's daily needs. Therefore, it is important for sidewalks to be safe, accessible, and well-maintained to enhance public health and maximize social capital.[1–3] This is especially true for people who are living with disabilities,[4] but also for those people who do not or cannot drive a car, such as many older adults and all children.[5] Sidewalk safety is a multidimensional concept that includes safety from potential trip hazards, pedestrian-vehicle crash hazards, and the hazards of personal crime. These, and other, considerations take on a special meaning at night, when visibility of sidewalk users is significantly reduced. Public space lighting (PSL), however, has been shown to enhance users' perception of safety, comfort, and accessibility[6-9] Adequate PSL levels are required at night for the safety, comfort, and accessibility of pedestrians, cyclists, and other sidewalk users by enabling people to detect potential hazards and then take appropriate action to avoid the hazard. Among these potential sidewalk hazards are "trip hazards",[10] which are defined by the Americans with Disabilities Act (ADA) as any vertical displacement of more than one-quarter inch[11] and may include ditches, excessive cross slopes,[12] or any abrupt vertical change in elevation caused by heaved slabs, tree roots, spalling, or cracks.[13] At night, there is an increased risk of trips and falls when pedestrians are unable to detect unexpected obstacles or impediments along sidewalks.[13] Therefore, adequate PSL is an important component of effective sidewalk design to ensure safe navigation at night for a wide range of users, their travel modes, and their physical abilities and preferences.

Safe navigation of the pedestrian environment at night must also consider the potential hazards associated with motor vehicle interactions. In the United States, more than 7,000 pedestrians were killed in traffic crashes with motor vehicles in 2020.[14] Moreover, because poor lighting conditions reduce the visibility of pedestrians, almost three-quarters of these pedestrian deaths occurred at night.[15, 16] This is especially compelling given that only about one-quarter of daily traffic volume occurs after dark.[17, 18] However, the increasing popularity of automobiles, which started around the 1920s,[19] further necessitates consideration of adequate levels of PSL for the pedestrian environment. Adequate levels of PSL are needed, because research indicates that road segments with a lower level of PSL tend to be associated with a higher number of pedestrian-vehicle crashes.[20] Conversely, research has shown that increased lighting levels have significantly reduced the number of pedestrian-vehicle crashes.[21] While adequate PSL of sidewalks is important for the safety and security of people, property, and public spaces,[7, 22] the design of our pedestrian environment, and especially crosswalks, requires that pedestrians, cyclists, and other mobility device users (*e.g.*, wheelchairs) are more visible to drivers,[23] regardless of the time of day.

In addition to trip hazards and traffic accidents, sidewalk users inherently feel less safe and less comfortable after dark. This lack of reassurance in one's safety after dark tends to be associated with decreased visibility of one's surroundings, increased opportunities for concealment, and typically fewer eyes on the street.[6, 7, 24-26] There is a growing body of research that provides convincing evidence of increased PSL of sidewalks helps users feel safer (*i.e.*, reassured) when walking at night.[24, 27-29] The concept of "pedestrian reassurance"[27] has been described as the feelings of sidewalk users' safety, comfort, and confidence when walking alone after dark.[30, 31] Designing sidewalks to promote pedestrian reassurance can collectively lead to a host of social, economic, environmental, plus personal, and public health benefits.[7]

In the context of pedestrian reassurance research, the definition of adequate lighting has been informed by the concept of an "optimum illuminance". Optimum illuminance is the threshold "beyond which further increase in illuminance has no significant effect on reassurance".[27] Previous studies into optimum illuminance found the spectrum of lighting intensity is strongly associated the spectrum of pedestrian reassurance.[8, 27, 32-35] Moreover, the statistical distribution of the relationship between the two exhibits an area with rapid change (*i.e.*, the escarpment) and another area beyond which there is negligible change (*i.e.*, the plateau, or optimal level).[8, 36] Despite a growing body of literature on the topic, research has not yet discovered a "precise estimate of optimal illuminance" (p. 1),[36] because the expectation of discovering a "one-size-fits-all" solution for nighttime illumination requirements is out of reach,[8] considering the wide variety of contextual settings and different sidewalk users. Nevertheless, research by Svechkina et al.[8] concluded that PSL of sidewalks in the range of 5 lx to 10 lx provided reasonably high levels of pedestrian reassurance, with only a negligible increase in reassurance with increasing illuminance. Similarly, this case study has adopted a set of adequate lighting guidelines to identify areas with sidewalks that may benefit from lighting enhancements Following guidance from Svechkina et al.,[8] other academic studies, and published guidelines[A], these guidelines are based on the breakpoints in a typical statistical relationship between illuminance and pedestrian reassurance with minimum and optimum thresholds of 5 and 10 horizontal lx, respectively. These guidelines were developed to provide guidance on the 'Goldilocks' locations and values that are considered adequately illuminated (*i.e.*, just right), as well as the locations and values that are considered either too bright or too dark.

METHODS AND PROCEDURES

PSL consists of many different elements, such as intensity, glare, color temperature, and others. This case study examined light intensity[B] (*i.e.*, illuminance), which is defined as the density of incident luminous flux with respect to area at a point on a real or imaginary surface, and it can be measured on horizontal, vertical, or semi-cylindrical surfaces.[37] This case study employed a technology-based approach to measure light intensity on a horizontal plane using a digital light meter (*i.e.*, Klein Tools, ET130), also known as a luminometer or luxmeter. While light intensity can be measured in foot candles (Imperial) or lux (metric), this case study used lux, where 1 lux equals the light output produced by a standard candle. For context, zero lux (lx) means the absence of detectable light (*i.e.*, complete darkness), 0.1 to 0.2 lx is typical from a full moon on a clear night, 300-500 lx is typical for indoor light intensities, and about 1,500 to 100,000 lx is typical for outdoors on a cloudy versus a clear sunny day, respectively. The Klein Tools, ET130 can measure luminosities from 0 to 40,000 lux with a resolution of 0.1 lux and repeatability of +/- three percent. Despite the typically minimal impact of moonlight, this case study collected light intensity measurements within three days of the new moon phase in October 2022 (*i.e.*, between the 22nd and 28th) to minimize the impact of moonglow.

With an interstate highway to the west, the study area for this project was a two-block neighborhood to the north, east, and south[C] of the Southern Utah University (SUU) campus, which is a public university with a student population of 12,582.[39] SUU is located within Cedar City, which is a micropolitan area in the southwest part of Utah (see Figure 1 inset map) with a population of 35,235.[40] Similar to a similar recent study,[8] this case study collected light intensity (lx) measurements at a systematic sample of points (*i.e.*, about every 80 steps) along the sidewalks within the study area. The light intensity values (lx) from the luxmeter were

[A] Similar research used segmented regression to identify discrete breakpoints in the relationship between illuminance and reassurance (*i.e.*, feeling very unsafe to feeling very safe) and it found the plateau (*i.e.*, optimum illuminance) ranged from 8.9 lx to 26 lx, depending on the location..[36] In line with the range proposed by Svechkina et al.,[8] and specifically for sidewalks and walkways with high traffic (*i.e.*, > 100 persons/ hour), the FHWA[20] recommends 10 semi-cylindrical lux for sidewalks as the optimum illuminance (*i.e.*, additional light beyond this level does not increase visibility). At areas with higher likelihood of pedestrian-vehicle crashes, the FHWA recommends an average vertical illuminance of 20 vertical lux for midblock crosswalks and, conservatively, 30 vertical lux at intersections should provide adequate visibility for detection in most circumstances. Although not specific to sidewalks, but to provide context, subjective perceptions of safety, comfort, and visibility suggest an optimum illuminance of 10 horizontal lux in a parking garage and only 2 horizontal lux in parking lots.[38]

[B] Light intensity and illuminance are used interchangeably in this manuscript, but they are technically not equivalent. This case study used a digital light meter, or luxmeter, to take single point measurements of light intensity on a horizontal plane. The differences between illuminance and light intensity should not impact the conclusions of this study.

[C] The study area did not include the area to the west of SUU campus, because the football field and facilities border Interstate 15 (I-15).

supplemented with (a) notes regarding whether the light came from a residential, commercial, or municipal light sources and (b) geographic coordinates (*i.e.*, latitude and longitude) to enable spatial analysis and mapping of the light intensity values.

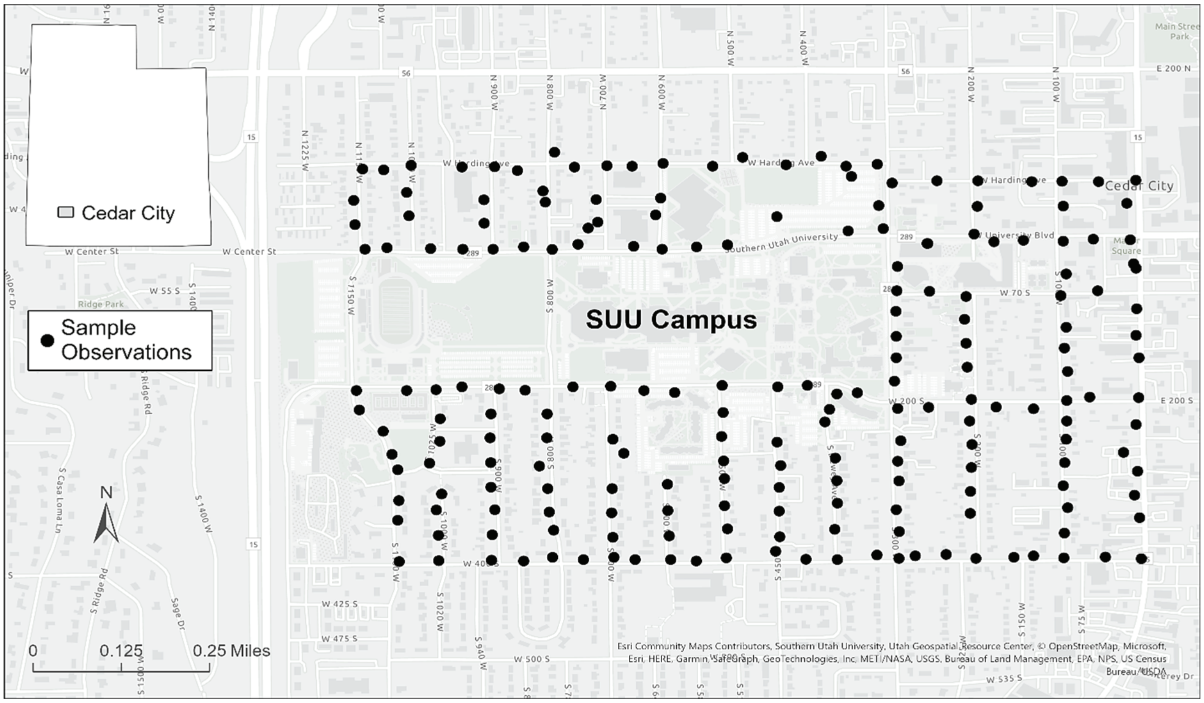

Figure 1. Map of study area and sample locations along sidewalks in Cedar City, Utah.

Using the geographic coordinates (*i.e.*, latitude and longitude) that were collected for all 208 measurements of light intensity (lx), the data were imported into ArcGIS Pro (v. 3.1.2). The software was used to illustrate the spatial distribution of observations and their light intensities across the study area. There are several tools that can analyze the spatial distribution (*i.e.*, spatial autocorrelation) to identify spatial clusters of statistically similar (and dissimilar) values across space. The Spatial Statistics Tools suite[41] of ArcGIS Pro software was used to run the High/Low Clustering (Getis-Ord General G) tool[42] to (a) measure the degree of clustering for high and low values among the full sample of 208 observations and (b) test the null hypothesis that light intensity (lx) values are randomly distributed. While the Getis-Ord general G statistic measures global (*viz.* across the whole study area) concentrations of high or low values for an entire study area, the Cluster and Outlier Analysis[43] uses the Anselin Local Moran's I statistic to identify statistically significant local (viz. within a portion of the study area) clusters of hot spots (high-high), cold spots (low-low), and spatial outliers (significantly different high or low values). The local neighborhood (*i.e.*, search radius) for the Cluster and Outlier Analysis was 6 nearest neighbors.

RESULTS

Horizontal light intensity was measured, in lux, for 208 systematically sampled locations along the sidewalks within the study area. Figure 2 illustrates the statistical distribution of these categorized light intensity values (lx) within the context of the adequate lighting guidelines adopted for this case study. In Figure 2, the zero-lux intensities have been separated into their own category for illustration purposes (*i.e.*, to avoid visually overwhelming the other categories). Summary statistics indicate the light intensities range from a minimum of 0.0 lx to a maximum of 79.2 lx with a mean of 2.6 lx (SD = 7.8). Several outliers exist, such as the maximum value of 79.2 lx, which was measured directly under a commercial electronic sign. The second highest value, 42 lx, was measured directly under a floodlight on the north side of the university's intramural field, and this value is more than five standard deviations from the mean. Regardless of the few outliers with uncharacteristically high values, the mean value ($\bar{x}$ = 2.6 lx) is clearly influenced by the high percentage of light intensities less than 5 lx, and especially those that measured zero lux.

The frequency distribution of horizontal light intensities (lx) on sidewalks in Figure 2 indicates that 61 percent of the observations have lux values equal to zero. When combined with light intensities ranging from 0.1 to 4.9 lx, more than 86 percent of the sample observations are too dark to meet the minimum threshold of 5 lx. Only 4.3% of the sample, or 9 of 208 observations, fall within the adequate lighting guidelines adopted by this case study. Another 9.1%, or 19 observations, exceeded the optimum illumination threshold of 10 lx. Conspicuously, of the 19 observations that exceeded the optimal illumination threshold, almost half (*i.e.*, 8) of them were associated with supplemental illumination sources, such as residential properties (n=2), businesses (n=2), commercial signs (n=1), university sports fields (n=2), or tennis courts (n=1).

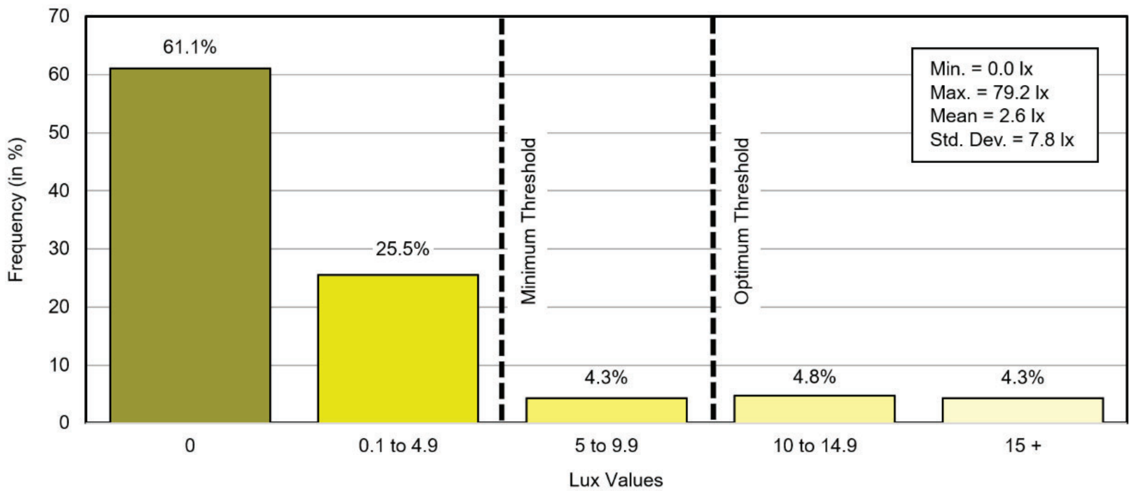

Figure 2. Frequency distribution of, and summary statistics for, sampled sidewalk light intensities (lx).

The map in Figure 3 uses a dark background of the street network with SUU campus located in the center to illustrate the spatial distribution of sampled sidewalk light intensities (lx) within the study area. The map uses graduated symbols with graduated color intensity to illustrate increasing categories of light intensity values, with the middle category illustrating the light intensities (5.0 – 9.9 lx) that met the adequate lighting guidelines adopted herein.

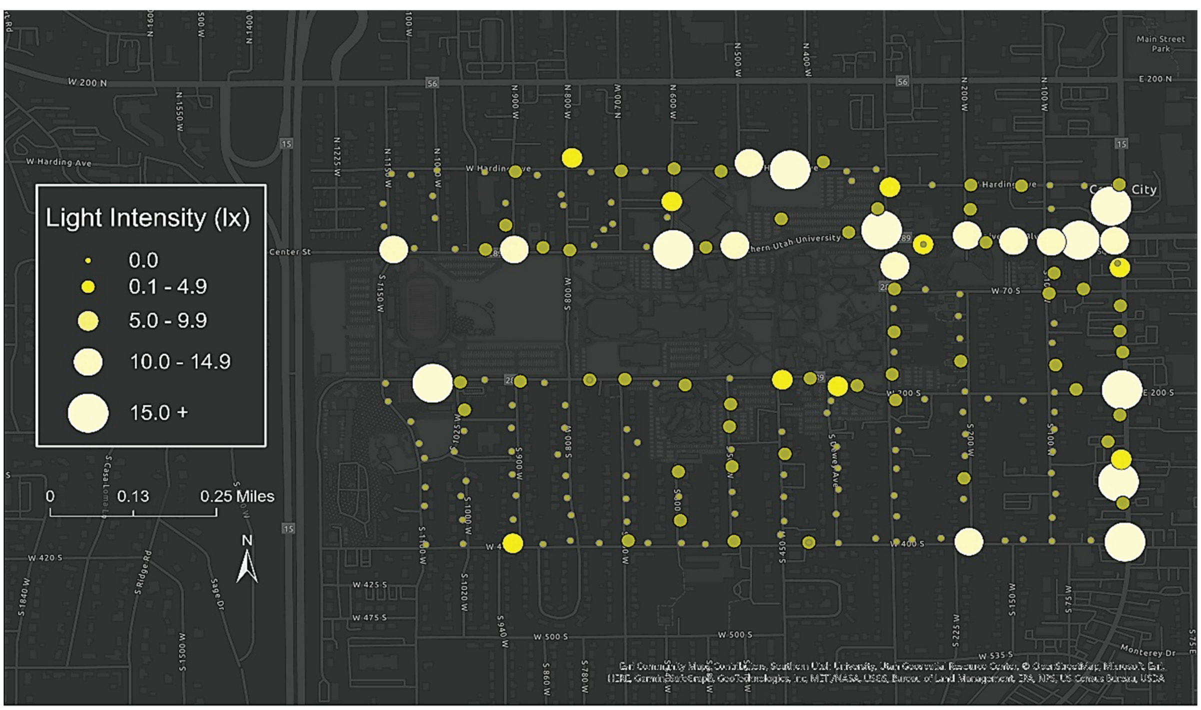

Figure 3. Spatial distribution of sampled and categorized light intensities (lx) within the study area.

Visual inspection of the light intensity (lx) values in Figure 3 suggests a clustered spatial pattern of high values on the northern side, and especially the northeast corner, of the study area with a smaller cluster of high light intensities in the southeast corner, which are both associated with commercial areas that border a state highway (a.k.a. Main Street). The study area also appears to have a significant cluster of low values, especially in the region south of SUU campus between W200 S and W 400 S. Otherwise, there appears to be random distribution of light intensity (lx) values across the study area. To quantify, and validate visual inspection, results from the Getis-Ord General G clustering statistic (z-score = 1.12, p = 0.262) suggest the light intensity (lx) values are randomly distributed across the study area at a global-scale. However, results of the local-scale cluster and outlier analysis are illustrated in Figure 4, and they indicate several areas with significant local spatial clusters of apparent similarity (*i.e.*, high-high, or low-low values) as well as other clusters of apparent dissimilarity (*i.e.*, high value outliers surrounded by mostly low values, and low values surrounded by mostly high values).

Figure 4. Cluster and outlier analysis of sampled light intensities (lx) within the study area.

Figure 4 illustrates the results from cluster and outlier analysis, and the results confirm, from Figure 3, the presence of statistically significant clusters of high-high values in the northeast corner of the study area. The cluster and outlier analysis also identified the southwest corner as having the largest cluster of significant low-low values, meaning it is the least illuminated (*i.e.*, darkest) district within the study area. There is another, much smaller, cluster of low-low values in the northwest portion of the study area. The results in Figure 4 also illustrate several significant outliers of high values (*i.e.*, low-high outliers) amidst mostly low (*i.e.*, zero-lux) observations in the southeast corner of the study area and along S 200 W. Meanwhile, the outliers of low values (*i.e.*, low-high outliers) amidst mostly high values are in the east half of the study area and mainly along Highway 15 (aka. Main Street) in its northeast (*i.e.*, historic downtown) and southeast corners (*i.e.*, where Main St. intersects W 400 S).

DISCUSSION

Sidewalks provide public access to goods and services that people require to meet their daily needs. Unfortunately, the planning and design of sidewalks and the concern for pedestrian safety have been ignored too often and overlooked by too many.[44] This neglect is surprising given that community *walkability* (*i.e.*, the ability to safely walk to desired destinations within a reasonable distance) has several important benefits; it helps to reduce air pollution and greenhouse gas emissions, improve mental health, reduce chronic disease, foster social interaction, and enhance sense of place, among several other social, economic, and environment benefits.[1, 31] Walkability is also an important measure of a community's livability and quality of life.[45-47] Levels of sidewalk PSL directly impact walkability after dark by impacting actual and perceived levels of pedestrian safety, comfort, and security (*i.e.*, reassurance). Beyond perceptions of safety, statistics clearly indicate that pedestrians are the most vulnerable population of road users, especially at night. More specifically, pedestrians are almost seven times more vulnerable in the dark compared to daylight.[48] Given these statistics, the Federal Highway Administration argues that pedestrians have the potential to gain significant safety performance benefits from new or improved PSL.[20]

In addition to safety from trip hazards and traffic accidents, PSL impacts perceived levels of safety and security (*i.e.*, pedestrian reassurance) in an area. Granted, PSL is only one of many factors affecting objective and perceived safety of urban public spaces after dark,[7,49] but research suggests that approximately 40 percent of outdoor crimes happen in areas where illuminance values are 5 lx or darker compared to only 3 percent of outdoor crimes happen in areas where illuminance values are 20 lx or more.[50]

Basically, when urban environments have adequate lighting, there tends to be an overall decrease in many types of deviant behavior.[51] In fact, studies have examined the relationship between perceived safety and PSL, linking higher amounts of illuminance with a greater feelings of safety (FoS).[8, 52] So, how much PSL is enough to provide adequate, or optimal, light intensity for effective planning and design of public spaces, including sidewalks, that would enable pedestrians, and drivers, to see potential hazards and meet the needs of most sidewalk users? Is more lighting automatically better, and for whom? Any discussion of lighting limits, especially if it is solely based on one dimension of lighting (*e.g.,* light intensity), must recognize the different lighting needs of many users, each with different preferences, abilities (*e.g.*, declining eyesight with age), and mobility devices (*e.g.*, cane, walker, scooter, power scooter, skateboard).

The definition of adequate lighting tends to be highly subjective, so any discussion of adequate lighting, or optimum illuminance, must recognize the importance of site- and situation-specific contextual factors.[36] Therefore, the practice of evaluating adequate lighting needs for pedestrian lighting varies widely among different regions, State Departments of Transportation (DOTs), and local agencies, and decisions are often made on a case-by-case basis.[20] Due to a lack of municipal- and state-wide standards, this case study adopted a set of objectively and statistically derived adequate lighting guidelines with lower and upper thresholds of 5 lx and 10 lx, respectively. While these guidelines are unlikely to meet the needs of all users, they were designed to assess whether the sidewalks in the study area are too dark, too bright, or adequate to promote pedestrian reassurance.

The results highlight especially low light intensities and poorly lit areas that are distributed across the study area. More specifically, only 4 percent of the sample observations fell within the adequate lighting guidelines and another 9 percent exceeded the guidelines. So, 13 percent of the sample observations either met or exceeded the minimum threshold of 5 lx that was adopted for this case study. That means 87 of the sample observations were too dark to provide pedestrians with feelings of safety, comfort, and security (*i.e.*, reassurance). It is important to emphasize, however, that light intensity is only one aspect of PSL that affects perceptions of safety, comfort, and security. Other dimensions include color temperature, glare, visual comfort, and a host of personal factors that impact individual FoS.[22] For example, studies suggest that FoS and comfort increase in areas illuminated with white light compared to the same area illuminated with yellowish light.[30] While light intensity (*i.e.*, brightness) certainly has an objective dimension, it also has a subjective dimension that varies among individuals. Therefore, future research should follow the guidance of recent studies[7, 8] that used smartphone apps to prompt participants to record their FoS in random locations under different lighting conditions to help determine subjective adequate lighting guidelines for the study area. Future research should also consider collecting pedestrian, or sidewalk user, counts to better identify (or prioritize) those areas that could most benefit from sidewalk lighting improvements.

This case study's limited sample size, straightforward research design, and emphasis on the objective dimension of light intensity (lx) means that this research is not without its limitations. For example, the time of year chosen for data collection impacted the results of this case study, because a few streetlights were burnt out, while other luminaires were malfunctioning and measured less than 1 lux. Consequently, the results of this case study only represent a limited temporal scale regarding sidewalk light intensities in the study area. For example, the data were collected during the autumn months, which resulted in a portion of the street trees retaining partial foliage that has the potential to reduce sidewalk illumination. On the other hand, leaf-off conditions (and the reflectivity of snow-covered surfaces) during the winter may have increased sidewalk illumination. The impact of street trees, and their foliage, was observed in at least two of the sample observations, where the trees blocked the light and created shadows that likely had a significant impact on measured sidewalk light intensity (lx). Similarly, another study noted that the type of tree and its maintenance along with luminaire design, type, height, and design may significantly affect the potential for street trees to impact sidewalk illumination.[53]

The apparent local clustering of high sidewalk illumination values along the eastern edge of the study area (*i.e.*, Main Street) was similarly reported by a previous study[54] that found a strong association between nighttime illumination and land use. For example, commercial areas tend to have more illuminated signs, industrial areas tend to use artificial lighting for work activities, while parks and residential areas typically have lower levels of nighttime illumination. The relationship between nighttime illumination and land use can provide insight into the patterns of human activity and development in an area, which has important implications for planning the neighborhood lightscape. This land use-illumination relationship also raises some concerns associated with the proximity of different land uses, such as commercial facilities in residential areas, and the associated risk of increased exposure to light pollution.[54] Light pollution refers to the excessive or misdirected artificial light that interferes with the natural darkness of the night sky. This type of pollution can have numerous negative impacts on human health, wildlife, and the environment. For humans, exposure to artificial light at night can disrupt circadian rhythms, leading to sleep disorders, depression, and other health problems.[55] It can also interfere with stargazing and astronomy, thus hindering scientific research and cultural traditions.[56] Wildlife is also impacted by light pollution[57] particularly nocturnal animals such as birds, insects, and sea turtles. Furthermore, light pollution can also waste energy and contribute to carbon emissions, leading to climate change.[58] However, increased illuminance of the pedestrian environment does not need to contribute to light pollution. To mitigate these impacts, efforts are being made to reduce the use of excessive lighting and ensure that outdoor light fixtures are fully shielded and directed downwards to illuminate only the pedestrian environment, to minimize light trespass and sky glow. These fixtures could also be installed on shorter light poles,[59] or install light fixtures in front of the crosswalk to increase the positive contrast of the pedestrian.[60]

CONCLUSION

Safe, accessible, and well-maintained sidewalks are an important part of a community because they enable access to goods and services that people require to meet their daily needs. This is especially true for those people (including university students) who do not have access to a motor vehicle. It is also a timely discussion as urban planners aim to encourage more people to choose active modes of transportation (*e.g.*, active communities, sustainable communities, healthy communities, 10-minute neighborhoods). However, inadequate sidewalk lighting poses a significant hazard to the safety, comfort, and security of pedestrians, which subsequently acts as a deterrent to choosing active modes of transportation after dark. The purpose of this case study was to quantitatively measure and analyze horizontal light intensity on sidewalks to determine where the light intensity was "adequate" and identify areas that are too dark (*i.e.*, could benefit from lighting enhancements). Unfortunately, the results of this case study indicate that most sidewalks in the study area were inadequate; most areas are too dark and, consequently, failed to comply with this case study's adequate lighting guidelines. The results from this case study strongly suggest that the sidewalks surrounding SUU's campus are too dark to provide for pedestrians', and other users', safety, comfort, and security needs. Therefore, it is important to consider targeted visibility enhancements that increase illumination of sidewalks while ensuring appropriate design of these enhancements, so they do not contribute to light pollution.

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ABOUT STUDENT AUTHOR(S)

Sabrina Waite is a senior majoring in both History and French, and she plans to graduate in the spring of 2024. Ian Nelson is a sophomore majoring in Geospatial Science, and he plans to graduate in the spring of 2026.

PRESS SUMMARY

This case study measured light intensity (lx) on sidewalks using a digital light meter. The results showed that most of the study area was in complete darkness (*i.e.,* zero lx) and 87 percent of the sample observations were too dark to meet the safety, comfort, and accessibility needs of sidewalk users. The results also highlight areas that require enhancements to visibility along the sidewalks within the study area.