Smart Street Lighting

Campus Pilot

AEDE 4567 | Spring Semester | The Ohio State University | April 28th, 2017 | Rebecca Jennison, Cassandra Clifford, Cassidy Horency, Benjamin Black, and Enrique Ng Zheng

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Executive Summary

The purpose of this report is to develop a thorough proposal for the implementation of a smart street lighting pilot at The Ohio State University (OSU) that effectively improves safety and energy efficiency on campus. This proposed pilot would both improve the campus and serve as a test case for the City of Columbus' Smart City Team to demonstrate the implementation of smart street lighting for their own projects.

To efficiently execute the project, we focused on four main objectives. For our first objective, we researched how sensor components for smart street lights worked and what benefits they could provide. We then investigated relevant case studies to better understand the benefits acquired as a result of the sensors and the subsequent policy changes and/or project initiatives that ensued. We also constructed a simplified prototype of the proposed technology for this objective, which generated data samples that aided in making calculations that are currently not readily available elsewhere. Our next objective was to evaluate the receptivity of the university to our proposed pilot by conducting a survey of the community. In analyzing how our project fit into OSU's sustainability goals, our team assessed to what degree the proposed pilot meets the needs of the Ohio State community. We then established the optimum area that would benefit most from the proposed technologies, by combining and overlaying datasets from various university departments. Our next objective was to determine the project's cost and feasibility. Our team reached out to a variety of companies who are associated with the proposed technologies with cost inquiries to calculate an estimate, and then investigated potential funding routes. For our final objective, we further analyzed the relationship between this campus pilot and the Smart City projects to gain understanding of how this could help the city.

Our findings confirmed that computer vision, dimming, and air quality monitoring sensors on street lights would be useful assets at OSU. These assets have been beneficial in other cities and can improve safety, energy efficiency, and traffic, while providing valuable data for the university. Our research indicated that, should the campus community support this project, it would help assist OSU's efforts towards meeting their established sustainability goals. In addition, with a cost totaling approximately $3,150, there are multiple routes of funding which could cover the expense of the project.

Our group recommends OSU retrofit a sample of four street lights on West Woodruff Avenue between Schoenbaum Hall and Scott Hall with dimming capabilities on all four lights, and computer vision and air quality sensors on one of the four. Once the added-value of this project is realized, we suggest OSU consider expanding smart street lighting throughout campus.

Introduction

OSU and the City of Columbus aspire to meet a variety of sustainability-related goals and to distinguish themselves in the growing field of sustainability. Implementing new and innovative technologies that can advance these goals and showcase the city as a hub of progress is a strategic move, both environmentally and economically. With the City of Columbus recently winning the United States Department of Transportation (USDOT) Smart City Challenge, the city now has the funding and support to fully solidify Columbus' position as a leader in the nationwide transition to Smart Cities. One of the many projects the city is considering involves the application of smart street lighting technologies—which involves the integration of any combination of normally separate technologies into streetlighting, while maintaining the street light's necessary purpose: to provide adequate lighting. The technologies being integrated are exceedingly new and widely vary in type and application. To help the city with their progress, our research team has drawn up this proposal for a smart street lighting pilot program, specified for implementation on OSU's campus. This proposal directly aids the campus—allowing for further expansion options of said pilot if so desired— and the city with thorough explanation of the implementation process, including the expected costs and benefits. For the creation of this proposal, our group focused on the following four objectives:

I. determining the optimal technologies that have proven advantageous in other cities,
II. evaluating OSU's receptivity to implementing this type of pilot,
III. estimating the cost to confirm its feasibility, and
IV. expounding upon the relationship between this campus pilot and the Smart City projects—utilizing the city's sustainability goals.

Through extensive research and benchmarking of current smarty city initiatives, we determined that an appropriate and beneficial pilot, test-case for OSU would involve four street lights on West Woodruff Avenue being retrofitted with dimming technologies. Additionally, one of the four lights would have air quality monitoring and computer vision technologies to collect data and better manage traffic, monitor pollution, and improve safety. These recommendations would create an effective test case for these pioneering smart street lighting technologies that will further progress of the sustainability goals of OSU as well as the City of Columbus.

Objective I: Proposed Technologies

The following three, proposed technologies—computer vision, dimming capabilities, and air quality monitoring—were chosen as the technologies that can provide the most benefit to both OSU and the City of Columbus. As previously stated, through in-depth research our team observed successful implementation of smart street lighting systems and determined which of the utilized technologies would be most effectively and easily be adapted to meet the needs of the university and city. Through this analysis, the aforesaid technologies were chosen due to their efficacy and ability to develop safety and transportation—two issues in which both OSU and the City of Columbus greatly desire to see improvement—without any invasive/intensive infrastructural changes. Each of these technologies, meeting the desires of both the university and city, are retrofittable—meaning they can be implemented without having to entirely replace the existing street lighting systems. Furthermore, each of these technologies have, again, been proven successful, which is demonstrated through the following national and international case studies.

COMPUTER VISION

Computer vision, a form of artificial intelligence, is the interdisciplinary field and act of a designed software mimicking the human visual display and processing information from an image or series of images (Sonka et al., 2008). This computer vision process can adapt "learned behaviors" and designated objects for detection to monitor and analyze, thus providing usable and highly accurate data of various patterns and interactions through statistical modeling (Morris, 2004). Putting this in more colloquial terms, the process is essentially the act of a computer being able to see, understand, and analyze a live video feed, thus collecting data and detecting irregularities that could pose risks.

There are many applications of such technologies relevant to an OSU smart street lighting pilot, such as traffic management and public safety. In utilizing pre-existing street light poles as power sources and mounting locations for video cameras and on-site processors, these street lights can function as a key part of a computer vision network—capable of real-time monitoring of traffic patterns, pedestrian-traffic interactions, public safety incidents, available street parking, etc. (Shingo, 2010). With the involved software and processing, these smart street lights can aide in subsequent events such as instantaneous alerts to various crimes and traffic accidents/abnormalities, reduction in response times of emergency vehicles and dispatchers, accurate pattern analysis to aide in policymaking, changes that can minimize traffic congestion, dangerous traffic-pedestrian interactions, and publicly distributed knowledge of real-time, available street parking.

Although this concept of smart street systems integrated with computer vision technologies is very young in its development, there are various examples of how such technologies are currently being deployed and successfully used in cities and universities around the world. Prominent and innovative companies such as TrafficVision, General Electric (GE), Eutecus, and Echelon are leading the way in developing computer vision software and technologies for smart street lighting in cities and employing pilots.

The company TrafficVision currently has their software deployed in several locations across North America. One of TrafficVision's first successful implementations of their computer vision software was with the Colorado Department of Transportation (CDOT). Colorado, like other states, suffers from traffic congestion tendencies and extreme variability in weather conditions—similar to that of Ohio. Issues like these have various side effects, as can be seen from a Texas Transportation Institute study of the Denver metro area: "along with the safety hazards of traffic accidents, Denver metro area commuters experienced an average of 49 hours of delay and wasted 24 gallons of fuel in 2014 due to congestion" (TrafficVision, CDOT, 2016). Upon completion of installation in 2015, Colorado realized impressive results. According to the CDOT, traffic incidents (including a wide-range of situations from broken down vehicles to fatal accidents) were responded to by emergency vehicles and dispatchers on average 14 minutes faster than without these computer vision technologies. This system is not only faster and more accurate than its predecessor, but also eliminates a majority of needed human influence, meaning a great deal of cost savings in unnecessary and inefficient positions and salaries.

These cost savings are even more prominent in another example of successful implementation of computer vision technologies by TrafficVision in Kansas City. In Kansas City, after adoption of these sensors in 2016, the city reported, “improved detection, notification and faster response times to incidents as they occurred; improved incident clearance times and, therefore safety; and reduced demand on operators tasked with many other responsibilities” (TrafficVision, KCSCOUT, 2017). Like the City of Columbus, Kansas City is a medium-sized metro area with more traffic cameras than can be properly monitored by a minimal amount of shift-based operators. Kansas City has seen great improvement regarding this issue with now over a quarter of all traffic incidents being detected and reported without human interaction (TrafficVision, KCSCOUT, 2017).

The City of San Diego, California—partnering with the Boston firm “Current, powered by GE”—recently spent $30 million replacing 14,000 streetlights with “smart” technology. Upon these 14,000 street lights, the city will place 6,200 sensors utilizing computer vision technologies by the year 2018 (Fox 5 San Diego, 2017). Although this implementation is still in its beginning stages, the project shows great promise for the advancement of the city. According to press releases from unnamed city officials, the system “can use real-time anonymous sensor data to direct drivers to open parking spaces, help first-responders during emergencies, track carbon emissions, and identify intersections that can be improved for pedestrians and cyclists. The anonymous information from the sensors can be used by developers to create apps and software that can benefit the community” (Fox 5 San Diego, 2017).

DIMMING CAPABILITIES

Another technology our team is suggesting to the university is dimming, due to its multitude of benefits. Installing dimming modules into a streetlight can lessen greenhouse gas emissions by reducing energy needs. At the University of California Davis, they predicted an energy savings of roughly 91% when adaptive LED lights and a dimming network were installed (**Appendix A, Table 1**) (Exterior Lighting Business Case, 2014). In Cambridge, Massachusetts, the city realized an energy savings of 80% when they transitioned their streetlights to LEDs and implemented dimming down to 30% brightness at night (Echelon, Cambridge Case Study, 2016). Energy reductions such as these could be experienced by the university in relative quantities with the implementation of a campus pilot.

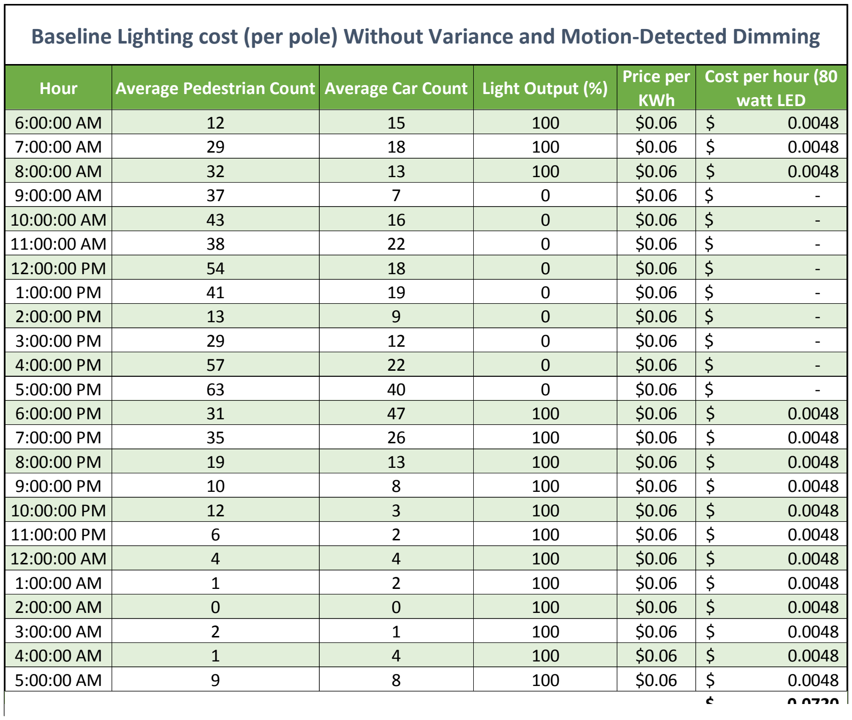
In addition to reducing cost and environmental impacts by reducing energy consumption, dimming sensors can aid in improving public safety. According to the American Medical Association (AMA), the transition to LED lights can harm people's vision. LED lights have a higher color temperature than traditional sodium lights and normally take on more of a blue tint in comparison to high pressure sodium lighting's warm glow. That high color temperature can cause a glare in sensitive eyes, and could cause issues for people driving or people crossing streets. One of the suggestions the AMA had was to install dimming sensors at night to help reduce the harsh and potentially dangerous light (AMA, 2016). Drivers around The Ohio State University as well as the abundance of pedestrians could benefit from a less glaring source of light.

Lastly, dimming LED lights can help promote a healthy circadian rhythm for both humans and wildlife. The brightness of an LED bulb is known to affect melatonin levels and therefore make it difficult for people to fall asleep (AMA, 2016). Not only can bright lighting negatively impact people's sleep schedules, it can also affect animal patterns such as migration and nesting (Raap, Pinxten, & Eens, 2015). That being stated, in implementing the proposed dimming technologies, these aforementioned affects will be reduced—lessening impacts to student sleep schedules and wildlife patterns, while providing adequate levels of lighting.

As we heard from our meeting with Tom Timcho and from attending the Linden Stakeholder meeting, there are qualms related to reducing street lighting (**Appendix B, Dataset #1**). Mainly, people are scared that less lighting will cause safety problems; however, a study shows that the opposite will occur. A town in Schropshire, England had been participating in a part-night lighting routine along with piloting dimming controls and white light technology. A survey of the town found that only 50.4% of responders noticed a change in number or brightness of street lights (Green et al. 2015). The study also reported that residents showed concern about a potential increase in crime; however, there was no proof of any increase in criminal activity during that time (Green et al. 2015). Furthermore, a study in England and Wales found there was no resulting increase in traffic accidents or crime when the street lights were turned off or dimmed. While this study did not consider any other safety measures the region may have taken around the same time, it is likely the energy saving technologies in both studies did not cause harm regarding traffic and crime (Steinbach et al., 2015).

To illustrate the cost benefits from the proposed dimming technologies, our team created a functioning prototype and collected data directly from the proposed area. After meeting with OSU's senior electrical engineer in technical services, Bob Wajnryb, our team was instructed that the current setup of campus' street lighting is a "curfew-based" system—turning on around dusk and off around dawn with other manual options (**Appendix B, Dataset #1**). This type of system operates with inefficiencies due to the lack of variance in energy consumption and motion detecting capabilities. Variance of energy consumption (indicated by percentage light output in **Tables 2, 3,** and **4**) is the level at which the light is "operating". In the campus' current system the light is either "on," at 100% energy consumption, or off, at 0% energy consumption, not allowing for varying levels in between. This variation of energy consumption, coupled with motion detection (i.e. only lighting at highest light output when needed and motion is detected) can save significant amounts of energy and, therefore, a significant amount of money.

Our team's approach to collecting data demonstrating these cost saving technologies is outlined in tables 2, 3, and 4 (**Tables 2, 3,** and **4**). We collected data for average hourly pedestrian/vehicle count and adjusted for the following three scenarios: lighting cost without variance and motion-detected dimming (the campus' current system), with variance and motion-detected dimming (defaulting to 100% energy consumption when motion is detected), and with variance and motion-detected dimming (defaulting 25% higher energy consumption when motion is detected). According to the senior energy programs manager, John Rappleye, the price per kilowatt hour (kWh) is $0.06 (**Appendix B, Dataset #1**). This, coupled with the understanding that a typical LED street light bulb is around 80 watts (0.08 kilowatts), our team



Baseline Lighting cost (per pole) Without Variance and Motion-Detected Dimming

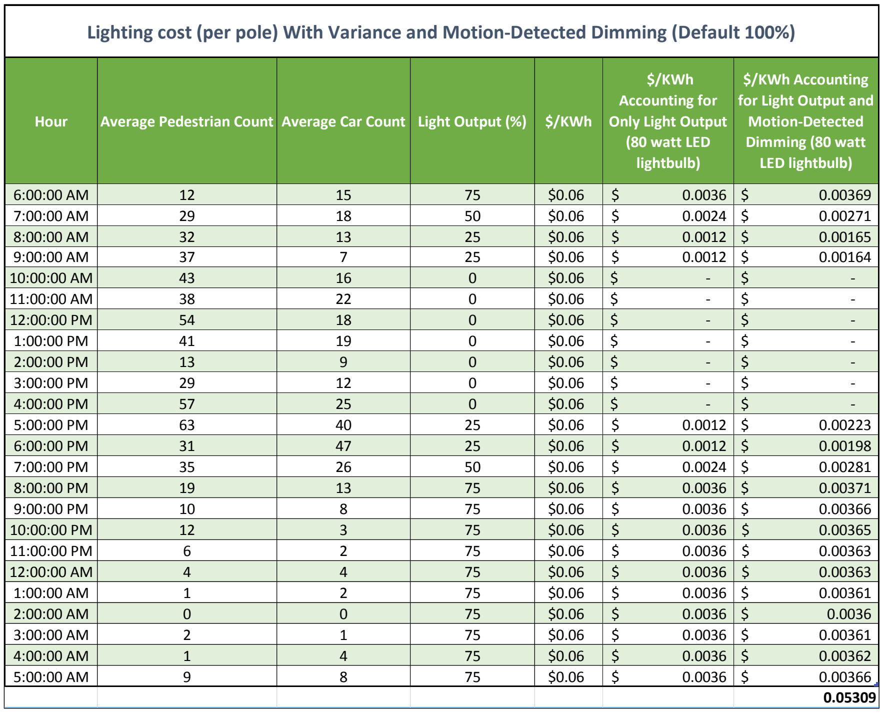
Hour	Average Pedestrian Count	Average Car Count	Light Output (%)	Price per KWh	Cost per hour (80 watt LED
6:00:00 AM	12	15	100	$0.06	$ 0.0048
7:00:00 AM	29	18	100	$0.06	$ 0.0048
8:00:00 AM	32	13	100	$0.06	$ 0.0048
9:00:00 AM	37	7	0	$0.06	$ -
10:00:00 AM	43	16	0	$0.06	$ -
11:00:00 AM	38	22	0	$0.06	$ -
12:00:00 PM	54	18	0	$0.06	$ -
1:00:00 PM	41	19	0	$0.06	$ -
2:00:00 PM	13	9	0	$0.06	$ -
3:00:00 PM	29	12	0	$0.06	$ -
4:00:00 PM	57	22	0	$0.06	$ -
5:00:00 PM	63	40	0	$0.06	$ -
6:00:00 PM	31	47	100	$0.06	$ 0.0048
7:00:00 PM	35	26	100	$0.06	$ 0.0048
8:00:00 PM	19	13	100	$0.06	$ 0.0048
9:00:00 PM	10	8	100	$0.06	$ 0.0048
10:00:00 PM	12	3	100	$0.06	$ 0.0048
11:00:00 PM	6	2	100	$0.06	$ 0.0048
12:00:00 AM	4	4	100	$0.06	$ 0.0048
1:00:00 AM	1	2	100	$0.06	$ 0.0048
2:00:00 AM	0	0	100	$0.06	$ 0.0048
3:00:00 AM	2	1	100	$0.06	$ 0.0048
4:00:00 AM	1	4	100	$0.06	$ 0.0048
5:00:00 AM	9	8	100	$0.06	$ 0.0048
					$ 0.0720

Table 2. Prototype generated dimming cost data demonstrating campus' current system—no variance or dimming technology.

developed a simple formula to determine the cost per hour for an 80 watt, LED light bulb, under the aforementioned scenarios.

Under the university's current system (**Table 2**), there is no dimming technology or variance capabilities, therefore the light's energy consumption is 100% and charged the full price for the hour. Adjusting for the wattage of the light bulb, our team multiplied the price of $0.06 by the wattage—0.08 kW—and established that the cost per hour for an 80 watt light bulb, at 100% is $0.0048. Given a typical day, the light is on for 15 hours, resulting in the total cost per light, per day to be $0.072. Adjusting for the estimated 2500 streetlights on campus for a full year (the number our team used to represent a year was 364.25 days), this means that annually the cost for street lighting is about $65,565.00 (**Table 2**).

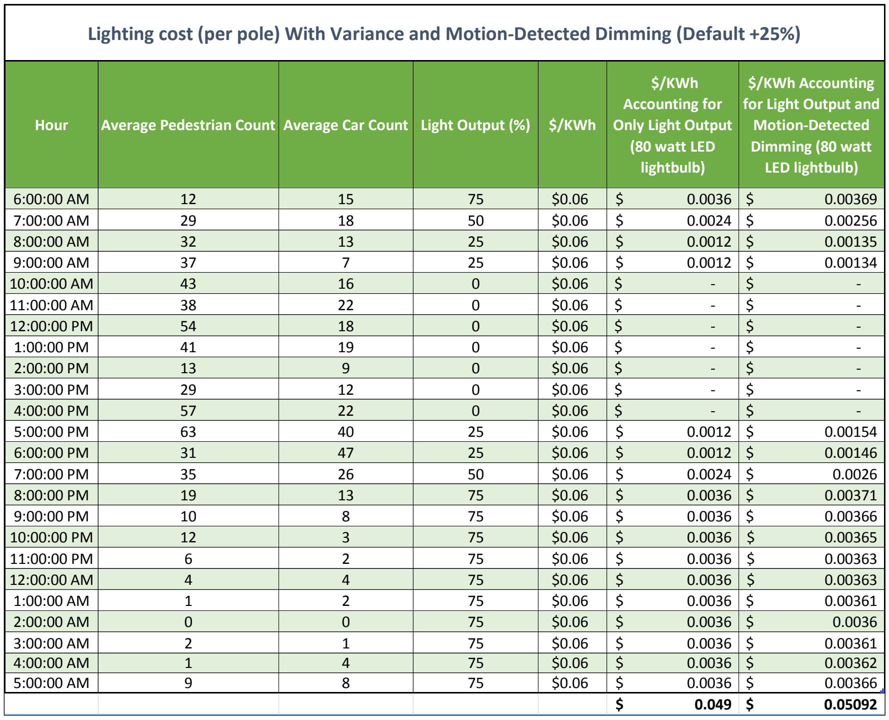
This same formula was used to populate Tables 3 and 4 with slight variations to account for the varying levels of energy consumption and motion-detected dimming capabilities—as the cost will be less when only using a fraction of the full energy consumption. This varied approach first entailed investigating, on average, what portion of the hour would be lit to the higher/maximum level and what portion would be lit to the other varying levels. This alludes to the main difference between the two scenarios. Table 3 depicts the light increasing to maximum (100%) energy consumption when motion is detected, whereas Table 4 depicts the light increasing to the next variance level (25% higher). When motion is detected, the prototype light brightens to the indicated level for 10 seconds—meaning that if 360 vehicles or pedestrians are detected, the light would be consuming the maximum level of energy for the entire hour and, therefore, the full price for the entire hour. As shown in both tables, the average pedestrian and vehicle counts were subtracted from 360, then divided by 360 to become a percentage. This percentage was then calculated (using the same method for **Table 2**) accounting for the varying levels of energy consumption (for example, when the light output is at 75%, the price/kWh is reduced by 25%, becoming $0.045/hour). Again, for both tables, the percentage created from the sum of average pedestrian and car counts uses the higher energy consumption, with the remaining percentage (created from the remaining number out of 360) uses the variance light output. When adjusted annually for 2500 lights, the scenario defaulting to 100%



Lighting cost (per pole) With Variance and Motion-Detected Dimming (Default 100%)

Hour	Average Pedestrian Count	Average Car Count	Light Output (%)	$/KWh	$/KWh Accounting for Only Light Output (80 watt LED lightbulb)	$/KWh Accounting for Light Output and Motion-Detected Dimming (80 watt LED lightbulb)
6:00:00 AM	12	15	75	$0.06	$ 0.0036	$ 0.00369
7:00:00 AM	29	18	50	$0.06	$ 0.0024	$ 0.00271
8:00:00 AM	32	13	25	$0.06	$ 0.0012	$ 0.00165
9:00:00 AM	37	7	25	$0.06	$ 0.0012	$ 0.00164
10:00:00 AM	43	16	0	$0.06	$ -	$ -
11:00:00 AM	38	22	0	$0.06	$ -	$ -
12:00:00 PM	54	18	0	$0.06	$ -	$ -
1:00:00 PM	41	19	0	$0.06	$ -	$ -
2:00:00 PM	13	9	0	$0.06	$ -	$ -
3:00:00 PM	29	12	0	$0.06	$ -	$ -
4:00:00 PM	57	25	0	$0.06	$ -	$ -
5:00:00 PM	63	40	25	$0.06	$ 0.0012	$ 0.00223
6:00:00 PM	31	47	25	$0.06	$ 0.0012	$ 0.00198
7:00:00 PM	35	26	50	$0.06	$ 0.0024	$ 0.00281
8:00:00 PM	19	13	75	$0.06	$ 0.0036	$ 0.00371
9:00:00 PM	10	8	75	$0.06	$ 0.0036	$ 0.00366
10:00:00 PM	12	3	75	$0.06	$ 0.0036	$ 0.00365
11:00:00 PM	6	2	75	$0.06	$ 0.0036	$ 0.00363
12:00:00 AM	4	4	75	$0.06	$ 0.0036	$ 0.00363
1:00:00 AM	1	2	75	$0.06	$ 0.0036	$ 0.00361
2:00:00 AM	0	0	75	$0.06	$ 0.0036	$ 0.0036
3:00:00 AM	2	1	75	$0.06	$ 0.0036	$ 0.00361
4:00:00 AM	1	4	75	$0.06	$ 0.0036	$ 0.00362
5:00:00 AM	9	8	75	$0.06	$ 0.0036	$ 0.00366
						0.05309

Table 3. Prototype generated cost data demonstrating scenario with variance and 100% default when motion is detected.



Lighting cost (per pole) With Variance and Motion-Detected Dimming (Default +25%)

Hour	Average Pedestrian Count	Average Car Count	Light Output (%)	$/KWh	$/KWh Accounting for Only Light Output (80 watt LED lightbulb)	$/KWh Accounting for Light Output and Motion-Detected Dimming (80 watt LED lightbulb)
6:00:00 AM	12	15	75	$0.06	$ 0.0036	$ 0.00369
7:00:00 AM	29	18	50	$0.06	$ 0.0024	$ 0.00256
8:00:00 AM	32	13	25	$0.06	$ 0.0012	$ 0.00135
9:00:00 AM	37	7	25	$0.06	$ 0.0012	$ 0.00134
10:00:00 AM	43	16	0	$0.06	$ -	$ -
11:00:00 AM	38	22	0	$0.06	$ -	$ -
12:00:00 PM	54	18	0	$0.06	$ -	$ -
1:00:00 PM	41	19	0	$0.06	$ -	$ -
2:00:00 PM	13	9	0	$0.06	$ -	$ -
3:00:00 PM	29	12	0	$0.06	$ -	$ -
4:00:00 PM	57	22	0	$0.06	$ -	$ -
5:00:00 PM	63	40	25	$0.06	$ 0.0012	$ 0.00154
6:00:00 PM	31	47	25	$0.06	$ 0.0012	$ 0.00146
7:00:00 PM	35	26	50	$0.06	$ 0.0024	$ 0.0026
8:00:00 PM	19	13	75	$0.06	$ 0.0036	$ 0.00371
9:00:00 PM	10	8	75	$0.06	$ 0.0036	$ 0.00366
10:00:00 PM	12	3	75	$0.06	$ 0.0036	$ 0.00365
11:00:00 PM	6	2	75	$0.06	$ 0.0036	$ 0.00363
12:00:00 AM	4	4	75	$0.06	$ 0.0036	$ 0.00363
1:00:00 AM	1	2	75	$0.06	$ 0.0036	$ 0.00361
2:00:00 AM	0	0	75	$0.06	$ 0.0036	$ 0.0036
3:00:00 AM	2	1	75	$0.06	$ 0.0036	$ 0.00361
4:00:00 AM	1	4	75	$0.06	$ 0.0036	$ 0.00362
5:00:00 AM	9	8	75	$0.06	$ 0.0036	$ 0.00366
					$ 0.049	**$ 0.05092**

Table 4. Prototype generated cost data demonstrating scenario with variance and +25% default when motion is detected.

energy consumption costs $48,345.08, and the scenario defaulting 25% higher costs $46,369.03—reductions of 26.26% and 29.28% respectively (**Table 5**).

Prototype Generated Dimming Cost Saving Estimations

	80 Watt LED w/o Variance and Motion-Detected Dimming	80 Watt LED w/ Variance and Motion-Detected Dimming (Default 100%)	80 Watt LED w/ Variance and Motion-Detected Dimming (Default +25%)
Annual Cost (2500 Streetlights)	**$65,565.00**	**$48,345.08**	**$46,369.03**
Cost Reduction (%)	**N/A (baseline)**	**26.26%**	**29.28%**

Table 5. Prototype generated cost data results table showing cost savings.

AIR QUALITY MONITORING

Air quality sensors are electrochemical cells calibrated to measure concentrations of gases in the ambient air by gas diffusion (Sennequier, 2013). Gas enters the sensor through a membrane that limits the rate of diffusion in order to control the sensitivity of the sensor (Sennequier, 2013). The calibrated sensors start a chemical reaction if a target gas is detected, such as CO2 (Sennequier, 2013). An electrical current is then produced from the reaction—providing a value to the CO2 concentration in the air (Sennequier, 2013). Measuring these various concentration levels presents many opportunities for beneficial tactics and policy-making aids that can reduce these aforementioned values.

Benefits from improving air quality have been quantified by organizations such as the EPA. The EPA calculated the benefits specifically of Clean Air Act amendments, which they found prevented the loss of 3.2 million school days, 13 million work days, and various other health complications (U.S EPA, 2011). These results were achievable because of targeting emissions from point sources as well as tightening regulations on fuel sources such as gasoline. The more pressing issues today are the emissions that are not tracked as easily, such as road traffic—an issue this proposed pilot attempts to address.

Smart cities aim to tackle these emissions by implementing air quality sensor networks. In our research, we found two case studies of cities implementing air sensor networks addressing traffic air quality. The first project is called InterCityAir and is located in Chester, United Kingdom. This project aims to test the feasibility of implementing a network of low-cost, air quality sensors with traffic management to alleviate traffic "hot spots" (areas of high-intensity traffic congestion) (Williams, 2015). The motivations for this project are both health-based and financial. There is a report by the Committee of Medical Affairs of Air Pollutants that attributes 5,000-6,000 premature deaths every year in the U.K to transport pollution. Regarding the monetary reasoning, poor air quality in 2010 resulted in the U.K facing a 300 million euro fine due to failure to meet the European Union targets (Williams, 2015). The need for air quality monitoring, which can directly aid in improvements in air quality, is evident as both health and monetary losses occur when air quality is poor.

The second case study involves a similar situation in Salamanca, Spain. According to the study, road traffic makes up 25-31% of total emissions in the European Union. The study also includes data provided by the European Union suggesting 225,000 deaths related to car emissions, with Spain representing 15,000 of them (Bielsa, 2011). The project is known as RESCATAME and is funded by the European Union through its LIFE program. The purpose of this project is to "achieve sustainable management of the traffic in the city of Salamanca using a pervasive air quality sensor network and prediction models" (Bielsa, 2011). This project is quite similar to the one in Chester as they both aim to use air quality data to improve traffic management. Both Chester and Salamanca are recent projects, so the data available is still scarce.

Point-based air quality sensors attached to street lights would allow the university to identify areas of concern, plan accordingly to improve air quality, and successfully evaluate their progress through real-time data. OSU will have many research opportunities enabled by an air quality sensor system, and students will be able to access this information in real-time. Students and locals may benefit from this information, as they will be aware of the peak hours of pollution and the precise location.

If the City of Columbus implemented such sensors, they would have the capability to assess areas where air quality is a concern and plan infrastructure accordingly to minimize emissions. Infrastructure may involve things such as new roadways or more responsive stoplights to address traffic congestion. Another strategy for improving air quality involves introducing green infrastructure such as parks to offset pollution in areas where sensors report poor air quality.

Objective II: Campus Receptivity

SURVEY RESULTS

To manage the scope of the project proposal, we performed a survey to assess how members of the campus community felt about the topics being addressed by the smart street lighting proposal. A randomly selected sample of 100 students and faculty members filled out the short survey, which involved first ranking the topics from 1-10 by personal importance to the respondent, then stating whether they strongly disagreed, disagreed, somewhat disagreed, felt neutral, somewhat agreed, agreed, or strongly agreed with a series of statements (**Appendix A, Table 6**).

The information gathered through the survey influenced the direction of the proposal. It was evident that safety and energy efficiency were the greatest concerns of university members, and thus this became the main focus for the smart street lighting components. Air quality was also ranked highly and due to the inexpensive addition of air quality sensors and the relatively high value of the data that can be collected from their use, this component was judged to be a valuable addition. Technologies benefiting parking availability were removed from our proposal because of the lesser importance to the campus, while traffic congestion remained important because addressing this issue would increase safety on campus.

Originally, a major concern with computer vision sensors was privacy. Those who consider them a violation of privacy often argue the security features. Our survey results indicated that the clear majority of the campus community does not object to their presence (**Appendix A, Figure 1**). Only 4% of those surveyed indicated a significant discomfort with the presence of public surveillance cameras on campus. Meanwhile, 66% of survey respondents indicated some level of agreement that public surveillance can reduce campus crime. With 34% disagreeing with the statement, “I feel safe walking on campus at night,” the extra comfort that security cameras could bring to the community and the crimes they may assist in preventing would overwhelm the minute discomforts.

Findings from the survey also indicated dissatisfaction with air quality on campus (only 62% answered with some level of agreement that air quality was acceptable) (**Appendix A, Figure 2**). In addition, 84% of those surveyed believed OSU is not doing enough for energy savings. All the issues that clearly resonated with members of the OSU community are addressed by our proposal. Safety, energy efficiency, air quality, and traffic congestion would all benefit from the implementation of smart street lighting on campus, beginning with our pilot recommendations. The survey results indicate that university members would likely support this project.

PROPOSED LOCATION

A thoroughly investigated and optimal location is pertinent to running a successful pilot. Since the computer vision component will handle any traffic or crime sensing, the University's safety and traffic information were the basis for our location decision.

For our safety data, we analyzed 136 location-specific public safety notices from the campus alerts archive within a ten-year span between 2007 and March of 2017. For the pilot, the team divided the campus locations into sectors, including South campus, North campus, central campus, medical campus, West campus, off campus, and "other." (**Appendix A, Table 7**).

Our analysis found that the top three areas of public safety notices occurred on North, South, and off campus. Off campus came in first with 58% of the public safety alerts, South campus came in second with 16.18%, and North campus in third with 11.76%. While the majority of the public safety notices occurred off campus, they varied greatly in area ranging from University Village to North Fourth Street. Based on that information, it was imperative to narrow the location scope down to either North or South campus (**Appendix A, Table 7**).

The second parameter we considered was student congestion. Computer vision can benefit pedestrian traffic so it was pertinent to find an area where plenty of students traveled. According to the campus heat map (**Appendix A, Figure 3**), North campus is the most heavily occupied area on any given school day. The strip of buildings along West Nineteenth Avenue and the Fisher College of Business saw some of the most congestion.

The third parameter relates to traffic accidents. We received all of our data from one of Ohio State's public safety analysts, Renee Kopczewski. She was able to tell us that the highest traffic area, vehicles and pedestrians, is along Woody Hayes Dr. /West Woodruff Ave. from Cannon Drive to College Road. (**Appendix B, Dataset #1**). As for traffic accidents, most occurred in parking lots and garages; however, if any roadway accidents did occur, they occurred in the area surrounding Cannon Dr. and the Medical Center. Renee also said it was worthwhile to note that injury-inducing accidents have occurred at a slightly higher amount in the last year around Cannon Dr. and West Woodruff Ave. between Tuttle Park Place and College Road.

Using the three parameters overlaid on each other, our team established that the optimal location for this proposed pilot is on Woodruff—in between Tuttle Road and College Road (**Appendix A, Figure 4**). This area combines the high congestion, high traffic, and high public safety incidences that can realize the most benefit from the proposed technologies in this pilot program.

OSU SUSTAINABILITY GOALS

OSU's strategic vision states they are, "recognized as a world leader in developing durable solutions to the pressing challenges of sustainability and in evolving a culture of sustainability through collaborative teaching, pioneering research, comprehensive outreach, and innovative operations, practices, and policies," (Ohio State Sustainability Goals, 2016). Our proposed pilot represents this statement through its demonstration of innovative and new technologies and its potential aid in collaborative teaching and research.

OSU's first sustainability goal is to "deliver a curriculum that provides Ohio State students at all stages of instruction—from general education to professional and technical programs—with opportunities to understand sustainability holistically, framed by the environment, science, technology, society, the economy, history, culture, and politics," (Ohio State Sustainability Goals, 2016). Their second sustainability goal is to "address the complexities of sustainability through a variety of learning formats, strategies and occasions," (Ohio State Sustainability Goals, 2016). Both goals reflect the purpose of our project. Based on the educational sections of OSU’s sustainability goals, there is a correlation between the university and student involvement.

OSU’s sustainability goals also describe research-based objectives. Their fourth goal is to “magnify sustainability scholarship output and impact to create new knowledge; solve real world problems, including our own operations; and increase OSU’s national/international reputation as a sustainability research leader,” (Ohio State Sustainability Goals, 2016). The university could use the research and data from this pilot project, further fulfilling this goal and creating useable data for staff and students. As presented through discussions with various university faculty members, such as Dr. Jim Davis, this project presents ample opportunity for classes across all disciplines to use the created data in student research studies and class projects (**Appendix B, Dataset #1**).

There are many shared aspects between our project and OSU’s sustainability goals. Based on the university's dedication to reaching these goals, we believe they would benefit from adopting and funding our pilot project. The university has an opportunity to emerge as a leader in this new field of smart cities and technologies, becoming a case study for other institutions.

LIMITATIONS

Although campus receptivity is positive overall, the team encountered several limiting factors involving campus communications across different departments and accessibility of needed information. The team faced difficulty in coordinating the efforts of the various university departments and struggled with a great deal of uncertainty regarding future campus projects that may affect the feasibility of this pilot program. While these factors proved challenging, our team was able to overcome them and succeed by developing a thorough understanding of the inter-workings of the university and learning the most effective and efficient ways of negotiating this system.

Objective III: Cost Estimate and Funding Options

As aforementioned, the cost estimate for our team's proposed pilot program is estimated at $3150. This cost estimate was generated using pricing quotes and information from various companies associated with the proposed technologies, providing services for a range from one to all of the proposed smart capabilities. The companies with which we exchanged emails and conference calls are as follows: AirBeam, Echelon, Flashnet, General Electric (GE), and TrafficVision. Given that the pricing information for each of the companies is confidential and not for public distribution, this data will not be disclosed for the specifics of each company. We developed this cost estimate by averaging each of the pricing quotes, then adjusting for the pilot and campus specific requirements. The pricing for individual sensors ranged from $250-$5000.When averaged all together, and only accounting for what is necessary in this pilot program (eliminated the cost for unneeded expenses such as new poles, certain aesthetic additions, extraneous software, etc.) the costs averaged at $3150 (**Appendix B, Dataset #8**).

There are several funding options that could be used to pay for this pilot program. These potential options include: the Energy, Environment and Sustainability Student Funding, the Coca-Cola Sustainability Fund, the President and Provost's Council on Sustainability (PPCS) funding (as a "gap filling" option), and funding from the USDOT Smart City Challenge project (The Ohio State University, 2017). Along with these options, several companies with whom we communicated indicated the potential for product donations. Public association with the university and the chance to run analyses on the sensors and software could help the companies maintain as effective and reliable of a product as possible.

Objective IV: City of Columbus

BENEFITS TO THE CITY OF COLUMBUS AND THE LINDEN COMMUNITY

Our team's pilot proposal has a multi-tiered design. This begins with implementing a pilot program on campus, which will then provide research and evidence to the City of Columbus to aid them in understanding the process of implementation and the value of the benefits. The Linden community is the city's focus areas for their proposed smart street lighting initiatives, and it could also benefit most from the adoption of our proposed street lighting technologies. Linden would benefit through improved safety as a result of computer vision technologies, effective air quality monitoring, a reduction in energy consumption, and cost savings. Representatives from our team attended Linden stakeholder meetings, which discussed personal trials and tribulations faced by this community. Safety and the overall wellbeing of the community is the highest priority for the citizens in the area; however, it was clearly stated that privacy is also of significant importance. Although the benefits from our team's proposed pilot program are desired by the Linden community, they would need to be implemented with discretion and the privacy of the citizens in mind—which could be effectively accomplished by analyzing our team's proposed university pilot project as a test case.

CITY RECEPTIVITY—CITY SUSTAINABILITY GOALS

While this proposal focuses on a pilot for OSU, the overarching goal is to make a project that can be adopted by Columbus for the Linden neighborhood. The Columbus Green Community Plan integrates values such as fostering safe, healthy, and vibrant living and ensuring equality, inclusion, and access to community resources by all residents. Another goal they include within all objectives is to increase employment opportunities that generate earnings sufficient for living (Green Memo III, 2015). This plan is part of Columbus' Green Team

Initiative, whose goal is to create plans to mitigate environmental damage caused by the City of Columbus and to better manage plans for future endeavors.

The Columbus Green Community Plan’s goals address issues surrounding the following topics: climate change, energy, transportation, waste reduction, preserving ecological systems, water, local food, built environment, and community engagement. The plan has several objectives that detail important correlations with our project. Objective number four in the transportation section is to “reduce vehicle-pedestrian crashes by 25% over the next five years” (Green Memo III, 2015). Achieving this objective could be made easier with the implementation of computer vision traffic sensors. Placing sensors on busy intersections, especially where there is a lot of pedestrian foot traffic, would aid in reduction of traffic problems and prevent injury and death from traffic-pedestrian based incidents. Objective number three in the community engagement section is to “build community pride by telling the green story of Columbus over the next five years [and] achieve name recognition as measured by the number of mentions in local and national publications and other media outlets.” The idea of Smart Columbus is to make Columbus more technologically advanced and sustainable, which our smart street lighting proposal will do. Once Smart Columbus is complete, Columbus can and will be the city that people look to for advice.

Our team expects the Columbus Smart City team to be receptive to this pilot program. Columbus can be one of the first cities in the world to fully implement a smart street lighting initiative, one which would provide social, environmental, and economic benefits.

Recommendations

Our team recommends that OSU implement four smart street lights on West Woodruff Avenue between Schoenbaum Hall and Scott Hall. The computer vision and air quality monitoring technologies should be installed on only one of the four poles to maximize the cost-effectiveness of this project. All four lights should have dimming modules installed to realize full cost/energy saving benefits. By implementing these innovative technologies, the university can improve public safety and traffic management/congestion, experience cost savings through energy savings and reduction in employee-necessary monitoring, and collect real-time data for aid in policy and decision-making. If the pilot is implemented at OSU, The City of Columbus could learn from its performance and utilize this knowledge in its own deployment of smart street lighting.

Using our recommended street lighting technologies as a guide, the City of Columbus should prioritize their efforts on implementing a similar project adapted to meet the specific needs of Linden. This proposal includes many different features and sensors that could provide a solid groundwork for future technology. This infrastructure would also aid Columbus in reducing energy and resource use, helping them achieve their sustainability goals.

As for furthering our project, we suggest the university administration conducts a meeting involving the major decision-makers regarding a “smart” street lighting pilot on campus. Some of the departments we suggest the meeting consist of are Facilities, Operations and Development (FOD), Transportation and Traffic Management (TTM), the Office of Energy and the Environment, and the Department of Public Safety. We also suggest a Smart Columbus representative be present to represent the City of Columbus’ stake in the campus pilot. We understand that street lighting affects a wide range of interests, and therefore think it is best that they all have their input. These decision-makers will be able to discuss any of the potential barriers, and will be able to decide whether the pilot is feasible and beneficial.

Conclusion

Our research indicated that the university is receptive to the idea of our pilot project, as it benefits the community, forwards their sustainability goals, and is affordable and feasible. Data drawn from our campus survey helped us to understand public opinion, directing our research toward the previously described technologies.

By executing this pilot, the university has the potential to realize a variety of economic, social, and environmental benefits that could encourage a more widespread campus adaption. This program could also be used as a case study to further inspire research about smart street lighting and to help the City of Columbus with their own projects.

While it is very possible that a “smart” street lighting campus pilot would be a successful addition to the university, there are some potential limitations in terms of its helpfulness. First, there is a chance that the data processing needed to run the sensors would significantly increase energy consumption and therefore go against the university’s sustainability goals of reducing building energy consumption (Ohio State Sustainability Goals, 2016). Secondly, there may be some potential overlapping of air quality monitoring as the university recently announced it is installing air quality sensors on some of the campus buses (“College teams up with CABS buses to collect air quality data,” 2017). And lastly, the campus pilot might not be able to provide the City of Columbus with all the information it might need. The proposed pilot only focuses on dimming controls, air quality sensors, and computer vision, and therefore will not be able to provide any information on other “smart” street lighting applications such as public Wi-Fi or LED transition. To overcome these barriers, our group recommends the university administration conduct a meeting involving all decision-makers regarding “smart” street lighting. This meeting will help determine the feasibility of the pilot, and further action can be taken from there.

In summary, our team recommends the university implement the aforementioned technologies and observe, evaluate, and build upon its results. Once the pilot program is in place, further research is needed to analyze the effects and investigate the efficacy of the project. Research will also be needed to establish a more accurate depiction of cost savings via motion-detected dimming.

By investing in this pilot project, OSU has the potential to benefit from improved public safety, reduction in traffic congestion and energy consumption, and cost savings—as well as the valuable position of being a leading influence and example case for the City of Columbus and its own smart street lighting initiatives.

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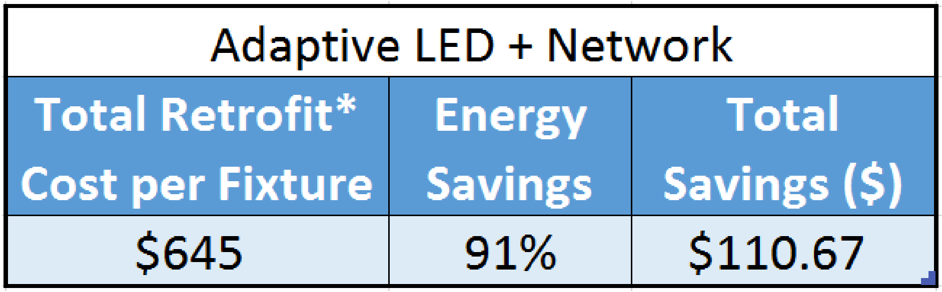
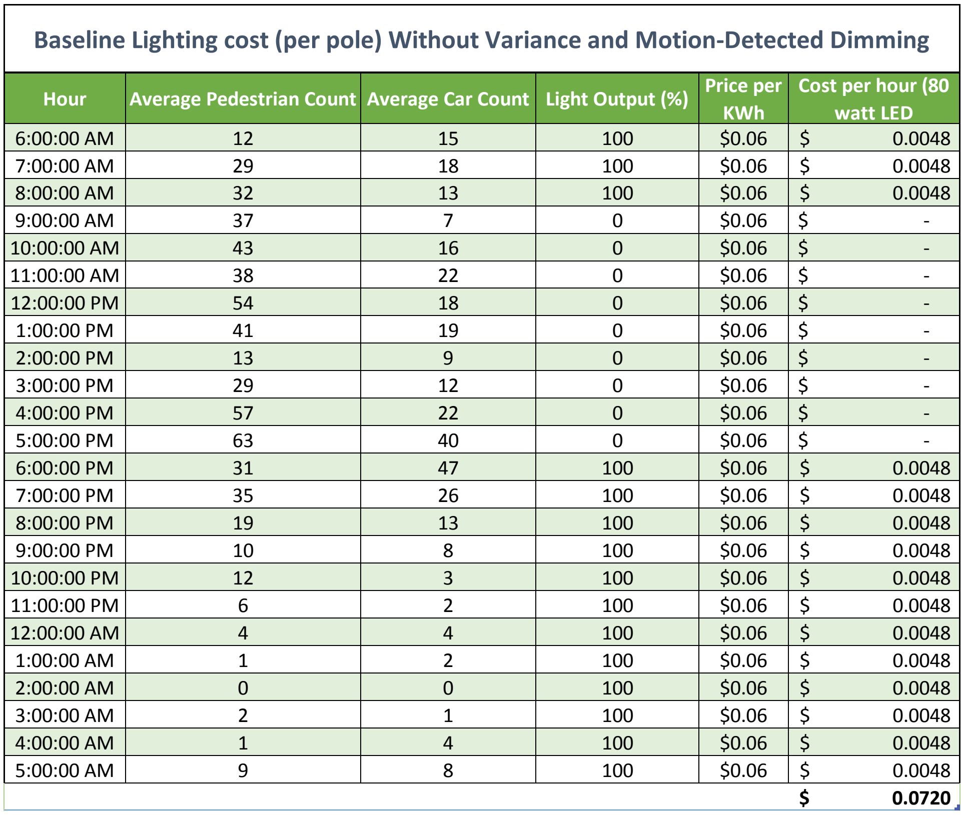
Appendices

APPENDIX A—TABLES AND FIGURES



Adaptive LED + Network		
Total Retrofit* Cost per Fixture	Energy Savings	Total Savings ($)
$645	91%	$110.67

Table 1. Compressed cost data for Adaptive LED technologies and integrated network services for UC Davis.



Baseline Lighting cost (per pole) Without Variance and Motion-Detected Dimming

Hour	Average Pedestrian Count	Average Car Count	Light Output (%)	Price per KWh	Cost per hour (80 watt LED
6:00:00 AM	12	15	100	$0.06	$ 0.0048
7:00:00 AM	29	18	100	$0.06	$ 0.0048
8:00:00 AM	32	13	100	$0.06	$ 0.0048
9:00:00 AM	37	7	0	$0.06	$ -
10:00:00 AM	43	16	0	$0.06	$ -
11:00:00 AM	38	22	0	$0.06	$ -
12:00:00 PM	54	18	0	$0.06	$ -
1:00:00 PM	41	19	0	$0.06	$ -
2:00:00 PM	13	9	0	$0.06	$ -
3:00:00 PM	29	12	0	$0.06	$ -
4:00:00 PM	57	22	0	$0.06	$ -
5:00:00 PM	63	40	0	$0.06	$ -
6:00:00 PM	31	47	100	$0.06	$ 0.0048
7:00:00 PM	35	26	100	$0.06	$ 0.0048
8:00:00 PM	19	13	100	$0.06	$ 0.0048
9:00:00 PM	10	8	100	$0.06	$ 0.0048
10:00:00 PM	12	3	100	$0.06	$ 0.0048
11:00:00 PM	6	2	100	$0.06	$ 0.0048
12:00:00 AM	4	4	100	$0.06	$ 0.0048
1:00:00 AM	1	2	100	$0.06	$ 0.0048
2:00:00 AM	0	0	100	$0.06	$ 0.0048
3:00:00 AM	2	1	100	$0.06	$ 0.0048
4:00:00 AM	1	4	100	$0.06	$ 0.0048
5:00:00 AM	9	8	100	$0.06	$ 0.0048
					$ 0.0720

Table 2. Prototype generated dimming cost data demonstrating campus' current system—no variance or dimming technology.

Lighting cost (per pole) With Variance and Motion-Detected Dimming (Default 100%)

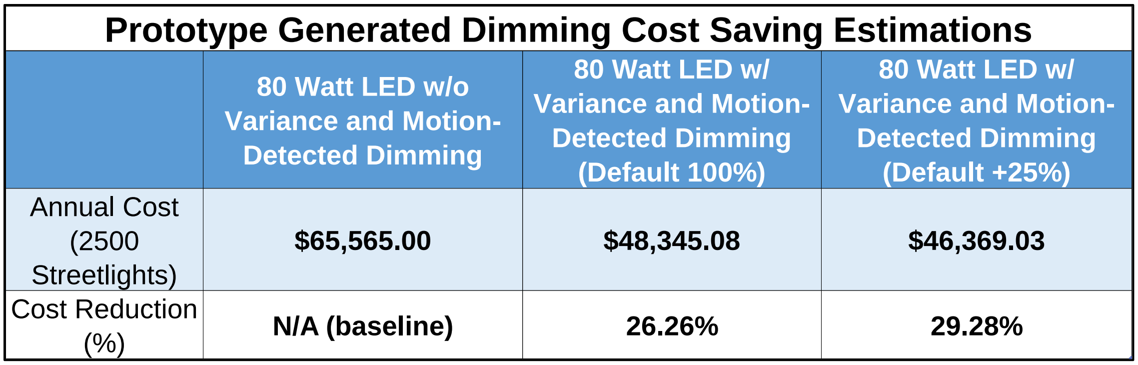
Hour	Average Pedestrian Count	Average Car Count	Light Output (%)	$/KWh	$/KWh Accounting for Only Light Output (80 watt LED lightbulb)	$/KWh Accounting for Light Output and Motion-Detected Dimming (80 watt LED lightbulb)
6:00:00 AM	12	15	75	$0.06	$ 0.0036	$ 0.00369
7:00:00 AM	29	18	50	$0.06	$ 0.0024	$ 0.00271
8:00:00 AM	32	13	25	$0.06	$ 0.0012	$ 0.00165
9:00:00 AM	37	7	25	$0.06	$ 0.0012	$ 0.00164
10:00:00 AM	43	16	0	$0.06	$ -	$ -
11:00:00 AM	38	22	0	$0.06	$ -	$ -
12:00:00 PM	54	18	0	$0.06	$ -	$ -
1:00:00 PM	41	19	0	$0.06	$ -	$ -
2:00:00 PM	13	9	0	$0.06	$ -	$ -
3:00:00 PM	29	12	0	$0.06	$ -	$ -
4:00:00 PM	57	25	0	$0.06	$ -	$ -
5:00:00 PM	63	40	25	$0.06	$ 0.0012	$ 0.00223
6:00:00 PM	31	47	25	$0.06	$ 0.0012	$ 0.00198
7:00:00 PM	35	26	50	$0.06	$ 0.0024	$ 0.00281
8:00:00 PM	19	13	75	$0.06	$ 0.0036	$ 0.00371
9:00:00 PM	10	8	75	$0.06	$ 0.0036	$ 0.00366
10:00:00 PM	12	3	75	$0.06	$ 0.0036	$ 0.00365
11:00:00 PM	6	2	75	$0.06	$ 0.0036	$ 0.00363
12:00:00 AM	4	4	75	$0.06	$ 0.0036	$ 0.00363
1:00:00 AM	1	2	75	$0.06	$ 0.0036	$ 0.00361
2:00:00 AM	0	0	75	$0.06	$ 0.0036	$ 0.0036
3:00:00 AM	2	1	75	$0.06	$ 0.0036	$ 0.00361
4:00:00 AM	1	4	75	$0.06	$ 0.0036	$ 0.00362
5:00:00 AM	9	8	75	$0.06	$ 0.0036	$ 0.00366
						0.05309

Table 3. Prototype generated cost data demonstrating scenario with variance and 100% default when motion is detected.

Lighting cost (per pole) With Variance and Motion-Detected Dimming (Default +25%)

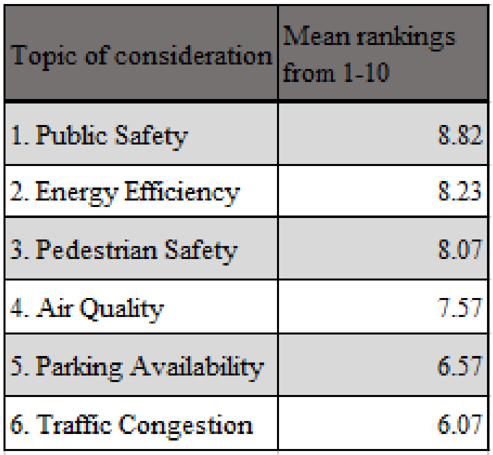
Hour	Average Pedestrian Count	Average Car Count	Light Output (%)	$/KWh	$/KWh Accounting for Only Light Output (80 watt LED lightbulb)	$/KWh Accounting for Light Output and Motion-Detected Dimming (80 watt LED lightbulb)
6:00:00 AM	12	15	75	$0.06	$ 0.0036	$ 0.00369
7:00:00 AM	29	18	50	$0.06	$ 0.0024	$ 0.00256
8:00:00 AM	32	13	25	$0.06	$ 0.0012	$ 0.00135
9:00:00 AM	37	7	25	$0.06	$ 0.0012	$ 0.00134
10:00:00 AM	43	16	0	$0.06	$ -	$ -
11:00:00 AM	38	22	0	$0.06	$ -	$ -
12:00:00 PM	54	18	0	$0.06	$ -	$ -
1:00:00 PM	41	19	0	$0.06	$ -	$ -
2:00:00 PM	13	9	0	$0.06	$ -	$ -
3:00:00 PM	29	12	0	$0.06	$ -	$ -
4:00:00 PM	57	22	0	$0.06	$ -	$ -
5:00:00 PM	63	40	25	$0.06	$ 0.0012	$ 0.00154
6:00:00 PM	31	47	25	$0.06	$ 0.0012	$ 0.00146
7:00:00 PM	35	26	50	$0.06	$ 0.0024	$ 0.0026
8:00:00 PM	19	13	75	$0.06	$ 0.0036	$ 0.00371
9:00:00 PM	10	8	75	$0.06	$ 0.0036	$ 0.00366
10:00:00 PM	12	3	75	$0.06	$ 0.0036	$ 0.00365
11:00:00 PM	6	2	75	$0.06	$ 0.0036	$ 0.00363
12:00:00 AM	4	4	75	$0.06	$ 0.0036	$ 0.00363
1:00:00 AM	1	2	75	$0.06	$ 0.0036	$ 0.00361
2:00:00 AM	0	0	75	$0.06	$ 0.0036	$ 0.0036
3:00:00 AM	2	1	75	$0.06	$ 0.0036	$ 0.00361
4:00:00 AM	1	4	75	$0.06	$ 0.0036	$ 0.00362
5:00:00 AM	9	8	75	$0.06	$ 0.0036	$ 0.00366
					$ 0.049	**$ 0.05092**

Table 4. Prototype generated cost data demonstrating scenario with variance and +25% default when motion is detected.



Prototype Generated Dimming Cost Saving Estimations			
	80 Watt LED w/o Variance and Motion-Detected Dimming	80 Watt LED w/ Variance and Motion-Detected Dimming (Default 100%)	80 Watt LED w/ Variance and Motion-Detected Dimming (Default +25%)
Annual Cost (2500 Streetlights)	**$65,565.00**	**$48,345.08**	**$46,369.03**
Cost Reduction (%)	**N/A (baseline)**	**26.26%**	**29.28%**

Table 5. Prototype generated cost data results table showing cost savings.



Topic of consideration	Mean rankings from 1-10
1. Public Safety	8.82
2. Energy Efficiency	8.23
3. Pedestrian Safety	8.07
4. Air Quality	7.57
5. Parking Availability	6.57
6. Traffic Congestion	6.07

Table 6. Table displaying the average rankings (on a scale from 1-10) of the surveyed, 100 individuals on the above 6 categories.

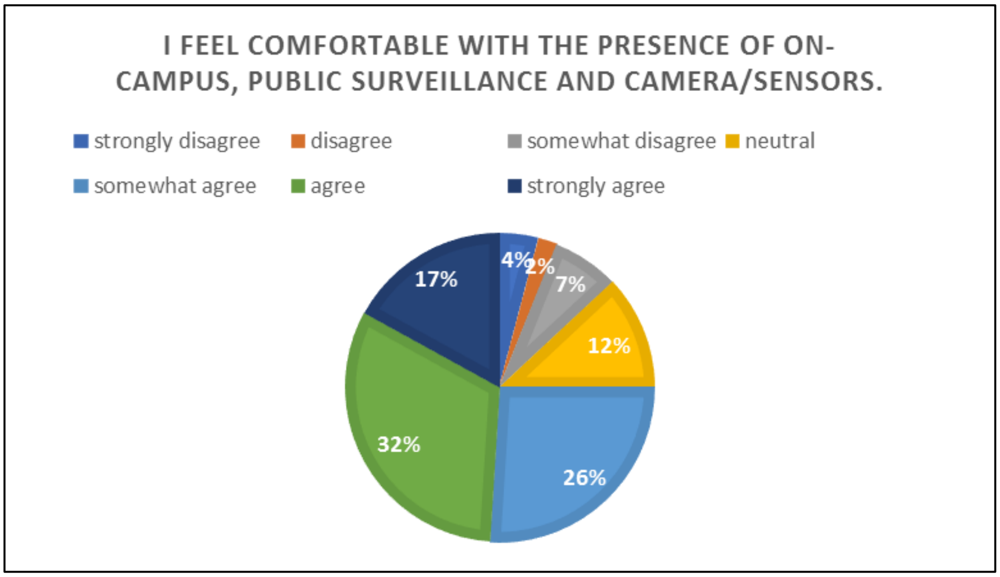


Figure 1. Chart displaying the survey results for the statement, “I feel comfortable with the presence of on-campus, public surveillance and cameras/sensors”.

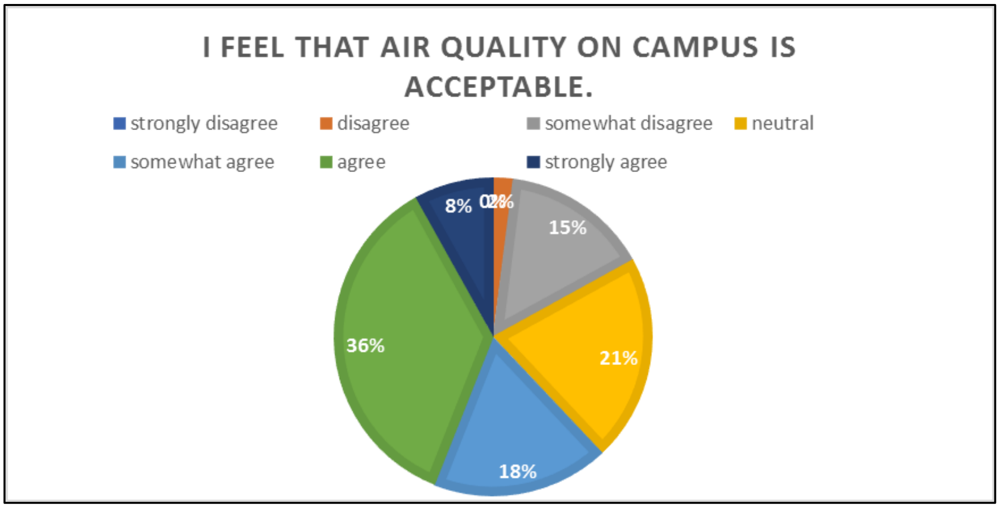
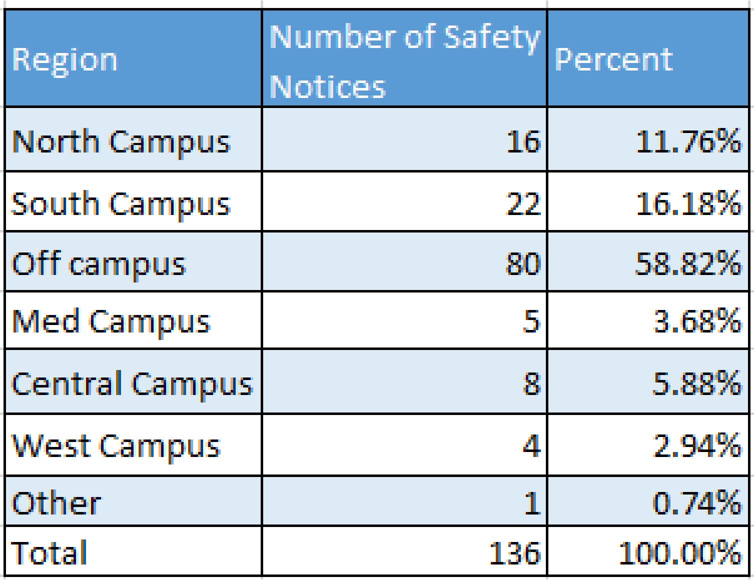


Figure 2. Chart displaying the survey results for the statement, “I feel that air quality on campus is acceptable”.



Region	Number of Safety Notices	Percent
North Campus	16	11.76%
South Campus	22	16.18%
Off campus	80	58.82%
Med Campus	5	3.68%
Central Campus	8	5.88%
West Campus	4	2.94%
Other	1	0.74%
Total	136	100.00%

Table 7. Table indicating the location and frequency of on- and off-campus locations.

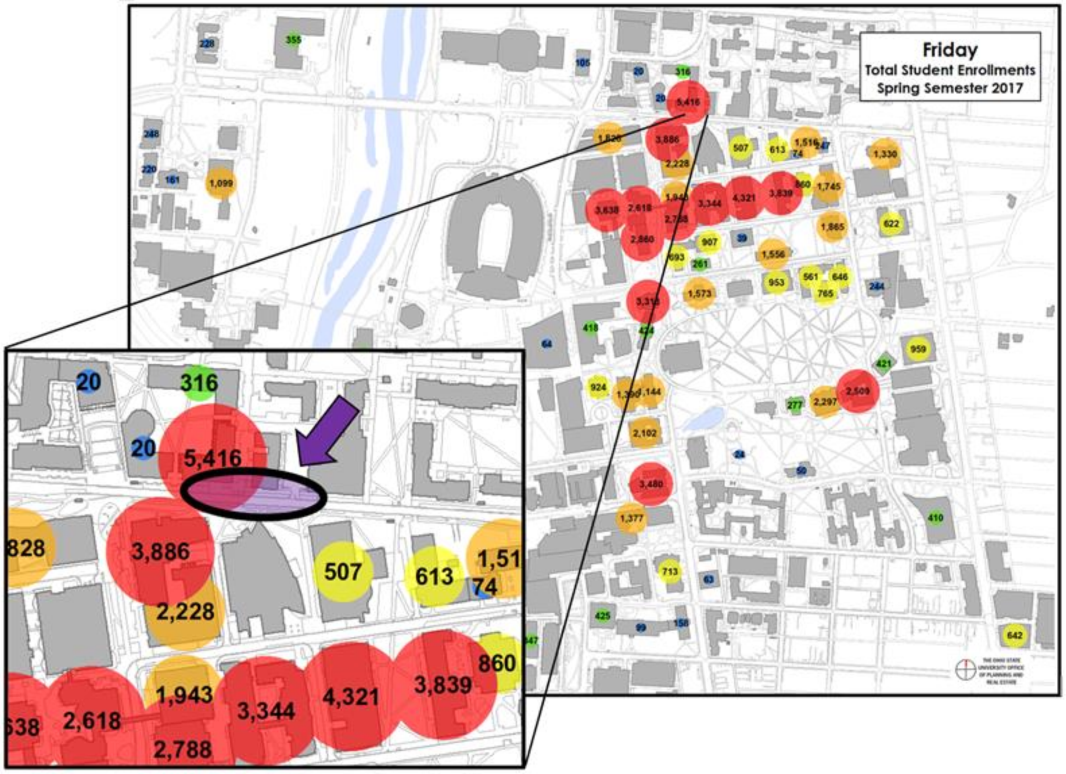


Figure 3. Spring Semester 2017 Student Heat Map.

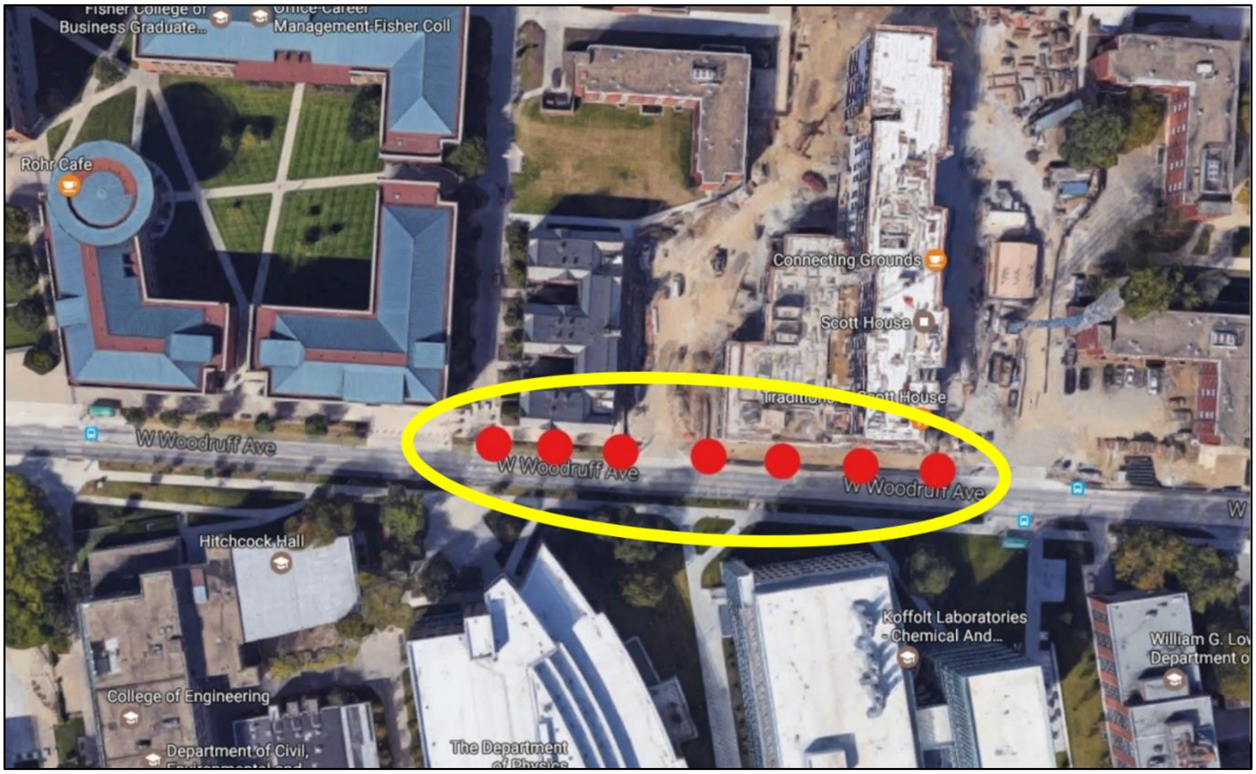


Figure 4. Altered Google Maps image displaying the proposed location for the proposed pilot project.

APPENDIX B—DATASETS

Dataset #1: Interviews.docx

Sources: In-person and over-the-phone interviews with the following city and university officials: Tom Timcho, Tom Reeves, Carlos Lugo, Bob Wajnryb, Greg Hitzhusen, John Rappleye, Patti Austin, Tony Gillund, Dr. Jim Davis, Howell Dalton McCullough IV, and Linden community stakeholders.

Description: This dataset is a collection of all relevant notes and information obtained through in-person and over-the-phone interviews throughout the duration of this capstone project. The information and data collected through these meetings served as key factors in our team's decision making process as well as greatly aided in determining and maintaining the direction of our project. Also, included within this dataset are brief notes from the Linden community's stakeholder meeting. This meeting gave our team the opportunity to discuss and work with Linden citizens on the issues most important to them, and translate those concerns to form a project that can both benefit their community as well as the university.

Dataset #2: Spring2017_StudentHeatMap.pdf

Sources: 2017 Student Heat Map

Description: This dataset is a graphic, developed by the department of Traffic and Transportation Management (TTM), indicating the average varying levels of pedestrian traffic/congestion throughout campus per week day for the year 2017. This graphic and data aided in establishing the most optimal area for the implementation for our project.

Dataset #3: PublicSafteyNotices.xlsx

Sources: Table of Public Safety Incidents

Description: This dataset was compiled by a member of our project team, Cassidy Horency, using information from The Ohio State University Department of Safety. This information and data helped determine the most optimal location for the implementation of our project, indicating areas with highest level of public safety incidents and crime and, therefore, areas of which would benefit most from safety improving technologies.

Dataset #4: DimmingCostPrototype.xlsx

Sources: Prototype LED Dimming Cost Tables

Description: This dataset is a compilation of all information and tables created from dimming-related data generated from our team made prototype. The prototype was placed at a designated location on Woodruff Ave. and was used in collecting data on the average number of pedestrians and vehicles (per hour) and the required, maximum variance given the allotted sunlight. This data was then used in simple calculations, paired with university given pricing, to determine the cost savings of with variance in energy consumption and motion-detected dimming technologies.

Dataset #5: capstonesurveyresults.xlsx

Sources: Survey Tables and Charts

Description: This dataset is a compilation of all information received as feedback from our team's survey. A survey was administered across campus to students (pursuing all levels of degrees in different disciplines), faculty and administration aimed to gather information about the campus community's opinion on issues of public safety, as well as determine to what extent issues, such as traffic congestion, are problematic or not. The data collected from this survey helped our team determine the campus community's receptivity to our project and aided in narrowing down our focus.

Dataset #6: ProposedLocation.docx

Sources: Image of Proposed Location (Woodruff Ave.)

Description: This dataset is an image of our team's decided upon location (Woodruff Ave.) collected from Google Map services online. Colored dots were added to accurately depict the precise location of the street lights suggested for the retrofitting of our project.

Dataset #7: UCDavis.pdf

Sources: UC Davis Cost Tables

Description: This Dataset is a combination of tables developed by the University of California, Davis (UC Davis) portraying the cost savings the university has realized since switching to a smart street lighting system similar to that of which we are proposing for The Ohio State University. This information from UC Davis present different cost options for different smart street lighting technologies and options. This data aided in our team's creation of a cost estimation for our proposed capstone project and provided evidence of the potential for cost savings from these smart technologies.

Dataset #8: CostEmails.docx

Sources: Email Transactions between our team and the following companies regarding cost estimates: TrafficVision, Echelon, UC Davis,

Description: This dataset is a compilation of all email transactions between each member of our teams and various companies associated with the proposed technologies in our project. The range of what each company produces ranges from one of the proposed technologies to all of them. This collection of sample pricing options and pricing information provided the bulk of the information that our team used in creating a cost estimate for our specific pilot project. The pricing information presented in this dataset is strictly confidential and not for public distribution however, our team managed to effectively use these estimates or our own purpose and disassociate the specific pricing to a specific company.